77th Annual Meeting of the Gesellschaft für Angewandte Mathematik und Mechanik e.V.

March 27th – 31st, 2006, Technische Universität Berlin

Book of Abstracts

Volker Mehrmann
Christian O. Paschereit
Wolfgang H. Müller
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Contents

Invited Lectures

All lectures will be held in the Audimax (Main Building)

Prandtl Lecture

Monday, March 27, 13:30 - 14:30

Compressible Turbulence: Aspects of Prediction and Analysis

Rainer Friedrich, Technische Universität München

Examples of compressible turbulent flows, related to high-speed flight, are given at the beginning. After discussing their characteristics in a statistical sense (Reynolds stress anisotropy, energy exchange between mean and fluctuating fields), tools for numerical prediction of such flows will be touched on. They are on one side, numerical methods of high accuracy in space and time to integrate nonlinear coupled systems of partial differential equations and on the other, simulation methods for the prediction of turbulent flows, like direct numerical simulation and large-eddy simulation.

These tools are then applied to predict three classes of compressible turbulent flows, namely wall-bounded flows (channel and pipe flow) and non-reacting as well as reacting mixing layers. In all these flows the effect of compressibility leads to an increase in Reynolds stress anisotropy as a result of decreasing pressure-strain correlations. For channel flow an explanation of this effect is given based on a Green's function solution of the pressure-Poisson equation. Reacting mixing layers provide an extra complication, since pressure fluctuations are not only affected by compressibility, but also by heat release. Given the fact that pressure-strain correlations already form a severe bottle-neck of turbulence modelling, combustion at high speed provides a further challenge for modellers.

Public Lecture

Wednesday, March 29, 18:30 - 19:30

MOLECULES IN MOTION

Christof Schütte, Freie Universität Berlin

All living systems work through interactions between molecules. Which interactions are possible and how they occur is determined by the structure, activity and dynamics of the molecules involved. We will dive into the molecular world in motion, observe some basic mechanisms of molecular dynamics, activity, and recognition, and in particular discuss examples in which mathematics could contribute to molecular research.

Plenary Lectures

Monday, March 27, 14:30 - 15:30

The Future of LAPACK and ScaLAPACK

James W. Demmel, University of California at Berkeley, USA

We are planning new releases of the widely used LAPACK and ScaLAPACK numerical linear algebra libraries.

Based on an on-going user survey (www.netlib.org/lapack-dev) and research by many people, we are proposing the following improvements: Faster algorithms (including better numerical methods, memory hierarchy optimizations, parallelism, and automatic performance tuning to accomodate new architectures), more accurate algorithms (including better numerical methods, and use of extra precision), expanded Functionality (including updating and downdating, new eigenproblems, etc. and putting more of LAPACK into ScaLAPACK) improved ease of use (friendlier interfaces in multiple languages).

To accomplish these goals we are also relying on better software engineering techniques and contributions from collaborators at many institutions. This is joint work with Jack Dongarra.

Tuesday, March 28, 08:30 - 09:30

Nonlinear oscillations in suspension bridge models

Joseph McKenna, University of Connecticut, USA

The early history of modern suspension bridges has many interesting examples of destructive oscillations. Examples include the early Golden Gate, the Tacoma Narrows, and others. We discuss these oscillations and show how many of the phenomena can be explained by the nonlinear effects inherent in large amplitude oscillation when cables are no longer in the range of a linear Hooke's law but begin to slacken at large amplitude. Examples of periodic vertical oscillations, torsional oscillations, and travelling waves will be considered.

Wednesday, March 29, 08:30 - 09:30

Modellierung anisotroper Materialien – Neue Entwicklungen

Jörg Schröder, Universität Duisburg-Essen

In vielen technischen Anwendungen ist die Modellierung anisotropen Materialverhaltens erforderlich; so sind z. B. biologische Gewebe, Textilmembranen und einige Keramiken durch eine ausgeprägte Richtungsabhängigkeit charakterisiert.

Eine der Herausforderungen in diesem Bereich liegt in der Konstruktion anisotroper hyperelastischer Materialgleichungen für finite Deformationen, welche die Existenz von Minimierern gewährleisten. Da für nichtlineare Randwertprobleme die Forderung nach Konvexität physikalisch nicht haltbar ist, bedient man sich so genannter verallgmeinerter Konvexitätsbegriffe. Als Mittel der Wahl bietet sich die Polykonvexität (J. Ball [1977]) an. Mit Hilfe der Invariantentheorie und geeigneten Tensor-Repräsentations-Theoremen ist es möglich, zumindest für einige Anisotropieklassen, entsprechende Energiefunktionen zu konstruieren.

Technisch interessante Anwendungen für anisotrope Materialien im Bereich kleiner Verzerrungen liegen in der Aktuatorik. Hier werden Keramiken ohne Symmetriezentrum eingesetzt. Mit dem evolutionären Durchbruch beim Einsatz piezoelektrischer Aktuatoren in der Automobilindustrie vor einigen Jahren ist das Interesse an der Modellierung elektromechanisch gekoppelter Keramiken stark gestiegen. Diese ferroelektrischen Materialien zeichnen sich durch ausgeprägte dielektrische und Schmetterlings-Hysteresekurven unter oszillierenden elektrischen Feldern aus. Dabei wird das makroskopische Verhalten durch Umschaltprozesse der so genannten Polarisierungsvektoren auf der Mikroskale beherrscht. Für die Modellierung komplexer polykristalliner Bauteile wird eine einfache gekoppelte Mehrskalensimulation im Rahmen einer koordinateninvarianten Formulierung vorgestellt.

Thursday, March 30, 08:30 - 09:30

From the kinetic theory of gases to the Euler or Navier-Stokes equations

François Golse, Université Pierre et Marie Curie, France

This lecture will review recent mathematical results on the problem of finding the hydrodynamic limits of the Boltzmann equation in the kinetic theory of gases. In particular, it will explain how different fluid regimes (viscous or inviscid, compressible or incompressible) can be obtained from the kinetic theory of monatomic gases. It will also briefly describe the different mathematical methods for treating these problems and discuss their respective merits.

Thursday, March 30, 09:30 - 10:30

Nonlinear dynamics of non-smooth mechanical systems

Dick H. van Campen, Eindhoven University of Technology, The Netherlands

This plenary lecture deals with the dynamics of mechanical systems with discontinuities.

Such systems are being referred to as discontinuous or non-smooth mechanical systems and their time evolution is often described by non-smooth differential equations. First, some examples will be given of non-smooth mechanical systems and several types of non-smooth dynamical systems will be distinguished. The focus of this lecture will be on equilibria and periodic solutions of non-smooth dynamical systems.

The number and stability of equilibria/periodic solutions can change at a certain critical value of a system parameter. Loosely speaking, this qualitative change in the structural behaviour of the system is called bifurcation, a word introduced by H. Poincaré. In this lecture it will be surveyed in which way the classical bifurcations in smooth non-linear dynamical systems possess an analogy in non-smooth dynamical systems.

Also, a generalization of Floquet theory is surveyed which explains bifurcation phenomena in periodic solutions of non-smooth non-autonomous dynamical systems of the Filippov type. Non-smooth dynamical systems may also exhibit non-conventional bifurcations, i.e. bifurcations that do not possess an analogy in smooth nonlinear dynamical systems. The lecture will conclude with some examples of interesting non-conventional bifurcations.

Thursday, March 30, 11:00 - 12:00

Fast Image Inpainting

Folkmar Bornemann, Technische Universität München

Image Inpainting turns the art of image restoration, retouching, and disocclusion into a computer-automated trade. Mathematically, it may be viewed as an interpolation problem in some fancy function spaces thought suitable for digital images. It has recently drawn the attention of the numerical PDE community, which has led to impressive results. However, stability restrictions of the suggested schemes yield computing times so far that are next to prohibitive in the realm of interactive digital image processing. We address this issue by constructing an appropriate transport equation that combines a fast solver with high perceptible quality of the resulting inpainted images.

The talk will survey the background of the inpainting problem and prominent pde-based methods before entering the discussion of the suggested new methods. Many images will be shown along the way, in parts with online demonstrations.

Friday, March 30, 08:30 - 09:30

Nitsche's method for interface problems

Peter Hansbo, Chalmers University of Technology, Sweden

Nitsche's method for interfaces can be viewed as a combination of the Lagrange multiplier and penalty methods, mbut without the explicit use of an independent multiplier and without the need of exceedingly large penalty parameters. With Nitsche's method one thus avoids the saddle point structure of the multiplier method as well as the bad conditioning of the multiplier method. We give a review of this method as applied to problems featuring real or artificial interfaces. Examples include unfitted and cut meshes for weak and strong discontinuities in solid mechanics as well as Stefan problems. Furthermore, the application to model coupling in fluid and solid mechanics will be discussed.

Friday, March 30, 09:30 - 10:30

Three-dimensional travelling gravity-capillary water waves

Marc Groves, Loughborough University, United Kingdom

The classical gravity-capillary water-wave problem is the study of the irrotational flow of a three-dimensional perfect fluid bounded below by a flat, rigid bottom and above by a free surface subject to the forces of gravity and surface tension. In this lecture I will present a survey of currently available existence theories for travelling-wave solutions of this problem, that is, waves which move in a specific direction with constant speed and without change of shape.

The talk will focus upon wave motions which are truly three-dimensional, so that the free suface of the water exhibits a two-dimensional pattern, and upon solutions of the complete hydrodynamic equations for water waves rather than model equations. Specific examples include (a) doubly periodic surface waves; b) wave atterns which have a single- or multi-pulse profile in one distinguished horizontal direction and are periodic in another; (c) so-called "fully-localised solitary waves" consisting of a localised trough-like disturbance of the free surface which decays to zero in all horizontal directions.

I will also sketch the mathematical techniques required to prove the existence of the above waves. The key is a formulation of the problem as a Hamiltonian system with infinitely many degrees of freedom together with an associated variational principle.

Friday, March 30, 11:00 - 12:00

Current developments in topology optimization and material design

Ole Sigmund, Technical University of Denmark

The topology optimization method is a computational tool originally developed for determining optimal material distribution for civil and mechanical structures. The method is based on alternating finite element computations and material redistributions steps determined by mathematical programming. The method was founded by Bendsoe and Kikuchi in 1988 and has now become a standard tool for mechanical design in the automotive, aerospace and other industrial areas. In recent years, the method has been extended to a large range of other physical design problems.

After a short introduction to the topology optimization method and a discussion of applications in the aerospace industry, the talk will concentrate on extensions and applications of the topology optimization method in fluid mechanics, in wave propagation problems such as phononic and photonic band gap structures, photonic crystal based optical wave guides, surface acoustic wave devices and in material design problems.

Friday, March 30, 12:00 - 13:00

Stable hybridization techniques in computational mechanics

Barbara Wohlmuth, Universität Stuttgart

Modern discretization schemes, based on domain decomposition methods or hierarchical modeling, are among the most powerful methods for the solution of large scale and heterogeneous problems in continuum mechanics.

Each new application results in an interesting and challenging problem of its own.

Nevertheless, the required domain decomposition techniques can be analyzed within an abstract framework very often. Basic ingredients for the analysis are trace results, a primal-dual pairing, uniform inf-sup conditions and stabilization terms.

In order to be as flexible as possible, the subdomains of a geometric decomposition can be meshed independently of each other. In this talk, we provide some examples for finite element schemes on non-matching grids and address stability issues. Of crucial importance for the asymptotic optimality is the transfer at the interfaces which has to reflect the coupling between essential and natural boundary conditions.

In the case of complex curved geometries in 3D, preasymptotic numerical instabilities can easily occur and the curvature of the surface has to be taken into account in order to enforce a stable scheme.

Numerical examples illustrate the flexibility and performance of the hybrid approach and the robustness of the iterative solver. Several applications are presented, including nonlinear elastodynamics, multibody contact problems and elasto-acoustic interactions.

1 Multigrid methods for optimal control of PDEs

Organizers:

Alfio Borzi, Universität Graz
Boris Vexler, Austrian Academy of Sciences

Monday, March 27, 16:00 - 18:00

Room: H 2013

Chair:

Alfio Borzi
Boris Vexler

16:00	Tai	H 2013

Domain Decomposition And Multigrid Methods For Optimal Control

Xue-Cheng Tai, University of Bergen, Norway

Domain decomposition (DD) and multigrid (MG) have been intensively studied for linear elliptic problems. In this work, we try to use the framework developed in [1,2,3] to extend domain decomposition and multigrid methods to get mesh independent preconditioners and iterative methods for solving some optimal control problems related to linear elliptic equations. The basic idea is to regard DD and MG methods as space decomposition techniques [4].

[1] Xue-Cheng Tai: Rate of convergence for some constraint decomposition methods for nonlinear variational inequalities, Numer. Math., 2002.
[2] X.-C. Tai and M. Espedal: Rate of convergence of some space decomposition method for linear and nonlinear elliptic problems. SIAM J. Numer. Anal., 35:1558-1570, 1998.
[3] X-C. Tai and J.-C. Xu: Global convergence of subspace correction methods for convex optimization problems. Math. Comp., 71:105-124, 2001.
[4] J. Xu: Iteration methods by space decomposition and subspace correction. SIAM Rev., 34:581-613, 1992.

16:20	Ulbrich	H 2013

Interior-point Multigrid Methods For Pde-constrained Optimization

Stefan Ulbrich, FB Mathematik, TU Darmstadt
Michael Ulbrich, Universität Hamburg

In this talk we introduce a primal-dual interior point framework for PDE-constrained optimization problems. Moreover, we show how multigrid methods as well as iterative solvers with multigrid-preconditioners can be used to solve the arising primal-dual Newton system efficiently. We consider stationary as well as instationary optimal control problems. Numerical results are presented to show the efficiency of the approach.

17:00	Biros	H 2013

Multilevel And Domain-decomposition Solvers For Inverse Problems

George Biros, Santi Swaroop Adavani, University of Pennsylvania, USA

Parabolic PDEs can model several different physical systems in science and engineering. Examples include convection-diffusion equations for groundwater and atmospheric transport, semi-linear diffusion equations for cardiac electrophysiology, and chemical reactions.

We are interested in devising efficient numerical schemes for inverse and control problems of such systems.

In this talk I will discuss the spectral properties of the inverse operator (reduced Hessian) and present linear and nonlinear solvers. The main focus will on multilevel algorithms for the linearized inverse problem. The basic simple level techniques are the King-Kaltenbacher class preconditioners, Borzi pointwise smoothers, and space-time domain decomposition techniques. I'll analyze their convergence rates, their effectiveness when combined in a full multigrid scheme, and verify the analysis with numerical results.

I will conclude with the description of a very large scale inversion example in which a full multigrid solver is a applied to a 4D data assimilation in atmospheric dispersion problem.

17:20	Schulz	H 2013

On Multigrid Abstracts In Shape Optimization

Volker Schulz, Universität Trier

Real life shape optimization can profit from multigrid structures. In this talk, several aspects which occur in aerodynamic design with regards to multigrid will be discussed. Some of them are the structure of the reduced Hessian operator, the consequences of regularization and particularities of multigrid methods in aerodynamic simulation.

2 Theory and Applications of Stochastic Optimization Methods

Organizers:

Thomas Vietor, Ford-Werke AG
Kurt Marti, Universität der Bundeswehr München

Monday, March 27, 16:00 - 18:00

Room: H 2032

Chair:

Kurt Marti
Thomas Vietor

16:00	Dabbene	H 2032

Approximate Solutions To Convex Optimization Under Stochastic Unce

Fabrizio Dabbene, Giuseppe Calafiore, IEIIT - CNR, Italy

In this lecture, we survey two standard philosophies for finding minimizing solutions of convex objective functions affected by uncertainty are considered. In a first approach, the solution should minimize the expected value of the objective w.r.t. uncertainty (average approach), while in a second one it should minimize the worst-case objective (worst-case, or min-max approach). Both approaches are however numerically hard to solve exactly, for general dependence of the cost function on the uncertain data. Here, a brief account is given on two techniques based on uncertainty randomization that permit to solve efficiently some suitable probabilistic relaxation of the indicated problems, with full generality with respect to the way in which the uncertainty enters the problem data. A specific application to uncertain least-squares problems is examined.

16:20	Marti	H 2032

Multipoint First Order Reliability Methods (mform)

Kurt Marti, Universität der Bundeswehr München

Having to take into account in structural analysis and optimal structural design stochastic variations of the vector $a = a(\omega)$ of model parameters, e.g., material resistance parameters, external loadings, cost coefficients, etc., the reliability of the structure is evaluated by means of the probability of survival/failure of the whole structural system or of certain relevant components. For the computation of the probability of survival, an appropriate so-called (limit) state or performance function $s^* = s^*(a, x)$ is needed to describe safe/unsafe stress states: A safe (stress) state exists if and only if $s^* < 0$, and a safe stress state cannot be guaranteed if and only if $s^* \geq 0$. The state function s^* depends on a and the vector of design variables x. The probability of survival can be represented then by

$$p_s(x) = P\Big(s^*\big(a(\omega), x\big) < 0\Big).$$

The computation of p_s or the related failure probability p_f is often based on a pure numerical evaluation of the state function, e.g. by simulation techniques (MCS) and/or by using certain approximation techniques, e.g. Response Surface Methods (RSM). However, the computation of p_s can be simplified considerably if an explicit representation of $s^* = s^*(a, x)$ is available, as in the analysis and design of mechanical structures, where the state function $s^* = s^*(a, x)$ can be represented by the minimum value function of a certain convex or linear optimization problem. Standard "FORM" (First Order Reliability Method) approximation techniques are based on a linear approximation of the failure domain (in z-space) $B_{f,x} = \Big\{z : s^*\big(\Gamma^{-1}(z), x\big) \geq 0\Big\}$ at a so–called "beta-point" z_x^*. Here, the random vector of physical model parameters a is transformed $z = \Gamma(a)$ first to a standard normal distributed random vector $z = z(\omega)$. The beta-point z_x^* is the projection of the origin 0 in z-space to $B_{f,x}$. The probability of survival can be approximated then by

$$p_s(x) \sim \Phi\big(\|z_x^*\|\big), \tag{1}$$

$\|\cdot\|$ = Euclidean norm, $\Phi = \Phi(t)$ is the cdf of the $N(0,1)$ normal distribution. It is known that approximation (1) is asymptotically correct, i.e. for $p_s \to 1$. Thus, the basic reliability condition $p_s \geq \alpha_s$ can be represented by

$$\|z_x^*\| \geq \Phi^{-1}(\alpha_s)$$

with a prescribed minimum probability α_s.

Obviously, the β-point z_x^* is a special boundary point of the domains of failure or survival. In order to improve the probability approximation (1), besides linearization of s^* at this special boundary point z_x^*, further approximations of the failure, survival domain, resp., are considered at other boundary points $b_{c,x}$ which can be obtained by minimizing/maximizing certain linear forms $L(z) = c^T z$, with a certain vector c, on the transformed failure or survival domain. Probability approximations of several degrees of accuracy are obtained then by considering single or joint constraints obtained by linearizing the state function $s^* = s^*(a,x)$ at the boundary points $b_{c^j,x}, j = 1,\ldots,J$, with given vectors $c^1,\ldots,c^J$. While single constraints lead immediately to explicit approximations

$$\tilde{p}_s(x) = \Phi\left(\frac{-c^T b_{c,x}}{\|c\|}\right)$$

of $p_s(x)$, as in case of standard FORM, for joint constraints we get

$$\tilde{p}_s(x) = P\Big(-c^{jT}\big(z(\omega) - b_{c^j,x}\big) < 0, j = 1,\ldots,J\Big).$$

Thus, a second approximation step is needed, based e.g. on certain Tschebyscheff inequalities.

The remaining problem is then the computation of the projection z_x^* and the boundary points $b_{c,x}$. Using the above mentioned representation of s^* by the minimum value function of a convex or linear program, *explicit* parameter optimization problems for the computation of the projection z_x^* and the boundary points $b_{c,x}$ are available. Obviously, parallel computation of the boundary points $b_{c^j,x}, j = 1,\ldots,J$, is possible.

16:40	**Kaminski**	**H 2032**

Stochastic Finite Element Method By Taylor Expansion Approach

Marcin Kaminski, Chair of Mechanics of Materials, Technical University of Lódz, Poland

The basic aim is to present an application of the stochastic perturbation technique based on the Taylor series expansion approach in some fundamental problems of mechanics solved using the Finite Element Method. Contrary to the Second Order Second Moment method, the idea displayed here is connected with general perturbation methodology, where the order of expansion together with the order of highest probabilistic moment being computed are related to a priori given accuracy of the relevant approximations and computational modeling needs. Although the methodology discussed here deals with a single random input variable, it can be extended to many both uncorrelated and correlated random variables and fields. Furthermore, it should be underlined that classical stochastic perturbation techniques known from the field were based on the single Taylor expansion, whereas here the double expansion is also proposed with the additional illustrations. This double expansion is proposed to remove the general weakness of this approach consisting in impossibility of computational modeling of random variations in space and time simultaneously.

The integral part of this elaboration is in numerical analysis, where fundamental variational equations of elastostatics, elastodynamics known from solid mechanics as well as variational principles in Newtonian fluids flows are transformed for the needs of the generalized perturbation technique. Those extensions are also presented in terms of Finite Element Method equations with some elementary numerical illustrations in the form unidirectional elastostatics, heat conduction and Couette flow problems discretized by the linear stochastic finite elements. Comparative numerical analysis performed in symbolic computational environment of the system MAPLE shows numerical convergence of the output probabilistic moments and, on the other hand, the dependence of the output moments on input coefficient of variation as well as perturbation parameter; some comparison with the Monte-Carlo simulation results is also available. This discussion shows briefly how to speed up the convergence of the method by additional increasing or decreasing of the perturbation parameter (originally taken as equal to one) and verifies theoretical assumptions of the entire method made before without satisfactory reasoning.

17:00	Schumacher	H 2032

Robust Design Considering Highly Non-linear Structural Behavior

Axel Schumacher, Christian Olschinka, Department Fahrzeugbau und Flugzeugtechnik, HAW-Hamburg

One part of the structural optimization is the question about the robustness of the optimal solutions. Especially in the highly non-linear automotive crash discipline, small differences from the expectation value of the influences can result in a totally different structural behavior.

For finding a robust behavior of the structure, we have to consider different reasons of uncertainties, e.g. material scatterings, manufacturing inaccuracy or mechanical load deviations during the crash situation. These scatterings can be described by distribution functions and the robustness can be calculated by means of the Monte Carlo approach. The calculation of extended functions, which include the uncertainties is often a good possibility and can be used in the optimization process.

More difficult are deviations from the desired global deformation behavior of structural components during the crash situation. In this case, a kind of fail-safe-approach, which guaranties by means of additional structural elements that a forbidden range of deformations will not occur, can be included in the robust design process.

The goal of this contribution is to present and discuss the different approaches to handle practical design problems of crash-relevant structures.

17:20	Wenzel	H 2032

Product Quality Improvement In The Simulation Driven Designprocess

Holger Wenzel, Engineous Software GmbH
Peter Mikolaj, MSC.Software GmbH

With the advancement of mathematically based optimization methods into the industrial product creation process one challenge of these methods becomes more and more apparent: Optimization drives the design into extreme locations of the design space. Here one or more constraints are active and even small perturbations of the input variables will result in a violation of these constraints; causing the design to break. These perturbations come e.g. from manufacturing tolerances or changing operating conditions and can not be controlled, but should be taken into account at product design time.

This work describes different techniques and examples how to assess and improve the impact that input fluctuations have on the product quality, which in this context consists of reliability and robustness. Both can be assessed simultaneously using Monte-Carlo-Simulations. If this technique is computationally too expensive, the reliability can be approximated by other techniques as the Mean-Value-First-Order- or First-Order-Reliability-Methods.

The quality of the design can be improved by Reliability Optimization or by a reformulation of the optimization problem that incorporates the stochastic variations into the objective function and constraints.

Based on simulation software by MSC, the applications discussed in this work show a wide variety in the solution to the problem; implementing one or more of the techniques mentioned before.

17:40	**Kobelev**	**H 2032**

Fractional Tensor Analysis In Stochastic Optimization

Vladimir Kobelev, Muhr und Bender Attendorn

The principles of tensor analysis with fractional partial derivatives are established. The generalization of summation conventions is introduced for the case of fractional indexes as an extension of common summation notation with integer indexes. The introduced notation allows the compact definition of common vector operators with fractional derivatives. The variational principles for the functionals with fractional derivatives are applied for the tensor functional arguments. The corresponding necessary extremum conditions of the functional as the generalization of Euler conditions for the case of fractional partial derivatives are established. Fundamental solutions (Green's functions) for operators of tensor analysis with fractional derivatives were found using the Fourier transforms. We analyze the asymptotic behavior for the fundamental solutions and its peculiarities for certain operators of tensor analysis with fractional derivatives. Finally, we discuss the applications of the invented methods for the stochastic optimization.

3 Discrete and continuous nonlinear variational problems

Organizers:

Felix Otto, Universität Bonn
Mark A. Peletier, Technische Universiteit Eindhoven
Wolfgang Reichel, Universität Basel

Monday, March 27, 16:00 - 18:00

Room: MA 001

Chair:

Wolfgang Reichel
Mark A. Peletier

16:00	**Horak**	**MA 001**

Numerical Mountain Pass And Its Applications

Jiri Horak, *Universität zu Köln*

The mountain pass theorem is an important tool in the calculus of variations and in finding solutions to nonlinear PDEs in general. The mountain pass structure, not only in the whole Banach space but also on manifolds given by C^1-functionals, can be exploited numerically, as well. The constrained mountain pass algorithm has the ability to approximate critical points which in an unconstrained setting would have a higher Morse index and would hence be difficult to capture. Its applications range from an analysis of the Fučík spectrum of the Laplace operator to models from physics and engineering like buckling of cylindrical shells.

16:30	**Melcher**	**MA 001**

Some Dynamic Problems In Magnetism

Christof Melcher, Institut für Mathematik, Humboldt-Universität zu Berlin

Dynamic processes in magnetism are well described by the Landau-Lifshitz-Gilbert equations that model a damped precession of the magnetization vector around the effective field which is given by the variation of the underlying interaction energy. Of particular interest is the induced motion of micromagnetic singularities like domain walls, especially in reduced models for thin films and multilayers. We discuss some consequences of the interplay between the underlying variational problem and the precession dynamics in the context of traveling wave solutions.

17:00	Röger	MA 001

Cell Membranes, Lipid Bilayers And The Elastica Functional

Matthias Röger, Mark A. Peletier, Centre for Analysis, Scientific computing and Applications, Eindhoven University of Technology, Netherlands

Cells membranes, typically formed by lipid bilayers, show a remarkable stability, namely resistance to stretching, bending and fractures. On a micro-scale lipid molecules are considered to consist of head and tails. Starting from a simple two bead model an energy on the meso-scale was derived. The bilayer appears here as "thickened surfaces". We give an asymptotic development of the meso-scale energy in terms of the thickness of the objects. In two space dimensions, we rediscover the elastica functional which classically describes the bending energy of curves. This connection is made precise by proving the Gamma-convergence of suitable scaled versions of the energy. A Wasserstein distance term in the functional suggests to use the geometry induced by the associated optimal mass transport problem.

17:30	Theil	MA 001

Periodic Mimimizers In Atomistic Systems

Florian Theil, Mathematics Institute, Warwick University, Great Britain

Many materials have a crystalline phase at low temperatures. The simplest example where this fundamental phenomenon can be studied are pair interaction energies of the type $E(\{y\}) = \sum_{1\leq x<x'\leq N} V(|y(x)-y(x')|)$ where $y(x)\in\mathbf{R}^2$ is the position of particle x and $V(r)\in\mathbf{R}$ is the pair-interaction energy of two particles which are placed at distance r. We focus on the zero temperature case and show rigorously that under suitable assumptions on the potential V which are compatible with the growth behavior of the Lennard-Jones potential the ground state energy per particle converges to an explicit constant E_*:

$$\lim_{N\to\infty}\frac{1}{N}\min_{y:\{1\ldots N\}\to\mathbf{R}^2} E(\{y\}) = E_*,$$

where $E_* \in \mathbf{R}$ is the minimum of a simple function on $[0, \infty)$. Furthermore, if suitable Dirichlet- or periodic boundary conditions are used, then the minimizers form a triangular lattice. To the best knowledge of the author this is the first result in the literature where periodicity of ground states is established for a physically relevant model which is invariant under the Euclidean symmetry group consisting of rotations and translations.

1 Mechanics of cells

Organizers:

Joachim P. Spatz, Universität Heidelberg
Ulrich Schwarz, Universität Heidelberg

Monday, March 27, 16:00 - 18:00

Room: H 104

Modelling mechanical aspects of cell and tissue dynamics

Chair:

Joachim P. Spatz
Ulrich Schwarz

16:00	Bathe	H 104

F-ACTIN BUNDLE MECHANICAL PROPERTIES

Mark Bathe, Institut für Theoretische Physik, Ludwig-Maximilians-Universität München

Animal cells express a myriad of actin-binding proteins (ABPs) that associate with Filamentous actin (F-actin) to form stiff bundles in vivo. The physiological function of F-actin bundles varies from passive mechanical structures such as microvilli present on the surface of epithelial cells in the intestinal lining to active structures such as filopodia formed at the leading edge of cells during migration. A biomimetic emulsion technique, recently introduced by our lab, has been used to measure directly the bending stiffness of isolated F-actin bundles associated with biologically-relevant ABPs. Results demonstrate that bundle stiffness depends sensitively on the number of actin filaments constituting the bundle, bundle length, and ABP type and concentration. Here, we use a combination of molecular simulation and analytical theory to elucidate the origin of the observed bundle mechanical properties. We also determine for the first time the molecular stiffnesses of the various ABPs examined.

16:30	Schwarz	H 104

Elastic Interactions Of Cells With Compliant Environments

Ulrich Schwarz, Center for Modelling and Simulation in the Biosciences, Universität Heidelberg

During recent years, a considerable body of experimental evidence has been accumulated which suggests that elastic properties of the extracellular environment are highly relevant for cellular decision making. We developed a method for calculating cellular forces exerted on micro-patterned elastic substrates and found that cell-matrix contacts function as mechanosensors by converting force into aggregation. In an elastically anisotropic environment, cells prefer to orient in the direction of maximal effective stiffness, possibly because build-up of force at cell-matrix contacts is more efficient in a stiff environment. This behaviour can be formulated as an extremum principle in linear elasticity theory. For single cells, we predict cell positioning and orientation for different sample geometries and boundary conditions of interest, in excellent agreement with experiments with fibroblasts on elastic substrates and in hydrogels. For intermediate cell densities, we predict string formation. Effective interactions between strings are short-ranged because cellular traction patterns screen each other. For high cell densities, we predict phase transitions between string-like and ring-like structures as a function of Poisson ratio.

17:00	Drasdo	H 104

The Role Of Biomechanics In The Growth Of Multi-cellular Systems

Dirk Drasdo, Interdisziplinäres Zentrum für Bioinformatik, Universität Leipzig

The role of biomechanics in the growth control of multi-cellular systems such as tumors and tissues is under extensive investigation. Here we present results of simulations with an agent (single-cell)-based model where each cell is parameterized by kinetic and biophysical properties for monolayers and multi-cellular spheroids. We show by direct comparison to experiments for monolayers growing on a flat substrate and for multi-cellular spheroids growing in liquid suspensions that the expansion kinetics can largely be explained by a biomechamical form of contact inhibition that leads to an inherent link between the length of the cell cycle at the local degree of deformation (or compression). To test our model we predict the expected kinetics and morphotype of monolayers and spheroids growing in a co-coculture for various properties of the environmental cells.

17:30	Weinkamer	H 104

Learning About Mechanotransduction In Bone From Its Microstructure

Richard Weinkamer, Max-Plank-Institut für Kolloid- und Grenzflächenforschung

The trabecular bone, present for example in human vertebral bodies, attracts research interest due to its hierarchical structure and to its ability to adapt its foam-like architecture to a changing loading environment. The dynamics of the structure is made possible by units of specialized cells, which continuously resorb and deposit small bone packets. The ability for adaptation results from a mechanical control of the remodeling process in the form of a higher probability for bone deposition (resorption) at sites with a high (low) local mechanical loading (Wolff-Roux law). A crucial unknown is the remodeling rule, which phenomenologically summarizes the mechanotransduction in bone, and which defines the relation between the local mechanical stimulus and the probability for bone resorption/deposition. Using a computer model in which the Wolff-Roux law is implemented our approach is to systematically vary the remodeling rule. The resulting changes in the microstructure and its time evolution are then characterized and compared to what is known from real bone allowing indirect conclusion on the form of the remodeling rule. With a separate model we address the changes at the hierarchical level of the bone material, which evolves in an interplay between remodeling and mineralization of the bone matrix.

2 Computational plasticity

Organizers:

Dierk Raabe, MPI für Eisenforschung
Peter Gumbsch, Fraunhofer-Institut für Werkstoffmechanik

Monday, March 27, 16:00 - 18:00

Room: H 105

Polycrystal Mechanics and Anisotropy

Chair:

Dierk Raabe

16:00	Van Houtte	H 105

MULTISCALE APPROACH FOR TEXTURE-BASED ANISOTROPIC YIELD LOCI

Paul Van Houtte, A. Van Bael, Department MTM, Katholieke Universiteit Leuven, Belgium

Constitutive models to be used in FE models for metal forming (at room temperature), or in models for the prediction of forming limit curves of sheet materials, should ideally be able to reproduce the flow stress, work hardening and work softening behaviour (also at changing strain paths), strain rate sensitivity, and plastic anisotropy as caused by crystallographic texture. Input from materials science and solid state physics is required for this. Fundamentally, materials science is an exercise of changing scales: from atomistic level to macroscopic behaviour; many different time and length scales need to be considered. The resulting models should reflect these different scales. A very critical issue then is the interaction from one scale to another. It is the purpose of the present paper to illustrate an application of this concept in polycrystal plasticity, using hierarchical models, i.e. that the model of a given scale contains parameters which must be identified by models on a finer scale. The application involves a model for a convex yield locus/plastic potential at macroscale, the parameters of which are to be identified by a 2-level model (meso/macro) for the polycrystal. The anisotropy due to texture can be assessed for in an efficient way. The possible extension to a 3-level model (micro, meso, macro) is discussed. This would be needed for the implementation of the effect of strain path changes.

16:20	Riedel	H 105

TEXTURE IN MG AND DUAL PHASE MATERIALS

Hermann Riedel, T. Walde, C. Poizat, Fraunhofer-Institut für Werkstoffmechanik
A. Prakash, J. Ocenasek, P. Gumbsch, Fraunhofer-Institut für Werkstoffmechanik

(Title shortened)
The evolution of texture in magnesium is described by a self-consistent texture model, which includes twinning and recrystallization. The model parameters are adjusted to fit measured stress-strain curves in tension and compression and the results demonstrate the pronounced tension-compression asymmetry of rolled magnesium sheets as a consequence of twinning. The softening at larger strains and elevated temperatures is explained as a result of recrystallization. It is further demonstrated that the texture, and therefore the yield, locus changes considerably during tension or compression tests.

Texture evolution in dual phase steels can also be described by a self-consistent model. Some special features of polycrystal deformation, however, cannot be captured by self-consistent models or similar homogenization methods. In such cases polycrystal models based on finite element analyses with continuum single-crystal plasticity are applied. As an example, the phenomenon of grain curling in bcc metals during wire drawing is reproduced by such a model.

16:40	Gottstein	H 105

SIMULATION OF TEXTURE AND ANISOTROPY OF ALUMINUM ALLOYS

Günter Gottstein, J. Neumann, RWTH Aachen
M. Crumbach, Institut für Metallkunde und Metallphysik, RWTH Aachen
R. Kopp, Institut für Bildsame Formgebung, RWTH Aachen

The processing and service properties of a metallic component are affected by the anisotropy of the material. This anisotropy is due to a crystallographic texture which is generated during materials processing. In particular, crystallographic slip during deformation and recrystallization during annealing strongly impact texture development. For prediction of anisotropy during the final forming operation the texture evolution during materials processing has to modeled. This requires high accuracy of texture simulation since erroneous predictions will propagate and aggravate along the process chain. The physical approach of deformation and recrystallization texture simulation will be introduced and applied to through-process texture simulation of select aluminum alloys.

17:00	**Böhlke**	**H 105**

MODELING OF ANISOTROPY

Thomas Böhlke, Institut für Mechanik, Otto-von-Guericke-Universität Magdeburg

(Title shortened)

From the numerical point of view, large scale FE computations based on the Taylor model are very time-intensive and storage-consuming if the crystallographic texture is approximated by several hundred discrete crystals. The presentation focuses on the problem of approximating a given crystallite orientation distribution function by a small set of texture components. The equivalence of this task to a Mixed Integer Quadratic Programming problem (MIQP) is shown (Boehlke et al., to appear in Scripta Materialia 2006). The Taylor model in its standard form, which is based on discrete crystal orientations, has the disadvantage that the anisotropy is significantly overestimated if only a small number of crystal orientations is used. Therefore a modified Taylor model is discussed which allows to reduce the overestimation. The peak intensity is reduced by modeling the isotropic background texture by an isotropic material law.

Furthermore, an extension of the widely used Mises-Hill anisotropic plasticity model is suggested and discussed. In a first step the Mises-Hill anisotropy tensor – which specifies the quadratic flow potential – is expressed in terms of the the 4th-order moment tensor of the crystallite orientation distribution function. It is well known that specific anisotropies of polycrystalline metals generally cannot be modeled by quadratic flow potentials. Motivated by this fact the concept of anisotropic equivalent stress measures is generalized by incorporating the higher-order moment tensors in a second step.

17:20	**Roters**	**H 105**

CRYSTAL PLASTICITY FEM AT LARGE SCALES AND AT SMALL SCALES

Franz Roters, A. Ma, Dierk Raabe, Max-Planck-Institut für Eisenforschung

Crystal plasticity FEM is gaining more and more importance in the simulation of plastic deformation. However, in its original form it is a single crystal model that accounts for the crystal structure and the orientation of a single crystal but does not consider any other features of the microstructure. These two facts lead to several complications in the application of CPFEM both at large scales and at small scales.

When applied to large scales, the key problem is the statistical representation of the materials crystallographic texture. The use of a full texture representation by single orientations on each integration point is computational too expensive for practical application. Therefore, two different approaches are introduced. One is the texture representation by texture components, the other one a direct sampling of the orientation distribution function. Both methods are applied to a deep drawing process and compared with respect to results and computational efficiency.

At small scales the situation is rather different. Here the representation of additional microstructural features such as grain boundaries is paramount for the correct simulation of the local distribution of stresses and strains. To achieve this more physics based constitutive models are needed. We present here a non-local dislocation density based constitutive model for FCC and BCC metals and its application to single as well as bicrystal deformation.

17:40	Miehe	H 105

A Fast Multiscale Model For Texture-induced Anisotropic Plasticity

Christian Miehe, Institut für Mechanik (Bauwesen), Universität Stuttgart

The lecture outlines recent developments towards fast computational orientation and stress updates in finite plasticity of polycrystals with texture-induced anisotropy. In a first step, we consider a purely macroscopic setting of anisotropic finite plasticity in the logarithmic strain space based on evolving structural tensors. Next, we outline recent achievements in the algorithmic formulation of Taylor-type polycrystal models with discrete grain orientations in terms of fast large-step-sized re-orientation updates for elastic-plastic and rigid-plastic single crystals. In a third step, the above two approaches are combined to a new multi-scale model, where the evolution of the macroscopic structural tensors is governed by an accompanying fast Taylor-type update of a discrete aggregate of single crystals. This approach yields a characteristic two-scale setting suitable for large-scale numerical computations. We demonstrate its performance by means of representative numerical simulations of f.c.c. polycrystals.

3 Feedback flow control

Organizers:

Bernd Noack, TU Berlin
Rudibert King, TU Berlin

Monday, March 27, 16:00 - 18:00

Room: H 1058

Chair:

Rudibert King
Bernd R. Noack

16:00	Schmidt	H 1058

Low-dimensional Input-output-modeling Of Distr. Parameter Systems

Michael Schmidt, Institut für Mathematik, TU Berlin

Model-based feedback flow control requires models of very moderate size, whereas flow systems are initially often formulated as distributed parameter systems based on Stokes, Navier-Stokes or Euler equations. Mathematical model reduction techniques aim at extracting the most essential system information, like the input-output behaviour, to bridge this gap. Most approaches like proper orthogonal decomposition, balanced truncation or Krylov subspace methods have been developed for finite-dimensional systems and take a sufficiently accurate spatial discretization of the underlying partial differential equation as starting point.

In this talk, we present a systematic framework for the low-dimensional modeling of the input-output behavior of linear time-invariant distributed parameter systems due to a direct discretization of the corresponding input-output mappings. This approach provides global error bounds for the approximation of the input-output-behavior and gives insight in how to choose efficiently the discretization parameters for the time and space discretization of inputs, states and outputs in order to obtain a desired accuracy. We present some numerical examples.

16:20	Becker	H 1058

Separation Control On A Trailing Edge Flap Using Extremum Seeking

Ralf Becker, Ralf Petz, Rudibert King, Wolfgang Nitsche, TU Berlin

We present experimental results on adaptive closed-loop separation control on a two dimensional generic high-lift configuration. Since model-based closed-loop flow control suffers form the lack of sufficient simple physical models for this configuration, a non-model-based control strategy, namely the gradient based extremum seeking scheme, is used here. The controller exploits spanwise distributed pressure measurements and adjusts pulsed jets near the leading edge of the single slotted flap. The jets are used for flow excitation in order to suppress separation over the flap at high angles of attack, high deflection angles or to reattach an already separated flow. Starting form a single-input single-output (SISO) design, the extremum seeking scheme is extended to both a SISO slope seeking approach and a multiple-input multiple-output (MIMO) approach. MIMO control accounts for spanwise distributed, small scale separation phenomena and shows the best performance. Additionally, this case even improves lift gain compared to preliminary open-loop studies. A lift increase is not only observed for angles of attack for which the unactuated flow obviously separates, but as well for smaller angles which were assumed before to lead to an unseparated flow. Hence, closed-loop results demonstrate the capability of slope seeking control to adjust the control signal automatically in an energy efficient sense such that separation is minimized even in the presence of disturbances.

16:40	Henningson	H 1058

Control Of Instabilities In A Cavity

Dan Henningson, Jerome Hoepffner, Espen Åkervik, KTH Mechanics, Sweden
Uwe Ehrenstein, University of Nice Sophia-Antipolis, France

A two-dimensional incompressible boundary-layer flow along a smooth-edged cavity is considered. Unstable global modes appear above a critical inflow Reynolds number of approximatively 300. We aim at stabilizing the flow using feedback control. Sensors measure shear stress at the downstream lip of the cavity, where the unstable modes are most energetic, and actuators apply blowing and suction upstream, where sensitivity is highest. The optimal control loop, in the form of control and estimation feedback gains, is computed through the solution of two Riccati equations. The high dimentionality of this strongly nonparallel flow, once discretized, challenges the design of an optimal feedback controller. A reduced dynamic model is thus constructed for small perturbations to the basic flow by

selecting the least stable eigenmodes of the linearized Navier-Stokes equations for this geometry. The flow system is discretized using Chebyshev collocation in both the streamwise and wall-normal direction and the global eigenmodes are computed by means of the Krylov-Arnoldi method. Flow stabilization is demonstrated using a model reduced to 50 states, provided the actuators are smooth, with slow time scales.

17:00	**Morzynski**	**H 1058**

Continuous Mode Interpolation For A Priori Flow Models & Control

Marek Morzynski, Witold Stankiewicz, Poznan University of Technology, Poland
Bernd R. Noack, Frank Thiele, TU Berlin HF1
Gilead Tadmor, Northeastern University, USA

Reduced Order Models (ROMs) reproducing the controlled flow dynamics are intensively studied. The requirements of simplicity of the model and resolving the different operating conditions are solved with the use of mode interpolation.

The linear mode interpolation is performed with the modes adequate for distant operating conditions. The method of determining the continuous set of the eigenmodes without any geometric transformations is presented. The novel method is demonstrated on the benchmark of the circular cylinder wake flow. The construction of parameterized model based on the solution of steady Navier-Stokes equations and interpolation of underlying eigenmodes is applied to derive a fully *a priori* model of the flow without any empirical data.

17:20	**Tadmor**	**H 1058**

Interpolated Galerkin Models And Their Use In Flow Control

Gilead Tadmor, CDSP, Northeastern University, USA
Bernd R. Noack, Rudibert King, Oliver Lehmann, TU Berlin
Marek Morzynski, Witold Stankiewicz, Poznan University of Technology, Poland

The high resolution of reference trajectories, achievable with low order empirical proper orthogonal decomposition (POD) Galerkin models, makes these models attractive in flow control applications. Yet this advantage is commonly offset by their sensitivity to flow parameter variations and inability to represent transients, actuation and disturbance effects. Ample representation is possible when modes are obtained from multiple operating conditions, but the increased dimension can also be detrimental in practical feedback implementation. Addressing the 2D cylinder wake flow, we show that good dynamic representation of natural and actuated transients between the natural attractor and the steady solution can be represented by a very low (three states) model, based on a parameterized family of mode sets. Each mode set includes the first harmonic POD mode pair of an intermediate vortex shedding level, and of a “shift mode”, representing the local dynamic mean-field correction. The various mode-sets are structurally similar and represent the continuous deformation of dominant coherent structures, as the flow transition from the natural attractor to the steady solution. Moreover, we show that empirical POD modes are not necessary and alternative mode sets can be based purely on linear stability analysis modes of appropriate linearizations of the Navier-Stokes equations.

The control algorithm is based on dissipative actuation, in which the concept of the phase of the nearly periodic vortex shedding process is fundamental. The correct concept of phase is associated with the selection of the best fitting mode-set. We demonstrate sensor based observers and feedback, and highlight intrinsic performance inhibitors. In particular, we review the inherent instability of a sensor based feedback, near the steady solution, and illustrate the contribution of sensor location to sensitivity to the flow state and to delays.

17:40	Cordier	H 1058

Control Of The Cylinder Wake In The Laminar Regime By Trpod

Laurent Cordier, Michel Bergmann, Jean-Pierre Brancher, LEMTA, France

In this communication we investigate the optimal control approach for the drag minimization of the circular cylinder wake flow in the laminar regime ($Re = 200$). The control function is the time harmonic angular velocity of the rotating cylinder. The resolution of the discretized optimality system, built from the Navier-Stokes equations as state equation, leads to tremendous computational costs. With the aim of making computationally effective the optimization process, a Proper Orthogonal Decomposition (POD) Reduced Order Model (ROM) is then derived to be used as state equation. The range of validity of the POD ROM is generally limited to a vicinity of the design parameters in the control parameter space. Therefore, to overcome this difficulty, we propose to use the Trust-Region Proper Orthogonal Decomposition (TRPOD) approach, originally introduced by Fahl (2000), to update the reduced order models during the optimization process. Benefiting from the trust-region philosophy, rigorous convergence results prove that the iterates produced by the TRPOD algorithm will converge to the solution of the high fidelity optimization problem. Due to the use of reduced order models, the computational work involved by the TRPOD is then greatly reduced. Finally, the application of the TRPOD to the cylinder wake flow configuration leads to a relative mean drag reduction greater than 30% for reduced numerical costs.

1 Numerical Analysis of Partial Differential Equations

Organizers:

Marco Verani, Politecnico of Milan
Sören Bartels, Humboldt-Universität zu Berlin

Tuesday, March 28, 09:30 - 12:00

Room: H 104

Chair:

Sören Bartels
Marco Verani

9:30	**Verani**	**H 104**

A Finite Element Formulation For A Shape Optimization Problem.

Marco Verani, MOX - Department of Mathematics, Politecnico of Milan, Italy
Pedro Morin, Instituto de Matemática Aplicada del Litoral, Santa Fe, Argentina
Ricardo H. Nochetto, Department of Mathematics, University of Maryland, College Park, USA

We present a variational framework for shape optimization problems. Our approach hinges on the following essential features: shape differential calculus, which expresses variations of bulk and surface energies with respect to domain changes; a semi-implicit time discretization, which requires no explicit parametrization of the domain boundary, and is sufficiently flexible to accomodate several scalar products for the computation of normal velocity; a finite element method for space discretization. We propose a Schur complement approach to solve the resulting linear systems. We discuss applications of this framework to optimal shape design for PDE, in particular to a problem arising in optimal design for drug eluting stents.

9:50	Jensen	H 104

Discontinuous Galerkin Methods For First-order Accretive Systems

Max Jensen, Institut für Mathematik, Humboldt-Universität zu Berlin

We study the numerical solution of Friedrichs systems by discontinuous Galerkin finite element methods (DGFEMs). Friedrichs systems are boundary value problems with linear first-order accretive partial differential operators and allow the unified treatment of a wide range of elliptic, parabolic, hyperbolic and changing-type equations.

DGFEMs have been successfully applied for the numerical solution of boundary value problems with discontinuous exact solution. We consider the convergence of the discontinuous Galerkin method in graph spaces, in which the exact solution of the Friedrichs system is only assumed to be weakly differentiable in characteristic direction. We identify criteria under which the finite element solution converges in the energy norm to the discontinuous exact solution. We thereby permit domains with corners and allow changes in the characteristic multiplicity of the domain boundary, which are in direct correspondence to type-changes in the boundary conditions.

10:10	Moura	H 104

Coupling 3d-1d Fluid-structure Interaction Models In Haemodynamics

Alexandra Moura, MOX - Department of Mathematics, Politecnico of Milan, Italy

Three-dimensional (3D) simulations of blood flow in medium to large vessels are now a common practice. These models consist of the 3D Navier-Stokes equations for incompressible Newtonian fluids coupled with a model for the vessel wall structure. However, it is still computationally unaffordable to simulate very large sections, let alone the whole, of the human circulatory system with fully 3D fluid-structure interaction models. Thus truncated 3D regions have to be considered.

Reduced models, one-dimensional (1D) or zero-dimensional (0D), can be used to approximate the remaining parts of the cardiovascular system at a low computational cost. These models have a lower level of accuracy, since they describe the evolution of averaged quantities, nevertheless they provide useful information which can be fed to the more complex model.

More precisely, the 1D models describe the wave propagation nature of blood flow and coupled with the 3D models can act also as absorbing boundary conditions.

We consider in this work the coupling of a 3D fluid-structure interaction model with a 1D hyperbolic model. We study the stability of the coupling and present some numerical results.

10:30	Vergara	H 104

Defective Boundary Conditions In Haemodynamics

Christian Vergara, MOX - Department of Mathematics, Politecnico of Milan, Italy

In the numerical simulation of blood flow problems there is sometimes the problem of solving the Navier-Stokes equations with boundary conditions prescribing the flow rate or the mean pressure on the artificial sections of the vascular district at hand. In order to have a well posed mathematical problem, these conditions need to be completed. In the bioengineering community, the flow rate problem is usually faced by choosing *a priori* a velocity profile on the inflow/outflow sections, to be fitted with the assigned flow rates, while the mean pressure problem by imposing zero tangential stress and a constant normal stress. Both these approaches strongly influence the numerical solutions.

We propose two new approaches: the first, exclusively for the flow rate problem, is based on an augmented formulation of the problem, in which the conditions on the flow rates are prescribed in a weak sense by means of Lagrangian multipliers. The second is based on the control theory and could be used both for the flow rate and for the mean pressure problem. We present some numerical algorithms and several numerical results and applications.

10:50	Cimrák	H 104

The Landau-lifshitz Model For Shape Optimization Of Mram Memories

Ivan Cimrák, Valdemar Melicher, Ghent University, Belgium

We are studying an optimal shape design of a magnetic core in Magneto-resistive Random Access Memories (MRAM) which possibly replace other types of RAM memories used nowadays. We are interested in correct mathematical analysis and numerical implementation.

MRAM consists of a plate with a grid of ferromagnetic cells separated by diamagnetic material. Above and below this plate two grids of wires are placed. For writing of one bit in a particular cell we use the current in two perpendicular wires which intersect above and below this cell. The magnetic field induced by these currents changes the magnetization of the core, which represents a written data.

Of course, the induced field will effect also neighboring cells. We try to optimize the shape of one cell such that the effects of writing on the neighboring cells are minimal.

For the description of the ferromagnetic phenomena in the core we use the Landau-Lifshitz model. A bit is successfully stored if the whole cell is magnetized "almost" in one direction given by, e.g., vector **p**. So the average projection of the magnetization onto **p** is the quantity characterizing the writing process. Using this quantity we are able to construct a regularized Tikhonov functional.

The geometry of ferromagnetic core is described by the level set formalism. To gain an optimal shape we employ a gradient method which in each step updates the level set function in descent direction.

11:10	**Bartels**	**H 104**

Approximation Of Landau-lifshitz-gilbert Equations

Sören Bartels, Humboldt-Universität zu Berlin

The Landau-Lifshitz-Gilbert equation describes magnetic behavior in ferromagnetic materials. The construction of numerical strategies to approximate weak solutions for this equation is made difficult by its top order nonlinearity and nonconvex constraint. In this talk, we discuss necessary scaling of numerical parameters and provide a refined convergence result for a fully explicit scheme first proposed by Alouges and Jaisson. The conditions on the time step size turn out to be very restrictive and this motivates the discussion of an implicit scheme which allows unconditional convergence. As application, we numerically study finite time blow-up in two dimensions for the regime of small damping parameter and indicate generalizations of the approximation scheme for the simulation of Maxwell-Landau-Lifshitz-Gilbert equations. The talk is based on joint work with A. Prohl (ETH Zurich).

2 Multiscale Systems in Refined Network Modeling: Analysis and Numerical Simulation

Organizers:

Mónica Selva Soto, Humboldt-Universität zu Berlin
Andreas Bartel, Bergische Universität Wuppertal

Tuesday, March 28, 09:30 - 12:00

Room: H 105

Chair:

Andreas Bartel
Mónica Selva Soto

9:30	Bodestedt	H 105

Perturbation Analysis Of An Integrated Circuit Pdae

Martin Bodestedt, Institut für Mathematik, TU Berlin

We perform a perturbation analysis on a Partial Differential Algebraic Equation (PDAE) modelling an electric network coupled with charge transport equations for semiconductors. It turns out that the perturbation index of the coupled system can be determined by investigating the topology of the electric network graph.

9:50	Selva Soto	H 105

A Coupled System For Electrical Circuits. Numerical Simulations.

Mónica Selva Soto, Institut für Mathematik, Humboldt-Universität zu Berlin

In this work we are interested in the numerical simulation of electrical circuits modelled by a coupled system of differential algebraic equations and partial differential equations. The partial differential equations describe the semiconductor devices in the circuit. For the numerical solution of this model we discretize in space the partial differential equations in the system and solve the resulting differential algebraic equation. During the talk a brief description of the model will be given and some of its properties will be presented. It is also our purpose to discuss some of our simulation results and compare them with those obtained using a different approach, the coupling of two simulators.

10:10	Brunk	H 105

COUPLING OF ENERGY-TRANSPORT MODEL WITH MNA-EQUATIONS FOR CIRCUITS

Markus Brunk, Ansgar Jüngel, Institut für Mathematik, Johannes Gutenberg Universität

Due to miniaturization of integrated circuits it becomes desirable to simulate electric circuits including distributed models of semiconductors. As with decreasing spatial dimension of the devices and increasing frequency of the operational voltage it becomes crucial to take into account thermal effects and transient behaviour, for majority carriers the transient energy-transport (ET) model is employed. For minority carriers we use the simpler drift-diffusion model. The ET-model can still be written in a drift-diffusion formulation, which is utilized in the discretization.

We describe the coupling of the network DAEs and the semiconductor PDEs. Furthermore we dwell on the numerical solution by use of mixed hybrid finite elements for space-discretization, which accounts for current-continuity.

Finally we will illustrate the results of the simulation of a simple circuit containing a semiconductor device.

10:30	Sickenberger	H 105

EFFICIENT TRANSIENT NOISE ANALYSIS IN CIRCUIT SIMULATION

Thorsten Sickenberger, Renate Winkler, Institut für Mathematik, Humboldt-Universität zu Berlin

Stochastic differential-algebraic equations (SDAEs) arise as a mathematical model for electrical network equations that are influenced by additional sources of Gaussian white noise.

We start with adaptive linear multi-step methods for stochastic differential equations (SDEs) and study mean-square consistency, stability in the mean-square sense and mean-square convergence. Further, in the case of small noise we develop a local error analysis in terms of the step-size and a small parameter, where the latter quantifies the smallness of the noise. We obtain conditions that ensure mean-square convergence for the special case of one- and two-step Maruyama schemes and we present a strategy for controlling the step-size in the numerical integration. It is based on estimating the mean-square local errors and leads to step-size sequences that are identical for all computed paths.

Test results of drift-implicit schemes with a mean-square step-size control are presented for SDEs and a stochastic circuit model.

10:50	Bartel	H 105

Analysis And Integration Of Multirate Pdae Including Wavelets

Andreas Bartel, Stephanie Knorr, Bergische Universität Wuppertal

In communication electronics, one couples analog and digital units. Here arise systems with largely differing time scales, which exhibit quasi-periodic behavior, naturally. Also in the coupling of electric network equations with heat conduction and other applications multiscaled systems occur and need special treatment for an efficient simulation.

In the case of quasi-periodic signals, one can asign multiple time variables to describe differing time scales of subsystems and in multitone inputs. This results in multivariate functions and transforms the descriptor model (DAE) of the electric network to a Multirate-Partial-Differential-Algebraic Equation (MPDAE). Indeed, this hyperbolic equations can be solved more efficiently using a method of characteristics.

In this talk, we discuss the MPDAE setup and its properties. To incooperation signals with digital-like structures, very steep gradients, a wavelet based MPDAE approach is introduced and its simulation aspects are discussed.

3 Iterative Methods for Large and Structured Matrix Computations

Organizers:

Bor Plestenjak, University of Ljubljana
Daniel Kressner, University of Zagreb

Tuesday, March 28, 09:30 - 12:00

Room: H 1058

Chair:

Daniel Kressner
Bor Plestenjak

09:30	**Hochstenbach**	**H 1058**

Advances In The Numerical Solution Of Polynomial Eigenproblems

Michiel Hochstenbach, *Case Western Reserve University, USA*

We will discuss various novel techniques in the numerical solution of polynomial eigenproblems:

- harmonic and refined Rayleigh–Ritz techniques to compute interior eigenpairs;
- how to compute eigenpairs corresponding to infinite eigenvalues;
- how to avoid infinite eigenvalues if we are interested in the largest eigenvalues.

The approaches will be combined with Jacobi-Davidson type techniques.
Part of this work is joint with Gerard Sleijpen, Utrecht University.

09:50	**Plestenjak**	**H 1058**

Numerical Methods For The Banded Quadratic Eigenvalue Problem

Bor Plestenjak, Department of Mathematics, University of Ljubljana, Slovenia

We consider numerical methods for the computation of the eigenvalues of the banded quadratic eigenvalue problem (QEP) $Q(\lambda)x = (\lambda^2 M + \lambda C + K)x = 0$. The eigenvalues are computed as zeros of the characteristic polynomial $p(\lambda) = \det(Q(\lambda))$.

In the first case the matrices are tridiagonal and the QEP is hyperbolic, i.e., M is positive definite and $(x^*Cx)^2 > 4(x^*Mx)(x^*Kx)$ for all $x \neq 0$. The eigenvalues are all real and we apply the bisection, Laguerre's method, and the Ehrlich-Aberth method. Initial approximations are provided by a divide-and-conquer approach using rank two modifications. For a stable and efficient evaluation of the characteristic polynomial p and its derivatives we can use the three-term recurrences, the QR factorization, or the LU factorization.

Numerical experiments suggest that this approach could also be applied to nonhyperbolic QEPs with a more general structure, such that the characteristic polynomial can be evaluated in a linear time. We will show how the Ehrlich-Aberth method combined with the LU factorization can be applied to the banded QEPs.

10:10	Jarlebring	H 1058

A Quadratic Eigenproblem In The Analysis Of A Time Delay System

Elias Jarlebring, Institut Computational Mathematics, TU Braunschweig

In this work we solve a *quadratic eigenvalue problem* occurring in a method to compute the set of delays of a *time delay system* (TDS)

$$\dot{x}(t) = A_0 x(t) + \sum_{k=1}^{m} A_k x(t - h_k),$$

such that the system has an imaginary eigenvalue. The computationally dominating part of the method is to find all eigenvalues z of modulus one of the quadratic eigenvalue problem

$$\begin{aligned} 0 \quad = \quad & \Bigg(I \otimes A_m + z^2 A_m \otimes I + \\ & z \left(\sum_{k=0}^{m-1} I \otimes A_k e^{-i\varphi_k} + A_k \otimes I e^{i\varphi_k} \right) \Bigg) u, \end{aligned}$$

where $\varphi_1, \ldots, \varphi_{m-1} \in \mathbb{R}$ are free parameters and u the vectorization of a Hermitian rank one matrix.

Because of its origin in the vectorization of a *Lyapunov type matrix equation*, the quadratic eigenvalue problem is, even for moderate size problems, of very large size. We show one way to treat this problem by exploiting the Lyapunov type structure of the quadratic eigenvalue problem when constructing an iterative solver. More precisely, we show that the *shift-invert operation* for the companion form of the quadratic eigenvalue problem can be efficiently computed by solving a *Sylvester equation*. The usefulness of the Lyapunov exploitation is demonstrated with examples.

11:00	**Kressner**	**H 1058**

Iterative Methods For Large Structured Eigenvalue Problems

Daniel Kressner, Department of Mathematics, University of Zagreb, Croatia

This talk overviews recent advances in solving structured eigenvalue problems for matrices which, besides being large and possibly sparse, carry additional structure. Among these matrices, we cover sums of Kronecker products, linearizations of polynomials, and structures that induce certain eigenvalue symmetries such as Hamiltonian matrices. Computational methods tailored to the structure have the potential to solve large-scale eigenvalue problems more efficiently and more reliably. We highlight both facts by a set of selected examples. Moreover, the role of structured condition numbers on the accuracy and convergence of iterative eigenvalue solvers is emphasized. Aimed at a wider audience, this talk summarizes existing knowledge and open problems connected to some of the subsequent talks in the minisymposium.

11:20	**Grubisic**	**H 1058**

On Accuracy Of Hierarchical Rayleigh-ritz Methods

Luka Grubisic, Institut für Reine und Angewandte Mathematik, RWTH Aachen

We present an analysis of the accuracy of hierarchical(adapted) finite element Rayleigh–Ritz method for elliptic self-adjoint eigenvalue problems. The celebrated Wilkinson's Schur complement trick is adapted and applied to yield a new class of Temple-Kato like inequalities which are particularly suited to a situation in which we are estimating a multiple eigenvalue (of an elliptic self-adjoint operator) by a cluster of Ritz values.

The new approximation estimates are combined with Doerfler and Nochetto's analysis of the saturation assumption (cf. *Numer. Math., 91(1)*) to obtain a detailed analysis of the (preconditioned) residual approximation measure of Neymeyr (cf. *Numer. Linear Algebra Appl., 9(4)*). We also show how to adapt this estimation method to a situation when one is approximating a cluster of eigenvalues.

New eigenvector and invariant subspace approximation estimates, in which the same (preconditioned) residual measure features, accompany the eigenvalue results. Numerical experiments, illustrating the theory, will also be presented.

11:40	Peláez Montalvo	H 1058

Structured Condition Number Of Multiple Eigenvalues

María José Peláez Montalvo, Julio Moro, Escuela Politécnica Superior, Universidad Carlos III de Madrid, Spain

We study how does the structure of a matrix influence the condition number of a multiple, eventually, defective eigenvalue. We present results on the Hölder condition number for particular classes of structured matrices, including complex symmetric, persymmetric, skew-symmetric, and skew-Hermitian matrices. We also present results on the Hölder condition number of a complex eigenvalue under real perturbations.

4 Nano-to-macro characterization of hard and soft biological tissues: The contribution of applied mechanics and mathematics

Organizers:

Bernd Markert, Universität Stuttgart
Christian Hellmich, TU Wien

Tuesday, March 28, 09:30 - 12:00

Room: H 2013

Chair:

Bernd Markert
Christian Hellmich

9:30	Rohan	H 2013

Homogenization Approach To Multi-compartment Model Of Perfusion

Eduard Rohan, Department of Mechanics, University of West Bohemia, Czech Rupublic

The paper deals with modelling of the coupled diffusion-deformation processes in biological tissues with potential applications in describing the blood perfusion, or fluid filtration phenomena in general. The micromodel to be homogenized is based on the Biot type model for the incompressible medium. Due to the strong heterogeneity in the permeability coefficients associated with three compartments of the representative microstructural cell (RMC), the homogenization of the model leads to the double diffusion phenomena. The resulting homogenized equations, involving the stress-equilibrium equation and other two equations governing the mass redistribution, describe the parallel diffusion in two high-conducting compartments (arterial and venous sectors) separated by the low conducting matrix which represents the perfused tissue. To obtain the homogenized model, the method of two scale convergence is applied. The homogenized coefficients are defined in terms of the characteristic response of the RMC. It is possible to identify the instantaneous and fading memory viscoelastic coefficients; other effective parameters, controlling the fluid redistribution between the compartments, are involved also in time convolutions. The numerical algorithms for the two scale modelling are discussed and illustrative examples are introduced.

9:50	Hellmich	H 2013

Bone (re)modeling: Poromicromechanical Aspects

Christian Hellmich, Cornelia Kober, Institut für Mechanik der Werkstoffe und Strukturen, TU Wien

Despite the complex hierarchical organization of bones, it was recently possible to identify a few elementary components at the micro and nanolevel of the material and their interactions, for the explanation of the diversity of macroscopic (poro-)elastic properties of different bones The mechanical properties (i.e. elasticity) of these elementary components are (up to experimental scattering) the same for all bones; they are “universal”, i.e., independent of tissue-type, species, and anatomical location. The mechanical interaction between these elementary components (mechanical morphology) and the dosages of these components in different tissues determine the macroscopic material properties. Having in mind that these dosages are dependent on complex biochemical control cycles (defining the metabolism of the organism), the purely mechanical theory can be linked to biology, biochemistry, and, on the applied side, to clinical practice.

In particular, the added value of micromechanics-based, well-validated anisotropic and inhomogeneous material properties for the understanding of the load carrying behavior at the organ level will be shown, by example of a human mandible. Two items are highly noteworthy: (i) Consideration of anisotropy implies minimization of (macroscopic) volumetric strains throughout the organ, reflecting (kind of) mechanical optimization of the organ; (ii) The (undrained) pore pressure distribution throughout the organ, resulting from a typical biting load case suggests characteristic mass flow vectors, indicating locations of concentrated nutrition supply. This would primarily enhance osteoblastic activity, leading to pronounced bone mass formation in these locations. Indeed, the locations identified through the simulation do match regions of high apparent mass density.

10:10	Steeb	H 2013

Remodeling And Adaptation Processes Of Biological Tissues

Holger Steeb, Tobias Ebinger, Stefan Diebels, Lehrstuhl für Technische Mechanik, Universität des Saarlandes

In the following contribution we investigate two different models describing mechanically-induced growth of biological tissues. (i. e. hyperplasia, cell migration, proliferation and hypertrophy).

The first model is based on an open system approach and is developed to describe the macroscopical adaptation of hard tissues, e. g. bones. Therefore, we apply an extended continuum theory to capture the spongy microstructure of the bone architecture. The reliability and efficiency of the model is demonstrated with respect to hip-replacement surgeries.

The limitation of the former investigation is worked out while extending the model to a multi-phase approach. We apply the concepts of the Theory of Porous Media to simulate growth and adaptation. In contrast to single-phase models, the growth process is governed by the mass exchange between the bulk material and the interstitial fluid. As a consequence, the present multi-phase approach intends to give more insight into the reasons of the governing biomechanical process, while the single-phase model describes the effects of tissue growth just phenomenologically by its consequences.

10:30	Markert	H 2013

Coupled Multi-field Analysis Of Avascular Tumor Growth

Bernd Markert, Alfredo Salinas, Wolfgang Ehlers, Institut für Mechanik (Bauwesen), Universität Stuttgart

The theoretical description and numerical analysis of avascular tumor growth in soft tissues poses a very difficult challenge due to the complicated biological scenario on hand. In regard to the complex metabolic processes governed by nutrient, angiogenic, and growth factors, it is convenient to proceed from a macroscopic modeling approach instead of getting lost in the description of the physiochemical mechanisms on the cellular level. Following this, a thermodynamically consistent model for volumetric tumor growth is developed by recourse to mixture and porous media theories. In particular, the hydrated organic tissue is treated as a biphasic mixture constituted by a porous solid (the cells), which is permeated by an organic fluid. Since the imbalances of production and degradation of the individual constituents associated with growth and necrosis of the tumor tissue are strongly influenced by several chemical factors (nutrients, enzymes, etc.), the model incorporates two additional caloric state variables. Essentially, they can be thought of as locally available "growth energies", which are determined by the constituent energy balances.

10:50	Hofstetter	H 2013

Continuum Micromechanics Estimation Of Wood Strength

Karin Hofstetter, Christian Hellmich, Josef Eberhardsteiner, Institut für Mechanik der Werkstoffe und Strukturen, TU Wien

Wood strength is highly anisotropic: The material resistance in stem direction is about an order of magnitude higher than that orthogonal to the stem. Obviously, this anisotropy stems from the intrinsic structural hierarchy of the material. Wood is composed of wood cells, which are hollow tubes oriented in the stem direction. The cell wall is built up by stiff cellulose fibrils with crystalline cores and amorphous surfaces, which are embedded in a soft polymer matrix composed of hemicellulose, lignin, extractives, and water. The orientation of cellulose fibrils and tubular holes and the spatial gradation of porosity leads to anisotropy and inhomogeneity of the macroscopic material behavior.

The relation between (macroscopic) elastic material properties of wood and physical quantities at lower scales was recently expressed in the framework of continuum micromechanics. We here extend these investigations to tissue-specific anisotropic strength properties. Macroscopic material strength is governed by strain peaks in the material microstructure, which can be suitably characterized by quadratic strain averages over material phases, being effective for material phase failure. Macroscopic stress states estimated from local shear failure of lignin agree very well with corresponding strength experiments. This expresses the paramount role of lignin as strength-determining component in wood.

11:10	Götzen	H 2013

Novel Phenotypic Characterization Of The Mouse Skeleton.

Nils Götzen, Michael M. Morlock, Institut für Biomechanik, TU Hamburg-Harburg Tobias Kummer, Michael Amling, Klinik und Poliklinik für Unfall-, Hand- und Wiederherstellungschirurgie, UK Hamburg-Eppendorf

The understanding of biology has been transformed by the introduction of recombinant DNA technologies. Within this context the laboratory mouse has gained significance as a model organism to study human biology. Currently, the major limitation to use the full capabilities of genetic engineering is the inability to characterize the obtained phenotypes adequately. This is especially true for the field of skeletal research where the biomechanical competence of the bones need to be characterized using very small specimens.

In this study vertebrae of different mouse models representing a broad spectrum of skeletal phenotypes were characterized using a novel specimen-specific approach: the combination of experimental biomechanics with high-resolution FE-simulation based on micro-computed tomography. Additionally morphometrical parameters of the architecture were determined and tissue mineralization was measured using a newly developed non-invasive technique.

The results confirm the feasibility of this approach: a reliable characterization of the biomechanical tissue properties is possible using whole-bone specimens. The advantage of the specimen-specific approach as well as of the bone imaging modalities could be shown. Although the described techniques are labor intensive and require expertise with respect to numerical and experimental analyses, detailed knowledge about the influence of specific genes on the skeletal structure can be gathered.

1 Multi body dynamics

Organizers:

Christoph Woernle, Universität Rostock
Peter Betsch, Universität Siegen

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 2013

Control, optimization and identification

Chair:

Christoph Woernle
Klaus Zimmermann

13:30	Eberhard	H 2013

Controller Design For Parallel Kinematics Using Flexible Mbs

Peter Eberhard, Alexandra Ratering, Institut für Technische und Numerische Mechanik, Universität Stuttgart

Machine tools with parallel and hybrid kinematics developed to surpass conventional machines in speed while achieving the same accuracy present new challenges in the design and control of machine tools. Parallel kinematics exhibit inherently nonlinear dynamics over the whole workspace, machine vibrations become important as a lightweight design is used and independently controlled drives become infeasible due to the parallel setup.

Advanced multi-variable and nonlinear position control methods such as the presented flatness-based design show the potential to significantly increase the machine tool performance in comparison to standard linear control methods. Simulation results for a high performance machine tool with scissor-like kinematics based on a multibody system model indicate that an improvement of the machine tool accuracy by several orders of magnitude is possible. Experimental and simulation results for a smaller but equivalent test machine proof that with the nonlinear controller the trajectory error can be reduced considerably compared to the standard linear controller.

The development of a flexible multibody system model makes it possible to incorporate the effect of elasticities into the controller design and evaluation. Extensive simulation studies will allow to judge the effect of different control concepts e.g.ȧdditional active vibration damping, disturbance input decoupling etc. on the performance of the test machine, which is going to be equipped with a more flexible arm in the experiment as well.

A. Ratering; P. Eberhard: Flatness-based Control of a Machine Tool with Lambda-Kinematic. In: Proc. of the NOLCOS 2004, 6th IfAC-Symposium on Nonlinear Control Systems 2004.
R. Rothfuss; J. Rudolph; M. Zeitz: Flachheit: Ein neuer Zugang zur Steuerung und Regelung nichtlinearer Systeme. Automatisierungstechnik, 11, 517-525, 1997.
W. Schiehlen; P. Eberhard: Technische Dynamik. Teubner, Wiesbaden, 2004.
A. Shabana: Dynamics of Multibody Systems. Cambridge University Press, Cambridge, 1998.

13:50	Zimmermann	H 2013

Modelling And Controlling Of Worm-like Locomotion Systems

Klaus Zimmermann, Carsten Behn, Joachim Steigenberger, Khaldoun Abaza, Fakultät für Maschinenbau, TU Ilmenau

In this paper we introduce a certain type of mathematical models of worm-like locomotion systems and sketch the corresponding theory. The investigations are aimed at gaining insight into how such systems move, at finding kinematic gaits and hints for implementation as a hardware object (artificial worm).

As a physical model of an artificial worm we consider a chain of point masses in a straight line. Consecutive points are connected by massless links which are endowed with hidden (muscle-like) actuators. Each point mass contacts the ground through scales or spikes (of common orientation) preventing velocities from changing sign and possibly causing friction when in motion. From an analytical mechanics point of view we are dealing with rheonomic holonomic systems of finite degree of freedom (DOF) under differential inequality constraints.

By chance it could practically be promising to consider dry friction instead of spikes. In a rough terrain the friction coefficients might be unknown and randomly changing. Also, we suppose that only structural properties (e.g. minimum phase condition, strict relative degree) are known. Therefore, with respect to controlling the locomotion system, we have to apply the method of adaptive control to track the developed kinematic gaits.

14:10	Stadlbauer	H 2013

Autonomer Mobiler Roboter Mit SCARA-armeinheit

Klaus Stadlbauer, Hartmut Bremer, Johannes Kepler Universität Linz

Autonome Mobile Roboter sind heutzutage schon vielfältig im Einsatz. Ob zum Reinigen von Flughäfen, zum Transport von Gütern oder zum Erkunden fremder Planeten, sie alle haben gemein, dass sie autonom agieren und reagieren müssen.

Die Modellierung dieses nichtholonomen Roboters – welcher von der Konfiguration einem konventionellen Automobil entspricht – erfolgt mit Hilfe der Projektionsgleichung in Subsystemdarstellung. Der große Vorteil der Projektionsgleichung liegt darin, dass die nichtholonomen Bindungen implizit in diesem System enthalten sind. Weiters ist das Verfahren sehr flexibel bei der Wahl der Referenzkoordinatensysteme.

Die SCARA-Armeinheit (SCARA = Selective Compliance Assembly Robot Arm) wird in vertikaler Lage als Manipulator angebracht. Hier sieht man den Vorteil der Projektionsgleichung in Subsystemdarstellung, da ohne großen Rechenaufwand beliebig viele weitere Arme hinzugefügt werden können.

Die Bewegungsgleichung wird in den Zustandsraum transformiert und mittels einer nichtlinearen Zustandsrückführung eingangs- ausgangslinearisiert. Mit Hilfe eines diesem linearisierten System überlagerten linearen Reglers kann das Gesamtsystem geregelt werden.

In diesem System übernimmt die Steuerung bzw. Regelung eine Embedded-Computer Plattform, die über das Echtzeitsystem RT-Linux angesteuert werden soll. Natürlich muss hierbei gewährleistet werden, dass die Rechenzeit der Plattform den Anforderungen der Sensoren, der Pfadplanung und der Regelung gerecht wird.

14:30	Tändl	H 2013

Optimization Of Spatial Tracks Using A Morphing Approach

Martin Tändl, Andres Kecskeméthy, Lehrstuhl für Mechanik, Universität Duisburg-Essen

This paper describes an approach for optimizing multibody systems involving spatial tracks, addressing the problem of finding an optimal set of design parameters when no good initial guess is available. Due to nonlinearities of the objective function and singularities in the kinematic model, the optimization steps fail to converge or the algorithm gets lost in unfeasible points.

The present paper presents – for the case of design of spatial tracks – a four-stage procedure for sequentially guiding a standard optimization routine (in this case the routine `e04unc` from the NAG) from an arbitrary initial guess to the optimal configuration: (a) simplification of the model using point masses, (b) "flattening" of the spatial trajectory to start with a feasible solution, (c) morphing the trajectory back along the direction of projection and (d) application of full-model effects such as Coulomb friction and kinematical loops in a polishing stage. The approach has been tested when optimizing real roller coaster tracks with respect to passenger acceleration and compared with a genetic algorithm implementation, showing that objective function morphing renders faster for the regarded type of systems.

14:50	Meinicke	H 2013

Eccentricity And Misalignment Correction Of A Low-cost Imu

Alexander Meinicke, Christoph Woernle, Fakultät Maschinenbau und Schiffstechnik, Antriebstechnik und Mechatronik, Universität Rostock
Jörg Wagner, Institut für Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Universität Stuttgart

Inertial Measurement Units (IMU) with standard sensor configuration contain three orthogonally aligned gyros and accelerometers. To transform the accelerometer outputs into a Cartesian Reference Frame (CRF) it is necessary to consider the misalignment and eccentricity of each accelerometer with respect to the CRF. Here eccentricity is defined as the offset between the effective centre of the accelerometers and the origin of a the CRF. The eccentricity correction is necessary because eccentric accelerometers measure accelerations different from those at the origin of the CRF of a rotating IMU. Simplifications of the transformation of the accelerometer outputs into the CRF cause a transformation error. Considering the identification uncertainty of the specific misalignment and eccentricity of a given IMU and the typical angular-rate and -acceleration of a given application, it is investigated how the transformation error is affected by different simplifications. It is found that a radically simplified formula commonly used in inertial navigation applications is suitable if translational motion of the IMU dominates over rotational motion. The analysis is motivated by the application of a low-cost IMU to improve the measurement of the three-dimensional motion of the payload of a multiple cable crane.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 2013

Elastic multibody systems

Chair:

Hans Troger
Peter Betsch

16:00	Gerstmayr	H 2013

Improved Convergence In The Absolute Nodal Coordinate Formulation

Johannes Gerstmayr, Universität Linz

In the absolute nodal coordinate formulation (ANCF) nodal positions and nodal slopes are used to obtain finite elements which can undergo large deformation, contain correct rigid body inertia and are not based on an incremental procedure. Thin beam and plate elements based on the ANCF have been designed in the past. It has been shown that these elements have computational advantages, such as a constant mass matrix and convenient methods to rigidly connect several elements without needing constraints. However, it has been found out that these elements suffered from locking, in the small and in the large deformation case, especially when these elements were very thin.

The present paper shows several methods to avoid the problem of locking by means of reduced integration, higher order elements and a transformation of the virtual work of internal forces into beam quantities. A problem that has not been addressed so far, is the accuracy of stress and strain, which is investigated for the static case and compared to commercial finite element codes. It is furthermore known that thin ANCF beam-elements usually contain thickness modes of very high frequency compared to low frequency bending modes. This leads to very bad condition numbers of the system matrices for the static and the dynamic case. A modification of the virtual work of internal forces based on a relaxation of the high stiffness components is introduced. This leads to less high frequency modes while the convergence of the overall beam deformation is unaffected. The different locking-free elements are therefore subjected to a mode analysis and the rate of convergence in the Newton method is studied for geometrically nonlinear behavior.

The improvements of the element are shown for standard static examples as well as dynamic examples that are well known from the literature of flexible multibody dynamics.

16:20	Jungnickel	H 2013

Elastic Components In Multibody Dynamics And Order-n-algorithm

Uwe Jungnickel, Peter Maißer, Thomas Grund, Institut für Mechatronik e.V.

Global and local Ritz formulations are widely used in flexible multibody dynamics (floating frame of reference methods). They have been developed from a discretisation of continuum mechanics and hence strongly have influenced the coupling between multibody system (MBS) and FEM tools. Component mode synthesis methods like the Craig-Bampton algorithm yield suitable transformations from physical coordinates in FEM to elastic coordinates in MBS tools.

The MBS-tool alaska generates mixed motion equations for rigid and elastic motions of the bodies, Lagrange's Equations. Flexible bodies are included in the system's tree structure which results in relative kinematics. Kinetic and potential energy are considered as functions of the joint coordinates and elastic coordinates within the tree and their time derivatives.

Alternatively, starting from the Boltzmann-Hamel-Equations in nonholonomic velocity coordinates an equivalent Order-N-Algorithm has been developed and implemented which effectively solves the dynamic equations with constraints. The constraint reactions in the tree joints of the system are eliminated by a recursive process. The algorithm generalizes the approach for rigid multibody systems to the flexible multibody system case. Because the dynamic equations contain the constraints on acceleration level constraint stabilization techniques must be used which can also be realized with the help of Order-N-Algorithms.

16:40	Leyendecker	H 2013

Efficient Integration Of Flexible Multibody Dynamics

Sigrid Leyendecker, Peter Betsch, Paul Steinmann, Universität Kaiserslautern

The modeling of flexible multibody dynamics as finite dimensional Hamiltonian system subject to holonomic constraints constitutes a general framework for a unified treatment of rigid and elastic components. Internal constraints, which are associated with the kinematic assumptions of the underlying continuous theory, as well as external constraints, representing the interconnection of different bodies by joints, can be accounted for in a likewise systematic way.

The discrete null space method developed in [1] provides an energy-momentum conserving integration scheme for the DAEs of motion of the constrained mechanical system. It relies on the elimination of the constraint forces from the discrete system along with a reparametrisation of the nodal unknowns. The resulting reduced scheme performs advantageously concerning different aspects: the constraints are fulfilled exactly, the condition number of the iteration matrix is independent of the time step and the dimension of the system is reduced to the minimal possible number saving computational costs.

A six-body-linkage possessing a single degree of freedom is analysed as an example of a closed loop structure. Furthermore the suitability of the discrete null space method for the simulation of large elastic deformations is demonstrated for a spatial slider crank mechanism.

[1] Betsch, P.: The discrete null space method for the energy consistent integration of constrained mechanical systems. Part I: Holonomic constraints, *Comput. Methods Appl. Mech. Engrg.*,**194**, 5159-5190, 2005.

17:00	**Troger**	**H 2013**

Rotational Motion Of A Discretized Buckled Beam

Hans Troger, Alois Steindl, TU Wien
Alexi Pissarev, Technical University Sofia

We investigate a vertical cylindrical beam with circular cross-section which is clamped at its lower end and free at its upper end. If the beam is longer than a critical length the beam will buckle due to its own weight into a planar configuration. Now we put the foundation of the beam on a platform which we rotate about the vertical axis. Quite naturally the question arises: will the buckled beam perform a motion where it also rotates about the vertical axis or will the beam keep the planar equilibrium position in space and only perform a rotation about the curved axis of the beam?

We introduce a discretized model of the beam with three degrees of freedom to answer this question. Crucial for the answer is whether we use an undamped or internally damped beam model.

17:20	**Dibold**	**H 2013**

Simulation Of A Deformable Mbs With Hydraulics And Control

Markus Dibold, Linz Center of Mechatronics GmbH
Johannes Gerstmayr, Hans Irschik, Abteilung für Technische Mechanik, Johannes Kepler Universität Linz

In the present contribution the systematic simulation of an entire machine, which consists of several structural mechanical elements, hydraulic actuation systems and a closed loop controller is studied. The mechanical part of the system includes several slender arms that undergo a large rigid-body motion with additional elastic deformations. Each arm of the system may consist of several beam elements that are described by means of the Bernoulli-Euler theory. Hydraulic actuators prescribe the rigid-body motion of each single arm. External forces such as gravity, reaction forces of the hydraulic actuators and disturbing forces induce the elastic deformations. To derive the equations of motion of the mechanical part of the system, we use the Lagrange equations of the second kind in combination with the Rayleigh-Ritz technique. This leads to nonlinear ordinary differential equations in time and the kinematical constraints are represented by a set of nonlinear algebraic equations. Together with the hydraulic part of the system, which gives two additional nonlinear differential equations per cylinder a system of algebro-differential equations is solved by means of suitable Runge-Kutta schemes. In a numerical study special emphasis is laid on the interaction of the disturbing forces and the elastic deformations.

17:40	Böhm	H 2013

Some Actual Results Of Tire Research After The Dfg Sfb 181

Friedrich Böhm, Albert Duda, Ralf Wille, Institut für Mechanik, TU Berlin

Applications of 2D and 3D tire models for car dynamics, landing of airplanes and for off-road vehicles are presented. For a big agricultural tire on pliable ground a multi-point measurement device in the inner of the tire was developed, in order to verify computed rolling deformations. The measurement results in a soil channel at TU Munich also were compared with results of flat band testing.

Theoretical investigations of tire behaviour were carried out on the basis of thin layered shell theory, together with Russian and Ukrainian scientists.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 2013

Numerical integration of ODE/DAE

Chair:

Peter Betsch
Hartmut Bremer

13:30	Steinbrecher	H 2013

Numerical Simulation Of Multibody Systems Via Runge-kutta Methods

Andreas Steinbrecher, Institut für Mathematik, TU Berlin

In this talk we will discuss a new approach suited for the numerical simulation of multibody systems as they appear in industrial applications by use of Runge-Kutta Methods. This approach is based on the strangeness concept and covers holonomic and nonholonomic constraints as well as their derivatives which correspond to the so called hidden constraints. Based on this discussion we will present a new integration method which is suited for the most general form of the equations of motion including holonomic and nonholonomic constraints, dynamical force elements, contact conditions, and possibly known solution invariants. This leads to an overdetermined nonlinear system of quasi-linear DAEs which will be solved in an appropriate way.

13:50	Höbarth	H 2013

Methodenvergleich Bei Der Modellierung Eines Mini Segway

Wolfgang Höbarth, Hartmut Bremer, Johannes-Kepler-Universität Linz

Bei einem Mini Segway handelt es sich um ein einachsiges Fahrzeug mit instabilem Aufbau. Bei der Modellierung von Fahrzeugen ohne Quergleiten der Räder müssen nichtholonome Bindungen eingeführt werden. Es gibt verschiedene Möglichkeiten diese Bindungen zu berücksichtigen. Anhand eines Segway Modells werden unterschiedliche Vorgehensweisen zur Modellbildung aufgezeigt.

Als analytische Methode wird Lagrange II verwendet. Hier muss die Bindung auf Geschwindigkeitsebene vorerst offen gelassen werden. Sie kann aber nachträglich mittels Kontaktkraft (Lagrangescher Parameter) oder mittels Nachprojektion in die freien Geschwindigkeitsrichtungen (Maggi Gleichung) eingebracht werden.

Als synthetische Methode zum Aufstellen der Bewegungsgleichung wird die Projektionsgleichung verwendet. Bei dieser Methode können direkt die nichtholonomen Minimalgeschwindigkeiten verwendet werden.

Zusätzlich wird versucht die Bewegungsgleichung mit Hilfe von reduzierten Koordinaten zu ermitteln. Hierbei treten bei der Verwendung von analytischen Methoden große Probleme auf, da die verwendeten, reduzierten Koordinaten die Geschwindigkeitsbindung bereits implizit erfüllen, was andererseits die Projektionsgleichung zu einem universell einsetzbaren Werkzeug macht.

Gemeinsam mit den notwendigen Reglerentwürfen für die Stabilisierung der aufrechten Position des Aufbaues werden die Simulationsergebnisse erläutert. An einem Labor Modell werden die wesentlichen Baugruppen vorgestellt und die erzielten Ergebnisse im Versuch vorgeführt.

14:10	Betsch	H 2013

On The Use Of Euler Parameters In Multibody Dynamics

Peter Betsch, Numerische Mechanik, Universität Siegen

Euler parameters (or unit quaternions) are known to be well-suited for the singularity-free description of finite rotations. Despite of this advantageous feature, the majority of rigid body integrators do not rely on Euler parameters. This observation might be closely related to the fact that the four Euler parameters are not independent. Thus the equations of motion in terms of Euler parameters inevitably assume the form of differential-algebraic equations (DAEs). Since the early investigations dealing with Euler parameters in multibody dynamics, numerical methods for DAEs have improved significantly. Nowadays robust energy consistent integrators are available which exactly reproduce the property of workless constraint forces.

The purpose of the present work is to revist the use of Euler parameters in the light of state-of-the-art integration schemes. In particular, the discrete null space method [1] is applied to the discretization of the underlying DAEs. Furthermore, comparison is made to an alternative singularity-free description of finite rotations by means of the nine redundant components of the direction cosine matrix [2].

[1] P. Betsch. The discrete null space method for the energy consistent integration of constrained mechanical systems. Part I: Holonomic constraints, Comput. Methods Appl. Mech. Engrg. 194: 5159-5190, 2005.
[2] P. Betsch, S. Leyendecker. The discrete null space method for the energy consistent integration of constrained mechanical systems. Part II: Multibody dynamics, Int. J. Numer. Methods Eng., in print.

14:30	Uhlar	H 2013

Energy Consistent Integration Of Planar Multibody Systems

Stefan Uhlar, Peter Betsch, Numerische Mechanik, Universität Siegen

The planar motion of rigid bodies and multibody systems can be easily described by coordinates belonging to a linear vector space. This is due to the fact that in the planar case finite rotations commute. Accordingly, using this type of generalized coordinates can be considered as canonical despription of planar multibody systems. However, the extension to the three-dimensional case is not straightforward. In contrast to that, employing the elements of the direction cosine matrix as redundant coordinates is possible for both planar and three-dimensional systems. This alternative approach leads in general to differential-algebraic equations (DAEs) governing the dynamics of rigid body systems. The main purpose of the present talk is to present a comparison of the two alternative descriptions. In both cases energy-consistent time intergation schemes are applied.

At first sight the second approach based on the elements of the direction cosine matrix seems to be awkward due to the presence of a large number of unknowns, namely redundant coordinates plus Lagrange multipliers for the enforcement of the rigidity constraints. An efficient energy consistent integration of the underlying DAEs can be accomplished by applying the discrete null space method [1]. This will be demonstrated for both tree-structured and closed-loop planar multibody systems.

[1] P. Betsch, The discrete null space method for the energy consistent integration of constrained mechanical systems. Part I: Holonomic constraints, Comput. Methods Appl. Mech. Engrg. 194: 5159-5190, 2005.

14:50	**Engelhardt**	**H 2013**

A Time-stepping Algorithm For Non-smooth Mechatronical Systems

Thomas Engelhardt, Felix Kahr, Heinz Ulbrich, Lehrstuhl für Angewandte Mechanik, TU München

For non-smooth mechanical systems, time-stepping schemes are shown to be often advantageous compared to classical ODE-formulations, especially when dealing with large systems with many constraints. In case the system also involves other mechatronical parts, e.g. hydraulic elements, the application of the method needs to be extended in order to take full advantage of the approach.

Hydraulic systems often show a behavior that may be described using uni- and bilateral constraints. Thus, stiff differential equations are avoided, for example for incompressible nodes, checkvalves, massless lines and more. But also non-linear controllers may be described efficiently with the same formulation. In order to account for the simultaneous integration of non-smooth hydraulic and mechanical systems, a half-explicit time-stepping scheme for non-linear, non-smooth, multidisciplinary mechatronical systems is presented. The dynamics of the mechanical and the hydraulic systems are described by an Augmented Lagrangian approach. The uni- and bilateral constraints are represented by projection equations (proximal functions) in the differential equations of the system. A fix-point iteration is applied to solve the complete set of equations.

As an illustration of the capabilities of this algorithm, several numerical simulations of both academic as well as an industrial problem are presented.

15:10	Kahr	H 2013

Set Valued Laws For The Efficient Simulation Of Hydraulic Systems

Felix Kahr, Thomas Engelhardt, Heinz Ulbrich, Lehrstuhl für Angewandte Mechanik, TU München

Many mechatronical systems show a highly dynamical non-smooth behaviour and are characterized by effects that take place in separate physical domains, i.e. mechanics, hydraulics and feedback-control. Time-stepping algorithms incorporating proximal functions feature many benefits on computational cost, robustness and stability for the integration of non-smooth mechanical systems.

In this talk, non-smooth mathematical models for hydraulic phenomena and components are presented. These models are substantial for the simulation of large mechatronical models, integrated by a global time-stepping scheme.

One approach is to substitute certain states, e.g. of nodes with small volumes or links with small masses, with set valued equations, both for smooth and non-smooth events. Thus, the stiffness of the differential equation is significantly reduced. Furthermore, changes of configuration in the system, e.g. closing valves with high friction or check valves, can be expressed in a consistent mathematical model. In contrast to classical ODE integration methods, this formulation does not require any root finding and modification of the structure of the equations. In addition to that, set valued laws can be superposed on states, for example to model effects like cavitation in compressible nodes and frictional effects in pipes.

The models are shown to be suitable for the simulation of power train components, such as valve trains in combustion engines, including cam tappets and hydraulic cam phasing systems.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 2013

Contact formulations

Chair:

Peter Eberhard
Peter Betsch

16:00	Förg	H 2013

Simulation Of Non-smooth Multi-body Systems With Tree Structure

Martin Förg, Heinz Ulbrich, Lehrstuhl für Angewandte Mechanik, TU München

Sophisticated computational methods have been established to apply mechanical models with unilateral constraints to a wide range of technical problems. However, the application of these methods is still limited by high computing times especially when large systems of industrial relevance have to be simulated. Therefore, the improvement of numerical algorithms is a focus of ongoing research.

For unconstrained systems with tree structure $\mathcal{O}(n)$ algorithms can drastically reduce the numerical effort solving the equations of motion. The inversion of the system's mass matrix is avoided by considering the kinematical relations between adjacent bodies. In this work the application of $\mathcal{O}(n)$ algorithms is extended to multi-body systems with unilateral constraints. For the mathematical description of such systems an Augmented Lagrangian approach is used where the equations of motion are augmented by projection equations representing the physical constraints. The overall set of non-smooth, nonlinear equations is solved by a fixed-point iteration scheme. Following the idea of classical $\mathcal{O}(n)$ formulations the inverse mass matrix that appears in the iteration scheme is not calculated explicitly.

As a numerical example a pendulum chain consisting of a several hundred rigid rods that are connected by joints is investigated. A rigid wall constrains the motion of the pendulum unilaterally resulting in a large coupled contact problem.

16:20	Gattringer	H 2013

Effiziente Simulation Von Mks Mit Kontaktbedingungen (ordnung N)

Hubert Gattringer, Hartmut Bremer, Johannes Kepler Universität Linz

Aufgrund der immer größer werden Komplexität von dynamischen Systemen in Forschung und Industrie ist man an einer effizienten Simulation interessiert. Bei der dynamischen Modellierung von baumstrukturierten Mehrkörpersystemen entstehen hochgradig nichtlineare Bewegungsgleichungen. Dabei wird von einer Beschreibung in Minimalform ausgegangen. Der Rechenaufwand zur Invertierung der Massenmatrix ist enorm. Er steigt mit kubischer Ordnung ($O(n)^3$) der Freiheitsgrade. Bei einer Modellierung des Mehrkörpersystems über die Projektionsgleichung in Subsystemdarstellung kann ein O(n) Verfahren hergeleitet werden. Werden einzelne Baugruppen (Subsysteme) zusammengefasst, lässt sich das Problem geeignet strukturieren, und über die den Subsystemen zugeordneten beschreibenden Geschwindigkeiten erhält man gut interpretierbare Zwischenergebnisse. Als Subsysteme können nicht nur starre Einheiten (z.B. Motor Getriebe Einheit), sondern auch hybride Systeme (z.B. Motor mit elastischem Balken) zum Einsatz kommen. Anstatt wie bei herkömmlichen Verfahren die Gesamtmassenmatrix invertieren zu müssen, kommt der O(n) Algorithmus mit einer Matrixinvertierung vom Relativfreiheitsgrad pro Subsystem aus. Bei einer Motor Getriebe Einheit ist das eine quadratische Matrix (Motor- und Armwinkel), bei hybriden Systemen kommen als Relativfreiheitsgrade noch die Ritz Koeffizienten dazu. Werden bei dem Mehrkörpersystem zusätzliche Kontakte aktiv, so kann das mithilfe einer Kontaktkraft (Lagrangescher Parameter) ins Modell aufgenommen werden. Auch für diesen Fall kann ein effizienter Algorithmus angegeben werden, der ohne eine Invertierung der Massenmatrix auskommt. Beim Übergang zum Kontaktfall tritt unweigerlich ein Stoß auf. Dieser wird ebenfalls im Sinne des O(n) Verfahrens behandelt. Als Anwendungsbeispiel wird auf eine zweibeinige Laufmaschine eingegangen.

16:40	**Stamm**	**H 2013**

Regularization Of 2d Frictional Contacts For Rigid Body Dynamics

Wolfgang Stamm, Alexander Fidlin, LuK GmbH & Co. oHG

Classic rigid body mechanics does not provide frictional forces acting in a 2D contact interface between two bodies during sticking. This is due to the statical undeterminacy related with this problem. Many technical systems, e.g. disk clutches, have such surface-to-surface contacts and it is sometimes desirable to treat them as rigid body systems despite the 2D contact. Alternatively it is possible to model the systems using elastic instead of rigid bodies, but this might lead to certain drawbacks. Here a new regularization model of such 2D contacts between rigid bodies is proposed. It is derived from a material model for elastoplasticity in continuum mechanics. Only dry friction is taken into account.

17:00	**Jiang**	**H 2013**

An Experimental And Numerical Study Of Deformable Bodies' Contact

Yu Jiang, Peter Eberhard, Institut für Technische und Numerische Mechanik, Universität Stuttgart

This study is concerned with the impact of a rotating disc at low velocities with a fixed strip. We perform an experimental analysis to study the dynamics and deformation of the strip and disc in impact. A throwing machine controlled by a dSPACE-Autobox is utilized to generate the translational and rotational motions of the disc. A high speed digital camera system is adopted to capture kinematical data of the disc. Strain gauges are mounted for getting deformation information of the strip. We also employ a Laser-Doppler-Vibrometer to obtain the displacement and velocity of points on the strip. The effects of strip flexibility and the motions before impact on those after impact are investigated in detail. For the numerical study finite-element-method models are used and important model parameters are discussed for getting reliable and efficient simulation results. Experimental results are compared with those from numerical simulations. Appropriate selection of the theory for interpreting experiments is shown to be critical.

17:20	Hesch	H 2013

Application Of The Discrete Null Space Method To Contact Problems

Christian Hesch, Peter Betsch, Numerische Mechanik, Universität Siegen

In the present talk large deformation contact problems of flexible bodies are addressed within a nonlinear finite element framework. Since 1979 the standard formulation for contact interactions of flexible bodies is the so called node-to-segment (NTS) method.

We aim at the development of energy consistent 'mechanical' integrators for the DAEs associated with the contact problem under consideration. The notion of a mechanical integrator includes nowadays well-established energy-momentum schemes for nonlinear elastodynamics. First steps towards the energy consistent time integration of frictionless dynamic contact problems can be found in the works by Laursen & Chawla, Armero & Petöcz and Laursen & Love.

Energy consistent mechanical integrators have been recently developed for DAE-formulations of constrained mechanical systems (Gonzalez [1]). These works are based on the direct discretization of the underlying DAEs leading to a saddle point system to be solved in each iteration of the iterative solution procedure. Due to the presence of Lagrange multipliers this approach leads to a large number of unknowns and potential conditioning problems. To remedy these drawbacks the discrete null space method (Betsch [2]) has been recently developed.

We apply the discrete null space method to both domain decomposition in the framework of nonlinear elastodynamics and large deformation contact problems.

[1] Gonzalez O. , Mechanical systems subject to holonomic constraints: Differential - algebraic formulations and conservative integration: Physica D **132**, 165-174 (1999)
[2] Betsch P., The discrete null space method for the energy consistent integration of constrained mechanical systems: Part I: Holonomic constraints: Computer Methods in Applied Mechanics and Engineering **194**, 5159-5190 (2005)

17:40	Zander	H 2013

Rotating Elastic Disks With Rigid Body Contacts In Mbs

Roland Zander, Heinz Ulbrich, Lehrstuhl für Angewandte Mechanik, TU München

This paper presents a model for rotating elastic disks which are affected by rigid body contacts normal to the disk surface. The model is basically a finite-element discretisation in one common moving frame of reference. The rigid body movement of the disk forms this moving reference. The finite elements allow for a local description of local disturbances which are introduced by constraints and impacts. In contrast, globally defined shape functions would lead to immediate influences of impacts on the entire discretised domain. This would state infinite sound-propagation velocities and would lead to tight couplings between different contacts in a multiple contact situation. Therefore, the numerical effort for solving contact problems would increase compared to the presented finite-element discretisation.

Contacts between the disk and point-obstacles are formulated not only on nodes but for arbitrary places on the disk, whereas the contact points can be given analytically. The system dynamics including constraints and impacts are treated following modern formulations for multibody systems with uni- and bilateral constraints.

As an example, investigations for a plain rotating disk affected by several other bodies are presented. These bodies perform both free motions and motions constrained to given trajectories. In future work, the model will be enhanced to conical forms and prepared for an application in simulation software for continuously variable transmission (CVT) gears.

Session 5
Thursday, March 30, 13:30 - 15:30

Room: H 2013

Granular materials, further topics

Chair:

Jörg F. Wagner
Christoph Woernle

13:30	**Alkhaldi**	H 2013

Computation Of Screening Phenomena In A Vertical Tumbling Cylinder

Hashem Alkhaldi, Peter Eberhard, Institut für Technische und Numerische Mechanik, Universität Stuttgart

Granular Materials are an integral part of our environment. Due to their wide variety of applications in the industrial and technological processes, they have captured a great interest in the recent research. The related studies are often based on numerical simulations and it is considered as challenging to investigate computational phenomena of dense granular systems.

Particle screening is an essential technology and important in granular studies. The particular problem of interest is the separation of round shape particles of different geometrical sizes using a rotating tumbling vertical cylinder. The concept of discrete-element method that considers the motion of each single particle individually is applied in this study. Particle-to-particle and particle-to-wall collisions will appear under the tumbling motion of the rotating structure. The normal and frictional forces between particles themselves and particles and surrounding walls of the structure are calculated according to the rules of a penalty method, which employs spring-damper models for this purpose. As a result of collisions, the particles will dissipate kinetic energy due to the normal and frictional contact losses.

Particle distribution and sifting rate of the separated particles have been studied taking into consideration different rotational speeds of the machine, various damping and frictional coefficient and different sizes of holes in the sifting plates at different levels of the structure. In an attempt to better understand of the mechanism of the particle transport between the different layers of the sifting system, experimental and computational studies have been performed.

13:50	**Lillie**	H 2013

Modelling Of Discrete Particles By Superellipsoids

Claudia Lillie, Peter Wriggers, Institut für Baumechanik und Numerische Mechanik, Universität Hannover

Discrete Elements are used for the simulation of granular materials (sand, ballast) as well as for molecular assemblies. Circles (2D) and spheres (3D) are often used in literature on the Discrete Element Method (DEM) however they represent a strong idealisation of the real geometry. Superellipsoids provide the opportunity to generate a wide variety of three-dimensional geometrical shapes (e.g. sphere, cube, cylinder).

The motion of each particle is described by means of rigid body dynamics. Suitable numerical integration methods are necessary which are able to conserve the essential physical quantities like momentum energy etc.. Possible choices are e.g. the explicit Verlet-Leapfrog method for the translation and the explicit fourth order Runge-Kutta method for the rotation. These and other methods were implemented and compared by means of test examples.

The implemented contact formulation takes damping as well as friction into account. The efficient implementation of the contact search is the main aim of this part of the work. It is subdivided into the neighbourhood search and the local search. A 'bisection' algorithm is used to calculate the gap between two superellipsoids within the search. For the neighbourhood search two binning algorithms were implemented and compared for several packages of particles.

14:10	Schiefer	H 2013

Ein Innovatives Sensorkonzept Zur „schmerzdetektierung“

Frank Schiefer, Georg-Peter Ostermeyer, Institut für Dynamik und Schwingungen, TU Braunschweig

Die Idee, ein Sensorkonzept zur „Schmerzdetektierung“ z. B. in MKS-Modellen zu entwickeln, ist ein weiteres Produkt der mesoskopischen Vielteilchentheorie [1], [2], mit der u. a. die Energieumwandlung in Wärmeenergie bei Stoß- und Reibvorgängen in den Grenzschichten der Kontaktkörper thermodynamisch korrekt beschrieben werden kann.

Zwischen den Eigenschaften von „Schmerz“ und Wärme gibt es offensichtlich Analogien. Zum einen vergrößert sich der „Schmerz“, je höher bestimmte Eigenschaften der äußeren Krafteinwirkung sind, und zum anderen lässt der „Schmerz“ mit der Zeit nach, wenn entsprechende Einwirkungen ausbleiben.

Allgemein ist „Schmerz“, wenn man nozizeptiven Schmerz auf technische Systeme überträgt, ein Vektor verschiedener physikalischer Phänomene. Mit Hilfe des entwickelten Sensorkonzeptes wird ein Energieeintrag gemessen, der implizit frequenzselektive Informationen über die Druck- und Ruckbeanspruchung und das Zeitverhalten enthält.

Es wird numerisch und experimentell gezeigt, wie mit einem solchen Sensor beispielsweise Nachgiebigkeiten von Oberflächen beurteilt werden können.

[1] Ostermeyer, G.-P.: A Mesoscopic Particle Method for Description of Thermomechanical and Friction Process, Physical Mesomechanics, 6, 25-32, 1999
[2] Ostermeyer, G.-P.: Mesoscopic Particles. MKS-Tool for multidisciplinary applications with different length and time scales, ECCOMAS 2005

14:30	**Müller**	**H 2013**

Topological Analysis Of The Configuration Space Of Mechanisms

Andreas Müller, Institut für Mechatronik Chemnitz

The kinematics of rigid body mechanisms is considered from a differential-geometric perspective. Three locally equivalent models for the kinematics of rigid body mechanisms are introduced. Each of these models consists in a configuration space and a parameter space according to a local parametrization of the first. Admissible parametrizations are such that the local topology of the respective configuration and parameter space is equivalent. Thereupon the parameter space is the central object.

The configuration space is the set of solutions of closure functions for kinematic loops - a variety generated by the closure functions. Kinematic properties of a mechanism are intrinsically determined by the topology of its configuration space, but also (and independently) by its closure functions. In particular, the local/global degree-of-freedom (DOF) is the local/global dimension of the configuration space, but the differential DOF is generally the number of locally independent closure functions and not necessarily the dimension of the tangent space to the configuration space!

The parameter space of model I is a real analytic variety, that of model II a real algebraic and that of model III a complex variety. Due to their local equivalence results for one particular model apply to all. But each model admits to apply specific mathematical tools. I.e. model II and III are analyzed using methods from algebraic geometry, while the analysis of model I is based on Lie group and screw algebraic methods.

The nature of kinematic singularities is investigated. Configurations are called kinematic singularities iff in any neighborhood of such configuration the kinematic properties undergo a qualitative change. The intrinsic property that characterizes singular configurations is the differential DOF. For a systematic approach to the mathematical analysis of the physical problem it is crucial to provide a thorough understanding of the physical meaning of kinematic singularities. E.g. it is common to mistakenly call a configuration singular if its differential and local DOF are different. This condition is only necessary but not sufficient, as for mechanisms that are paradoxical-in-the-small.

A complete picture of the kinematics needs both, the configuration space and the set of closure functions. The tangent space and tangent cone are differential geometric objects associated to a variety. Aiming a kinematic characterization two additional objects are introduced: the kinematic tangent space and the kinematic tangent cone. Both are related to the ideal of the constraint functions. A computationally simple algorithm for their determination is proposed. Its application is shown on several examples.

14:50	Mladenova	H 2013

Presentations Of The Rotations In The Space Movements

Clementina Mladenova, Institute of Mechanics, Bulgarian Academy of Sciences

The rotations are met everywhere - in physics and engineering problems, computer simulations and visualizations, computer graphics, and therefore in the whole computerized world. Nowadays because of the modern and fast processors, the representation of the rotation group is still very important so that the hardware and the software to work efficiently together. The purpose of this work is to present different representations of the rotations as well as the parameterizations of the SO(3) group, and to show their role in the efficient modelling in both the manipulator kinematics and computer vision. The theoretical base is the knowledge of Lie groups and differential geometry in the problems of rigid body mechanics.

Session 6
Thursday, March 30, 16:00 - 18:00

Room: H 2013

Miscellaneous

Chair:

Sigrid Leyendecker

16:00	Vohar	H 2013

Optimization Of Elastic Systems Using Ancf Finite Elements

Bojan Vohar, Marko Kegl, Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Slovenia

The objective of this study is to investigate the possibilities of using the beam finite elements formulated in the absolute nodal coordinate formulation (ANCF) in optimization procedure of elastic dynamic systems. Such beam elements are suitable for large rotation and large deformation problems of multibody systems, such as elastic manipulators, vehicles and mechanisms. Since they are able to describe nonlinear deformation accurately, they are also very useful for simulations of cables, belts, slender robot arms and other lightweight multibody structures. In the absolute nodal coordinate formulation, slopes and displacements are used as the nodal coordinates instead of infinitesimal or finite rotations. This way one can avoid cumbersome interpolation of rotational coordinates. In this investigation some of the recently introduced ANCF beam elements have been compared. Their accuracy has been tested using different models for the description of the internal elastic forces. The beam elements have been modified accordingly to enable sensitivity analysis required in the optimization process. Implementation of modified beam elements is illustrated in the framework of the gradient-based optimization procedure. The efficiency of such optimization is tested on few basic examples.

16:20	Kazic	H 2013

Stability Of Mechanical Systems With General Types Of Forces

Mila Kazic, Ranislav Bulatovic, Department of Mechanical Engineering, University of Montenegro, Serbia and Montenegro

The stability of linear mechanical systems subjected to dissipative, gyroscopic, potential and circulatory forces is investigated. From a practical point of view

it is of interest to find stability conditions which are in a simple way related to the properties of the system matrices. Several criteria in this direction are formulated which supplement and improve previously obtained results of the same type. Simple examples are given to illustrate the stability criteria.

16:40	Shamolin	H 2013

Almost Conservative Systems In Dynamics Of A Rigid Body

Maxim V. Shamolin, Institute of Mechanics, Lomonosov Moscow State University, Russian Federation

In this activity we obtain the families of portraits and cases of integrable variable dissipation system with so called zero mean dissipation in Dynamics of rigid bodies.

We consider a class of motions of a system that is constrained in such a way that the velocity of certain characteristic point of a rigid body can be assumed to be constant throughout the whole time of motion. We carry out a complete qualitative analysis of the obtained dynamical system in the quasi-velocity space. The symmetries in the systems are pointed out, the explicit formula of the first integral as a transcendental function of quasi-velocities is presented.

17:00	Sek	H 2013

Atypical Dynamic Problems Of Ferroconcrete Slabe Ceilings

Marcin Sek, Wladyslaw Mironowicz, Wroclaw University of Technology, Poland

Some unusual problems relating to the dynamics of the industrial ferroconcrete slab ceilings weighed down with machines were considered. The choice was made on the ground of the research results concerning the real constructions. Questions which were discussed concerned the change of the stiffness as the result of incorrect execution of the ceiling as well as damages arising during its use. These are three kinds of problems: these of the construction which became weaker due to the machine oil's or chemical substances' effect, unilateral constraints problems (damage of the vibroisolation either of the machine or of the supporting construction's components), problems resulting from the incorrect arrangement of the reinforcement of the ceiling's plates and from the bad concrete's quality. Above-mentioned questions were considered in deterministic and random depiction.

17:20	Steffen	H 2013

Modelling The Fundamental Diagram Of Pedestrian Movement

Bernhard Steffen, Armin Seyfried, Thomas Lippert, ZAM, Forschungszentrum Jülich

The motion of pedestrian crowds (e.g. for simulation of an evacuation situation) can be modelled as a multi-body system of self driven particles with repulsive interaction. There are many unknown parameters to such models, which have to be adjusted correctly to give proper predictions of evacuation times, local densities, and forces on rails or obstacles. We compare simulation results for different sets of model parameters with experimental data for the simple system of pedestrians is the single-file movement. While most models of repulsive interaction, after proper adjustment of the parameters, are able to give the correct average speed for a given density, most are not able to reproduce the pattern of fluctuations observed. The parameters of the sozial force model, which gives quite good agreement in detail, can be related to quantities that can be measured independently, like step length.

2 Biomechanics

Organizers:

Ellen Kuhl, TU Kaiserslautern
Wolfgang Ehlers, Universität Stuttgart

Session 1
Wednesday, March 29, 13:30 - 15:30

Room: H 2032

Arterial Wall and Blood Circuit Mechanics

Chair:

Wolfgang Ehlers

13:30	Holzapfel	H 2032

Arterial Models From Uniaxial Extension Tests And Histology

Gerhard A. Holzapfel, School of Engineering Sciences, Royal Institute of Technology, Sweden

An approach is proposed that allows the determination of material models from uniaxial tests and histostructural data including fiber orientation of the tissue [1]. A combination of neo-Hookean and Fung-type strain-energy functions is utilized, and inequality constraints imposed on the constitutive parameters are derived providing strict local convexity and preferred fiber orientations. It is shown how the Fung-type model gets a pseudo-structural aspect inherent in the phenomenological model; a correlation between the fiber structure and the parameters of the Fung-type model is explicitly provided. In order to apply the proposed approach, quasi-static uniaxial extension tests of preconditioned prepared strips from the intima, media and adventitia of a human aorta with non-atherosclerotic intimal thickening are acquired in axial and circumferential directions; structural information from histological analyses for each aortic tissue are documented. Data reveal a remarkable thickness, load-bearing capacity and stiffness of the intimal samples in comparison with the media and adventitia. Constitutive parameters for each aortic tissue layer are determined by solving the constrained problem using a penalty function method; a new approach for the estimation of appropriate start values is proposed. Finally, the predictivity and efficacy of the material models is shown by comparing model data with data from the uniaxial extension tests and histological image analyses.

[1] G. A. Holzapfel. Determination of material models for arterial walls from uniaxial extension tests and histological structure. *J. Theor. Biol.*, 2006, 238:290-302.

13:50	Balzani	H 2032

Modeling Of Residual Stresses And Damage In Arterial Walls

Daniel Balzani, Jörg Schröder, Fachbereich Bauwissenschaften, Universität Duisburg-Essen
Dietmar Gross, Institut für Mechanik, TU Darmstadt

A method is presented for the numerical simulation of residual stresses in arterial walls. Generally, when axial segments of arterial walls are sliced in radial direction they spring open. Thus, there exist residual stresses in the unloaded configuration. For incorporating these eigenstresses we firstly consider a sliced artery, which is assumed to be stress-free, and close the gap between the opened transmural surfaces by a displacement-driven procedure introducing some kind of interface elements formulated in the relative displacement of associated nodal points. Subsequently we construct a new mesh of the closed artery and apply a method to incorporate the residual stresses without using the interface elements. In order to guarantee the existence of minimizers we use a polyconvex energy function for the description of the hyperelastic behavior in the physiological domain of arterial walls. For the modeling of the discontinuous damage effects, observed when arteries are overexpanded, we apply a model which assumes that the damage occurs mainly in fiber direction. As a numerical example we consider the cross-section of a diseased artery in order to provide an impression of the performance of the model.

14:10	Triep	H 2032

Numerical Simulation Of The Flow In A Micro-axial Blood Pump

Michael Triep, Ch. Brücker, TU Bergakademie Freiberg
Th. Sieß, Impella CardioSystems GmbH

In recent years the tendency of miniaturization has shown promising results for applications of medical instruments in keyhole-surgery. Small rotary pump systems have been developed for the treatment of patients with cardiac insufficiency

as well as for applications in Intra- and Extra-Corporal Circulation. The downsizing of pumps, however, goes with higher rotational speeds and smaller clearances between impeller and housing, which may lead to high shear stresses. To increase the efficiency of these pump types and to reduce the shear induced hemolysis a detailed knowledge of the entire flow field in the device is necessary. With regard to the limitations of experimental investigations, computational fluid dynamics (CFD) has proved to be a complementary tool in localizing critical flow regions and in determining derived quantities such as shear stresses. Steady-state, three-dimensional, turbulent simulations are carried out for various working conditions in a given geometry of a novel micro-axial blood pump. The results obtained via the CFD simulations are in a good qualitative and quantitative agreement with recent digital particle image velocimetry (DPIV) measurements.

14:30	Patralski	H 2032

Identification Of The Aortic Leaflet Valve Material.

Christopher Patralski, Piotr Konderla, Lower Silesian Center of Heart Diseases, Wroclaw University of Technology, Poland

The main aim of this study is the choice of the material model for the leaflet of the aortic valve on the basis of physical tests and information about histological structures. We consider the material model at two levels of resolution.

The paper presents the model of the valve cusp material treated as a trilaminar shell at two resolution levels. At the first stage, i.e. at the microstructure level the parameters of the basic components of the material were identified. These were collagen fibres, elastin fibres and a low-stiffness matrix. To identify particular layers use was made of the results of histological experiments and strength tests.

At the second stage, i.e. at the level of the leaflet valve structure, the homogenization of the material to a two-dimensional problem of the shell was attempted.

14:50	Weinberg	H 2032

Response Of Kidney Tissue To Dynamical Loading

Kerstin Weinberg, Institut für Mechanik, TU Berlin

In shock-wave lithotripsy – a medical procedure to fragment kidney stones – the patient is subjected to hypersonic waves focused at the kidney stone. Although this procedure is widely applied, the physics behind this medical treatment, in particular the question of why injuries in the surrounding kidney tissue arise, is still under investigation. Here we contribute to the solution of this problem with large scale numerical simulations of a human kidney under shock-wave loading.

For this purpose we developed a complex constitutive model of the biomechanical kidney system. Assuming a multiplicative decomposition of the deformation gradient and adopting an internal variable formulation for the visco-plastic deformation the model is able to handle large deformations, time-effects, rate-sensitivity and material damage.

By finite element simulations we study the shock-wave propagation into the kidney tissue and analyze the resulting stress states. Unknown material parameters are calibrated and special attention is paid on the definition of a damage criterion. The numerical simulations predict localized damage in the human kidney in the focal region of the shock waves.

Session 2
Wednesday, March 29, 16:00 - 18:00

Room: H 2032

Soft Tissue Biomechanics

Chair:

Ellen Kuhl

16:00	Görke	H 2032

An Anisotropic Viscoelastic Soft Tissue Model At Large Strains

Uwe-Jens Görke, Anke Bucher, Reiner Kreißig, TU Chemnitz
Hubert Günther, TBZ-Pariv Chemnitz und AO Research Institute Davos

Soft biological tissues represent complex inhomogeneous, and as a rule multiphase materials subjected to large strains under *in vivo* mechanical conditions. Apart from a number of other structural-related features they are characterized by a rate-dependent material behaviour.

Frequently, in the literature the rate-dependency of biphasic soft tissues is exclusively attributed to fluid-solid interactions. However, recent observations demonstrate that intrinsic viscoelastic properties of the solid matrix must not be neglected.

The authors propose to model rate-dependent phenomena of the solid phase of soft biological tissues within the context of a phenomenological material approach resulting from an overstress concept. The basic idea of this superposition methodology is the multiplicative decomposition of the deformation gradient, and the related additive decomposition of the stress tensor whose underlying physics can be illustrated on rheological models adapted to large strain conditions.

Due to the presence of directed fibrous constituents (e.g. collagen fibers in articular cartilage) soft tissues should be considered as anisotropic materials. Therefore, apart from a corresponding hyperelastic description, the viscous overstress model has been completed by a transversely isotropic approach.

The theoretical background and the numerical algorithms of the viscoelastic material model are presented. This model has been implemented into a commercially available FE-code. Some numerical examples are discussed.

16:20	Acartürk	H 2032

Finite Swelling With Weakly Fulfilled Boundary Conditions

Ayhan Acartürk, Wolfgang Ehlers, Bernd Markert, Institut für Angewandte Mechanik, Universität Stuttgart

Biological soft tissues exhibit a swelling behaviour and consist of multiple phases, a solid phase composed of collgagen fibers and charged PGA chains and a fluid phase composed of the liquid solvent and the ions of dissolved salt.

In this contribution, a thermodynamically consistent model describing swelling phenomena is derived using the Theory of Porous Media. The model consists of four constituents, a charged solid and an aqueous solution composed of water and the ions of dissolved salt. The solid is modelled by a finite elasticity law accounting for the multiphasic micro structure, whereas the fluid is considered as a viscous *Newton*ian fluid. One finally ends up with four balance relations, the volume balance of the fluid, the concentration balance of the cations, the momentum balance and the balance of charges of the overall mixture.

The resulting set of partial differential equations is solved within the framework of the FEM. Therefore, the weak forms are derived and the resulting set of equations for the primary variables pore pressure p, cation concentration c and solid displacement $\mathbf{u}_S$, is implemented into the FE tool PANDAS. Finally, a three dimensional example of a swelling hydrogel disc is shown.

16:40	Ricken	H 2032

On The Description Of Growth In Saturated Living Tissues

Tim Ricken, Institut für Mechanik, Universität Duisburg-Essen

Biological soft tissues are highly complex materials capable of performing a wide range of functions. Two basic properties of biological soft tissues are optimized load transfer and the capacity for growth respectively. The former is often realized by a combination of inner anisotropic structure components such as fibers situated in porous saturated tissue. Therefore, the optimized load transfer is solved for both the maximum stress and the hydrostatic pressure. The growth results from a phase transition inside the soft tissue where mass exchange between the biological skeleton and the saturating fluid is observed.

In this contribution a formulation is proposed for the phenomenological description of transverse isotropic and fluid saturated soft and hard living tissues including the phenomena of growth. This is done within the framework of a macro-mechanical description based on the Theory of Porous Media (TPM). In order to characterize the transverse isotropic skeleton behavior an invariant formulation of the Helmholtz free energy function is used. Owing to the interior structure, anisotropic tissue permeability can be observed. A transverse isotropic permeability tensor in an invariant formulation is introduced to account for these phenomena.

The biological growth process in soft tissues is also investigated. In contrast to formulations wherein the mixture body is treated as a one component material, a two-phase model is suggested using the TPM, where the continuum simultaneously consists of particles of the tissue skeleton as well as the saturating fluid. In view of the growth description, this method allows a closed system approach wherein the mass source of one phase inside the body results completely from the respective other phase. As a consequence, the validity of the mixture balance equation of mass can be guaranteed without the introduction of a surface mass flux. After presenting the developed framework of the calculation concept describing growth in transverse isotropic biological soft tissues, some representative numerical examples are examined.

17:00	Karajan	H 2032

Suitable Initial Conditions For Multiphasic Fe Analyses Of The Ivd

Nils Karajan, Wolfgang Ehlers, Bernd Markert, Institut für Angewandte Mechanik, Universität Stuttgart

The intervertebral disc (IVD) as a complex representative of charged, hydrated biological soft tissues is of great research interest regarding numerical simulation techniques. Herein, especially the Finite Element Method (FEM) plays a major role in combination with a well-founded continuum theory.

In this contribution, a macroscopic model based on the Theory of Porous Media (TPM) is presented allowing for a consistent treatment of multiphasic continua with internal interactions. Following this, two phases are introduced: the collagen fiber-reinforced extracellular matrix exhibiting a nonlinear viscoelastic behavior and the viscous interstitial fluid. Furthermore, the resultant solid and fluid phases are electrochemically active by carrying fixed negative charges and containing dissolved ions and cations, respectively. This characteristic causes an osmotic pressure (Donnan osmosis), which is superimposed with the hydraulic contribution to a total pore pressure.

Finally, numerical analyses of a human IVD with different initial conditions are discussed. Herein, one can proceed from an overall stress-free reference configuration, which leads to a pre-stressed but undeformed solid skeleton due to the effective stress principle. Secondly, an unbalanced initial state is investigated, which will be computed to an equilibrium state between the osmotic pressure and the solid extra stress leading to a deformed and pre-stressed solid skeleton.

Session 3
Thursday, March 30, 13:30 - 15:30

Room: H 2032

Bone Mechanics, Growth and Remodelling

Chair:

Gerhard Holzapfel

13:30	Winter	H 2032

Ein Beitrag Zum Plastischen Verhalten Des Zellularen Knochen

Werner Winter, Lehrstuhl für Technische Mechanik, Universität Erlangen-Nürnberg

Für die Ermittlung werkstoffmechanischer Kennwerte des zellularen Knochen auf der Makroebene werden zellulare Modellstrukturen verwendet. Beim elastischen Stoffgesetz lässt sich bekanntlich die Abhängigkeit der elastischen Materialparameter von der relativen Dichte der zellularen Modellstrukturen nachweisen. In diesem Beitrag werden die Fließorte mehrachsig beanspruchter zellularen Modellstrukturen mit elastisch-idealplastischem Verhalten des Grundwerkstoffes (Mesobene) vorgestellt und daraus ein plastisches Stoffgesetz auf der Makroebene abgeleitet. Es zeigt sich, dass sich das plastische Verhalten des zellularen Knochen über ein plastisches Potenzial charakterisieren lässt, das von der ersten Invarianten des Spannungstensors und der zweiten Invarianten des Spannungsdeviators abhängig ist. Neben der Abhängigkeit der im plastischen Potenzial vorhandenen Materialparameter von der relativen Dichte, wird weiter verdeutlicht, dass im zellularen Knochen plastische Volumenänderungen auftreten. Zur Kalibrierung der Materialparameter im plastischen Stoffgesetzes wird ein einachsiger Versuch u.a. mit Messung der plastischen Querdehnung durchgeführt. Für die berührungslose Messung der Formänderungen kommt ein Laserextensometer zum Einsatz.

13:50	Ebinger	H 2032

Optimization Of Hip Femural Neck Fracture Surgery

Tobias Ebinger, Holger Steeb, Stefan Diebels, Thorsten Tjardes, Lehrstuhl für Angewandte Mechanik, Universität des Saarlandes

At the moment an optimization process in the surgery of femural neck fractures can be observed. While in former years mainly the complete head of the femur was replaced by an implant, now there is the trend to save the head if possible and

to fixate it at the femur. Thereby, the following questions arise: How to find the optimal fixation? Has the fixation a limitation in lifetime due to the remodeling process of the trabeculae? Which criteria have to be fulfilled so that a fixation is sufficient and the implant can be abandoned? And in case of a necessary implant: which is the optimal shape of the implant?

The biomechanical modeling and numerical simulation of the surgery provides the possibility of getting answers to some of the questions. Different kinds of fixation can be tried on the same femur. Furthermore possible remodeling processes, which may lead to failure of the fixation, can be prognosed. On the one hand some idealizations are involved in the biomechanical model: the exact geometry is not known, improper material parameters, improper loading generally approximated by a complex of loads acting on the femur etc. On the other hand the model should be as simple as possible and, nevertheless, represent all recent effects.

On the basis of a 2-dim and 3-dim biomechanical anisotropic model for growth the possibilities and limitations of biomechanical models are discussed.

14:10	**Himpel**	**H 2032**

Fibre Reorientation In Transversely Isotropic Materials

Grieta Himpel, Andreas Menzel, Ellen Kuhl, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

Transversely isotropic materials are commonly described by one characteristic direction in the material configuration, which generally is assumed to be constant. However for some applications it makes sense to consider a reorientation of the characteristic direction, as for instance the orientation of biological materials adapts to the mechanical loading, see e.g. [1]. Other examples are piezoelectric materials, which change their electric polarisation due to an electric or mechanical loading, as described in [2], and liquid crystals changing their orientation on account of an electric field, see [3]. Furthermore simulations with a reorientation of the characteristic direction can be used in the context of optimisation of composites. In this contribution we restrict ourselves to the modelling of hyper-elasticity and assume a time dependent reorientation of the characteristic direction due to the maximum principal strain direction, see for instance [4]. Thereby we concentrate on the numerical implementation into a finite element code.

[1] Kuhl E, Garikipati K, Arruda EM, Grosh K. "Remodeling of biological tissue: Mechanically induced reorientation of a transversely isotropic chain network", *Journal of the Mechanics and Physics of Solids* **53**:1552-1573, 2005.
[2] Smith RC. "Smart Material Systems", *Society for Industrial and Applied Mechanics*, 2005
[3] Ericksen JL. "Introduction to the thermodynamics of solids", *Springer*, 1998
[4] Menzel A. "Modelling of anisotropic growth in biological tissues – A new approach and computational aspects", *Biomechanics and Modeling in Mechanobiol-*

ogy **3**(3):147-171, 2005.

14:30	Charlebois	H 2032

An Elastic, Plastic And Damage Constitutive Model For Bone Tissue

Mathieu Charlebois, Philippe Zysset, Institut für Leichtbau und Struktur-Biomechanik, TU Wien
David Garcia, Alain Curnier, Laboratoire de Mécanique Appliquée et d'Analyse de Fiabilité, École Polytechnique Fédérale de Lausanne, Switzerland

Constitutive laws for bone tissue are of major interest for simulating the biomechanical behaviour of whole bones and bone-implant systems. Accordingly, the objective of this work was to formulate, implement and test a novel 3D constitutive model for elasticity, plasticity and damage of bone tissue in the framework of standard generalized materials. A rheological model is proposed that consists of an elastic spring in series with an inelastic assembly made of a plastic pad in parallel with a damageable spring. The state variables are the total strain, the plastic strain and a scalar damage variable representing the relative decrease of the effective elasticity tensor. The rate-independent evolution of the plastic strain and damage variable is based on flow rules associated with distinct generalized Hill criteria that allow for different behaviour in tension and compression. This formulation results in three distinct modes of deformation: a purely elastic mode, a plastic-damage mode corresponding to the generation of microcracks and a plastic mode characterizing sliding of existing cracks. The analytical consistent tangent operators of the model were derived for each mode, implemented and successfully tested in a mathematics software.

14:50	Rosenberg	H 2032

Contribution To The Theory Of Growth And Remodelling

Josef Rosenberg, Ludek Hyncik, University of West Bohemia, Czech Republic

Growth (the change of volume) and remodelling (change of the material properties) involve a lot of real processes, e.g. behavior of living tissues, development of defects in materials or changes of properties of smart materials. To describe these effects, we can find different theories. In this contribution, the theory of DiCarlo will be used. Here, the growth and remodelling are described by operator $\mathbf{G}$ and for its evolution, the following equations were developed

$$\begin{aligned} \dot{\mathbf{G}}\mathbf{G}^{-1} &= -\mathbf{E} + \mathbf{B} \\ \mathbf{E} &= W\mathbf{I} - \mathbf{F}_r^T \tau \end{aligned}$$

where $\mathbf{E}$ is the Eshelby tensor, W is the free Helmholtz energy and $\mathbf{F}_r$ is the operator mapping the relaxed configuration that is obtained by growth from the original configuration into the actual configuration. $\mathbf{B}$ is the tensor describing the control of the growth process. Even this tensor and the form of W, that is the function of $\mathbf{F}_r$, are free parameters which can be chosen to describe the concrete material behavior. In this contribution, some possibilities of this choice are shown on a simple example of the 1D continuum. One possibility is the decomposition of the stress tensor on the elastic and dissipative components. This allows describing different passive changes like viscoelasticity. The second example is the definition of $\mathbf{B}$ to describe the behavior of the muscle fibre using the Hill´s type model. It is an example of the active control of the growth.

Acknowledgment: The work is supported by the Ministry of Education of the Czech Republic, project MSM 4977751303.

Session 4
Thursday, March 30, 16:00 - 18:00

Room: H 2032

Basic Modelling and Moving Biological Systems

Chair:

Udo Nackenhorst

16:00	Stelzner	H 2032

Kinematik Und Dynamik Aus Experimentell Ermittelten Bewegungen

Günther Stelzner, Wolfgang Seemann, Institut für Technische Mechanik, Universität Karlsruhe

Ein wesentliches Aufgabengebiet im Bereich der Biomechanik ist die Entwicklung moderner Methoden und Verfahren zur Analyse menschlicher Bewegungsabläufe. Die Bestimmung innerer Belastungen während einer bestimmten Bewegung ist ebenfalls ein interessantes Ziel biomechanischer Untersuchungen. Ein wichtiges Instrument zur Bearbeitung derartiger Fragestellungen ist die Simulation. Bei der Entwicklung eines Simulationsmodells auf der Grundlage von Steuermaßen und Messdaten realer Bewegungen des Menschen hängt die Genauigkeit der Berechnung entscheidend von einer detailgetreuen Modellierung und der Güte der Messdaten ab.

Die mit Hilfe der Motion-Capture-Technik gewonnenen Trajektorien menschlicher Gliedmaßen sind i. A. fehlerbehaftet. Benutzt man diese Messungen zur Untersuchung der Belastungen des Bewegungsapparates während eines bestimmten Bewegungsvorganges, so ist zu beachten, dass die inverse Dynamik bei einem nicht mit der Messung konsistenten Modell zwar die Bewegung reproduzieren kann, hierbei aber große Artefakte in den berechneten Kräften und Momenten auftreten. Es wird ein Konzept zur Korrektur der fehlerbehafteten Messdaten im Hinblick auf die kinematische Konsistenz vorgestellt. Weiterhin soll die Projektion der gemessenen menschlichen Bewegungen auf ein Starrkörpermodell mit weniger Freiheitsgraden vollzogen werden. Die Vorgehensweise wird anhand ausgewählter Beispiele demonstriert.

16:20	Rues	H 2032

Joint And Muscle Forces During Clenching

Stefan Rues, J. Lenz, H. J. Schindler, Fakultät für Mathematik, Universität Karlsruhe
Karl Schweizerhof, Institut für Mechanik, Universität Karlsruhe

The masticatory system is highly redundant. Therefore, knowledge about the activation patterns of the chewing muscles is necessary to be able to calculate the joint and muscle forces and, in particular, to identify tasks leading to high joint forces. In 10 healthy male subjects electromyographic activities of all muscles during clenching tasks were recorded. Simultaneously, the resultant bite force was measured with an intraoral measuring device. For each test person a 3D-model of the musculature was constructed using horizontal and frontal MRTs. From these models the lines of action and the physiological cross sectional areas were identified. Based on the measured data, a force law relating the electrical activity of a muscle to the developed force, was determined for isometric muscle contractions. Thus, all acting forces and the so-called intrinsic muscle stress, an unknown parameter in the force law, could finally be calculated from the equilibrium conditions. The results show that 1) motor control seems to favour a directional effectiveness of the muscles; 2) subjects differ in the generation of the amount of muscle force, yet not in the overall activation patterns; 3) for vertical clenching each joint force amounts to about 60 to 70% of the resultant bite force.

16:40	Strobach	H 2032

An Analysis Of Simplified Muscle Activation Parameterization

Daniel Strobach, Andres Kecskeméthy, Universität Duisburg-Essen

This paper analyzes a simplified method for rough identification of muscle activation profiles of general motor tasks by means of dynamic optimization. Muscle activation profiles are parameterized with 6 parameters per muscle, using linear combinations of two smooth C^∞ functions closely related to the Gaussian distribution function used in stochastics.

The method is applied to a simplified subsystem of the human leg consisting of a planar hip and knee joint, comprising one antagonistic muscle pair at the knee (*vastus intermedius* and *biceps femoris caput brevis*). The muscle model used in this application is a Hill-type model including muscle contraction dynamics. To simulate the swing phase of human gait, a rheonomic constraint is imposed on the hip joint.

The optimization results show that, (1) the method can reduce the number of parameters and CPU time consumption significantly in comparison to other parameterizations without loss in result quality and (2) that there is an interaction between height and width of activation peaks that leads to poor convergence in the optimization process. For circumventing these problems additional penalty terms are suggested.

17:00	Arghir	H 2032

Study Of The Human Body Vibrations For The Seated Vehicle Driver

Mariana Arghir, Simona Rodean, Technical University of Cluj-Napoca, Romania

The paper presents some aspects about the dynamic response of the human body subjected to the vertical vibration in the travel inside the auto vehicle. There is a model presented in the specialized literature. This is transformed for the given study because was necessary to realize the vertical vibration along the human body. The human body is a system, having characteristics of: mass, damping and elasticity or stiffness. That means the human body can be considered a mechanical structure and can be studied as a mechanical complex system. The perturbance is a harmonically action force produced by the vehicle seat. There are two different studies: using a linear lumped parameter systems seated human body model, using a nonlinear lumped parameter systems seat human body model. The differential equations system of the human body has the same form and meaning as a system given by natural structure. The study is made with MATHCAD program. It presents the human body eigenvalues and the biodynamic response of human seat interactions into a vehicle.

17:20	Rezunenko	H 2032

Study Of Partial Differential Equations With State-dependent Delay

Alexander Rezunenko, Department of Mechanics and Mathematics, Kharkov University, Ukraine

A model of partial differential equations (PDEs) with state-dependent delay is investigated.

In many applied problems the value of delay, or more generally, the delay terms are not constant. We are interested in systems with a state-dependent delay term. The study of such systems has attracted much attention and many deep results were obtained for ordinary differential equations with discrete state-dependent delay. For the later equations it is natural to consider solutions from the space of Lipschitz continuous in time functions. Unfortunately, solutions of PDEs do not belong to this space so one has to find another approaches.

We consider weak solutions of a class of nonlinear parabolic PDEs with finite distributed state-dependent (state-selective) delay. The existence of weak solutions and a global attractor of the corresponding dynamical system is proved. This approach can be used to treat many applied problems, particularly, such biological ones as the diffusive Nicholson's blowflies equation.

17:40	Sander	H 2032

Efficient Simulation Of Dynamic Stresses In The Human Knee

Oliver Sander, DFG Research Center MATHEON, FU Berlin

We present a method for efficient, high-resolution, patient-specific simulation of the loads and stresses in a human knee joint during a gait cycle. Femur and tibia are modelled using first-order finite elements on a grid generated semi-automatically from a CT scan of the patient. We therefore obtain patient-specific information which can be very useful in operation and therapy planning. A new stabilized Newmark time scheme allows the time integration of Newton's equations of motion with arbitrarily large time steps. At each time step a large minimization problem has to be solved. Additional difficulty arises from the nonpenetration condition imposed on the bones, which lead to inequality constaints for the minimization problem. A generalization of standard multigrid solvers, the so-called monotone multigrid solver, can solve such contact problems with optimal efficiency. We show numerical results for test problems with analytically known solutions as well as real-world examples using the Visible-Human data set.

3 Damage and fracture

Organizers:

Wolfgang Brocks, Institute for Materials Research
Ralf Müller, TU Darmstadt

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 110

Analytical models and fracture criteria

Chair:

Wolfgang Brocks
Frederik Reusch

13:30	Schütte	H 110

On The Elastic Symmetries Of Growing Mixed-mode Cracks

Henning Schütte, Kianoush M.-Abbasi, Institut für Mechanik, Ruhr-Universität Bochum

Many continuum damage mechanics models for quasi-brittle materials are based on the reduction of stiffness due to elliptical crack or penny-shaped microcracks in the material. Because of this a numerical study of growing elliptical cracks in a unit cube is undertaken with the help of an FEM simulation.The propagation of the crack is governed by the principle of maximum driving force, which is a direct consequence of the variational principle of a body containing a crack. For each propagation step the tensor of elasticity is calculated and its symmetries are analyzed. It will be shown that the elastic symmetry in each step is close to orthotropy and can be approximated by an equivalent elliptical crack. To incorporate the results of the numerical analysis in a continuum damage model it is possible to avoid the FEM simulation of crack growth in a unit cell, representing a continuum point, by using a replacement crack approach. For an elliptical crack there are analytical solutions available for the SIFs and so for the direction of growth and change of shape of the crack. An analytical solution for the change of elasticity due to a growing mixed mode crack is given. This is used to present a replacement crack model, in which in each step the grown crack is replaced by an equivalent elliptical crack. The resulting compliance changes are compared to the results of the direct FEM simulation.

13:50	Paluszynski	H 110

Isotropic Softening Model For High-cycle Fatigue

Blazej Paluszynski, Institut für Technische Mechanik, Universität Karlsruhe (TH)

As well known the high cycle loading of structural elements above the fatigue limit results in catastrophic propagation of macroscopic fatigue crack. Therefore it is in demand to find a method, which would allow for early prediction of the fatigue life-time of the structural member.

The series of force-driven tests carried on 30CrNiMo8 steel have shown that, although the stresses by high-cycle fatigue do not reach the tensile stress, the material strength (measured indirectly from the strain-stress loop) decreases from the very begin of the test, hence the damage appears and progresses from the very begin of the loading history.

In this study a thermodynamically consistent strain driven constitutive model for isotropic damage accumulation by high-cycle fatigue of a homogeneous isotropic material is proposed. In order to account for the above-mentioned experimental observations the model is coupled to a softening rule. The numerical aspects concerning the implementation of the model in the commercial FEM software ABAQUS and discussion of the representative numerical results will be provided at the end of the talk.

14:10	M.-Abbasi	H 110

Evolution Of Elastic T-stresses Of Growing Mixed-mode Cracks

Kianoush M.-Abbasi, Henning Schütte, Institut für Mechanik, Ruhr-Universität Bochum

Finite element simulations of central line-cracks and internal penny-shaped cracks have been performed to simulate the mixed-mode quasi-static crack growth, from which the elastic T-stresses acting at the crack tip (along the crack front in 3-D case) are calculated as the crack grows.

The models provide a general framework for mixed-mode linear elastic fracture mechanics, under small strain assumptions. The fracture criterion is the maximum driving force criterion, proposed by LE, SCHÜTTE & STUMPF (1999), which is a direct consequence of the variational principle of a cracked body in equilibrium.

LEBLOND & TORLAI (1990) addressed the stress expansion for an arbitrarily shaped crack with an arbitrarily curved front in an elastic 3-D body, according to which there are three non-singular stresses, the so-called T-stresses, acting at the crack front. The number of T-stresses would reduce to two for general mixed-mode 2-D crack problems.
With our models, we show the evolution of elastic T-stresses for central line-cracks and internal penny-shaped cracks.
The computed results show that T_2 tends to zero as the mixed-mode crack grows, for both 2-D and 3-D crack problems, so tending asymptotically to the mode-I solution.

14:30	**Loboda**	**H 110**

On Some Relations Between Different Interface Crack Models

Volodymyr Loboda, Department of Theoretical and Applied Mechanics, Dniepropetrovsk National University, Ukraine
Klaus Herrmann, Fakultät für Maschinenbau, Universität Paderborn

The most well-known and developed model of an interface crack is the so-called "open"-crack or classical model which posseses an oscillating singularity at the crack tip. Because it calls the physically unreal overlapping of the crack faces the contact zone model was developed by Comninou several decades ago. The new artificial contact zone model which in particular cases can lead either to the classical model or to the real contact zone length was developed by the authors of this report and applied for cracks in isotropic, anisotropic and piezoelectric bimaterials. This could be done by using exact alytical solutions of the associated problems of linear relationships and due to the construction of relatively simple formulas for the fracture mechanical parameters and the contact zone length.

In the present report a thorough analysis of the mentioned formulas and its comparison with the correspondent classical results has been performed. This analysis showed the way of presentation of the main results for an artificial contact zone model in the manner very similar to the classical model, and due to this phenomenon the essential simplification of the investigation of the contact zone model has been attained. The application of the obtained results to interface cracks in anisotropic and piezoelectric bimaterials has been demonstrated.

14:50	**Kostenko**	**H 110**

Investigation Of Elastoplastic Problem For Cylindrical Shells ...

Iryna Kostenko, Dep. of Numerical Mathematics and Programming, National University "Lvivska Politechnica", Ukranie

The paper presents effect of influence of plastical areas for the cylindrical shell weakened by acrossing cracks of the given length. Elastoplastic problem for shell with cracks is reduced by dk-model to analog the elasticity problem for shell with through cracks unknown length, the faces of which are under the unknown stresses and moments, satisfying the plasticity conditions for thin shell. It is known that the elasticity problem is reduced to the system of singular integral equations with discontinuos righthand sizes. The numerical analysis of the influence of length plastical area on the stressed state is made. One can solve the singular integral equations of the first kind with kernels K(u,s) and free terms f(s) by the approximate methods.The kernels and free termsare defined on the interval [-1,1] and they are continuous functions of their arguments. The quadrature formula for the singular integral is constructed using the Lagrange interpolation polynomials on Chebyshev nodes. The regular integral is approximated using Gauss-type formulas. By this approach we reduce the system of singular integral equations to the system of the algebraic equations, which can be solved by numerical methods.

15:10	**Govorukha**	**H 110**

Analytical-numerical Analysis Of An Interface Crack

Volodymyr Govorukha, Department of Computational Mathematics and Mathematical Cybernetics, Dniepropetrovsk National University, Ukraine

An interface crack with an artificial contact zone at the right-hand side crack tip between two dissimilar finite-sized piezoelectric materials under remote mixed-mode loading is considered. To find the singular electromechanical field at the crack tip, an asymptotic near-tip solution in connection with the conventional finite element method is derived. For mechanical and electrical loads, the stress intensity factors at the singular points are obtained. As a particular case of this solution, the contact zone model (in Comninous sense) is derived. The transcendental equation and an asymptotic formula are used for the determination of the real contact zone length and the associated stress intensity factors. The dependencies of the real contact zone lengths on the coefficients of normal-shear external load are illustrated in graphical form. For a particular case of a short crack with respect to the bimaterial size, the numerical results are compared with the exact analytical solutions, obtained for a piezoelectric bimaterial plane with an interface crack.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: H 111

Composite structures, microstructures, interfaces

Chair:

Paul Steinmann
Ralf Müller

13:30	Balzani	H 111

Delamination Analysis Of Ud Composites Using Interface Elements

Claudio Balzani, Werner Wagner, Institut für Baustatik, Universität Karlsruhe (TH)

Unidirectional fiber-reinforced composite laminates are widely used, especially in aircraft industries. In order to exploit material reserves complex fracture modes should be accounted for in the design phase of such materials. In this work, stiffened curved panels are examined which are typical aircraft fuselage structures. Since delamination can lead to a significant reduction of the load-carrying capacity of such structures the effects of this particular fracture mode is investigated in the framework of the finite element method. A special interface element is proposed which allows for the prediction of various delaminations under mixed-mode loading conditions. A constitutive law is introduced which is mainly inspired by publications of de-Andrés et al. [1999] and Ortiz & Pandolfi [1999]. This constitutive law is characterized by a cohesive free energy function without any point of discontinuity. It is governed by exponential softening response. The model avoids the interpenetration of the crack faces by incorporating a penalty term in the free energy function. Some numerical examples show the applicability of the model. The results are compared with an often-used model with linear softening, cf. Camanho & Dávila [2002], with analytical solutions and material testing results.

13:50	Ernst	H 111

Mikromechanische Festigkeitsberechnung Von Faserverbunden

Gerald Ernst, Christian Hühne, Raimund Rolfes, Institut für Statik und Dynamik, Universität Hannover

Die Festigkeit textiler Faserverbunde ist aufgrund der vielfältigen Einflüsse der Fasergeometrie bisher nur experimentell bestimmbar. Mit einer mikromechani-

schen Einheitszelle von einer textilen Verstärkungsschicht soll die Berechnung der Festigkeit realisiert werden.

Im Rahmen der World-Wide-Failure-Exercise (WWFE) wurde eine Vielzahl von Versuchen an unidirektionalen Verbunden zusammengestellt.

Anhand dieser Versuche wird die prinzipielle Anwendbarkeit eines Mikromechanischen Repräsentativen Volumenelementes (RVE) für die Berechnung der Festigkeiten untersucht.

In dem RVE werden Faser und Matrix einer UD-Lage diskret abgebildet.

Mit einem Kontinuumschädigungsansatz wird die Ausbreitung von Rissen in der Matrix berechnet. Dieses Vorgehen ist notwendig um den Versagensvorgang und seine Auswirkungen auf das Tragverhalten zu beurteilen.

In Abhängigkeit von der Rissrichtung kann es entweder zum kompletten Versagen des Laminates oder zu einer Schädigung kommen, die eine weitere Belastung des Laminates zulässt.

Bei der Berechnung der Rissausbreitung wurden verschiedene Regularisierungsmethoden, wie das Bruchenergiekonzept, die viskoplastische Regularisierung und eine nichtlokale Schädigungsformulierung, untersucht.

14:10	Kula	H 111

Modelling Of Composite Plates Including Damage

Krzysztof Kula, Mieczyslaw Kuczma, Institute of Structural Engineering, University of Zielona Góra, Poland

We are concerned with the modelling and numerical simulation of fibre-composite plates in the nonlinear range due to large strains and damage. We apply the layer-wise approach by dividing the plate into a number of layers. Each layer is elastic-brittle and assumed to be orthotropic in the local material coordinate system. The appearance of damage is controlled according to the failure criteria due to Hashin, Tsai-Hill and Tsai-Wu. When the failure condition is satisfied, the mechanical properties of the material are modified appropriately, depending on the type of damage (fibre breakage, matrix crack, fibre-matrix shear). We have programmed the model with a user subroutine in the ABAQUS environment and carried out a number of numerical simulations. We have compared the numerical results with the experimental data available in the literature. The obtained results show a remarkable influence of large displacements on the plate behaviour, and it was observed a large difference in the level of load between the first ply failure and ultimate failure of the plate.

14:30	Kühn	H 111

Modelling Of Microstructures In Ceramics To Simulate Crack Growth

Martin Kühn, Sascha Knell, Martin Oliver Steinhauser, Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut (EMI)

To examine crack Growth in aluminum oxide ceramics their microstructure is approximated as convex polyhedra in 3D space. To represent the grains a power diagram is used that is an extension of the classical Voronoi diagram. It is known that any simple arrangement of Polyhedra in 3D space can be represented by a power diagram. The model is optimized so that statistical properties of an arbitrary 2D slice are similar to experimental data acquired by polished cut images of high density aluminium oxide ceramics. After small subsequent simplifications to eliminate small edges that cause unfavoured mesh geometries the grains are resolved into tetrahedra. To gain also models in 2D space an arbitrary slice of the 3D model is resolved into triangles.

These models are used to conduct FEM simulations to explore material properties in general and crack growth in particular dependent on the microstructure of the underlying ceramics.

14:50	**Piat**	**H 111**

Numerical Modelling Of Brittle Fracture In Porous Cfc-materials

Romana Piat, Eckart Schnack, Institut für Technische Mechanik, Universität Karlsruhe

Both energy and stress criteria are necessary conditions for fracture but neither one nor the other are sufficient. Combination of these criteria is proposed in [Leguillon 2002]. This criterion is used for numerical simulation of the crack propagation by 4-point bending test in porous material. Firstly were held studies about influence of the porosity, pores distribution on the crack propagation. These studies were held for circular pores. Other sides the shapes of the pores in the authentic materials are more complicated. Example of such materials are carbon-carbon composites [Piat et al. 2003, Piat and Schnack 2003]. Micrographs of the cross-sections these materials are used for FEM modelling of the crack propagation on the basis of proposed criterion. Results of the numerical modelling are compared with experimental results.

15:10	**Utzinger**	**H 111**

Theory And Numerics Of Laminar Welded Lightweight Structures

Johannes Utzinger, Andreas Menzel, Ellen Kuhl, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

In the field of composites, laminar welding of lightweight structures consisting of metal/fibre-reinforced polymers is a very seminal issue, concerning for example the automotive industry. The theoretical and numerical modeling as well as the simulation of the mentioned composites is a crucial and integrating subarea. By using various material laws in a traction-separation context, different experimental and analytical methods must be consulted to verify the mesomechanical models. First of all, this talk gives a short overview over the manufacturing alternatives of laminar welded metal/fibre-reinforced polymer composites, followed by a concise outline concerning experimental and analytical techniques. This is followed by a detailed characterization of the applied theoretical and numerical methods. In this context, interfacial elasto-plasticity with damage plays a major role. The talk is closed by a comparison of numerical and experimental results.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: H 110

Analytical models and fracture criteria

Chair:

Bernard Fedelich
Henning Schütte

16:00	Emmrich	H 110

The Peridynamic Equation Of Motion In Non-local Elasticity Theory

Etienne Emmrich, Institut für Mathematik, TU Berlin
Olaf Weckner, Department of Mechanical Engineering, Massachusetts Institute of Technology, USA

During the last few years, non-local theories in solid mechanics that account for effects of long-range interactions have become topical again. One of these theories is the so-called peridynamic modelling, introduced by Silling in 1998.

The governing equation of motion is the partial integro-differential equation

$$\rho(\boldsymbol{x})\partial_t^2\boldsymbol{u}(\boldsymbol{x},t) = \int\limits_{\mathcal{H}(\boldsymbol{x})} \boldsymbol{f}(\boldsymbol{x},\hat{\boldsymbol{x}},\boldsymbol{u}(\boldsymbol{x},t),\boldsymbol{u}(\hat{\boldsymbol{x}},t),t)\,\mathrm{d}\hat{\boldsymbol{x}} + \boldsymbol{b}(\boldsymbol{x},t),\ \boldsymbol{x}\in\mathcal{V},\ t>0\,,$$

for the displacement field $\boldsymbol{u} = \boldsymbol{u}(\boldsymbol{x},t)$ of a body with the mass density ρ that occupies the reference volume $\mathcal{V}$, supplemented by initial conditions. Here, $\boldsymbol{f}$ is the pairwise force field that describes the interaction of material particles, and $\boldsymbol{b}$ collects outer forces. Moreover, $\mathcal{H}(\boldsymbol{x}) = \{\hat{\boldsymbol{x}} \in \mathcal{V} : |\hat{\boldsymbol{x}} - \boldsymbol{x}| < \delta\}$ is the peridynamic horizon for prescribed $\delta > 0$.

An essential feature is that $\boldsymbol{f}$ is independent of any spatial derivative. It is, therefore, a promising approach for problems in which discontinuities emerge and has recently been successfully applied in numerical simulations of the fracture of a plate with notches, the undirected growth of cracks, the wrinkling and tearing of membranes, the deformation of composite materials etc.

In this talk, we give an overview of the peridynamic modelling as well as the numerical and theoretical results obtained so far. We then suggest different quadrature formulae methods for the spatial approximation of the underlying equation. Concentrating on the description of a linear microelastic material, we present new results concerning the well-posedness of the problem, the evolution of jump discontinuities, and the conservation of energy.

16:20	Reusch	H 110

Non-local Adaptive Simulation Of Ductile Damage In Prmmcs

Frederik Reusch, Christian Hortig, Serkan Ertürk, Bob Svendsen, Lehrstuhl für Mechanik, Universität Dortmund

This work will present a recently developed non-local formulation of a damage model for ductile damage at locally large deformations and its successful application to the finite element simulation of crack propagation in particle-reinforced metal matrix composites (PRMMCs).

This is carried out in the framework of adaptive mesh refinement and model adaptivity with the help of a new modular python-based system for adaptivity applied to the commercial program ABAQUS using different non-local remeshing criteria.

The results for artificial and real composite microstructures document quantitatively the effect of the delocalization of the model damage process and the minimization of mesh-dependence on the evolution of the localized damage process zone in the matrix material and the global structural response.

16:40	Radeke	H 110

Statistical Strength Analysis Of Dense Particle Systems

Charles Radeke, Meinhard Kuna, D. Stoyan, TU Bergakademie Freiberg

In the contribution numerical simulation and geometrical modeling are presented of dense packings of brittle particles under static loading due to restricted mobility (bulk crushing, silo, etc). By means of a special FEM technique the geometrical and mechanical properties of the particles are modeled, which are represented by planar discs. Based on the obtained force network inside the packing a criterion of particle failure will be derived from detailed finite element analyses of parameterized various disc configurations. The criterion takes into account the inhomogeneous stress state inside a single particle caused by the forces of surrounding particles. Using the theory of Griffith and Weibull this yields a scalar value, the so called Weibull-stress σ_w. Therewith the failure probability of loaded granular media can be calculated locally and in general.

The developed statistical strength analysis is applied to various types of packings and gives insight into the relation between geometrical configurations and failure.

17:00	Fernandez	H 110

Numerical Analysis Of An Elastic Contact Problem With Damage

<u>José R. Fernandez</u>, Marco Campo, Facultad de Matemáticas, Universidad de Santiago de Compostela, Spain

The processes of quasistatic evolution of the mechanical state of an elastic body in frictionless contact with a deformable obstacle, and the development of material damage which results from internal compression or tension, are modelled and numerically analyzed. A normal compliance contact condition is employed to model the contact. The problem is formulated as a nonlinear elliptic equation for the displacements coupled with a parabolic equation for the damage field. The existence of the unique local weak solution is stated. Then, a fully discrete scheme is introduced using the finite element method to approximate the spatial variable and an Euler scheme to discretize the time derivatives. Error estimates are derived on the approximate solutions, from which the linear convergence of the algorithm is deduced under suitable regularity conditions. Finally, some two-dimensional numerical simulations are performed to show the accuracy of the scheme and its behaviour.

17:20	Rusinov	H 110

To The Construction Of Creep Long-term Fracture Criterion

<u>Alexandr Rusinov</u>, S.P.Timoshenko Institute of Mechanics, Ukraine

The problem of the construction of creep long-term fracture criteria taking in account sings of principal stresses is considered. Task solution of the life time evaluation under the plane stress state in creep is ordinary carried out by means of long-term fracture criteria. These criteria allow us to lead the influence of plane stress state to the action of equivalent uniaxial tensile load using specially fitted equivalent stress. In this case the reliability of estimate of findings essentially depends on the criterion structure and on the method of determining the material constants. The variety of classes of structural materials and multiformity of stress conditions predetermine correspondingly a great number of long-term fracture criteria. However existing criteria can be used only for certain materials under certain stresses. The problem of the choice and experimental justification of long-term fracture criteria of isotropic materials under plane stress state in creep is solved by using a new method of criterion construction. The criteria are given by a linear interpolation range with respect to viscous and brittle fracture and take into account the sings of principal stresses. The criterion structure takes kinds of loading into account by using Nadai-Lode parameter and contains one material constant.The basic experiment for determining the material constant includes standard tests on long-term fracture in uniaxial tension and a test on long-term fracture under plane stress state. Two cases of stress state are considered : when the sings of principal stresses coincide and when the signs mismatch. The first stress state is realized in thin-walled tubular specimens loaded by internal pressure, internal pressure with tension and internal pressure with bending. In this case criterion is given by linear interpolation of the maximum normal stress(brittle fracture) and the shearing stress intensity(viscous fracture). The second state is realized in thin-walled tubular specimens loaded by torsion, tension with torsion and interpolation range is limited by double maximum shearing stress(brittle fracture) and octahedral shearing stress(viscous fracture). This criterion is approved on unified long-term fracture diagrams of isotopic materials. All experimental data were adopted from the works of other authors. The calculation results are compared with experimetal data and shown to closely fitting between themselves.

17:40	Iankov	H 110

Identification Of Material Parameters In The Rousselier Model

Roumen Iankov, Institute of Mechanics, Bulgaria

Different models describing ductile failure of metals have been developed in recent years in Continuum Damage Mechanics(CDM). The interest to local approaches and micromechanical modeling of damage increasing in last years. There are many proposals in literature by Gurson , Rice and Tracey, Rousselier, Lemaitre, Chaboche etc. widely accepted to describe ductile fracture of metals. The model proposed by Gurson and later phenomenologically extended by Tvergaard and Needleman (so called GTN model) has been most frequently used in CDM. Rousselier (so called R model) used a more general framework and derived a yield function similar to that used by Needleman and Tvergaard by assuming general plastic and thermodynamic potentials. Experimental identification of the damage law parameters requires suitable tests. The constants of the damage law are currently obtained by performing several complicated and sometimes costly experiments. The physical damage parameters are obtained in such a way that the FE predicted curve will fit the experimental plot deduced from a tensile material test. The objective function comparing numerical results from finite element calculations with the experimental results identified by a series of tensile tests performed on the same specimen will be defined. The optimization problem based on the above mentioned objective function will be defined and solved. Main objective of the work is to develop numerical tools for the numerical identification of parameters in the Rousselier porous damage material model. The FE code ABAQUS is used to model the experiment and to identify parameters in the Rousselier damage model

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: H 111

Composite structures, microstructures, interfaces

Chair:

Gerard A. Maugin
Wolfgang Brocks

16:00	Vallee	H 111

Construction Of A Bipotential For A Multivalued Constitutive Law

Claude Vallee, Géry De Saxce, Marius Buliga, Camelia Lerintiu, Laboratoire de Mécanique des Solides, Université de Poitiers, France

Let X be a topological vector space and Y be its dual. A bipotential is a real or infinite valued function b defined on $X \times Y$, separately convex and l.s.c. with respect to each variable, satisfying the inequality:

$$b(x, y) \geq \langle x, y \rangle.$$

This non smooth mechanics tool allows modelling various non associative multivalued constitutive laws of dissipative materials (friction contact, soils, cyclic plasticity of metals, damage).

The present work intents to answer the following question: Let be a given graph M included in $X \times Y$ representing a material behaviour. Is there a bipotential b for which M is the set of (x, y) such that

$$b(x, y) = \langle x, y \rangle,$$

and how to construct it?

We state a simple necessary and sufficient condition for the existence of b. If it is fulfilled, we construct b in three steps:

- we cover M with a family $(M_\lambda)_{\lambda \in \Lambda}$ of maximal cyclically monotone graphs,
- we use Rockafellar theorem to construct the dual superpotentials ϕ_λ and ϕ'_λ associated to each M_λ,
- we obtain b as inferior envelop of functions, provided ϕ_λ and ϕ'_λ satisfy a suitable implicit convexity inequality.

This algorithm is illustrated by examples.

16:20	Timmel	H 111

An Approach For Micromechanical Modelling Of Damage Mechanisms

Mario Timmel, Michael Kaliske, Stefan Kolling, Institut für Statik und Dynamik der Tragstrukturen, Universität Leipzig

The numerical simulation of materials subjected to high strain rates requires the consideration of material damage to take softening into account. In this context, phenomenological damage approaches are widespread in commercial finite element codes. In our presentation, we discuss a micromechanical approach to compute damage effects. Based on Eshelbys work, a closed form solution of field quantities of a microsystem with embedded inclusions in a matrix material is suggested.

In our work, we use this basis to describe the evolution of the inclusions configuration. Due to the assumption of a low stiffness of the embedded particles, the growth of damaged regions is approximated. The information how evolution should take place to maximize the dissipation is obtained by configurational forces which have been established as a useful tool in micromechanics. Configurational forces are computed on the phase boundary between the inclusion and the surrounding matrix. To allow an analytical description, the embedded particles will be approximated by an ellipsoidal shape. With the aid of homogenization techniques, the description of microstructural evolution is used to substitute phenomenological damage implicated constitutive laws in finite element method.

16:40	Ertürk	H 111

Rve And Unit-cell Simulations Of Damage And Failure In Prmmcs

Serkan Ertürk, Frederik Reusch, Bob Svendsen, Lehrstuhl für Mechanik, Universität Dortmund

The purpose of this work is the comparison of damage and failure modeling on the basis of unit-cell calculations and homogenization methods. To this end, such behaviour in particle-reinforced metal matrix composites (PRMMCs) is investigated. In particular, the processes of void nucleation (due, e.g., to particle debonding and/or cracking) and growth are investigated in conjunction with the distribution of particle sizes and locations in the unit cell are of interest here. The development of the void volume fraction resulting from these processes in the unit cell is compared with the corresponding RVE-prediction as based on the Gurson-Tvergaard-Needleman model for ductile damage and failure.

17:00	Menshykov	H 111

Analysis Of Critical Strains And Loads In Layered Composites

Oleksandr Menshykov, S.P.Timoshenko Institute of Mechanics, Ukraine
Igor Guz, Maryna Menshykova, Centre for Micro- and Nanomechanics, University of Aberdeen, UK

The present work is devoted to investigation of the compressive fracture for heterogeneous (piecewise homogeneous) materials with specific kinds of delaminations (defects with connected edges). The critical buckling strains and loads at which ply instability in laminated composites occurs under uniaxial and biaxial compression were evaluated. The upper and lower bounds for critical strains and loads were determined using the results for perfectly bounded and sliding layers. In order to calculate the bounds exact three-dimensional solutions of the internal instability problem (fibre micro-buckling) were found. Numerical results show how the type of loading and properties of layers (linear elastic, elastic-plastic, hyper-elastic incompressible) affect the solution for the first two or four (in the case of hyper-elastic material) modes of stability loss, which are commonly observed. To facilitate the analysis, the software package with the graphical user-friendly interface was developed using MATLAB.

17:20	Craciun	H 111

Interface Crack In A Pre-stressed Orthotropic Elastic Composite

Eduard-Marius Craciun, Adrian Carabineanu, Fac. of Mathematics and Informatics, University Ovidius, Romania

We consider an interface crack in prestressed deformed elastic composite in antiplane state acted by shear loadings. Also it is assumed that the initial deformed equilibrium configuration of the body is locally stable.

Using an interface boundary condition as those used by L.R.F. Rose (J. Mech. Phys. Solids, 1987) and D. Bigoni et al (Int. J. of Solids Structures, 1996) we obtain non homogenous Riemann-Hilbert problem and a null jump boundary value problem.

Using Plemelj's function and the theory of Cauchy's integral we obtain a non linear complex differential equation, with the unknown our complex potential in an antiplane state.

Numerical methods used, allow us to obtain our complex potential and using the representation of the incremental fields we find the components of the incremental stress and displacement.

17:40	Lapusta	H 111

Near-surface Microbuckling In Fiber Composites

Yuri Lapusta, French Institute of Advanced Mechanics, France

A model of near-surface microbuckling in polymer matrix composites is discussed. It includes the boundary effects and allows an explicit modelling of different interactions of the composite's microcomponents and defects. The problem is solved in 3D. The fibre-matrix interfaces are considered as surfaces, responsible for the stress transfer. Calculations are carried out in the assumption of periodic fiber distributions along the boundary. Simple material models are used to describe separately the mechanical behaviour of the microcomponents. Some idealized interface situations describing perfect and imperfect bonding are analysed. Calculations show that the microbuckling modes are strongly influenced by the mechanical properties of the microconstituents, geometrical parameters of the microstructure, the boundary of the composite, and by the quality of the fibre-matrix interfaces. The mathematical formulation and the solution procedure is extended to three-phase and multi-phase materials.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: H 110

Numerics

Chair:

Frederik Reusch
Paul Steinmann

13:30	Glaser	H 110

Propagating Cracks With X-fem And Material Force Method

Jürgen Glaser, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

Based on the X-FEM formulation quasi-static crack propagation in an otherwise continuous linear-elastic material is described applying the material force method.

While the X-FEM allows the modelling of a crack independently of the mesh and without remeshing in case of propagating cracks, the Material Force Method is an elegant tool to assess fracture mechanics problems. Thus it is convenient to combine both concepts in order to describe crack propagation.

The X-FEM modifies the standard Finite Element approach in order to describe the discontinuous displacement field across a crack (and the asymptotic crack-tip field) through a partition of unity method. Additional degrees of freedom at nodes in the vicinity of the crack which are connected to a step function are representing the discontinuity.

In the material description of continuum mechanics material or configurational forces on a particle are generated by a variation of the material position of that particle while the spatial coordinate remains fixed. In other words material forces and the variation of the material position are energetically conjugate.

As the X-FEM discretization leads to two types of nodal degrees of freedom, the standard ones and those connected to the displacement jump accross the crack face, two kinds of material node point forces are emanating from the X-FEM formulation: the well-known material forces at standard degrees of freedom and additional material forces at enriched degrees of freedom. The resulting material force at standard degrees of freedom in the vicinity of the crack tip is energetically conjugate to a variation of the crack lenght (i.e. a variation of the material position of the crack tip) and thus represents a driving force for crack propagation. It is closely related to the J-integral of fracture mechanics. A corresponding energetic pairing has to connect the material forces at enriched degrees of freedom to a variation of these degrees of freedom.

The application of the material force method to quasi-static crack propagation within the framework of the X-FEM will be illustrated by several examples with a focus on the nodal material forces at standard degrees of freedom as a criterion for crack propagation. The nature of the material forces at enriched degrees of freedom will be discussed.

13:50	Peters	H 110

Numerical Aspects Of The Extended Finite Element Method

Markus Peters, Klaus Hackl, Institut für Mechanik, Ruhr-Universität Bochum

The eXtended Finite Element Method (XFEM) is a very efficient way to reduce mesh dependencies when analysing crack growth. Displacements and stresses around the crack tip are calculated using additional shape functions which span the analytical displacement field around a crack tip.

The crack growth criterion is based on the computation of the stress intensity factors K. When the calculation of K is done using the J-integral over a circular domain Ω, for two or more cracks the radius of Ω has to be chosen in such a way that there is only one crack tip lying in the domain.

Because of the fact that the accuracy of the resulting stress intensity factors differs very much depending on

- the radius of Ω
- the number of elements used in the XFEM computation and
- the shape functions which were used for the standard FE term

we want to compare the results of the stress intensity factors by using different numerical configurations for the three items mentioned above.

14:10	Geißler	H 110

An Adaptive Finite Element Approach For Brittle Fracture

Gordon Geißler, Michael Kaliske, Institut für Statik und Dynamik der Tragstrukturen, Universität Leipzig

The extension of the finite element method to take discrete failure into account is a current research field. In recent times, first results in terms of cohesive elements have been introduced into commercial applications. Such element formulations are able to cover the discrete behaviour of interfaces between different materials or the mechanical processes of thin layers. These approaches are not suitable for simulations with unknown crack paths in homogeneous materials.

The presented strategy starts with an undamaged structure and modifies the model during the ongoing computations. The idea is to generate additional elements, based on the cohesive element formulation, to approximate arbitrary crack paths. For this purpose a failure criterion is introduced. For nodes where the limiting value is reached cohesive elements are introduced between the volume element boundaries of accordingly facets and corresponding nodes are duplicated. Necessary modifications for this application on system level as well as the element and the material formulation are explained in detail. By means of some numerical examples, the functionality of the presented procedure is demonstrated.

14:30	**Reese**	**H 110**

One Fragmentation Procedure For Brittle Material Cracking

Sven Holger Reese, Peter Wriggers, IBNM Universität Hannover

Realistic modeling of 3d fragmentation procedures with minimal incorporation of restrictions to the crack path is still a challenge in modern computational engineering simulations. The presented approach is used to model failure and cracking in concrete structures, applying an explicit finite element integration scheme. For efficient modeling of regions with highly localized strains, enrichment of the standard Galerkin finite element approximation is an established method.

In the used Strong Discontinuity Approach (SDA) the enhanced assumed strains enrich the standard Galerkin part of the finite element interpolation. This ensures, that the resulting discontinuities in the displacement field can be traced in a realistic way, which allows the non-geometrical representation of crack discontinuities.

The SDA will now be extended by inserting real discontinuities. By this mixed continuous-discontinuous model, the element representation is transfered from a non-geometrical to a geometrical one. Therefore, full adaptive procedures have to be incorporated in the 3d finite element model.

In order to obtain suitable surfaces for crack-closing contact computations and for discrete element coupling formulations, an continuous surface condition has to be guaranteed by the adaptive fragmentation algorithm. Some advancements, to minimize the mesh dependent identification of the material instabilities and to determine significant fracture plane normals will be presented.

14:50	**Hebel**	**H 110**

Modelling Crack Initiation By Means Of Finite Fracture Mechanics

Jochen Hebel, Wilfried Becker, TU Darmstadt

Although classical stress-based failure criteria are being used for a wide class of problems, they are, because of the singular stress fields, not directly applicable to notch problems as they would predict failure at any load level. For this problem class, fracture mechanics concepts are not applicable either as there is no crack at a perfect notch. Recently, hybrid failure criteria taking into account the singular stress field as well as the energy balance for emerging cracks of a finite length have been proposed to overcome this problem. In this paper, a universally applicable approach based on finite fracture mechanics is shown being implemented in a finite element procedure. Bimaterial notches under thermomechanical loading are analysed to predict brittle crack initiation for interfacial cracks as well as for cracks growing into the joined components.

15:10	Weber	H 110

Efficient Crack Growth Analyses By Combining Fast Methods For Bem

Wilhelm Weber, Karsten Kolk, Günther Kuhn, Lehrstuhl für Technische Mechanik, Universität Erlangen-Nürnberg

For the simulation of fatigue crack growth an incremental procedure is applied. Within each increment a stress analysis has to be performed. Based on the asymptotic stress field the stress intensity factors (SIFs) are calculated by an extrapolation method. Then, a new crack front is determined by a reliable 3D crack growth criterion. Finally, the numerical model has to be updated for the next increment. The time dominant factor in each increment is the computation of the stress field. Due to the stress concentration problem the boundary element method (BEM) is utilized. To speed-up the calculation several independent fast methods are exploited. For models containing a crack the dual discontinuity method (DDM) was generated. An algebraic technique is the adaptive cross approximation (ACA) method which is acting on the system matrix itself. The application of the substructure technique leads to a blockwise band matrix and therefore reduces the memory requirements. Further savings in memory and computation time are reached by modelling cracks with the DDM and using the ACA method in each substructure. The efficiency of the combined methods will be shown by a standard fracture mechanics specimen and a complex industrial example.

Session 6
Wednesday, March 29, 13:30 - 15:30

Room: H 111

Numerics

Chair:

Henning Schütte
Gerard A. Maugin

13:30	Hilgert	H 111

Numerical Simulation Of Crack Growth

Oliver Hilgert, Jörg Schröder, Institut für Mechanik, Universität Duisburg-Essen
J. Löblein, Forschung und Vorausentwicklung, Robert Bosch GmbH

In recent years the X-FEM based on the partition of unity method has shown to be a powerful tool to model crack growth. Nevertheless the strong discontinuity approach (SDA) is a simple method to simulate crack growth in an efficient way, too. Both methods model the crack surface by introducing additonal d.o.f.. The main difference of the two methods are the additional global d.o.f. in the X-FEM and the additional local d.o.f. in the SDA. In general the strong discontinuity approach lacks of crack path continuity across element edges because of the condensation of the locally embedded additional d.o.f. on element level. For an overview of these models we refer to Jirásek, M. [2000]. Thus jumps in the displacement field at element edges arise. Here the strong discontinuity approach is used approximating the displacement jump linearly across the crack length similar as e.g. in Alfaiate, J., Simone, A.,Sluys, L.J. [2003]. Based on the introduction of global additional d.o.f. that lie on the crack edges, crack path continuity is automatically given. These global d.o.f. are introduced to approximate the discontinuous part of the displacement field which has been splitted into a continuous and the aforementioned discontinuous part. The sum of the two parts represents the total diplacement field including a possible jump. The finite element formulation presented here is based on Löblein, J. & Schröder, J. [2005] and is extended with a dynamic regularisation by considering inertia effects. Shortly, the cohesive traction law describing the post crack behaviour is explained. Some numerical examples verify the versatility of the formulation.

13:50	Schmidt	H 111

Damage Detection On Crates Of Beverages By Means Of Neuronumerics

Markus Schmidt, Cornelia Eder, Antonio Delgado, Lehrstuhl für Fluidmechanik und Prozessautomation, TU München

The inspection of returned crates of beverages as well as bottles in industrial automatic filling lines is mainly performed by optical systems. The deficiency of all these systems is their incapacity to detect small and hidden damages or flaws. A novel innovative method called neuronumerics combines vibrational structure-analysis and finite-element-based simulations with artificial neural networks (ANN).

A transient excitation is used to put the crate into vibration. The resulting vibrational response of the specimen is recorded in the form of acceleration and frequency response spectra are computed. The spectra of damaged crates of beverages differ clearly from those of intact crates and represent reliable criteria for the detection of damages.

The selection of individual crates is performed automatically by an multilayer-perceptron artificial neural network (ANN) which is trained with data obtained from experiment and from numerics. Numerical simulation is carried out by use of the finite-element methods. A modal analysis is used for getting insight into the basic vibration behaviour of the crate. Thus, using neuronumerics, cracks are detected with an accuracy of more then 99 %. The present object of research is the realisation of an industrial application for a bottling plant, based on the laboratory system.

14:10	Gürses	H 111

Robust Algorithm For Brittle Fracture Based On Energy Minimization

Ercan Gürses, Christian Miehe, Institut für Mechanik (Bauwesen), Universität Stuttgart

The lecture outlines a variational formulation of brittle fracture in solids and its numerical implementation by a distinct finite element method. The starting point is a variational setting of elastic fracture mechanics that recasts a monotonic quasistatic fracture process into a sequence of incremental energy minimization problems. This extremum formulation includes the classical Griffith theory of brittle fracture. The proposed algorithm exploits this variational structure and introduces discretized crack patterns, the edges of the finite element mesh considered, with material-force-driven incremental crack–segment releases. These releases of crack segments constitute a sequence of positive definite subproblems with successively decreasing overall stiffness, providing an extremely robust algorithmic setting in the postcritical range. The formulation is also embedded into an accompanying crack–pattern adjustment procedure with material-force-based indicators. The adjustment procedure allows reorientations of finite elements at the crack-tip providing a considerable improvement in the predictions of the crack trajectories when compared with the experimental observations. The capabilities of the proposed algorithm will be demonstrated by means of several single and also multiple crack propagation examples.

14:30	**Stankovic**	**H 111**

Numerical Prediction Of Macroscopic Material Failure

Lidija Stankovic, Jörn Mosler, Lehrstuhl für Technische Mechanik, Ruhr-Universität Bochum

The aim of this contribution is the numerical determination of macroscopic material properties based on constitutive relationships characterising the microscale. More precisely, a macroscopic failure criterion is computed using a three dimensional finite element formulation. The proposed finite element model implements the Strong Discontinuity Approach (SDA) in order to include the localised, fully nonlinear kinematics associated with the failure on the microscale. This numerical application exploits further the Enhanced-Assumed-Strain (EAS) concept to decompose additively the deformation gradient into a conforming part corresponding to a smooth deformation mapping and an enhanced part reflecting the final failure kinematics of the microscale. The adopted numerical model allows the incorporation of any plasticity based cohesive law and can be applied to a broad range of damage theories as well.

This finite element formulation is then used for the modelling of the microscale and for the discretization of a representative volume element (RVE).

The macroscopic material behaviour results from numerical computations of the RVE.

14:50	**Steinhauser**	**H 111**

Numerical Simulation Of Fracture And Failure In Brittle Solids

Martin Oliver Steinhauser, Sascha Knell, Martin Kühn, Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut (EMI)

We investigate the failure behavior of dense brittle materials such as ceramics on different length scales based on two different numerical approaches. Within the framework of molecular dynamics simulations we model a macroscopic solid state specimen as a network of particles (Discrete Elements) that are allowed to overlap. Using appropriate potentials which model resistance against pressure and tensile loading, we perform standard quasi-static numerical experiments to validate our model.

In addition we present a high-speed impact simulation of our brittle solid in a standard experimental set-up, the edge-on impact test and investigate the initiation and propagation of cracks and failure in the material.

Alternatively, we model the explicit 3-dimensional grain structure of ceramic materials on a length scale of microns as seen in polished micrograph sections. The structures are generated as power diagrams. We have implemented an optimization procedure to fit virtual cross sections of our initially randomly generated power diagrams to the grain size and grain circumference distributions of experimental systems. The generated grain structure is then simulated under load using a finite element mesh.

Our numerical results agree well with experimental findings concerning fracture and failure behavior.

15:10	Korobeinik	H 111

Brittle Dynamic Fragmentation: A Constant Cohesive Force Approach

Mikhail Korobeinik, Le Khanh Chau, Lehrstuhl für Allgemeine Mechanik, Ruhr-Universität Bochum

In this paper dynamic fragmentation analysis that includes elastic wave propagation and cohesive failure process is carried out for a one dimensional brittle bar. A specific choice of external loading and initial/boundary conditions assures constant strain rate during elastic loading preceding the fragmentation. When the stress reaches a certain critical value fragmentation process starts simultaneously at a number of points equally spaced along the bar. The analytical expressions for displacements and stresses for the forming fragment were found under the assumption of constant cohesive stress during fragmentation. Average fragment size and time of completion of fragmentation were determined as functions of applied initial strain rate. The results are compared with existing numerical results as well as with analytical energy based models.

Session 7
Wednesday, March 29, 16:00 - 18:00

Room: H 110

Material forces

Chair:

Müller
Fedelich

16:00	**Maugin**	**H 110**

Open And Recently Answered Questions In The Configurational Mechan

Gerard Maugin, Laboratoire de Modelisation en Mecanique, Université Pierre et Marie Curie, France

Mechanics of materials on the material manifold, also called "configurational" or "Eshelbian" mechanics, provides a natural and safe basis for the formulation of the thermomechanics of forces driving evolving defects and material inhomogeneities. Fully expressed on this material manifold, it exploits a parametrization of space-time in terms of material coordinates X and Newtonian time t, and yields the notion of energy-momentum. The following critical questions are examined, and most of them answered.

1. Can we formulate the conservation equation known as the balance of canonical momentum (material momentum) without specifying the energy density?

2. What is the energy density to be considered in the presence of thermal and other dissipative processes?

3. Is there any confusion between the conservation of material momentum and an equation governing a microstructure?

4. Does this formulation help one to clarify the difference between internal degrees of freedom and internal variables of state?

16:20	**Näser**	**H 110**

Formulation Of Material Force Approach For Finite Inelasticity

Bastian Näser, Michael Kaliske, Ralf Müller, Institut für Statik und Dynamik der Tragstrukturen, Universität Leipzig

The material force approach is an elegant and efficient way to compute the thermodynamically driving force on an inhomogeneity. These material forces are beneficial for micro-mechanical investigations, fracture mechanics, mesh optimizations, just to mention some main applications.

In the case of inelastic materials, the so-called material body forces extend by an additional term containing the gradient of the internal variable and the corresponding work conjugated value.

This contribution presents the formulation of the material forces for large strain plasticity and viscoelasticity based on a multiplicative split of the deformation gradient. Furthermore, the implementation for evolution laws based on the strain tensors will be given and the dependency on the rotation of the intermediate configuration will be shown.

16:40	Denzer	H 110

Advances In Material Forces Of Inhomogeneous Materials

Ralf Denzer, Franz Josef Barth, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

In this work we discuss some advances in the numerical treatment of material forces in the case of inhomogeneous and heterogeneous materials. Contrary to homogeneous hyperelastic materials additional material volume forces are induced by inhomogeneities and heterogeneities of materials. We discuss the contribution of these material volume forces to the crack driving force in fracture mechanics and there numerical calculation.

We study the effect of inhomogeneities on the example of functionally graded hyperelastic materials. In this case the stored energy density function W_0 depends explicitly on the placements $\boldsymbol{X}$ of a "physical particle" in the material configuration $\mathcal{B}_0$. The influence of heterogeneities is discussed for isotropic continuum gradient damage and plasticity. Here the gradients of the damage variable and the internal variables, respectivily, leads to material heterogeneities in the vicinity of the crack tip and thus induces material volume forces.

Numerical results for a number of model problems in fracture mechanics with respect to functionally graded materials, continuum gradient damage and plasticity are presented and discussed.

17:00	Horst	H 110

Configurational Forces In The Context Of A Kinked Crack

Thomas Horst, Bernd Lauke, Gert Heinrich, Leibniz-Institut für Polymerforschung Dresden e.V.

Configurational forces are widely used to describe translational sensitivities of defects in solid materials. In fracture mechanics, only the component of such a non-Newtonian force acting on the crack tip along the originated crack has attributed importance as J-integral. It can be interpreted as the bulk energy release rate as the crack extends without kinking. Since the calculation of the vectorial quantity as a post-processing step subsequent to an finite element computation is easy to implement, the application of all components is convenient. But the energetical interpretation of components different from J-integral in fracture problems is not clear.

As example we consider a crack in a homogeneous isotropic linear elastic material under in-plane mixed mode loading since in this case stress and strain fields in the vicinity of the crack tip are known. By means of the kinked crack solution we can therefore interpret all components of the configurational force energetically.

17:20	**Steinmann**	**H 110**

Surface Potentials In Deformational And Configurational Mechanics

Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

Deformational and configurational mechanics or rather the spatial and material settings of continuum mechanics refer to balances of momentum as defined on the tangent spaces to the spatial and material configuration of a deformable body. The former involves common deformational forces whereas the latter is connected to the notion of configurational forces and is the key ingredient in defect mechanics. In the derivation of the relation between these two formulations the possibility for surface tractions deriving from a surface potential is commonly neglected. Thus this contribution strives for a careful consideration of surface potentials in both the spatial and the material setting. Thereby the derivations necessiate heavy use of the geometry of surfaces. As a result the dualty of the spatial and material settings is highlighted.

17:40	**Apostolescu**	**H 110**

A Visualization Platform For Landing Gear Retraction And Extension

Nicolae Apostolescu, National Institute for Aerospace Research "Elie Carafoli", Romania

This paper is to describes software technologies which are used to develop a platform for vizual evaluation of a variety of dynamical systems, in order to build, analyse and finally, optimize theirs geometry and kinematics. The combination of CATIA, SimMechanics, VRML and Java was exploited for modeling and construction of highly interactive animations of mechanical components of an aircraft landing gear during retraction and extension. Integration SimMechanics tools and enhancements such as API interface, Java methods, and special methods for the simulation descriptors, give integrators more control over functionality of this system limitated by constraints. This software combination was optimized to meet the needs of this particular application. SimMechanics create a simplified three-dimensional rigid-body model and simulates the motion of mechanical devices applying forces and torques to the actuators, then generates mechanical performance measurements associated with this motion. The verification of its geometry and constraints, consists in a kinematics analysis by piloting the actuator displacement in order to get the landing gear up-locking position. VRML including Java functions, offers to the user, through multiple windows, a realistic visualization of the mechanical system dynamics and various results types.

Session 8
Thursday, March 30, 13:30 - 15:30

Room: H 110

Cyclic and thermal loading, ferroelectrics

Chair:

Ralf Müller

13:30	Fedelich	H 110

MODELLING OF CRACK GROWTH UNDER CYCLIC LOADING AT HIGH TEMPERATURE

Bernard Fedelich, Yusuf Kiyak, Bundesanstalt für Materialprüfung (BAM)

The blades of the first stages in gas turbines or aero-engines are nowadays usually made of single crystal Ni-base superalloys due to their higher creep resistance. The stress concentrations at the cooling holes are known to promote cracking. The prediction of the crack behaviour under high temperature cyclic loading is thus an essential element of any blade lifing procedure.

Crack growth in a single crystal Ni-base superalloy has been simulated with the FE program Abaqus by the node release technique. The FE nodes are released on the basis of the measured crack growth rate during tests. For this purpose, a specific constitutive law for Ni-base single crystal superalloys has been developed. Furthermore, the oxidation of the crack flanks has been taken into account.

The simulation results are compared with test results on the basis of the computed crack tip opening displacement (CTOD). For this purpose, the crack is propagated until a stabilized value of the CTOD is obtained. This is usually the case when the crack has crossed the initial plastic zone. The procedure provides an evaluation of the effects of cycle form, crystal orientation, plasticity and oxide induced crack closure.

13:50	Gockel	H 110

MATERIAL SIMULATION AND DAMAGE ANALYSIS AT THERMAL SHOCK CONDITION

Franz-Barthold Gockel, Rolf Mahnken, Lehrstuhl für Technische Mechanik, Universität Paderborn

For simulation of thermal shocked structures of high temperature resistant stainless steel the Chaboche model delivers a wide range of possibilities. In particular, the model considers creep, isotropic and kinematic hardening and rate dependency for mechanical loading at different temperatures. For application of the Chaboche model material parameters are generated from cyclic stress strain experiments, thus allowing the finite-element-simulation of thermal shocked cylindrical specimen. In addition a 3-dimensional full surface digitalisation of a cylinder after cyclic thermal shock experiments is performed in order to obtain deformation data and which are used for validation, adaptation und optimization of the FEM-simulation. As a main result of the experimental and numerical investigations the dependency of the accumulated deformation for the number of load cycles is obtained and their configuration and limits are discussed.

In addition we present experimental damage analysis data with the eddy current method applied to the specimen surface as a result from thermal shock experiments. The results represent locations of structure changes and crack propagation on the specimen surface. This supports the formulation of adequate live time prediction models, especially subject to thermal shock load conditions.

14:10	Neumeister	H 110

On Boundary Conditions At Non-conducting Cracks In Ferroelectrics

Peter Neumeister, Hannes Kessler, Christoph Häusler, Herbert Balke, IFKM, TU Dresden

Boundary conditions along the faces of non-conducting cracks in ferroelectrics are essential to understand and predict the effect of electric field, piezoelectric coupling and surface charge densities due to remanent polarisations on the crack tip loading. Starting from the classical non-linear boundary condition of Hao and Shen that gives the relation between crack opening and electric potential drop above the crack special linear cases can be derived. Numerical and experimental investigations show that a part of them gives satisfying results for mode I loading. This conclusion is also applied to interface cracks. Nevertheless, the basic boundary condition is incomplete since mechanical reactions at the crack faces (Maxwell tractions) as well as surface charges arising from the separation of remanent polarised matter are not considered. First approaches concerning the basic understanding of these phenomena and their effect on the fracture process are discussed.

14:30	Enderlein	H 110

A Ferroelectric Micromechanical Model For Fatigue Crack Growth

Marco Enderlein, A. Ricoeur, Meinhard Kuna, TU Bergakademie Freiberg

Piezoelectric ceramics consist of domains with specific polarization directions. When subjected to electric fields or stresses, parts of these domains can switch their local polarization (domain wall motion), causing macroscopic nonlinear electromechanical behavior. Concerning the reliability and durability of piezoelectric structures, cracks play an important role, due to the inherent brittleness of ceramic materials. In the fracture process zone around the crack tip, the crack growth is controlled by the nonlinear domain switching effects. Since the switching zones may be large, the application of linear fracture mechanics is confined.

To simulate the nonlinear behavior a micromechanical model has been implemented in a finite element code. In the algorithm, a specific material orientation is assigned to each integration point of each finite element, representing a homogenized region of a typical domain structure. During the simulation, the distribution of the domains inside these regions is controlled by a domain wall motion criterion, determining the local polarization and depolarization of the structure. First results show a good description of the material behavior. Currently, the model is applied to crack problems, allowing for an investigation of fatigue crack growth mechanisms under electric and mixed electromechanical loading conditions.

14:50	**Wippler**	**H 110**

3D Bem-analysis Of Cracks In Piezoelectric Structures

Karsten Wippler, Meinhard Kuna, Institut für Mechanik und Fluiddynamik, TU Bergakademie Freiberg

The aim of this contribution is the modeling of cracks in three-dimensional piezoelectric structures by means of boundary elements. So far a single region, direct collocation boundary element code has been implemented, where the anisotropic, piezoelectric fundamental solutions for the coupled electromechanical field problem are calculated applying the Radon transform. For the discretization of the boundary, continuous as well as discontinuous boundary elements with quadratic shape functions are used. The crack itself is modeled by special elements accounting for the $r^{\frac{1}{2}}$-behavior of the displacements and electric potentials and the $r^{-\frac{1}{2}}$-singularity of the tractions and electric displacements around the crack front. Once the piezoelectric field problem has been solved, fracture mechanics quantities are calculated as mechanical and electrical field intensity factors. Thereby, the properties of the introduced crack tip elements are utilized. Recent extensions allow for direct evaluation of energy release rates by performing a crack shape sensitivity analysis by means of material differentiation.

15:10	**Shatylo**	**H 110**

Fatigue Crack Propagation In Nonlinear Material With Microdefects

Lyudmyla Shatylo, S.P. Timoshenko Institute of Mechanics, Ukraine

Long term and cyclic loading is account for appearance of the cracks in material among which randomly oriented microcracks and macroscopic or main crack formed by voids and other growing microdefects. As is well known, damages are distributed in all volume of solid, moreover their density reaches the maximal value near main crack front where stress concentration is particularly large. In my work the process of fatigue crack growth in nonlinearly elastic material or plastic material with strengthening are investigated. Stress distribution near crack tip in the damaged material is studied. Damage of material is taken into account by means of equivalent constants. Elastic coefficients and characteristics of strengthening depend on the failure essentially and can execute the role of the control parameter during material state determination, including in time of the fatigue crack propagation process. Continuum damage mechanics equations with one scalar parameter of damage measure is used. The relations of this measure to parameter of numbers of pennyshaped microcracks in unit of volume is obtained. It is let investigate the three-dimensional problem of dispersion damage influence upon propagation process of the fatigue crack on the basic of classical equations of continuum mechanics.

4 Structural mechanics

Organizers:

Wilfried Becker, TU Darmstadt
Werner Wagner, Universität Karlsruhe

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 104

Elastic Systems

Chair:

Reinhold Kienzler
Jerzy Rakowski

13:30	Rakowski	H 104

Stiffness Matrix Of Timoshenko Beam With Nonlinear Elastic Support

Jerzy Rakowski, Institute of Structural Engineering, Poznan University of Technology, Poland

The static analysis of a beam elastically supported on its ends including the shear-force effect is studied. The general case for the plane Timoshenko beam element supported by springs with arbitrary linear and rotary stiffnesses is considered. The slope-deflection equations are derived. The closed-form solution of this equation enables one the stiffness matrix determination for all kinematically and statically possible schemes of shear flexible beams. The rigid-joint nodes correspond to the infinite-stiffness supports, the free displacement nodes correspond to the zero-stiffness spring supports. The investigations are extended for Timoshenko beams with nonlinear elastic supports. The reactions (forces and moments) are proportional to the third power of support displacements. The adequate slope-deflection equations are derived and the analytical solution of this equation in the closed-form is given. The influence of support nonlinearity on the Timoshenko beam

stiffness matrix is analyzed and the numerical parameter study is carried out.

13:50	Kienzler	H 104

On Hole-growing Processes In Elastic Plates

Reinhold Kienzler, FB Produktionstechnik, Universität Bremen
F. D. Fischer, Institut für Mechanik, Montanuniversität Leoben
P. Fratzl, Abt. „Biomaterialien", Max-Planck-Institut für Kolloid- und Grenzflächenforschung

It has been observed that crystals may have holes as they appear in biological systems like the skeletal structure in echinoderms. The hole growing process occurs in a stress field due to shrinking of the material. The hole-growth kinetic involves changes in the total Gibbs free energy related to newly formed surfaces, dissipation due to diffusion processes, release of mechanical energy due to the formation of the hole and lowering of the chemical energy of the system. In this paper, we concentrate to find out an analytical expression for the total mechanical energy release.

Taking, at first, an infinite plate with a circular hole under a biaxial state of stress as example, Griffith's method, Irwin's method and the method involving path-independent integrals are described and discussed. It turns out that the application of path-independent integrals represents the most convenient approach. The latter method is then applied to the eigen-stress or eigen-strain problem characterized by a ring load serving as a model for the shrinking process within the biological system. An analytical expression for the release of total energy due to the hole-forming process is established, which can be related to further coexisting energy terms in biological structures.

14:10	Hornig	H 104

Analysis Of Load Transfer In Thermo-elastic Membranes

Jörg Hornig, Airbus Deutschland GmbH

For extremely thin walled shell structures the flexural stiffness may be negligible in analysis. Modeling of these structures as membranes simplifies the theoretical formulation and reduces the computational effort. However, in case of compressive in-plane loads, the prediction of membrane theory for the load transition behavior may be incorrect, if the wrinkling phenomenon is not taken into account. Therefore wrinkling algorithms were established in the past.

Thermal strains will influence the occurrence of wrinkling and the state of membrane forces. In order to analyze thermo-mechanical effects in conjunction with membrane wrinkling, the Roddeman wrinkling theory was modified. For small strains the incorporation of thermal effects into the wrinkling algorithm is straight forward. This small strain formulation is sufficient for the most practical applications. A method for large strains was developed and elaborated for thermo-elastic rubberlike materials. The wrinkling algorithm is easy to implement into existing FE-programs. Results of numerical analysis will be presented.

14:30	Saurin	H 104

Variational Approaches In The Beam Theory

Vasily Saurin, Georgii Kostin, Russian Academy of Sciences

Various simplified models are applied in the solid mechanics to describe effectively stress-strain state of elastic bodies. The beam theory based on intuitive hypotheses proposed by J. Bernoulli is of especial importance. But this essentially one-dimensional theory does not take into account such important mechanical properties as shear deformation and material anisotropy. The correction formulae were considered (e.g. by Timoshenko for static and by Reyleigh for dynamic problems) to display the influence of Poisson's ratio on beam deflections. However, the beam equations and these corrections do not directly follow out the elasticity theory or variational principles. In this paper the approach based on small parameter expansion of unknown stress and displacement functions is applied to derive beam equations based on classical variational principles and method of intergo-differential relations. The influence of Poisson's ratio on compliance of elastic rod with rectangular cross-section is investigated. The obtained results are compared with the classical beam solution as well as with numerical approximations of the corresponding linear elasticity problem. In frame of the plane section hypothesis the stress fields under arbitrary loading and the first order differential equations for displacements are derived both for isotopic and anisotropic beams. The analytical beam solutions for different boundary conditions are presented.

14:50	Marynets	H 104

The Stresses In Annular Lapped Plates

Olexandr Marynets, Fedor Sanin, Vladimir Shvaiko, Dnepropetrovsk National University, Ukraine

The present paper deals with the determination of the stresses in thin inflexible adhesive layer of two annular plates at the following boundary conditions: construction surface is stresses free, normal radial and self-balanced shearing forces are known at cylindrical sections on the lap ends. Shearing forces can be approximated and the problem put by can be led to the stresses distribution in the ring, which is periodically located in long thick cylinder. To satisfy zero boundary conditions it is necessary to apply normal and shearing forces system at the lateral cylinder surfaces out of the ring region. Under these circumstances observance of boundary and balancing conditions of underlined area must be fulfilled both as a separate ring and its any separate part. The obtained expressions allow us to determine stresses in the ring and in adhesive layer. The results have been compared to the results of experimental investigation by photoelasticity method and submitted by the diagrams.

15:10	Grigorenko	H 104

Mechanical Behavior Of Elastic Cylinder With Various Cross-section

Alexander Grigorenko, Yaroslav Grigorenko, Liliya Rozhok, S.P. Timosenko Institute of Mechanics, Ukraine

Study of the mechanical behavior of elastic cylinders is of great interest for the development of the inherent logic of fundamental investigations as well as is of great importance for many practical problems. Strict requirements to estimation of the strength characteristics, striving for more total allowance for real properties of structural materials, revealing and studying of three-dimensional effects that held in thin-walled elements make it necessary to calculate the mechanical properties of cylinders in a spatial statement.

In the present work, the authors propose a general efficient numerical-analytical approach for investigation of the stress-strain state and some dynamic characteristics of anisotropic cylinders with circular and non-circular cross-section under specified boundary conditions at their bounding surfaces and ends. The approach is based on the reduction of the initial equations of spatial elasticity theory to systems of ordinary differential equations for boundary-value problems and for problems on eigenvalues.

As an example of application of the approaches developed, the stress-strain and free vibrations problems for anisotropic both hollow and solid cylinders with circular cross-section were solved. The static and dynamic behavior of anisotropic hollow cylinders various noncircular cross-section was studied.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: H 105

Contact

Chair:

Udo Nackenhorst
Bernd W. Zastrau

13:30	Ziefle	H 105

On The Treatment Of Frictional Rolling Contact

Matthias Ziefle, Udo Nackenhorst, Institut für Baumechanik und Numerische Mechanik, Universität Hannover

In FEM analysis of rolling contact problems Arbitrary Lagrangian-Eulerian (ALE) methods are the state of the art. These methods allow mesh refinements concentrated to the contact region and offer a time independent formulation of stationary elastic rolling. Inserting an arbitrary moved reference configuration between the referential and the current configuration leads to a decomposition of motion into a rigid body rotation and a pure deformation. The relative-kinematic description of rolling leads to a relative motion between finite element mesh and material points. Thus in contrast to a pure Lagrangian description of rolling the relative movement of the material particles is not determined. The contact problem is assumed as deformable-rigid and its boundary conditions are included by the penalty-method. For the computation of the frictional tire-road contact the slip velocities have to be integrated along the streamlines of the material particles. These pathlines are traced by solving an additional advection equation with a Discontinuous Galerkin (DG) method. In the given approach the advected variables are allowed to be discontinuous over the element edges. This permits an accurate and efficient numerical advection of steep gradients which appear in the contact area.

13:50	Willner	H 105

Contact Of Fractal Surfaces - Experimental And Numerical Results

Kai Willner, Daniel Goerke, Lehrstuhl für Technische Mechanik, Universität Erlangen-Nürnberg

Measurements of rough surfaces show that the roughness topography can be described as a fractal over several length scales. A suitable description is then given by a discrete structure function. For a large class of typical surfaces measured structure functions can be approximated by a three-parameter function, employing the rms-value of the roughness, a transition length between fractal behaviour at high wavenumbers and stationary behaviour at low wavenumbers, and the fractal dimension in the fractal region, respectively, as intrinsic parameters to describe an isotropic rough surface.

To study the normal contact behaviour of such fractal surfaces numerically, the authors present a numerical model which allows to describe the elasto-plastic normal contact of isotropic fractal surfaces. This model is tested against experimental data which are obtained from contact tests of several aluminum specimens.

The paper gives a short review of the numerical model and describes the experimental set-up for the contact tests. Numerical and experimental data for several aluminum specimens with different surface properties are shown and compared.

14:10	Pauk	H 105

Modelling Of The Frictional Heating Generated In Rolling Contact

Volodymyr Pauk, Bernd Zastrau, Technical University of Kielce, Poland

Rolling contact problem for two thermoelastic cylinders involving frictional heating due to the microsliding in the contact area is considered. Previous formulations of this kind of the rolling contact [1-3] were presented under assumption that the heat is generated over the whole contact path, the sliding velocity is constant and the contact pressure is Hertz-like. In the paper [4] we proposed a more exact model of the frictional heating in rolling contact, assuming that one body is insulator. In this paper we assume that both cylinders are thermoelastic. Thermal contact between rollers is assumed to be non-ideal. The problem is reduced to the system of integral equations, which is solved numerically. The effect of the heat generated on the rolling contact is investigated.

1. Cameron A., Gordon A.N., Symm G.T. Contact temperature in rolling/sliding surfaces. Proc. Royal Soc. London, 1965, A286.
2. Tanvir M.A. Temperature rise due to slip between wheel and rail, an analytical solution for Hertzian contact. Wear, 1980, 61.
3. Knothe K, Liebelt S. Determination of temperature for sliding contact with applications for wheel-rail system. Wear, 1995, 189.
4. Pauk V., Zastrau B. 2D Rolling contact problem involving frictional heating. Int. J. Mech. Sci., 2002, 44.

14:30	Nettingsmeier	H 105

Frictional Contact Of Rubber On Rough Surfaces

Jana Nettingsmeier, Peter Wriggers, Institut für Baumechanik und numerische Mechanik, Universität Hannover

The aim of this work is the derivation of a realistic friction law based on micromechanical observations. The internal damping in a viscoelastic material implies a global frictional behaviour. The friction advances to zero for very high and low sliding velocities, but reaches a maximum for middle speed. This is known as hysteretic friction and represents the main part of rubber friction.

Due to the multiscale character of the surface roughness, the problem is modeled on different length scales. The frictional behaviour on each scale is analyzed and projected onto the next higher scale. The fractal road surface is approximated by a superposition of several harmonic functions. Starting with frictionless contact on the finest scale, the contact behaviour is transferred to the next scale. The friction coefficient is adapted to the local conditions (normal stress, sliding velocity) obtained in each contact element.

The properties of elastomer materials are sensitive to temperature changes. Therefore it is necessary to determine the material heating due to internal energy dissipation.

14:50	**Konyukhov**	**H 105**

High Order FE And Covariant Description For Contact Problems

Alexander Konyukhov, Karl Schweizerhof, Institut für Mechanik, Universität Karlsruhe

Within the modeling of contact problems using low order finite elements a problem concerning the discontinuity of contact tractions at the neighboring element boundaries is arising. Various smoothness techniques to overcome this problem have been developed. These techniques are mainly based on covering of surfaces discretized by finite elements with patches possessing proper smoothness (e.g. Bezier splines, NURB splines), see Wriggers [1], Laursen [2].

However, these approximations do not coincide with the exact geometry of contact bodies, e.g. there is a void between the smooth surface and the finite element surface. The influence of this assumption is not yet discovered in the literature. In order to investigate this problem two problems have to be solved. The first problem is that the geometry of the contact bodies must be represented exactly. The second problem is that the contact description must be independent of the order of surface approximations. One powerful method to satisfy the exact geometry is to apply high order finite elements, see Rank et al. [3].

As an additional element a covariant contact description, developed in [4], [5] gives us a powerful tool to derive all necessary parameters for the iterative solution independently on the order of approximations of contact surfaces. Thus, the aim of the current presentation is to combine a high order finite element technique with a covariant description of contact problems. The influence of the aforemention assumptions are investigated then by solving the benchmark problems possessing analytical solutions, e.g. the Hertz problem.

[1] Wriggers P. *Computational Contact Mechanics.* Chichester: Wiley, 2002.
[2] Laursen T.A. *Computational Contact and Impact Mechanics. Fundamentals of Modeling Interfacial Phenomena in Nonlinear Finite Element Analysis.* Springer, 2002.
[3] Rank E., Düster A., Nübel V., Preusch K., Bruhns O.T. High order finite elements for shells. *Comput. Meth. Appl. Mech. Eng.,* **194**, pp. 2494-2512, 2005.
[4] Konyukhov, A., Schweizerhof, K. Contact formulation via a velocity description allowing efficiency improvements in frictionless contact analysis. *Comput. Mech.,* **33**, pp. 165-173, 2004.
[5] Konyukhov, A., Schweizerhof, K. Covariant description for frictional contact problems. *Comput. Mech.,* **35**, pp. 190-213, 2005.

15:10	Luege	H 105

Finite Strain Model For Contact Interface In Forming Processes

Mariela Luege, Bibiana Luccioni, Instituto de Estructuras, Universidad Nacional de Tucumán, Argentina

A phenomenological friction law for the continuous sliding of a polymer on a surface of aluminum for lubricated and dry conditions as it occurs in forming processes is presented in this paper.

Experimental results carried out by Israelachvili and coworkers characterise a pure frictional behaviour depending on the sliding distance for a polymer surface sliding on a dry smooth surface. Boundary lubricated smooth interfaces, on the other hand, show a transition from a pure frictional behaviour to a viscous one depending on the thickness of the sheared lubricant boundary layer and on the sliding velocity.

Based on these findings a contact model is developed in the framework of continuum thermodynamics and for large strains. On the contact area, the local constitutive laws are derived from two specific surface potentials, the free energy and the dissipation potential. The dry frictional behaviour for the polymer-aluminum interface is modelled by a modified version of the Coulomb's law with the friction coefficient depending on the accumulated sliding distance. The transition to boundary lubrication with nonlinear viscous behaviour is controlled by a threshold on the shearing force and depends on the thickness of the lubricant's layer and the sliding velocity.

The model is formulated with respect to a convected kinematic frame and employs the Lie derivative to ensure the frame indifference of the contact rate variables. The model is implemented in the explicit dynamic finite element code Stampack for the numerical simulation of forming processes.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: H 104

Viscoelastic / Elastoplastic Systems

Chair:

Stefanie Reese
Bernhard Eidel

16:00	Wang	H 104

Modeling And Simulation Of Springback In Sheet Metal Structures

Jian Wang, Vladislav Levkovitch, Stefanie Reese, Lehrstuhl für Mechanik, Universität Dortmund
M. Schwarze, Bob Svendsen

Accurate simulation of sheet metal forming processes including springback in sheet metal structures requires taking a number of effects into account. Such processes involve in particular (i) complex loading path changes, (ii) contact and friction between the tool and work-piece, and (iii) the large deformations of very thin structures. In particular, (i) has a marked effect on the material microstructure and behavior, in particular the hardening behavior. Since standard non-linear combined hardening models do not account for cross hardening during orthogonal loading-path changes, these have been extended in the current work. On the structural side, the role of the element formulation, as well as the type of contact modeling during forming and tool release modeling, are also investigated. These modeling and simulation aspects are illustrated with the help of the structural simulation of (1) tension-bending of sheet metal strips, (2) ring-splitting of deep-drawn sheet metal specimens. Comparison with experimental results will be given.

16:20	Sparr	H 104

Numerical Simulation Of Cold Ring Rolling

Holger Sparr, Volker Ulbricht, Institut für Festkörpermechanik, TU Dresden

Cold ring rolling is a metal forming process, which has been and is employed industrially already. Profiled rings with a constant cross section, e.g. used for bearings, are produced by an incremental forming in a locally bounded zone through a repeated contact of tools and workpiece. Because of the complexity the ring rolling inheres the process parameters depend largely on empirical knowledge and experiments. It is desirable to investigate certain process parameters by numerical simulations to gain more insight into the actual process and to identify their effects on the final product quality. The numerical simulation involves elastic and plastic deformation as well as contact and friction problems at the same time, where adapted modeling techniques are applied to reduce the computational effort.

16:40	Vogler	H 104

A Visco-plastic Material Law With Applications To Crash Problems

Matthias Vogler, Andre Haufe, Friedrich Gruttman, TU Darmstadt
Stefan Kolling, Institut für Werkstoffe und Mechanik im Bauwesen, TU Darmstadt

Crazing of thermoplastics and structural instabilities in crushable foams result macroscopically in a non-smooth yield surface. In order to describe this behaviour, a phenomenological model is suggested using a piecewise linear formulation to describe the C0-continous yield surface. Hereby, the yield function depends on the strain rate and on the first and second invariant of the stress tensor. The increase of volume during plastic deformation is considered by the use of a plastic potential. Furthermore, non-linear hardening is considered via tabulated input, i.e. experimental test data may be used directly without time consuming parameter identification. For the use of shell elements, plane stress iteration has also been implemented. Moreover, thermodynamic bounds of the model are derived and ductile damage is used to approximate the unloading behaviour of the material. In the presentation, the theoretical background is discussed and the implementation is shown in detail. Some illustrative examples are shown for different materials and compared to other models.

17:00	Stoffel	H 104

Anisotropic Damage Of Shock Wave-loaded Plates

Marcus Stoffel, Rüdiger Schmidt, Dieter Weichert, Institut für Allgemeine Mechanik, RWTH Aachen

In the present study circular metal plates are subjected alternately to impulsive loadings in shock tubes. After the first loading and due to inelastic deformations, buckling of the pre-deformed plates occurs. Repeated loading then leads to material damage and finally to loss of integrity of the structure. To predict the observed failure two damage laws are applied and the development of damage growth for both material models is traced in finite element simulations. The calculations are based on a geometrically non-linear first-order shear deformation shell theory. The

experiments are carried out in two shock tubes using different plate geometries and materials. By means of self-developed short time measurement techniques displacements and buckling shapes are recorded during the shock period.

17:20	**Lyashenko**	**H 104**

The Stress Concentration In The Components Of The Viscous-elastic

Yana Lyashenko, S.P. Timoshenko Institute of Mechanics, Ukraine

The paper is devoted to solution of the spatial of the problem of mechanics of composites. The components of the inhomogeneous environment have viscous-elastic properties. Material is influenced by static loading. Heterogeneity of the environment gives redistribution of stresses in the components. Viscous-elasticity of the components course of considering time influence on the stress-strain status of the materiale. Structure of this material is consisted of any components and is microscopic isotropic. Viscous-elastic properties of the composite are defined by means of Volterra?s principle. For this elastic moduli change by Rabotnov integral operators. Averaging method, moment arbitrary function method is used to research stochastic inhomogeneous medium. The stress concentration coefficients are obtained. From this results we have a conclusion that components stresses increase and matrix stresses decrease. Computational investigation for series of composite component characteristics is conduct. The calculation results are in good agreement with experimental data. The calculation results are in good agreement with experimental data both in the initial stage of a process and in the integral of long-term (up to 50,000 hours) deformation.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: H 105

Stability

Chair:

Karl Schweizerhof
Yordan Kyosev

16:00	Mackiewicz	H 105

Elastic Buckling Of An Open Cylindrical Shell Under Pure Bending

Mikolaj Mackiewicz, Krzysztof Magnucki, Institute of Applied Mechanics, Poznan University of Technology, Poland

The paper is devoted to elastic stability problem of an open cylindrical shell under pure bending. Two curvilinear edges of an open cylindrical shell are simply supported while two straight edges are free. Two partial differential equations for linear buckling of shells are assumed and the adequate boundary conditions are defined. The deflection function has an imposed form, which guarantees that all boundary conditions are accurately fulfilled. On the ground of assumed deflection function form, one of stability equations and boundary conditions the Airy force function is analytically determined. The second stability equation is solved with the use of Galerkin method, which leads to generalized eigenvalue problem. Deflection function parameters as well as critical stress value are obtained from the generalized eigenvalue problem solution. Numerical investigation is applied to wide range of different cylindrical shells. Results are presented in Figures and Tables, they are analysed and compared with the results known from literature.

16:20	Laszczyk	H 105

Critical Load Of An Axially Compressed Sandwich Cylindrical Panel

Zbigniew Laszczyk, Waclaw Szyc, Institute of Applied Mechanics, Poznan University of Technology, Poland

The problem of critical stress analysis of a open sandwich cylindrical thin-walled panel with two curvilinear edges simply supported and straightlinear edges free under axial compression is presented. The large angle of the shell sector, geometrical and physical symmetry of facings are assumed. The classical broken line

hypothesis is replaced by its modified generalized version. The plane-stress state is assumed in facings while a light-weight core is also subject to shear stresses. In addition, the same deflection of each layer in the normal direction of mid-surface is assumed. Displacements of each layer for moderately large deflections are described by non-linear geometrical relations. Stresses in layers are derived from constitutive relations. On the base of force and moment equilibrium conditions for the shell element the set of the fundamental equations is derived. The set is solved with the help of the orthogonalizational Bubnov-Galerkin method with the use of function that approximates amplitude parameter of deflection surface. The nonlinear algebraic equation is obtained as the solution result. Physical and geometrical parameters of the shell, deflection factor and loading are connected inside the equation. It is possible, among others, to obtain from here the critical load value. Presented results were compared with FEM calculation.

16:40	Haßler	H 105

Stability Analysis Of Fluid Loaded Or Supported Shell Structures

Marc Haßler, Karl Schweizerhof, Institut für Mechanik, Universität Karlsruhe (TH)

Thin shell or membrane structures containing gas or fluid are widely standard, such as oil and water tanks, gas containers or atmospheric balloons. The fluid/gas loading or support may have a major influence on the stability behavior of those membrane-like structures under other external loadings as for example in the Tensairity-concept of Luchsinger et al., where internal air pressure in combination with some external strengthening is used to overcome buckling of thin walled girders. The goal of this approach, which is based on the earlier works of the authors group, is to present some investigation of the influence of such gas or fluid support (without actually discretizing the fluid/gas) on the eigenvalues and eigenmodes of the stiffness matrix of shell or membrane-like structures undergoing large displacements to allow conclusions concerning stability. For this purpose an efficient algorithm is derived, which benefits from the dyadic rank updates of the stiffness matrix due to volume dependence of the fluid/gas loading.
medskip

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17:00	Debowski	H 105

Dynamic Stability Of A Porous Rectangular Plate

Daniel Debowski, Krzysztof Magnucki, Institute of Mechanical Engineering and Machine Operation, University of Zielona Góra, Poland

The study is devoted to a axial compressed porous-cellular rectangular plate. Mechanical properties of the plate vary across is its thickness which is defined by the non-linear function with dimensionless variable and coefficient of porosity. The material model used in the current paper is as described by Magnucki, Stasiewicz papers. The middle plane of the plate is the symmetry plane.

First of all, a displacement field of any cross section of the plane was defined. The geometric and physical (according to Hook's law) relationships are linear. Afterwards, the components of strain and stress states in the plate were found. The Hamilton's principle to the problem of dynamic stability is used. This principle was allowed to formulate a system of five differential equations of dynamic stability of the plate satisfying boundary conditions. This basic system of differential equations was approximately solved with the use of Galerkin's method. The forms of unknown functions were assumed and the system of equations was reduced to a single ordinary differential equation of motion.

The critical load determined used numerically processed was solved. Results of solution shown in the Figures for a family of isotropic porous-cellular plates. The effect of porosity on the critical loads is presented. In the particular case of a rectangular plate made of an isotropic homogeneous material, the elasticity coefficients do not depend on the coordinate (thickness direction), giving a classical plate. The results obtained for porous plates are compared to a homogeneous isotropic rectangular plate.

17:20	Belica	H 105

Dynamic Stability Of A Porous Cylindrical Shell

Tomasz Belica, Krzysztof Magnucki, Institute of Mechanical Engineering and Machine Operation

This paper is devoted to a closed cylindrical shell made of a porous-cellular material. The mechanical properties vary continuously on the thickness of a shell. The mechanical model of porosity is as described as presented by Magnucki, Stasiewicz. A shell is simply supported on edges.

On the ground of assumed displacement functions the deformation of shell is defined. The displacement field of any cross section and linear geometrical and physical relationships are assumed in cylindrical coordinate system. The components of deformation and stress state were found. Using the Hamilton's principle the system of differential equations of dynamic stability is obtained. The forms of unknown functions are assumed and the system of differential equations is reduced to a simple ordinary equation of dynamic stability (Mathieu's equation) of shell. The derived equation are used for solving a problem of dynamic stability of porous-cellular shell with intensity of load directed in generators of shell.

The critical loads are derived for a family of porous shells. The unstable space of family porous shells is found. The influence a coefficient of porosity on the stability regions in Figures is presented. The results obtained for porous shell are compared to a homogeneous isotropic cylindrical shell.

17:40	**Kyosev**	**H 105**

Stability Problems Of The Textile Wound Structures

Yordan Kyosev, Ingo Reinbach, Thomas Gries, Institut für Textiltechnik, RWTH Aachen

Wound structures are widely used in the textile production for storing (depositing) and transportation of textile yarns during the time between their production and their implementation in a certain product. Each package usually consists of only one yarn, which is wound over the cylindrical or conical tube, so that a stable structure is formed. The stability of the structure depends on the large number of processes and material parameters and they are still not investigated completely. Well known are stability conditions for piece of yarn over the surface, based on the static friction coefficient and usage of the geodesic angle of the surface. These conditions do not describe completely the stability of the whole package. In order to investigate the stability of the whole wound package, the different hierarchical levels of the structure are analysed separately. Stability conditions according to the principle of minimum potential energy are defined for yarn cross section, or yarn point, yarn piece (with certain length, that is much greater then the yarn diameter) and for the layer. They are implemented in a software program for wound package simulation, which allows numerical analyse and optimisation of the package structure. The theory and software are directed to the textile bobbin with random and precise structure, but can be applied also for the case of filament winding around mandrel, used for composite production.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: H 104

Finite Element Methods

Chair:

Peter Wriggers
Jörg Schröder

13:30	Sänger	H 104

A Comparison Of Nonlinear Beam Finite Element Formulations

Nicolas Sänger, Peter Betsch, Numerische Mechanik, Universität Siegen

Two alternative nonlinear finite element formulations emanating from the Simo-Reissner beam theory are considered. The orientation of the beam cross section is characterized by a director frame which can be either represented by means of rotational parameters or the direction cosine matrix. In the planar case the use of a single angle can be considered as the canonical formulation. The corresponding finite element approximation relies on the interpolation of the nodal angles.

However, the extension of this approach to the three-dimensional case is nontrivial and often leads to element formulations beeing not frame-indifferent. On the other hand, the interpolation of the nodal direction cosines in general yields frame-indifferent element formulations [1]. Since the direction cosines are not independent, additional algebraic constraints need be incorporated into the element formulation leading to a comparatively large number of unknowns. Indeed, the semi-discrete finite element formulation thus obtained is governed by differential-algebraic equations (DAEs). The algebraic constraints can be eliminated by applying the methodology developed in [2]. In the present context this approach resembles approximation procedures typically found in the so-called degenerated continuum approach.

The present talk focuses on a comparison of the two aforementioned finite element beam formulations for planar problems.

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13:50	Mosler	H 104

A Novel H-adaptive Finite Element Method For Standard Dissipative

Jörn Mosler, Lehrstuhl für Technische Mechanik, Ruhr-Uni Bochum
Michael Ortiz, Computational Solid Mechanics, California Institute of Technology, USA

A novel h-adaptive finite element strategy for standard dissipative media at finite strains based on energy minimization is presented. The method can be applied to any (incremental) minimization problem to be analyzed by finite elements. Similarly to an error estimator by Babŭska & Rheinboldt, the proposed error indicator is based on solving a local Dirichlet-type problem. However, in contrast to the original work, a different error indicator is considered. Provided the underlying physical problem is governed by a minimization problem, the difference between the energy of the elements defining the local problem computed from the initial finite element interpolation and that associated with the local Dirichlet-type problem is used as an indicator. If this difference reaches a certain threshold, the elements defining the local problem are refined by applying a modified longest edge bisection according to Rivara. Since this re-meshing strategy leads to a nested family of triangulations, the transfer of history variables necessary to describe dissipative materials is relatively inexpensive. The presented h-adaption is only driven by energy-minimization. As a consequence, anisotropic meshes may evolve if they are energetically favorable. The versatility and rate of convergence of the resulting approach are illustrated by means of selected numerical examples.

14:10	Boerner	H 104

A Finite Element Formulation Based On The Cosserat Point Theory

Eiris Friederike Boerner, Peter Wriggers, Institut für Baumechanik und numerische Mechanik, Universität Hannover

The theory of Cosserat points is the basis of a finite element formulation for a solid three-dimensional continuum, which was presented by Nadler & Rubin (2003). Previous investigations Loehnert et al. (2005) have revealed, that this formulation is free of showing undesired locking or hourglassing-phenomena. It additionally shows excellent behaviour for large deformations in any type of incompressible material and for sensitive structures such as plates or shells. Within the theory of Cosserat points, the position vectors $\mathbf{X}$ and $\mathbf{x}$ of an 8-node-brick element are described through director vectors $\mathbf{D}_i$ and $\mathbf{d}_i$.

$$\mathbf{X} = \sum_{i=0}^{7} N^i(\theta^1, \theta^2, \theta^3)\mathbf{D}_i \quad , \quad \mathbf{x} = \sum_{i=0}^{7} N^i(\theta^1, \theta^2, \theta^3)\mathbf{d}_i$$

The special choice of shape functions N^i allows to split the deformation as well as resulting stresses into homogeneous and inhomogeneous parts respectively. The stresses due to the inhomogeneous part of the deformation are obtained by incorporating analytical solutions to an assortment of inhomogeneous deformation modes for a rectangular parallelepiped shaped reference element.

This work shows approaches on how to overcome the difficulty of initially distorted element geometries that differ strongly from the shape of a rectangular parallelepiped. The formulation initially was restricted to a Neo-Hookean material. This work will present the extension to a general elastic Ogden material as well as to metal plasticity for large deformations with isotropic hardening. It will also give insight to the properties of the Cosserat point element and its behaviour for rubber-like and elasto-plastic materials.

14:30	**Schwarz**	**H 104**

Remarks On A Least Square Mixed Finite Element For Elasticity

Alexander Schwarz, Jörg Schröder, Institut für Mechanik, Universität Duisburg-Essen

In the present work we discuss a least square method for the solution of plane elastic problems. The underlying functional is a two field formulation in the displacements and the stresses. A main focus of the presentation lies on implementation aspects.

The formulation of the element is based on a unit triangle with a Gaussian quadrature rule for the numerical integration. Furthermore, transformation rules for displacements and stresses are discussed.

For the continuous approximation of the displacements standard linear Lagrange polynominals are used. The displacement interpolants are associated with the vertices of the triangle. For the approximation of the stresses shape functions related to the edges are chosen.

These vector-valued functions are used for the approximation of the rows of the stress tensor $(\sigma_{11}, \sigma_{12})$ and $(\sigma_{21}, \sigma_{22})$. Those functions belong to a Raviart-Thomas space, which guarantees a compliant discretization of the required space $H(div, \Omega)$. A characteristic attribute of functions $\mathbf{v}$ in $H(div, \Omega)$ is given by it's definition $H(div, \Omega) := \left\{\mathbf{v} \in L^2(\Omega) : div\,\mathbf{v} \in L^2(\Omega)\right\}$. The governing equations for a simple least square mixed finite element are derived.

14:50	**Fleischer**	**H 104**

Anwendungsaspekte Der Submodelltechnik Der Fem

Mario Fleischer, Institut für Festkörpermechanik, TU Dresden

Die Submodelltechnik der FEM ist in der Statik deformierbarer Körper ein bekanntes Verfahren. Es hat sich zur effizienten Behandlung komplexer Modelle, bei gleichzeitig hoher Genauigkeit abgeleiteter Größen (Spannungen und Dehnungen) an kritischen Stellen (z.B. Kerben), bewährt. Bei dieser Methode werden im ersten Schritt in einem geometrisch vereinfachten Modell die globalen Verschiebungsfelder bestimmt. Im Folgeschritt werden an einem Modell mit den geometrischen Details (Submodell) am Schnittrand die interpolierten Verschiebungswerte als Randbedingungen aufgebracht. Da das Submodell durch hohe Detailtreue gekennzeichnet ist, liefert der zweite Schritt i. a. die genaueren Ergebnisse. In Erweiterung zur Statik tauchen in der Dynamik nach dem zweiten Newton'schen Axiom neben äußeren angreifenden Kräften und Momenten auch innere Belastungen – die Trägheitsbelastungen – auf. Die Anwendung der Submodelltechnik auf dynamische Probleme wirft daher z.B. die Frage auf, welchen Einfluß die Wahl des Submodells auf die modalen Größen hat. Vor allem im Bereich höherer Eigenfrequenzen tauchen Eigenschwingungsformen auf, deren Ausprägungen von geometrischen Details abhängig sind.

Anhand eines einfachen Beispiels wird diesen Fragen nachgegangen und Möglichkeiten demonstriert, diesen Problemen begegnen zu können.

15:10	Bucher	H 104

Mapping Algorithms Of Field Variables In Nonlinear Adaptive Fem

Anke Bucher, Arnd Meyer, Uwe-Jens Görke, Reiner Kreißig, TU Chemnitz

A realistic Finite Element (FE) simulation of the mechanical behaviour of components and structures essentially depends on the implementation of suitable material models as well as on convenient meshes. Critical areas of the structure may be a priori unknown or may change their location during the loading. Therefore the generation of suitably designed initial grids is not always possible. An efficient processing of mechanical problems considering finite strains demands the ability of local mesh adaptation. Within the context of hierarchical remeshing strategies, the mapping of the field variables becomes a crucial point with respect to nonlinear problems. The external load is divided into several load steps. For each load step the initial-boundary value problem has to be solved based on the results of the former load step. If an adaptation of the mesh has been executed, the field variables have to be transferred from the father to the newly created son elements.

At the Chemnitz University of Technology a special mapping procedure was developed and implemented into the in-house FE code SPC-PM2AdNl. This mapping algorithm distinguishes itself by the additional integration of the material law at the nodes of the elements, and not only at the Gauss points as common. As a consequence the values of the field variables at the nodes of the FE mesh are calculated with the same numerical accuracy as at the Gauss points. Furthermore, field variables are directly calculated at the nodes and can simply be transferred to the Gauss points of the son elements using their shape functions.

Several mapping techniques for the transfer of field variables known from literature are compared with our own development with respect to efficency and reliability.

Session 6
Wednesday, March 29, 13:30 - 15:30

Room: H 105

Applications

Chair:

Lars Panning
Peter Ruge

13:30	Wranik	H 105

Schiefwinklige Verbundene Stahlbetonplatten Im Brückenbau

Jozef Wranik, Instytut Budownictwa, Uniwersytet Zielonogorski, Poland

Schiefwinklige in der Längsrichtung verbundene bis zu 0,90 m dicke Stahlbetonplatten treten bei einem nicht alltäglichen Brückenquerverschub ein. Es wird ein Berechnungsmodell mit nichtlinearem elastischem Stofgesetz festgelegt. Das nichtlineare elastische Stoffgesetz kann im Allgemeinen durch Differentiation der Verzerrungsenergiedichte gefunden werden. Die Verzerrungsenergiedichte ist im Wesentlichen von dem Grad der Bewehrung und der Richtung des Bewehrungsnetzes abhängig. Die Bewehrung, die wiederum von dem Vektor der Plattenschnittkräfte abhängt, kann aber erst nach der Bemessung der Bewehrung festgelegt werden. Das bedeutet, dass das nichtlineare Stoffgesetz nicht vorgegeben werden kann. Es ist erst nach der Lösung der nichtlinearen Operatorgleichung für die Platte festgelegt.

Die Platte ist in der Längsrichtung eine Verbundkonstruktion Beton-Beton, wobei längs der Verbundfugen ein Schlupf der verankerten Bewehrungstäben entstehen kann. Dieses System kann mittels des Kraftgrößenverfahren gelöst werden. Das Plattenausgangssystem kann mittels Schnitten längs der Verbundfugen festgelegt werden. Es entsteht ein aus drei Platten gebildetes Hauptsystem mit den überzähligen generalisierten Biegemomenten und Querkräften. Die Torsionsmomente werden nach Kelvin zu den Querkräften zuaddiert. Die Verträglichkeitsbedingungen längs einer Verbundfuge sind die Fredholmschen Integralgleichungen. Die Lösung ist mittels eines iterativen Verfahrens möglich.

13:50	Birk	H 105

Longitudinal Track-structure Interaction On Railway Bridges

Carolin Birk, Peter Ruge, Institut für Statik und Dynamik der Tragwerke, Fakultät Bauingenieurwesen, TU Dresden

This contribution is devoted to longitudinal loads on railway bridges with continuously welded rails. Here, the interaction between track and structure cannot be neglected. In this context the coupling element between rail and bridge deck is of great significance. The latter consists of the ballast or the fastening in case of a ballasted or rigid track, respectively. It is characterized by a nonlinear stiffness law which allows the rail to slip relative to the coupling element if the displacement of the rail relative to the structure exceeds a critical value $\tilde{u}$.

Longitudinal rail stresses are caused by uniform temperature change or bending of the supporting structure, braking and the sudden change of ballast stiffness when the train reaches the bridge. State of the art is the independent analysis of the first three loading cases taking into account the above nonlinear stiffness law of the ballast. The final results are obtained by summation. In doing so, the displacement history of the coupling element is completely neglected.

However, the consideration of the actual state of deformation of the latter is of crucial importance for a realistic simulation of longitudinal track-bridge interaction processes. Depending on the actual exhaustion of the coupling element a certain deformation capacity is available for a subsequent loading case to proceed elastically. Based on this consideration a truly nonlinear description of the longitudinal track-bridge interaction problem is proposed. The deformation history is fully taken into account in a correct combination of loading cases. Exact stiffness formulations for the above-mentioned situations are used in the numerical model.

A typical track-bridge system is analysed as an example using both the conventional and the truly nonlinear approach. A considerable reduction of the maximum tensile rail stress is obtained using the correct combination of loading cases. This result is confirmed in a parameter study for a variety of bridges of different length and abutment stiffness.

14:10	Brys	H 105

Biegesteife Rahmenknoten In Verbundkonstruktionen Stahl-beton

Gerard Brys, Jozef Wranik, Jacek Korentz, Instytut Budownictwa, Uniwersytet Zielonogorski, Poland

Die Ausbildung von Rahmenknoten hängt im wesentlichen von der Art der zu verbindenden Stütze mit dem Riegel und dem gewünschten Verhalten der Verbindung hinsichtlich der Beanspruchbarkeit und der Nachgiebigkeit ab. Knoten verschieblicher biegesteifer Rahmen mit Riegel als Verbunddecken sollen als biegesteife Momentenknoten ausgebildet werden. Das Konstruieren und die Bemessung der Knoten sind bisher nicht genug aufgeklärt. In diesem Beitrag wird eine Lösung vorgeschlagen, die sich auf den statischen Grenzwertsatz der Plastizitetstheorie, nähmlich auf strut-und-tie-method abstützt. Ein Rahmenknoten ist ein diskontinuierlicher durch das Prinzip von De Saint-Venant festgelegte Bereich, der als Scheibe zu behandeln ist. Augrund der Spannungstrajektorien für die linear-elastische Lösung des Scheibensproblems, werden die Druck- und Zugstreben festgelegt. Das

Problem ist die Weiterleitung der Druckstrebenkraft, die die Verbundfuge unter einem beliebigen Winkel durchkreuzt. Die Lösung dieses Problems wurde bearbeitet und wird dargestellt.

14:30	Wille	H 105

Zum Übergang Von Der Inneren Zur äusseren Reifenmechanik

Ralf Wille, Friedrich Böhm, Albert Duda, TU Berlin

Während sich die äußere Reifenmechanik mit dem Einfluss der Räder auf das Fahrzeugverhalten beschäftigt, ist die innere Reifenmechanik auf die Festigkeitsuntersuchung des geschichteten anisotropen Luftreifens gerichtet. Analytische und numerische Untersuchungen von Reifensubstrukturen auf unterschiedlichen Modellierungsniveaus sind die Voraussetzung für ein besseres Verstehen des Reifenverhaltens und für die angemessene Wahl praktisch realisierbarer Berechnungswege.

Am Beispiel der Untersuchung des Überganges eines Sandwich-Schalenmodells für Karkasse, schubübertragende Gummizwischenschicht und Reifengürtel zu einem Membranmodell für die Seitenwand wird der Einfluss des inneren Reifenaufbaus auf das äußere Reifenverhalten aufgezeigt. Die berechneten Steifigkeitsparameter werden bei der Berechnung des transienten Fahrzeugverhaltens beim Fahren auf starrer und deformierbarer Fahrbahn mit dem Massenpunkt-Modell von Böhm genutzt. Die berechneten Kontaktparameter werden mit experimentellen Daten verglichen, die mit einem Messsystem im Innern eines Ackerschleppereifens beim Rollen auf Flachbahnprüfständen und in Bodenkanälen gewonnen wurden.

14:50	Schmidt-Fellner	H 105

Experimental Analysis Of Shrouded Blades With Friction Contact

Annika Schmidt-Fellner, Christian Siewert, Lars Panning, Institut für Dynamik und Schwingungen, Universität Hannover

Turbine blades are subjected to high thermal and mechanical loads. Damages at the blades are frequent causes for the failure of turbo machines. To reduce the vibration amplitudes and the resulting dynamic stresses, friction damping devices are widely used. Because of the relative displacements in the contact of the friction damping devices between the blades, additional damping is generated due to energy dissipation.

In this paper experimental measurements of heated blades coupled by tip shrouds are presented. A simulation of frictionally damped turbine blades and an optimization of different friction damping devices can be defined with an existing calculation method. For an optimal dimensioning of these friction damping devices a close description of the forces in the friction contact and a mathematical implementation of the mechanical contact model is necessary. For a practical validation of the calculation method by measurements, realistic contact parameters have to be identified. The application of the calculation method to the experimental measurements gives also an insight of the influence of the temperature towards the contact parameters, especially the coefficient of friction.

15:10	Panning	H 105

Symmetric And Asymmetric Underplatform Dampers For Turbine Blades

Lars Panning, Institut für Dynamik und Schwingungen, Universität Hannover

Friction damping devices like underplatform dampers are widely used in turbomachinery applications to reduce vibration amplitudes and to increase lifetime and reliability of the bladed disk. Nowadays, in practical applications, a variety of different underplatform damper geometries is applied. Nevertheless, a detailed study of the influence of the geometric and dynamic properties of the damper is still not available.

Within this paper a model is demonstrated to predict the vibration amplitudes of bladed disks with almost arbitrary underplatform damper types. Here, the most frequently applied damper types like cylindrical and wedge as well as asymmetrical dampers are investigated and compared to each other with respect to their effectiveness. Especially the influence of the damper geometry on the resonance frequency and vibration amplitude is pointed out. In particular, asymmetrical contact conditions are studied.

Examples of real underplatform dampers applied to gas turbine blades will be presented to validate the developed model and to confirm the necessity to take the damper geometry in account in order to get predictions with sufficient accuracy.

Session 7
Wednesday, March 29, 16:00 - 18:00

Room: H 104

Composites

Chair:

Eckart Schnack
Bozena Kuczma

16:00	Wigger	H 104

Size Effects At Corners Of Anisotropic Material Discontinuities

Hubertus Michael Wigger, Wilfried Becker, Fachbereich Maschinenbau, TU Darmstadt

Reinforcement patches of composite laminates often possess corners due to design and manufacturing necessities. Hence, the patches reconstitute the demanded effective strength or stiffness in the region considered but at their boundaries also constitute a source for stress localizations. The complex potential method is a means for the investigation of such stress localizations. With the help of appropriate complex potentials the mechanical in-plane fields around the reinforcement corner can be expressed as series representations. A first analysis step is to obtain the exponents which cause singular behavior of the membrane forces. Then, the determination of appropriately defined generalized membrane force intensity factors is used to show whether and how the singularity exponents are in effect. On this basis it is possible to deduce what impact a specific loading condition or the reinforcement corner's material combination and geometry have on the character of the singularity.

16:20	Tsotsova	H 104

Inverse Identification Of Delaminations In Layered Cfrp-composites

Rumena Tsotsova, Eckart Schnack, Institut für Technische Mechanik, Universität Karlsruhe (TH)

The purpose of this study is to propose a solution of the inverse problem related to determination of delamination regions in CFRP-laminates subjected to tensile load, when known the surface measurement data.

The determination of the crack position, topology and shape can be considered as a free-discontinuity problem with the unknown pair *(u, S)*, where u represents the elastic displacement vector in the unfractured part of the laminate and S the crack surface. An empiric-computational algorithm AICRA (Alternating Iterative Crack Reconstruction Algorithm) developed for an a priori known interlaminar surfaces can be applied for every interface between two composite layers. To analyse the numerical solution properties and to identify the true delamination region from the obtained solution pairs *(u, S)* we consider a functional, based on the variational formulation provided by Mumford and Shah. A variational approximation with elliptic lower semicontinuous functional via Γ-*convergence* enables to find a local minimizer.

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16:40	**Artel**	**H 104**

Analysis Of Free-edge Effects By Boundary Finite-element Method

Jens Artel, Wilfried Becker, Institut für Mechanik, TU Darmstadt

The scaled boundary finite-element method is a novel analysis technique, which combines the advantages of the finite element method and the boundary element method. Although a discretization of the boundary of the considered domain is sufficient, the method is finite element based and no fundamental solution is required as it is necessary in the boundary element method.

The free-edge effect in laminated plates is investigated by means of this new method. To simulate a laminated plate which is given by an infinite extended half plane, only the free edge has to be discretized. The mechanical loading is applied by a prescribed displacement field in order to simulate a uniaxial strain field.

The fundamental ideas of the method are presented and the derivation for elastostatics is given. Furthermore, the implementation of the required kinematic coupling equations is shown in order to apply a displacement field. In some benchmark examples results of the scaled boundary finite-element method are compared with those of the finite element method. Several classes of laminate lay-ups are investigated under mechanical loading. It is shown that the method converges to the exact solution in the finite element sense with comparatively little numerical effort.

17:00	**Kuczma**	**H 104**

Partially Connected Composite Beams

Mieczyslaw Kuczma, Bożena Kuczma, University of Zielona Góra, Poland

We will present a novel approach of modelling the bending problem of composite beams, such as steel-concrete beams, in which partial interaction between the component elements is taken into account. Usually, the mechanical bond between steel and concrete, established by means of various types of shear connectors, is assumed to be perfect. We propose a simple 1-D model that allows for a mutual slip of the concrete plate and the steel girder. Shear connectors are modelled using a distributed interface element.

First, we define the problem as a system of differential equations and inequalities, then in the form of a variational inequality which finally, after finite element approximation, is solved as a sequence of linear complementarity problems.

The analytical and numerical results we have obtained reveal interesting features of this interaction problem.

17:20	**Timchenko**	**H 104**

Free Vibration Analysis Of Composite Plates And Shells With Comple

Galina Timchenko, National Technical University KhPI, Kharkov, Ukraine

Composite plates and shells are widely used in modern machines and structures as main elements of designs. So there are many articles at which theoretical and practical problems of investigation of multi layered shells and plates are considered.

Algorithm of free vibrations problem solving based on variation method and R-function theory is presented. Mathematical problem statement is given in framework of two refined theories of the first and second order. Using this algorithm some problem for laminated plates of complex form in plane are solved. The effect of various mechanical and geometrical parameters on natural vibrations of laminated plates is studied. The dependence of natural frequencies upon the physical properties of core is investigated. The paper concludes with a detailed investigation of the influence of variation in material property parameters and plate geometry variables on the natural frequency.

17:40	**Shevchuk**	**H 104**

Determining Mechanical State Of The Body-multilayer Coating System

Victor Shevchuk, Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, Ukraine

The determination of mechanical state of elastic bodies with composite coatings is connected with formulating and solving appropriate problems of mathematical physics for multilayer systems. The exact solutions of these problems are cumbersome, practically ineffective and are usually used as standards in elaborating approximate methods. It is therefore natural to attempt building up approximate solutions, which are satisfactorily accurate for practical purposes.

This paper suggests an approach which essentially simplifies solving the problems of finding the stress-deformed state of constructions with thin multilayer coatings. It is based on the modelling of such coatings by thin shells with appropriate geometrico-mechanical properties of a coating. In such an approach, the influence of thin coatings on the mechanical state of the body-coating system is described by special generalized boundary conditions. These conditions on mechanical parameters allow formulating and solving non-classical boundary-value problems of elasticity theory for determination of stresses in the bodies with thin piecewise homogeneous coatings.

The accuracy of the approach has been successfully estimated by the comparison of approximate and exact solutions of the problem for the stressed state of a solid cylinder with the n-layer coating under constant external pressure. The suggested approach has thus proved to be effective.

Session 8
Wednesday, March 29, 16:00 - 18:00

Room: H 105

Miscellaneous

Chair:

Rolf Lammering
Wolfgang Seemann

16:00	Vishnevsky	H 105

Study On The Thermo-mechanical Behavior Of Superelastic Niti Wires

Andrey Vishnevsky, Rolf Lammering, Helmut-Schmidt-Universität Hamburg

The strong coupling of thermal and mechanical properties and the highly inhomogeneous strain distribution in tension tests motivate for thorough investigations on NiTi shape memory alloys. For these tests a complex experimental set-up has been developed which allows for the simultaneous measurement of stress, strain, and temperature. A laser extensometer allows for strain measurements with a high spatial and temporal resolution. The results of mechanical tests of NiTi wire-specimens under various time-depending loadings are presented.

The experimental results show the influence of strain rate, number of cycles, and deformation level on the progress of stress induced phase transformation in the specimens. A critical evaluation of the experimental results in view of a potential constitutive modeling is given.

16:20	Lammering	H 105

A Piezoelectric Finite Shell Element In Convective Coordinates

Rolf Lammering, Fan Yang, Institut für Mechanik, Helmut-Schmidt-Universität

In smart structures technology, piezoelectric material is widely used for sensor and actuator purposes. For the simulation of the mechanical behaviour of such structures with integrated piezoelectric material, the *Finite Element Method* (FEM) is often employed [1].

In this contribution, an isoparametric piezoelectric shell element will be presented which is based on convective coordinates and which allows for the analysis of arbitrary shell geometries. A two-field variation formulation [2] is used in which the displacements and the electric potentials serve as independent variables. Especially, for thin-walled structures under certain boundary conditions and load cases, the displacement based element will tend to shear and membrane locking. In order to avoid this poor behaviour, the *Assumed Natural Strain* (ANS) method [3] is introduced into the piezoelectric shell element. An example is presented to show the applicability and effectivity of this newly derived element formulation.

[1] Kögl, M. and Bucalem, M.L. *Piezoelectric MITC Plate Elements.* WCCM V, http://wccm.tuwien.ac.at, 2002
[2] Lammering, R. and Mesecke-Rischmann, S.: *Multi-field variational formulations and related finite elements for piezoelectric shells.* Smart Mater. Struct., 12, (6), 904-913, 2003
[3] Bathe, K.-J. and Dvorkin, E.N.: *A continuum mechanics based four node shell element for general nonlinear analysis.* Eng. Comp., 1, 77-88, 1984

16:40	Koenemann	H 105

Elasticity As A Change Of State In The Sense Of The First Law ...

Falk Koenemann, RSI Eupen, Belgium

Of the three sister disciplines continuum mechanics, thermodynamics, and solid state physics, the latter two were founded after the discovery of the First Law (1842) when potential theory (1830-1850) was already known. However, continuum mechanics was founded by Euler (1776) and concluded by Cauchy (1821), long before the general outline of classical physics was understood. By its mathematical structure, elasticity theory is conservative; by nature, however, elastic behavior is non-conservative and a change of state. An approach to elasticity based on the First Law is presented. The equation of state is transformed from scalar into vector form, and generalized to be applicable to solids. Two vector fields are derived from potentials. By observing the thermodynamic equilibrium condition it is possible to consider two independent constraints, external boundary conditions and material properties, and to merge them through the condition that system and surrounding are solidly bonded.

The new theory successfully predicts all major aspects of material behavior, especially elastic dilatancy, all geometric and energetic properties of pure and simple shear deformation (elastic and plastic), orientation of cracks in solids, and offers a mechanism for the origin of turbulence. In contrast to the Euler-Cauchy theory, it is a proper mathematical field theory.

17:00	Delibas	H 105

Simulation Of Rate Dependent Properties Of Piezoelectric Materials

Bülent Delibas, Wolfgang Seemann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

Nowadays piezoelectric and ferroelectric materials are becoming a much more interesting part of smart materials in scientific and engineering applications. In spite of having good characteristics, piezoelectric and ferroelectric materials have significant nonlinearities, which limit them the application in high performance usage. In this paper the nonlinear behavior of tetragonal perovskite type piezoceramic materials is simulated theoretically using two and three dimensional micromechanical models which are based on physical insights of the material. Intergranular effects are significant factors for nonlinearities of polycrystalline ferroelectric materials. Even piezoelectric actuators and sensors show nonlinearities when they are operated with electrical loading, which is much lower than coercive electric field level. A new electromechanical energy equation for the threshold of domain switching is introduced in order to explain nonlinearities stemming from both nonlinear domain switching and intergranular effects. The material parameters like coercive electric field and critical spontaneous polarization or strain quantities are not implemented in the electromechanical energy relation. By using this new model, mechanical strain versus electric field butterfly curves under small electrical loading conditions are also simulated. Hence, a rate dependent concept is applied in butterfly curves by means of linear kinetics model.

17:20	Ispas	H 105

GEOMETRICAL MODELING OF TRT2 MODULAR ROBOT

Viorel Ispas, Virgil Ispas, Mariana Arghir, Faculty of Machine Design, Technical University of Cluj-Napoca, Romania

In this work is presented the geometrical modeling of the serial modular robots, of TRT2 type built from two modula of linear motions and from one modulus having rotational motion.

The study method used in this paper was the method of the rotation matrices to determine the parameters wich expresses the position and the orientation of each axis of the (Ti) reference frame about the previous frame. The vector of operational coordinates and the matrices of homogeneous transformations lead an general coordinates $qk(k = 1, 2, 3)$.

The adequate work space of TRT2 modular robot was completed with a numerical example, known the robot dimensions and the directions of each axis.

17:40	Ispas	H 105

KINEMATICS MODELING OF TRT2 MODULAR ROBOT

Virgil Ispas, Mariana Arghir, Viorel Ispas, Faculty of Machine Design, Technical University of Cluj-Napoca, Romania

In the paper, the authors present two methods for the kinematics modeling of the TRT2 modular robot. The methods are: the first iterative method and the Newton Euler method.

The first iterative method consists to apply the backup relations for the velocities field, that characterize the motion of the robot modula. In this case, they are obtained the absolute velocity of the mobile reference origin, linked with gripper and the angular absolute velocity of the mobile reference system around its origin. Using them, we can obtain the time variation laws of the generalized coordinates $qk(k = 1, 2, 3)$, and finally the generalized velocities expressions. The Newton Euler method is given for a kinematics chain of robot, from fixed base to gripper. It obtains through successive iterations of the kinematics parameters that characterized the absolute and relative motions of each element of the robot structure. In this way, they can obtain the linear and angular velocities, respectively the linear and angular accelerations of each modulus of the robot system.

Inside the numerical application, they are presume known the motion laws of a characteristic point on the gripper, the time variation laws of the generalized coordinates and the robot dimensions, asking the graphical representations of the trajectory, velocity and acceleration of the given point.

Session 9
Thursday, March 30, 13:30 - 15:30

Room: H 104

Optimization

Chair:

Franz-Joseph Barthold
Klaus Hackl

13:30	Materna	H 104

Coherence Of Structural Optimization And Configurational Mechanics

Daniel Materna, Franz-Joseph Barthold, Numerical Methods and Information Processing, University of Dortmund

This contribution is concerned with the similarities of structural optimization and configurational mechanics. In structural optimization sensitivity analysis is used to obtain the sensitivity of continuum mechanical functions with respect to variations of the material body, i.e. the reference configuration. In the same manner in configurational mechanics we are interested in changes of the material body, e.g. crack propagation or phase transition problems. Consequently, variational design sensitivity analysis and the numerical techniques from structural optimization are applicable to problems from configurational mechanics and vice versa.

This talk elaborates firstly some further details of the continuum mechanical setting of configurational mechanics from the design variation point of view. Secondly, the known optimization strategies from structural optimization are applied to the numerical treatment within configurational mechanics.

Furthermore, in an abstract sense the search for a optimal mesh of a given discretization is even a structural optimization problem. Different solution strategies for these kind of optimization problems will be used and compared with other numerical approaches from the configurational mechanics point of view by means of selected examples.

13:50	Kotucha	H 104

Numerical Instabilities In Structural Optimization

Gregor Kotucha, Klaus Hackl, Institut für Mechanik, Ruhr-Universität Bochum

The formulation of structural optimization problems on the basis of the finite-element-method often leads to numerical instabilities resulting in non-optimal designs, which turn out to be difficult to realize from the engineering point of view.

In the case of topology optimization problems the formation of designs characterized by oscillating density distributions such as the well-known checkerboard-patterns can be observed, whereas the solution of shape optimization problems often results in unfavourable designs with non-smooth boundary surfaces caused by high-frequency oscillations of the boundary shape functions. Furthermore a strong dependence of the obtained designs on the finite-element-mesh can be observed in both cases.

In this context we have already shown, that the topology design problem can be regularized by penalizing spatial oscillations of the density function by means of a penalty-approach based on the density gradient.

In the present talk we apply the idea of problem regularization by penalizing oscillations of the design variable to overcome the numerical difficulties related to the shape design problem, where an analogous approach restricting the total length of the boundary can be introduced.

14:10	Rodak	H 104

Bicriterion Optimization Of Cold-formed Thin-walled Beams

Marcin Rodak, Institute of Applied Mechanics, Poznan University of Technology, Poland

Cold-formed beams are widely used in civil and mechanical engineering because of their good strength properties and relatively low weight. Nevertheless, they distinguish with some disadvantages, like local and distortional buckling, which rarely appear in hot-rolled beams. Advantages of cold-formed beams may be exploited if the dimensions and shape of cross-section of a beam are calculated with the help of structural optimization.

The paper presents a bicriterion optimization of an open cross section of cold-formed thin-walled beams. The first criterion is the area of a cross section and the second one is the maximum deflection of a beam. Global, distortional and local buckling constraints are included into the optimization problem. Vlasov's theory is applied for describing the behavior of beams. The problem is solved with application of minimum in Pareto sense. In the work Pareto frontiers are generated and results of numerical calculations are presented in the form of figures and graphs.

14:30	Hyca	H 104

Optimization Of Initial Deflection Of Beam-columns

Milan Hyca, Faculty of Mechanical Engineering, Technical University in Liberec, Czech Republic

The problem of optimizing initial deflection of a beam-column subjected to axial compression and lateral and bending moment loads is presented in the paper. The analysis considers the linear elastic planar problem of determining deflection and internal forces in elastic, geometrically imperfect, prismatic, hinged-end beam-columns subjected to compressive end forces and lateral and bending moment loads with arbitrary integrable discontinuities, acting in the plane of initial deflection. Adopting the filtering properties of generalized functions provides us with concise and explicit solution which makes it possible to formulate functional problems representing conditions for determining an optimal initial deflection variation along the beam-column which (a) excludes the resultant internal bending moment along the beam-column (thus minimizing maximum resultant stress variation along the beam-column) or (b) guarantees a prescribed variation of the resultant deflection of the beam-column (inclusive of zero resultant deflection along the beam-column as the case may be). To the author´s knowledge this method has not been published before.

14:50	**Walczak**	**H 104**

Mechanism Synthesis With The Use Of Neural Network

Tomasz Walczak, Poznan University of Technology, Poland

The synthesis of mechanism of four-bar linkage with the use of neural network is presented in this paper. The problem consists in determining the dimensions of linkage a coupler point to outline a required curve, hereby the path synthesis is considered. Two-step approach is proposed to optimize the process: the determination of approximated dimensions of the linkage, and thereafter, using them as initial dimensions in the optimizations process by means of genetic algorithm. In this paper the attention is focused on the first step, that is finding the best mating dimensions from the set used in the learning process of the neural network. An input of neural network are Fourier coefficients of expansion angle derivative function (ADF) ascribed to a closed curve outlined by the coupler point of the linkage. An output in the learning process are linkage dimensions corresponding to appropriate curves. Thereafter, for a required curve characteristic (i.e. ADF) one obtains approximated dimensions with required accuracy. The architecture and learning process of the used neural network are described. The presented method is very effective and easy to implementation.

15:10	**Starosta**	**H 104**

On Some Application Of Genetic Algorithm In Mechanism Synthesis

Roman Starosta, Poznan University of Technology, Poland

The great increase in computer power contributes to development computing techniques of mechanism synthesis which is the problem of significant importance in theory of mechanism. Optimal synthesis of the planar mechanism (four-bar linkage) is presented in this paper. The path synthesis is considered here, i.e. the tracing point of the mechanism is subjected to generate required trajectory. The problem is time independent. The genetic algorithm starts with rough solutions obtained by using neural network. The next step consists in rescaling, translating and rotating obtained curve. The dimensions of the linkage are transformed appropriately. The initial population (i.e. dimensions of linkages) is generated by a random variation of the derived output of the neural network. The tracing point of the mechanism, obtained in this way, outlines the similar path to the desired one. Then, the genetic algorithm is used to improve the matching of the curve generated in the synthesis task. The two-step approach to the problem significantly improves the convergence to the optimal solution. The other advantage is its simplicity of implementation. The task was implemented in FORTRAN 95 programming environment, which is convenient tool to fast mathematical calculations and simulations of mechanism motion.

Session 10
Thursday, March 30, 13:30 - 15:30

Room: H 105

Numerical Methods 1

Chair:

Rolf Krause
Stefanie Reese

13:30	Bitzenbauer	H 105

Mehrskalenberechnungen Bei Inhomogenen Körpern

Johann Bitzenbauer, *Karl Schweizerhof, Institut für Mechanik, Universität Karlsruhe*

Die Finite Elemente Untersuchung linearer und nichtlinearer Randwertprobleme der Elastizitätstheorie führt bei vorhandenen und durchgängig diskretisierten Mikrostrukturen üblicherweise auf sehr große dünnbesetzte Gleichungssysteme. Als ein effizientes Lösungsverfahren empfehlen sich Mehrgittermethoden. Während bei klassischen Mehrgitterverfahren die minimale Anzahl der zur Geometriebeschreibung notwendigen Finiten Elemente von der Geometrie selbst abhängig ist, besteht bei der Composite Finite Elemente Methode [1] ein gröbstmögliches Gitter zur Diskretisierung einer beliebigen Geometrie stets aus einem Element. Ein auf der CFE-Methode basierender Mehrgitteralgorithmus nebst zugehörigen Transferoperatoren zur Berechnung inhomogener elastischer Körper wird vorgestellt. Im Gegensatz zu algebraischen Mehrgittermethoden, bei denen zur Konstruktion der Transferoperatoren die Steifigkeitsmatrizen des diskretisierten Problems herangezogen werden, nutzt der präsentierte Algorithmus Geometrieinformationen aus, ohne dabei jedoch die beim klassischen geometrischen Multigrid auftretenden Einschränkungen zu besitzen.

[1] S.A. Sauter: Vergröberung von Finite-Elemente-Räumen. Habilitation, Universität Kiel, 1997.

13:50	Hoppe	H 105

Numerical Simulation Of Crack-propagation In Shells

Ulrich Hoppe, *Klaus Hackl, Institut für Mechanik, Ruhr-Universität Bochum*

This talk is concerned with the numerical simulation of dynamic crack propagation and fragmentation of thin plates and shells. The approach is based on the extended finite element method (XFEM), which enables arbitrary crack paths that need not be aligned with the finite element boundaries. The extended finite element method is based on the partition of unity concept and enhances the standard finite element shape functions by additional terms, e.g., accounting for crack discontinuities or crack-tip singularities.

The talk focuses on the kinematic description of thin shells with a crack through the thickness. Different approaches to model the crack opening displacement using translational and rotational degrees of freedom are discussed. The crack-tip process zone is described by a cohesive interface model accounting for shear and normal cohesive strength of the material. The good performance of the method is demonstrated through numerical examples.

14:10	Helldörfer	H 105

COUPLING OF 3D BOUNDARY ELEMENTS AND CURVED FINITE SHELL ELEMENTS

Bastian Helldörfer, Michael Haas, Günther Kuhn, Lehrstuhl für Technische Mechanik, Universität Erlangen-Nürnberg

A strategy for the mixed-dimensional coupling of curved finite shell elements and three dimensional boundary elements is presented.

The coupling of both numerical techniques is achieved by interpreting a closed boundary element domain as a finite macro element. For the BEM region a stiffness formulation is generated by the Symmetric Galerkin Boundary Element Method (SGBEM), which then is assembled to the global finite element system.

Finite shell elements are coupled with three dimensional boundary elements in a weak form, i.e. the work performed in the coupling interfaces of the shell and the solid domain must be equal. Based on this equality of work, highly accurate shell to solid coupling equations are derived for curved coupling interfaces and formulated as multi point constraints in terms of kinematic quantities. It is shown how these can be set up automatically during a structural analysis.

In combination with a commercial finite element system an in-house SGBEM code is used for automatically coupled FEM/BEM analyses. Several examples show the highly accurate results compared to common coupling techniques.

14:30	Krause	H 105

A NEW STABILIZED IMPLICIT NEWMARK SCHEME FOR DYNAMIC CONTACT ...

Rolf Krause, Institut für Numerische Simulation, Universität Bonn
Peter Deuflhard, Susanne Ertel, ZIB

For the numerical solution of dynamic contact problems, Newmark-based time discretization schemes are widely employed. Unfortunately, when using these schemes, artificial oscillations in displacements and stresses at the contact boundary can be observed. In the case of contact, the energy of the system is not conserved and may even increase. The reason for this behavior can be found in the inequality constraints at the contact interface which model the non-penetration condition between the two bodies coming into contact. We present a new stabilized Newmark-based implicit time discretization scheme, which reduces the oscillations in the solution at the contact boundary significantly. Our stabilization is based on a L^2-projection of the unconstrained predictor. Since our method is implicit, in each time step we have to solve a variational inequality for the displacements and a variational inequality arising from the L^2-projection. This is done using monotone multigrid methods, which allow for the solution of nonlinear contact problems with linear multigrid speed. Moreover, using a lumped mass-matrix, the variational inequality corresponding to the L^2-projection can be solved easily by solving decoupled local problems.

We present numerical results illustrating the performance and the properties of our method.

14:50	**Rickelt**	**H 105**

An Efficient Strategy For Lifetime Calculation Of Large Structures

Christian Rickelt, Stefanie Reese, Institut für Allgemeine Mechanik und Festigkeitslehre, TU Braunschweig

The present paper is motivated by the increasing concern to accomplish more realistic lifetime estimations of complex structures. But in spite of the fast development of computer technology the life cycle computation is still to complex to be carried out without advantageous and efficient strategies to reduce computational costs.

In this contribution we present a discretisation strategy which takes into account that only small parts of a structure demand a non-linear analysis. Accordingly we strictly decompose our system on the structural level into non-linear and linear subsystems.

Further we may reduce the number of degrees-of-freedom of the latter, because they influence the evolution of damage only indirectly. Hence we join our proposed substructure strategy with projection-based model reduction techniques, like modal truncation, Ritz vectors or the proper orthogonal decomposition.

In the non-linear substructures we model the evolution of ductile damage behaviour of metals taking into consideration large inelastic strains. At the material level we exploit the advantages of a formulation in principle axes in combination with the exponential mapping algorithm.

This material model is implemented into the computationally efficient Q1SP finite element formulation, which is based on the concept of reduced integration with hourglass stabilisation.

15:10	Abdelhakim	H 105

An H-matrix Type Preconditioner For Contact Problems

Lotfi Abdelhakim, Department of Mathematics, Széchenyi István University, Hungary

The purpose of this work is to study for small strains, the quasistatic two-body contact problem with friction. The mechanical interation between the bodies is modeled, under the assumption of small displacement, by the bilateral or unilateral contact condition, and Coulomb's friction law relating the contact force and the displacement. The central aspect of this work is the adaptation of a preconditioner construction developped by B. Kiss et al., in [3] for non-overlapping decomposition domain method to the contact problem. The circulant matrix representations of the $H^{\frac{1}{2}}$ seminorm has been proved to be spectrally equivalent to the Schur Complement in [4]. Using this equivalence, the interface problem is transformed to an equivalent problem which is solved by two-stage iterative technique consisting in solving consecutively a problem with prescribed tangential force and a problem with prescribed normal force. Each problem is solved with adequate mathematical programming methods [5]. Our preconditioner construction is based on the application of the H-matrix technique [1] together with the representation of the $H^{1/2}$ seminorm by a sum of partial seminorms [2]. The advantage of this preconditioner construction is, that its preconditioning property is optimal and most of the H-marix blocks are empty.

[1] W. Hackbush and B. N. Khoromskij, A sparse H-matrix arithmetic. II. Application to multi-dimensional problems. Computing 64, 21-47, 2000.
[2] B. Kiss, A. Krebsz, G. Molnárka, On the Separability of the $H^{1/2}$Norm in Finite Element Spaces, Hungarian Electronic Journal (http://hej.szif.hu) Vol(1) ANM-980205-A, 1998.

Session 11
Thursday, March 30, 16:00 - 18:00

Room: H 104

Dynamics / Oscillations

Chair:

Becker, Wilfried

16:00	Magnucka-Blandzi	H 104

Vibration Of A Circular Porous-cellular Plate

Ewa Magnucka-Blandzi, Poznan University of Technology, Poland

The subject of investigation is a circular porous-cellular plate under uniform pressure. Mechanical properties of the isotropic porous cellular metal vary accross the thickness of the plate. Middle plane of the plate is its symmetry plane. Fields of diseplacements and stresses with respect the nonlinear hypothesis are described. Basing on Hamilton principle three motion equations of the plate are formulated. These equations are approximately solved. The vibration problem is reduced to the second-order differential equation. Numerical investigations are realised for family of plates. Natural frequencies are determined. The obtained results are shown in Figures. To the end of the investigation comparition analyses with respect to homogeneous plates is presented.

16:20	Koszela	H 104

Chaotic Vibration In Nonlinear Problems Of Bar Structures

Piotr Koszela, Magdalena Napiorkowska-Alykow, Wrocław University of Technology, Poland

In the response of nonlinear mathematical models which describe vibrations of structural elements such as beams, plates and shells one could observe an irregular behaviour which is called chaos. Loss of the information on initial states in deterministic dynamical systems after a short time of theirs evolution, increasing amplitudes of displacements, velocities and accelerations, sensitive dependency on initial conditions makes chaos dangerous phenomenon in mechanics of construction. In this article are shown the quantitative and qualitative identification methods (Lyapunov characteristic exponents, atractor dimension, bifurcation diagrams, Fourier spectra analysis and Poincaré sections) of chaotic dynamics in physically and geometrically nonlinear structural models. The aim of this paper is to review and to systematise nonlinear mechanical problems (especcialy beam vibrations) in which chaotic phenomena occurs. Main goal is to verify influence of chaos on safety of bars structures elements.

16:40	Avramov	H 104

Free And Forced Nonlinear Oscillations Of Cylindrical Shells

Konstantin Avramov, Francesco Pellicano, National Technical University KhPI, Ukraine

The results of the asymptotic analysis of reduced models of cylindrical shells nonlinear oscillations are treated in this paper. Three-mode approximate model is used to study nonlinear dynamics of simply supported cylindrical shell. The composition of the nonlinear normal vibrations mode approach and multiple scales method is suggested to study free nonlinear oscillations. It is shown that only one nonlinear normal mode, which is determined by imperfections, exists. The bifurcations of this normal mode are studied. Quasi periodic motions appear in bifurcations points.

The forced oscillations of cylindrical shells in the case of the internal resonance between the eigenfrequency of the conjugate modes and axisymmetric one are studied. The system of three ordinary differential equations is derived by Galerkin method to study traveling and standing waves. This system is analyzed by the multiple scales method. As a result the system of six differential modulation equations is obtained. The fixed points of this system are studied analytically and using continuation technique. The approach to study stability of standing and traveling waves is suggested.

Nonlinear oscillations of a seismically excited cylindrical shell with big disk at the end are studied too. It is suggested that bending and longitudinal oscillations with moderate amplitudes take place. The Sanders Koiter theory is used to model the shell oscillations. The boundaries of dynamical instabilities are derived by multiple scales method.

17:00	Pilgun	H 104

Nonlinear Free Vibrations Of Shallow Shells Of Arbitrary Shape

Galina Pilgun, National Technical University KhPI, Ukraine

Geometrically nonlinear free flexural vibrations of shallow shells based on complex planforms with different boundary conditions are considered. The Donnell-Mushtari-Vlasov shallow shell equations of motion are used for the problem's statement. The algorithm is constructed on reducing the nonlinear shell theory government equation to the second order ordinary nonlinear differential equation of Duffing type. Its factors are determined in a result of consecutive solving several boundary value problems by variational Ritz method. Numerical methods are used to solve the Duffing type equation.

The distinctive feature of the offered method is the defining eigenfunctions analytically by the R-function method (RFM). This fact allows to obtain natural frequencies for shallow shells with any form of median surface and various type of boundary conditions. The given numerical results and their comparison with well known from other works confirm the reliability and efficiency of the suggested method.

Session 12
Thursday, March 30, 16:00 - 18:00

Room: H 105

Numerical Methods 2

Chair:

Ryszard Kutylowski
Tomasz Kozbial

16:00	Ziopaja	H 105

Damage Detection And Estimation Using Wavelet Transform

Krzysztof Ziopaja, Zbigniew Pozorski, Andrzej Garstecki, Institute of Structural Engineering, Poznan University of Technology, Poland

Permanent increase of fields of application of wavelet transform has been observed in the last decade. Wavelet transform have also been used efficiently in structural identification and damage detection. One of the most challenging issues has become assessment of the magnitude of damage using the wavelet transform.

In the present paper mechanically loaded 1-D structures and thermally loaded 2-D structures are considered. In case of 1-D members response signals in the form of displacements are processed, whereas in 2-D structures temperature field is used. Employing a discrete wavelet transforms of the response signals the damage zones are discovered and localized. Next, we try to assess the magnitude of damage by the analysis of various details of wavelet decomposition.

In the present study computer simulated experiments and response signals are used. Measurement errors are accounted for by introduction of a white noise. Various types of wavelets and damage models are considered. The results of the analyses are compared with the approach based on the Lipschitz exponent, usually combined with the continuous wavelet transform.

16:20	Wasniewski	H 105

Symmetric Galerkin Bem For Shallow Spherical Shell

Grzegorz Wasniewski, Kazimierz Myslecki, Wrocław University of Technology, Poland

The paper deals with the symmetric Galerkin boundary element method formulation for the shallow spherical shell. Considerations, for the sake of simplicity, are reduced only to homogenous Dirichlet boundary conditions - full attachment and constant load. A matrix equations system for fundamental solution functions estimation is reduced to a scalar one by the Hoermander method. This differential equation is subjected to Fourier transformation. An image of the fundamental solution is expanded into a power series. Inverse transformation gives an original of the fundamental solution as an infinite sum of the fundamental solutions of the Laplace operator of any order. All the fundamental solution functions are obtained in the same form. For constant load problem, integral equations are reduced to the boundary integrals only. For Galerkin weighted residual approach, symmetry of BEM algebraic equations system matrix is proved. A simple verification problem, deals with square in plane full-attached shell, is enclosed.

16:40	Kozbial	H 105

Application Of Daubechies Wavelets Approximation To Plate Bending

Tomasz Kozbial, Wrocław University of Technology, Poland

In this paper a new wavelet-based approach is presented for solving two-dimensional boundary-value mechanical problems on the example of plate bending. The deflection equation of a bending plate is approximated by two-dimensional Daubechies wavelets using a least-squares Galerkin method.

Due to the order of the differential equation in mechanics of plate structures is four, a way to perform the calculations of high order connection coefficients (that is, integrals of products of basis functions with their high order derivatives) will be introduced.

The implementation of two-dimensional Daubechies scaling and wavelet functions approximation to plate bending will be exhibited numerically in some examples. It will be shown that this method has good precision and reliability.

17:00	Buskiewicz	H 105

Synthesis Of Workspace By Using Angle Derivative Function (adf)

Jacek Buskiewicz, Poznan University of Technology, Poland

The determination of the distance (error) between a required curve and a curve generated by a tracing point is the important task in path generation synthesis. In most cases the error is defined as the mean-square distance between the generated and the desired path. But the error computed in a such way is often overestimated, when, for example, one curve is translated or rotated with respect to the other. Translation and rotation effects were thoroughly examined. Dibakar and Mruthyunjaya (Synthesis of Workspaces of planar manipulators with arbitrary topology using shape representation and simulated annealing, Mech. Mach. Theory 34 (1999)) discussed method currently developed and defined a global property based vector representation for the shape of workspaces containing properties of a closed curve, such as length of curve, center of gravity, principal moments of inertia.

In the paper an angle derivative function (ADF) is proposed to represent a closed curve. The ADF is computed after integrating the angle of the curve slope to a constant axis with respect to arc variable measured along the curve. The ADF is expanding into Fourier series and represented finally by a set of normalized Fourier coefficients. The method guarantees that the ADF is invariant with respect to rotation, scaling, translation, mirror deflection, change the start point on the curve and direction of points enumerating. The advantage is that the shape of the curve can be reconstruct from the ADF.

17:20	Cialkowski	H 105

Minimal Entropy Production Principle For Solving An Inverse Proble

Michal Cialkowski, Technical University of Poznan

In the problems pertaining to cooling the blades of gas turbines the solution to the integral inverse problem acquires considerable significance. In case of such a task the temperature distribution at the outside surface and value of the heat transferred to the blade cooling liquid are known. For a steady temperature field the temperature distribution at the surface of cooling channel is searched. The problem has been solved by minimization of the functional of entropy production or the functional of energy dissipation.

5 Oscillations

Organizers:

Peter Eberhard, Universität Stuttgart
Wolfgang Seemann, Universität Karlsruhe

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 2033

Bremsen

Chair:

P. Eberhard
W. Seemann

13:30	Kröger	H 2033

Modellierung Der Reibkraftverläufe Einer Bremse

Matthias Kröger, Martin Rudolph, Wolfgang Hogenkamp, Institut für Dynamik und Schwingungen, Universität Hannover

Die Reibkraftverläufe einer Pkw-Bremse zeigen starke Abhängigkeiten von der Gleitgeschwindigkeit, dem Bremsdruck und der Geschwindigkeit. Zudem finden während des Bremsens komplexe Veränderungsprozesse in der Bremsbelagsoberfläche statt. Dieses führt zu Abhängigkeiten der Bremskraft, nicht nur vom aktuellen Systemzustand, sondern auch von der Vorgeschichte.

Auch wenn inzwischen erste Erfolg versprechende Ansätze zum physikalischen und chemischen Verständnis der Vorgänge in der Kontaktfläche existieren, ist es bisher nicht gelungen, diese Ansätze zur erfolgreichen Beschreibung der makroskopischen Reibkraft zu nutzen.

Das hier gezeigte Reibkraftmodell basiert auf der grundlegenden Modellvorstellung sich bildender makroskopischer und mikroskopischer Kontaktflächen und deren Abhängigkeit vom Reibprozess (Pressung, Gleitgeschwindigkeit, Temperatur). Die Parameter des daraus abgeleiteten Reibkraftmodells sind anhand von Messungen identifiziert worden. In einem weiten Anwendungsbereich liefert dieses Modell eine gute Vorhersage der Reibkraft.

13:50	Spelsberg-Korspeter	H 2033

Moving Continua And Brake Squeal – Part 1: Euler-bernoulli Beam

Gottfried Spelsberg-Korspeter, Daniel Hochlenert, Peter Hagedorn, Institut für Mechanik, TU Darmstadt

Brake squeal is a high frequency noise (1-12 kHz) of brake systems. It does not affect the performance of the brake system but is detrimental to the passenger's comfort and the subjective quality of the vehicle. The design of noise-free disk brakes of modern cars demands a significant amount of costly experiments because the source and excitation mechanism of brake squeal is not yet completely understood.

This paper is devoted to the formulation and identification of a possible excitation mechanism of brake squeal involving moving continua under frictional contact. The underlying model is a travelling beam sliding through two idealized brake pads. It is shown that self excited vibrations due to Coulomb friction occur even with a constant coefficient of friction. Furthermore it is pointed out that the consistent formulation of the contact between the surface of the beam and the brake pads is essential for the stability behavior. The insights gained from the travelling beam are foundation for an enhanced model of a disk brake using a rotating Kirchhoff plate (Part 2). The Ritz discretization scheme used to solve the equations of motion is investigated regarding convergence and the essential features in the contact problem are discussed.

14:10	Hochlenert	H 2033

Moving Continua And Brake Squeal – Part 2: Kirchhoff Plate

Daniel Hochlenert, Gottfried Spelsberg-Korspeter, Peter Hagedorn, Institut für Mechanik, TU Darmstadt

This paper extends the model of the travelling beam (Part 1) to a rotating annular Kirchhoff plate in frictional contact with idealized brake pads. Based on the analysis for a corresponding travelling beam the essential properties of the contact kinematics are derived and it is shown that the Coulomb type friction renders the system susceptible to self excited vibrations. The equations of motion are solved using a Ritz discretization scheme. As in the travelling beam it is shown that self excited vibrations occur even with a constant friction coefficient. A falling friction characteristic frequently mentioned in literature is not essential for instability. Furthermore, the three dimensional frictional contact yields viscous damping terms not occurring in the two dimensional model for the travelling beam.

The stability analysis results in traceable design proposals for a disk brake.

14:30	Schlagner	H 2033

Quietschen Von Kfz-scheibenbremsen

Stefan Schlagner, Utz Von Wagner, TU Berlin

Quietschen ist ein lästiges Phänomen bei Kfz-Scheibenbremsen welches aus selbsterregten Schwingungen resultiert. Der Vortrag präsentiert zum einen Ergebnisse experimenteller Untersuchungen an serienmäßigen Bremsen mit Hilfe von „smart pads“ – aktiven Bremsbelägen mit implementierten piezokeramischen Aktoren und Sensoren; zum anderen den Vergleich mit Modellen. Besonderes Augenmerk wird dabei auf die anfachende Wirkung der Reibungskräfte als Ursache des Phänomens gelegt.

14:50	Hetzler	H 2033

Investigations On Low-frequency Noise Of Disc-brakes

Hartmut Hetzler, Wolfgang Seemann, Institut für Technische Mechanik, Universität Karlsruhe (TH)

Today, low frequency disc-brake noises are commonly explained as self-sustained stick-slip oscillations. Although, at a first glance this explanation seems to match experimental observations, there are indices that cast doubt on it. This fact gave rise to further experimental investigations as well as analytical analysis. To motivate the mechanical modelling, the influence of the accessories (calliper, hydraulic piston, etc.) is experimentally investigated. Furthermore, considering the test data the hypothesis of short periods of stiction in the contact zone is questioned. Based on a thorough discussion of the functionality and considering the experimentally observed relevance of the several parts for the occurrence of the low-frequency noises, a minimal model as well as a MDOF-model are derived. Finally, the stability and bifurcation behaviour of these models is discussed analytically.

15:10	Steindl	H 2033

Bifurcations Of Slip-stick Travelling Waves In A Breake-like Syste

Alois Steindl, Institut für Mechanik und Mechatronik, TU Wien

We consider a system composed of an elastic tube in frictional contact with a rotating rigid cylinder. At the contact surface several types of rotating slip-stick and also slip-stick-separation waves with different wave numbers can be observed. In order to determine the stability of these travelling waves, we have to solve a non-local eigenvalue problem. We also attempt to locate the stability boundaries in parameter space, where bifurcations occur. We are especially interested in Hopf bifurcations, which have already been observed in numerical simulations.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: H 2032

Schwingungsdaempfung und Pendel

Chair:

A. Fidlin
F. Ziegler

13:30	Ziegler	H 2032

A Novel, Vertically Acting Tuned Liquid Column Damper

Franz Ziegler, Institut für Hochbau und Akustik, TU Wien

The tuned liquid column damper (TLCD) increases the effective structural damping of horizontal vibrations similar to the classical tuned mechanical damper (TMD). When sealed, and with the gas-spring effect taken into account, the frequency range of application is extended to about five Hertz, Hochrainer and Ziegler (2004). The TLCD was imperfectly redesigned to account for vibrations in the vertical direction by Sun and Nakaoka (1990). In co-operation with M. Reiterer, an optimized (symmetric and fully sealed) design is presented that makes the damping as efficient as a TMD and extends the frequency range of application through the novel gas-spring. The geometric analogy between the TLCD and the TMD is re-derived making the first step in the tuning procedure 'classical'. Fine tuning in state space when either the TLCD is split into smaller ones in parallel action, or if several TLCD are tuned to counteract a single mode of vibration of the main system, renders an even more robust passive action. The experimentally observed averaged turbulent damping of the relative fluid flow and the weakly nonlinear gas-spring render the TLCD insensitive to overloads. The TLCD is free of maintenance and the rigid pipe-in-pipe is a low cost design.

13:50	Barthels	H 2032

Freie Zielanfahrt

Pierre Barthels, Jörg Wauer, Institut für Technische Mechanik, Universität Karlsruhe (TH)

Von „freier Zielanfahrt“ spricht man in der Fördertechnik wenn der Bewegungsablauf von Förder- und Hebezeugen (z. B. Gabelstapler) durch einen Menschen gesteuert wird und die Bewegung somit vorgegeben aber zufällig ist. Die hierbei auftretenden Transversalschwingungen der teleskopierbaren Segmente des Mastes reduzieren die Leistungsfähigkeit der Maschine und führen zu Sicherheitsproblemen. Dieser Beitrag befasst sich mit der Schwingungsunterdrückung bei solchen Systemen, wobei eine dem jeweiligen Systemzustand entsprechend geregelte Kraft auf ein Segment des Mastes aufgebracht wird. Die einzelnen Segmente des Mastes werden als Balken modelliert. Unter Berücksichtigung des Spiels in den Kontaktbereichen und einer vorgegebenen Teleskopierbewegung führt das Prinzip von Hamilton auf ein gekoppeltes, nichtlineares, zeitvariantes System partieller Differentialgleichungen. Vorspannungseffekte durch die zu transportierende Last und durch das Eigengewicht der einzelnen Segmente werden bei diesem Modell berücksichtigt. Die Diskretisierung der Bewegungsgleichungen erfolgt durch das Galerkin-Verfahren. Durch den direkten Zugriff auf die Systemgleichungen können bewährte Methoden der Regelungstechnik zur Schwingungsunterdrückung genutzt werden.

14:10	Mikhlin	H 2032

Vibration Absorption By Using The Essentially Nonlinear Subsystem

Yuri Mikhlin, S. N. Reshetnikova, National Technical University KPI, Ukraine

Concept of nonlinear normal modes (NNMs) is used to study vibrations of elastic structure attached with a single-DOF nonlinear absorber. Three types of absorbers are considered: an essentially nonlinear oscillator with a single equilibrium position, a snap-through truss and a vibro-impact oscillator.

The localized and non-localized NNMs are selected. If the localized mode is stable, and the non-localized mode is unstable, the system energy is concentrated in the nonlinear absorber, and the elastic vibrations absorption takes place. The NNMs can be determined by the small parameter method. NNMs, close to one of the stable equilibrium positions, and the snap-through motions are determined in the model containing the shallow snap-through truss. Non-smooth transformation by Pilipchuk is used to analyze NNMs in the system containing the vibro-impact absorber.

Stability of the NNMs is studied by the Ince algebraization and the multiple scales method. The forced resonances and its stability are investigated in such systems too.

1. A.Vakakis, L.Manevitch, Yu. Mikhlin, V. Pilipchuk and A. Zevin. Normal Modes and Localization in Nonlinear Systems. New-York: Wiley, 1996.
2. K. Avramov and Yu. Mikhlin. Snap-through truss as a vibration absorber. J. of Vibration and Control, 2004, 10 (2), 291-308.
3. Yu. Mikhlin and S. Reshetnikova. Dynamical interaction of an elastic system and essentially nonlinear absorber. J. of Sound and Vibration, 2005, 283, 91-120.

14:30	Stangl	H 2032

Dynamics Of An Elastic Pendulum With Internal Flow Of Fluid

Michael Stangl, Hans Irschik, Institut für Technische Mechanik, Johannes Kepler Universität Linz

In the present paper the dynamics of an elastic pendulum with an internal flow of fluid are investigated. The proposed approach includes the application of Lagrange equations capable of treating non-material volumes with a flow of mass through its boundary in combination with a formulation common in multibody dynamics, the floating frame of reference formulation. Since materials used in pipe systems often are relatively soft (e.g. ebonite), they can undergo large deformations. In order to derive equations of motion eligible for modeling large deformations of the pipe, the Bernoulli-Euler beam theory is formulated in the context of the material description of continuum mechanics. Possible reductions of the dimension of the system applying a minimum set of assumptions will be shown. The resulting nonlinear equations of motion are studied numerically using the time-integration code HOTINT in addition to a numerical stability analysis applying XPPAUT.

14:50	Fidlin	H 2032

Low Frequency Effects In Bi-harmonically Excited Pendulum

Alexander Fidlin, LuK GmbH & Co. oHG

The effect of the harmonic high-frequency vibration of the suspension point on a mathematical pendulum is well known. It can be described as stiffening/softening or stabilization/destabilization of the up-pointing and down-pointing equilibriums for pure vertical or pure horizontal excitation. If the excitation is tilted the effect of biasing appears in addition. The effects of bi-harmonic excitation are more complex. Two of them are discussed in the recent paper. The first one occurs if one of the excitation frequencies is high and another one is low. Then the so called shifted or conjugated resonances can be observed. The second one takes place if the two excitation frequencies are high but their difference is small (slowly modulated high-frequency excitation). It is shown that in that case it is possible to choose the bi-harmonic excitation in order to quench the resonance of the pendulum without changing its basic frequency. The analysis is fulfilled both for the external and parametric excitations.

15:10	Borowiec	H 2032

Vibration Of Pendulum With Oscillating Support And Extra Torque

Marek Borowiec, Grzegorz Litak, Department of Applied Mechanics, Technical University of Lublin, Poland
Hans Troger, Institut für Mechanik und Mechatronik, TU Wien

The periodically driven planar pendulum is one of the simplest mechanical systems which can exhibit chaotic behaviour. We investigate its motion for a vertically periodically oscillating point of suspension and under the action of an additional constant torque which can be applied by a rotating shaft with friction. We study the influence of the amount of the torque on the transition to chaotic motions of the pendulum.

Applying Melnikov's criterion we analyze first the case of small torque and then the case of moderate torque. In the small torque limit the unperturbed potential is symmetric [1] and the saddle points $\phi = \pm\pi$ can be identified on the cylindrical phase space. In the case of moderate torque the unpertubed system is governed by a non-symmetric potential [2,3] which complicates the Melnikov analysis considerably. We also compare the results of these two different approaches with the aim to define the domain of validity of the small torque analysis.

To confirm the analytic results we calculate also Lyapunov exponents, Poincaré maps and bifurcation diagrams for specially selected parameter values of the system.

[1] A. Steindl, H. Troger, *Chaotic Motion in Mechanical and Engineering Systems*, in Engineering Applications of Dynamics of Chaos, (Eds. W. Szemplińska-Stupnicka, H. Troger) Springer Wien 1991, pp. 150-223.
[2] A. A. Andronov, A. A. Vitt, S. E. Khaikin, *Theory of Oscillators*, Dover Publications, New York, 1966.
[3] G. Litak, M. Borowiec, Oscillators with Asymmetric Single and Double Well Potentials: Transition to Chaos Revisited, *Acta Mechanica* (2005) submitted.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: H 2033

Kontakt

Chair:

R. Seifried
A. Bockstedte

16:00	Seifried	H 2033

Multiple Impacts Of Transversely Struck Aluminum Beams

Robert Seifried, Institut für Technische und Numerische Mechanik, Universität Stuttgart

Impacts on slender bodies, such as rods, beams and plates might excite strong wave phenomena and structural vibrations. In this paper transverse impacts of steel spheres on aluminum beams are investigated numerically and experimentally. For the numerical investigation modally-reduced models are used in combination with local contact models. Three local contact models are presented: a concurrently computed FE-contact, a pre-computed FE-contact and the Hertzian contact law. A comparison with complete FE-models shows a high efficiency of the presented combined models. The proposed numerical models are verified by extensive experimental investigations using Laser-Doppler-Vibrometers for displacement and velocity measurements.

The numerical and experimental investigations show that impacts of steel spheres on aluminum beams yield strong structural vibrations. Due to these strong structural vibrations the transversely struck beams show multiple successive impacts within a very short time period and resulting in a chaotic behavior. As a result, some of the investigated impacts show significant differences between measurements and simulations while others show good agreement. It turns out that the amount of initial kinetic energy transmitted into structural vibrations scatters between 40% and 90% - strongly depending on the initial velocity of the sphere. This is found consistently in the numerical and experimental investigations.

16:20	Schwarzer	H 2033

Bifurcation Behavior Of A 1dof Sliding Friction Oscillator

Daniel Schwarzer, Hartmut Hetzler, Wolfgang Seemann, Institut für Technische Mechanik, Universität Karlsruhe (TH)

In literature, there exists a lot of characteristics for the description of the friction between the surfaces of two tribological partners. Here, the friction coefficient is described in the sense of Coulomb as proportional to the normal force and in the sense of Stribeck as dependend of the relative velocity between the interacting partners. This friction characteristic is investigated by examining the behavior of a simple 1 DOF friction oscillator, which is commonly referred to as "mass-on-a-belt"-oscillator.

In a first step an exponentially decaying friction characteristic is examined, for which it is shown that the observed system can undergo a subcritical Hopf-bifurcation changing the stability of the steady-state fix point from unstable to stable while an unstable limit cycle is born in a small surrounding of this fix point in the phase plot. Obviously in that case the classical approach to investigate friction-induced vibrations by means of an eigenvalue-analysis at the steady state may not give the whole picture, since the basin of attraction of the stable fix-point may be rather small.

Additionally some different shapes of the friction characteristics, for example one of Stribeck type with dominant viscous friction, are compared. It is figured out that the bifurcation behaviour is strongly dependend on the shape of the friction characteristic.

16:40	Keitzel	H 2033

Influence Of The Contact Model On The Onset Of Sprag-slip

Hanna Keitzel, Norbert Hoffmann, Institut für Mechanik und Meerestechnik, TU Hamburg-Harburg

In systems with sliding-friction often strong self-excited vibrations do occur. One of the possible underlying mechanisms is the so-called sprag-slip instability. In the present work the onset of sprag-slip is investigated by a simple model in which an inclined elastic beam slides over a rigid belt moving with constant velocity. For a Coulomb friction law and a contact model with constant contact stiffness for a certain range of parameters the system loses its static solution corresponding to the steady sliding state. Simultaneously with this loss of existence of the static solution the qualitative properties of the system's flow field in phase space change, resembling a transition from stable to unstable behavior. To investigate the influence of contact models and related parameters on the details of this onset of sprag-slip also Hertz theory of elastic contact is applied.

17:00	Hoffmann	H 2033

Nonconservative Beatings In Systems With Sliding Friction

Norbert Hoffmann, TU Hamburg-Harburg

Systems with friction are non-conservative as a consequence of the fundamental physical character of friction. Usually friction is associated with dissipative effects, but sometimes also with self-excitation. When beating states in linearly stable system configurations close to the threshold of instability are considered, it turns out that sliding friction has a significant influence on the energy budget and may, depending on the initial conditions, lead to substantial transient amplification of the total vibrational energy over half a beating period. The phenomenon basically goes back to the non-normality of the system's eigenvectors, and intuitive as well as formal explanations for the effect's mechanism are given. In addition it is shown that the transient vibration amplification may lead to unexpected appearance of stick-slip limit-cycles in cases of comparably small energy levels of the initial conditions; actually the effect might be understood as the structural analogy of the so-called non-normality transition to turbulence known and debated in fluid dynamics. Finally a simple optimization technique is provided to determine those initial conditions that lead to maximal transient amplification of vibrational energy or of the velocity component relevant for relative sliding velocity. This technique might be used to improve the derivation of safety-factors when safe parameter ranges of operation have to be specified in terms of distance to the borderline of linear instability.

17:20	**Brinkmeier**	**H 2033**

Simulation And Measurements Of Rolling Tire Dynamics

Maik Brinkmeier, Udo Nackenhorst, Institut für Baumechanik und Numerische Mechanik, Universität Hannover

The simulation of rolling tires including stationary rolling, modal analysis, excitation with roughness of road surfaces and sound radiation is presented for state of the art industrial tire models. The target of this research, part of the german project "Leiser Straßenverkehr", is the reduction of traffic noise, whereas the main source, namely the tire/road system, is investigated in contrast to other techniques like sound insulating walls.

The needs and methods for the solution of the resulting large scale problems are discussed next to special properties of rotating structures, high frequency behavior of rubber material and approaches for the reduction of computational cost. For the validation of the model measurements of real tires and roads are used. These include shaker tests of the standing tire and acoustics of tires rolling on a drum. The same set-ups are applied to the simulation for the comparison of frequency response functions and sound pressure levels.

17:40	**Glösmann**	**H 2033**

FAHRWEGMONITORING VON RAD-SCHIENE-SYSTEMEN

Philipp Glösmann, Edwin Kreuzer, Mechanik und Meerestechnik, TU Hamburg-Harburg

Die Wartung und Instandhaltung der Schienennetze ist aufwendig und kostenintensiv. Zur Untersuchung der Fahrwege werden spezielle Meßzüge eingesetzt, die innerhalb vorgeschriebener Zeitintervalle die geometrische Beschaffenheit einer Schienenstrecke aufzeichnen. Die gespeicherten Datenmengen sind so groß, daß zur Beurteilung der Fahrbahnqualität nur wenige Größen, z. B. die Spurweite, die Krümmung, die Neigung und die Gleisüberhöhung (Querneigung) ausgewertet werden. Dabei wird von der gemessenen Geometrie auf das dynamische Verhalten geschlossen. Eine Berücksichtigung der tatsächlichen Dynamik des Rad-Schiene-Systems findet nicht statt.

In diesem Beitrag wird ein Versuchsaufbau zur Beurteilung von Schienenfahrwegen aufgrund des dynamischen Verhaltens zwischen Rad und Schiene vorgestellt: Die Bewegung eines Schienenfahrzeugs wird während des regulären Zugbetriebs gemessen. Anschließend werden Ansätze diskutiert, um mit der Karhunen-Loève-Transformation die Systemdynamik gezielt in zeitlicher und räumlicher Dimension zu reduzieren.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: H 2032

Seile und Schwingungsanalyse

Chair:

N. Wagner
A. Heinen

16:00	Renezeder	H 2032

Three-dimensional Simulation Of A Circulating Monocable Ropeway

Hans Christian Renezeder, Alois Steindl, Hans Troger, Institut für Mechanik und Mechatronik, TU Wien

Ropeways play an important role for transportation in mountainous regions. Unfortunately, even if utmost care is taken in their operation, every year several accidents occur. Some due to human mistakes, but some others also due to a combination of bad design and bad operational conditions.

In this short lecture an aerial ropeway is considered where the transporting units (e.g. gondolas) are attached to a single carrying and hauling rope. In the practical operation of such ropeways (ski lifts) occasionally violent oscillations of the cable with amplitudes of some meters are observed. Such oscillations are not only a problem of comfort for the passengers but can also be a safety problem.

A three-dimensional Finite Element model of such a ski-lift is used to simulate the practically interesting case of sag-oscillations. All the relevant parameters that are the positions of the rolls, the length and the number of the cable spans as well as the distribution of the mass points along the cable, which model cabines, are taken into account.

16:20	Aps	H 2032

Wirkung Von Störungen Auf Die Stabilität Von Seilschwingungen

Ulrich Aps, Jens-Uwe Thalheim, Anton Heinen, Institut für Mechanik und Statik, Universität der Bundeswehr München

Ausgehend von nichtlinearen Finite-Elemente-Gleichungen für schwingende Seile werden für unterschiedliche Stabilitätsprobleme infolge harmonischer Anregung eines Seilbefestigungspunktes Ergebnisse für verschiedenartige Instabilitätsprobleme vorgestellt. In Abhängigkeit von der Frequenz der Bewegung des Seilbefestigungspunktes kann das betrachtete Seil nach einer kleinen Störung im Sinne Ljapunovs in instabile Bewegungsabläufe übergehen, wie z. B. in eine horizontale oder eine rotatorische Bewegungsform.

Im Rahmen dieses Beitrages wird für unterschiedlich vorgegebene Störeinflüsse zu einem bestimmten Zeitpunkt der ursprüngliche Schwingungszustand des Seiles geringfügig geändert und mittels einer nichtlinearen Berechnung untersucht, ob eine Rückkehr des Seiles in den Grundbewegungszustand (stabiles Verhalten) oder in einen durch ein geändertes Schwingungsverhalten gekennzeichneten Nachbarbewegungszustand (instabiles Verhalten) erfolgt. Es wird gezeigt, dass die unterschiedlichen Störungen erwartungsgemäss zu einem verschiedenartigen Verhalten während des Einschwingvorgangs führen, nicht jedoch die sich einstellenden Grenzzyklen der jeweils instabilen Parameterschwingung beeinflussen. Bei Bewegungen des Seilbefestigungspunktes mit einer im stabilen Bereich liegenden Erregerfrequenz führen die verschiedenen Störungen zu unterschiedlichen Störausschlägen, danach kehren alle Seilbewegungen wieder in ihren ursprünglichen, stabilen Grundbewegungszustand zurück. Die im Grenzzyklus auftretenden Amplituden zeigen gute Übereinstimmung mit den Messergebnissen aus praktischen Versuchen von Reif.

16:40	Heinen	H 2032

Neufassung Und Anwendung Einer Nichtlinearen Seiltheorie

Anton Heinen, Jens-Uwe Thalheim, Institut für Mechanik und Statik, Universität der Bundeswehr München

Vorgestellt wird eine geometrisch nichtlineare Seiltheorie, basierend auf Grundlagen der Kontinuumsmechanik. So werden analog zum Spannungsbegriff der Kontinuumsmechanik nichtphysikalische Seilkräfte in Richtung der Tangentenvektoren des Momentanzustandes eingeführt. Diese Seilkräfte sind abweichend von fast allen Formulierungen im Ingenieurbereich somit nicht auf Einheitsvektoren bezogen. Ihnen dürfen nicht die üblichen Ingenieurdehnungen zugeordnet werden, sondern es müssen im Stoffgesetz die Greenschen Längsverzerrungen verwendet werden. Eine Seiltheorie auf dieser Basis hat den Vorteil einfacherer, maximal kubischer Nichtlinearitäten, während die übliche Seiltheorie – bedingt durch die Ingenieurdehnungen – Wurzelausdrücke in den Verschiebungskomponenten aufweist, die meistens durch Reihenentwicklungen approximiert werden müssen. Solche Näherungen sind bei der hier vorgestellten Theorie nicht erforderlich.

Gezeigt wird, wie diese neugefasste nichtlineare Theorie in bekannte Formulierungen der Literatur überführt werden kann. Es wird auf Berechnungen hingewiesen, deren Ergebnisse gut mit Versuchsergebnissen in der Literatur übereinstimmen. Vorteilhaft angewendet werden können die vorgestellten nichtlinearen Seilgleichungen – in Verbindung mit der FE-Methode – auf komplizierte Schwingungs-

phänomene, wie z. B. parametererregte und Regen-Wind-induzierte Seilschwingungen.

17:00	**Wagner**	**H 2032**

Inverse Eigenvalue Problems In Structural Dynamics

Nils Wagner, Institut für Angewandte und Experimentelle Mechanik, Universität Stuttgart

We study the inverse eigenvalue problem of a specially structured matrix pencil, which arises from the discretization of the differential equation governing the transverse vibration of a beam with varying cross section. The stiffness matrix is obtained by the summation of element stiffness matrices, which are functions of certain parameters such as the areas of cross section of the members. The mass matrix is obtained in a similar way. The problem here is to determine the set of parameters such that the associated eigenvalue problem has the specified eigenvalues. Numerical examples are given to demonstrate our results.

17:20	**Reicke**	**H 2032**

Vibration Analysis In Mechanical And Medical Engineering

Lars Reicke, Matthias Kröger, Institut für Dynamik und Schwingungen, Universität Hannover

For ordinary applications with regard to vibration analysis, the Fourier transform of the original signal or its autocorrelation function is commonly used. Even though this yields to adequate conclusions for stationary signals, the analysis of non-stationary signals requires more sophisticated methods.

This contribution gives an overview of the state-of-the-art of time-frequency analysis. Starting with linear integral transforms, like the short-time Fourier transform as well as the wavelet transform, the time-frequency uncertainty principle is introduced. Signal-dependent transforms, e.g. the Karhunen-Loève transform, provide a deeper insight into the inner relations of a stochastic process. The nonlinear Wigner-Ville distribution, which is a two-dimensional Fourier transform of the time-frequency ambiguity function, is not restricted by the uncertainty principle.

The time-frequency analysis mentioned above are performed on signals of mechanical and medical origin. The decomposition into the signal's basic components and the extraction of the signal's principal properties improves the conclusions significantly. Furthermore a faithful selection of the appropriate method reduces calculation time and enhances the performance of vibration analysis.

17:40	Abramyan	H 2032

Stability Of A Sdofo With A Time Varying Mass

Andrey Abramyan, Institute for Problems Of Mechanical Engineering, Russian Academy of Sciencies

Systems with time-varying mass occur in robotics, rotating crankshafts, conveyors systems, excavators, cranes, biomechanics and in fluid-structure interaction problems. Mechanical systems of the type heavy mass and relatively soft spring can be succesfully approximated by a single degree of freedom oscillator (SDOFO). The oscillations of electric transmission lines and cables of cable -stayed bridges with water rivulets on their surface are also examples of time-varying dynamic systems. For that constructions the 1-mode Galerkin approximation of the continuous model will lead to the same equation as for the SDOFO. SDOFOs are considered as a representetive model for testing the numerical behaviour of new computational algorithms with respect to different types of constructions and the forces which are acting on the system. In the present paper for the first time an exact analytical solution of the problem of a stability of SDOFO with periodic stepwise time-varying mass has been developed which allows to obtain stability diagrams. With the help of the obtained solution the method of investigation of stability of SDOFO which mass change in time as an arbitrary smooth function has been introduced.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: H 2033

Technische Anwendungen I

Chair:

J. Wojnarowski
N. Hoffmann

13:30	Rott	H 2033

A Comparison Of Analytical Cutting Force Models

Oliver Rott, Dietmar Hömberg, WIAS Berlin

The modelling of the dynamic processes in milling and the determination of stable cutting conditions are becoming increasingly important in order to control manufacturing sequences. Analytic approaches and time domain simulations based on simplified dynamic systems are used to identify chatter-free machining conditions. Stresses applied to the system are generally estimated by cutting force models. From a mathematical point of view it is important to determine the influence of the cutting force model on the stability limits. Therefore numerical simulations of a simplified and generic milling machine model variing the cutting force approach are performed. In order to distinguish stable from unstable cutting conditions a numerical stability criterion is used. The resulting stability charts are then investigated and analysed to show the influence of the different cutting force models.

13:50	Wojnarowski	H 2033

Influence Of The Tension Of Band Saw On The Critical Working Speed

Jozef Wojnarowski, Silesian University of Technology, Poland

The band machine is the newest and most versatile because its ability to do such a high range of all cut-off jobs efficiently and cost-effectively in the modern industry. That is why a band-saw used for sawing work piece of different shape made of steel or non ferrous metal is subject of the dynamical analysis. The vibrations of the saw promote its wear, increase the roughness and warp of the surface of the cut elements.

Vibrations exited in the driving system, oscillating changes of the distance between the wheel bearings as well as geometrical and material imperfections at the joints of the saw-band, reduce effectiveness of the saw work.

This latter reason is of essential importance in the case of cutting-off machines with a high-speed motion of the saw.

Transverse vibrations of the cutting band of the saw in the cutting zone are also caused by lateral pulsating forces imposed on the saw teeth.

In the presented model the transverse vibrations of the band saw have been analyzed. After simplification and transformation we can derive a formula for the calculation of the frequency of the free vibrations of the band saw and the formula to calculate the critical value speed v_{kr} of the saw as a function of their initial tension math S.

Transverse displacements of vibrations excited in an endless band saw of a cutting-off machine for metals may attain considerable values, mainly due to the pulsating character of axial load of the saw.

Using the formula obtained the influence of the tension of the saw on the value of its critical speed will be presented at the conference.

Ko T. J., Kim H. S.: Mechanistic force model in band sawing, International Journal of Machine tools and Manufacture, Nr 39, 1999, Pergamon, pp. 1185-1197

Wojnarowski J., et al: Computer model of the endless band saw blade during investigation of dynamic phenomena in cutting processes, z.10, Silesian University of Technology Gliwice 2002, pp.280 [in Polish]

14:10	Byrtus	H 2033

On Modelling And Analysis Of Gear Drives With Nonlinear Couplings

Miroslav Byrtus, Vladimír Zeman, Department of Mechanics, University of West Bohemia in Pilsen, Czech Republic

The attention is paid to modelling of vibration of shaft systems with gears and rolling-element bearings using the modal synthesis method with DOF number reduction. This method is based on the system decomposition into subsystems, modelling of linearized subsystems by FEM and on discretization of nonlinear couplings between subsystems. Final condensed mathematical model is created by means of spectral and modal submatrices corresponding to the lower vibration mode shapes of the mutually uncoupled and undamped subsystems.

The influence of the bearing model which respects real number of rolling bodies and real roller nonlinear contact forces acting between journals and the outer housing in dependance on their deflection is respected. Moreover it deals with the system vibration when in consequence of low static load and internal excitation generated in gear meshing the dynamic response is characterized by the gear mesh interruption. Therefore vibrations are accompanied by impact motions, bifurcation of solution and chaotic motions. The gear drive motions are explained by direct time-integration method using the condensed model. The presented approach to the nonlinear vibration analysis of the large multibody gear drives is applied to a simple test-gearbox.

14:30	Wetzel	H 2033

On The Crosswind Stability Of High Speed Railway Vehicles

Christian Wetzel, Ludovic Giusti, Carsten Proppe, Institut für Technische Mechanik, Universität Karlsruhe (TH)

The crosswind stability against overturning is a major national and due to the increasing interoperability also an important international design criterium for high speed railway vehicles. In recent years efforts were made to derive an uniform rule in testing railway vehicles. In this case especially probabilistic methods were proposed. These probabilistic technics are common design criteria for wind turbines. In this talk a sophisticated method to compute the reliability of railway vehicles under strong crosswind is presented. In consideration of the given gust signal and the high-frequency turbulent fluctuations of the wind the response of a simplified train model is computed. The major failure criterium to determine the reliability is the lowest wheel-rail contact force of the railway vehicle. Special attention is given to the stochastic modeling of the high-frequency turbulent fluctuations of the wind and to the effect of these fluctuations to the crosswind stability. In this context results from computations are presented.

14:50	Bockstedte	H 2033

Hoisting Manipulation For Flying Cranes

Andreas Bockstedte, Edwin Kreuzer, Mechanik und Meerestechnik, TU Hamburg-Harburg

The influence of hoisting on the dynamics of cranes with variable cable length is studied.

Due to nonlinear dynamics, payload oscillations are boosted by hoisting, the effect also being known from the so-called spaghetti problem. Additionally, most techniques for active damping fail in the case of cranes with uncontrolled (e.g. *flying crane*) or fixed pivot point of the suspension due to a lack of effective control inputs.

The aim of the discussed damping strategy based on modal coupling control is to manipulate the desired hoisting velocity by superposition of a suitably modulated motion in order to reduce amplifications of the pendulations.

Experimental results are presented for a simple pendulum. Numerical investigations extend the control strategy to an examplary 3-dimensional multibody system featuring the *flying-crane*-concept as designed for cargo airships.

15:10	Pick	H 2033

Analysis Of Critical Motions Of Floating Structures

Marc-André Pick, Edwin Kreuzer, Institut für Mechanik und Meerestechnik, TU Hamburg-Harburg
Jörg Wagner, Institut für Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Universität Stuttgart

Validation of numerical methods for describing the motion of a ship in sea conditions by adequate experiments is a major field of research in ocean engineering. In order to develop a method for the systematic determination of critical and safe operational conditions and for classification of capsize scenarios bifurcation analyses are performed. The computational effort for these analyses is enormous using a full model describing the nonlinear dynamics of a floating body. Therefore, a method for model reduction is currently being developed at the Institute of Mechanics and Ocean Engineering at TUHH. Bases for the validation of this new method are experiments conducted in the institute's wave tank. The determination of position and attitude of the body is performed with an integrated measurement system: Measurements of an inertial measurement unit (IMU) and of a video system are combined using a Kalman Filter. The measurement data are used for both, logging position and attitude, and for giving feedback to an inboard dynamical positioning system. Therefore, the vision system, the Kalman Filter and the positioning system have to be realized in a real-time environment using different real time operating PCs synchronized by ethernet communication.

Session 7
Wednesday, March 29, 16:00 - 18:00

Room: H 2033

Technische Anwendungen II

Chair:

T. Kletschkowski
L. Popa

16:00	Moldenhauer	H 2033

Efficient Calculation Of Tread Block Vibrations

Patrick Moldenhauer, Matthias Kröger, Institut für Dynamik und Schwingungen, Universität Hannover

In many technical applications, e.g. seals, belts and tyres, the contact of rubber elements influences the dynamical behaviour of the system. In the tyre/road contact friction depends on many parameters like relative velocity, roughness, normal pressure, temperature and material properties. The slip at high rolling speeds causes high-frequency deformations and vibrations.

Within the scope of this work the dynamic behaviour of a tyre tread block is described by a point contact model. Based on a finite element description of the system the number of degrees of freedom is substantially reduced by means of the Hurty/Craig/Bampton transformation. This strategy allows the simulation of highly dynamic processes. The rough surface on which the tread block slides is modelled as smooth but with a friction characteristic of the respective material pairing depending on the relative velocity. This procedure leads to a simple and fast contact algorithm and a further reduction of the computational time.

With the presented point contact model of a tyre tread block dynamic effects like friction induced vibrations are simulated. Typical limit cycles of the tread block are presented. These phenomena can be responsible for the squealing of car tyres.

16:20	Strehlau	H 2033

Simulation Von Pyroschocks

Ulrik Strehlau, Utz Von Wagner, TU Berlin

Unter Pyroschock versteht man die Impulsantwort einer Struktur gegenüber einer Belastung, die durch Zünden einer pyrotechnischen Vorrichtung (Sprengstoff oder

Treibstoff) verursacht wird. Pyrotechnische Hilfsmittel werden in der Luft- und Raumfahrt zur Trennung von Strukturelementen während des Fluges sehr verbreitet angewendet, weil sie relativ leicht zur Wirkung gebracht werden können. Die dabei auftretende mechanische Last ist aber auch eine wesentliche Ursache von Ausfällen. Für Testverfahren an Strukturen wird dabei die Einwirkung des Sprengstoffs durch mechanische Schocks simuliert. Wichtig ist dabei die vorhersagbare und reproduzierbare Erzeugung vorgegebener Beschleunigungsverläufe am Testobjekt.

16:40	**Kletschkowski**	**H 2033**

Electro-vibro-acoustical Simulation Of Linear Vibrations In Ducts

Thomas Kletschkowski, Delf Sachau, Rana Umer Draz, Helmut-Schmidt-Universität/Universit der Bundeswehr Hamburg

Due to standing waves, the detection of acoustic hot spots can be difficult in enclosed environments or cabins. For this reason, measurements in interiors are often conducted by creating artificial free-field conditions. For this purpose, a lot of passive damping material has to be mounted on the interior walls to absorb all reflections.

In order to avoid this time consuming procedure, a sound intensity probe with active free-field (SIAF) should be used. Therefore, a first SIAF-prototype has been developed that consists of two electro-dynamical loudspeakers mounted at the ends of a finite acoustic duct. The dynamical behaviour of this system is determined by the properties of the loudspeakers as well as by the acoustic properties of the ducts.

In order to simulate the behaviour of this coupled system, a finite element model that represents the acoustic properties of the duct has been coupled with the discrete electro-mechanical equations of motion used to describe the dynamics of the loudspeakers.

The final electro-vibro-acoustical model has been implemented in Matlab, and the dynamic of the system has been studied numerically. The results of these simulations are essential to study the dependence of the natural frequencies and deletion points on the system parameters.

17:00	**Oleskiewicz**	**H 2033**

Losses In Negative Capacitance Circuit For Piezo Vibration Control

Robert Oleskiewicz, Marcus Neubauer, Tomasz Krzyzynski, Mechanical Department, Koszalin University of Technology, Poland

Piezo elements because of their unique ability of converting mechanical energy into electrical energy and vice versa can be found in numerous mechanical vibration damping and absorbing applications. A desired effect may be customised by an external impedance shunt branch connected to the plates of the piezo element. The recent research shows that the negative capacitance connected in serial with the passive shunt significantly improves the damping and absorbing performance of such systems. Negative capacitance circuit is built up of an electronic gyrator realized by the operational amplifier. Since the operational amplifiers are not the ideal elements, the performance of the proposed systems is limited, especially for small values of the electromechanical coupling coefficient of the piezo elements. The main limitation, beside the maximum voltages and currents at which the operational amplifiers operate, comes from the difficulties of the tuning to the optimal parameter of the negative capacitance, which is calculated according to the optimum criteria for damping or absorbing case leading to the minimisation of the mass vibrations in desired frequency range. In the paper, the input and output impedance of the negative impedance converter is studied. The influence of the certain imperfections in the design of the electronic gyrator is based on the system consisting of the 1DOF mechanical oscillator, and a shunted piezo element.

17:20	**Neumann**	**H 2033**

Periodic&chaotic Attractor Detection Of A Vibro-impact Oscillator

Nicolai Neumann, Thomas Sattel, Jörg Wallaschek, Heinz-Nixdorf Institut, Universität Paderborn

The dynamics of a novel piezoelectric device for drilling of brittle materials is investigated. This device consists of a resonant driven piezoelectric actuator, a drill stem, and a free-flying mass oscillating and impacting between the tip of the piezoelectric actuator and one end of the drill stem. Basic understanding of the device´s dynamic behaviour is crucial for enhancing the drilling performance or to redesign the system for different corer or drill stem geometries. However, such a basic understanding is still missing. Experiments with a prototype device as well as simulations with simple models show irregular motion of the impacting mass. Our approach is to use set-oriented numerical methods to investigate the global dynamic behaviour of simple models in the state space. Parameter ranges with periodic or chaotic attractors as well as their basins of attraction can be found. Information on the probability of attaining a particular attractor is obtained by quantifying its corresponding basin of attraction. Additionally, the drilling performance for each parameter set is indicated by using the invariant measure for the energy transfer between actuator and drill stem.

17:40	**Popa**	**H 2033**

Contributions To The Study Of Torsional Vibrations Of Crankshaft

Liviu Popa, Diana-Flavia Popa, Dept. of Mechanics and Computer Programming, Technical University of Cluj-Napoca, Romania

The paper contains a mathematical calculus method for the torsion systems, representing physical models of cranked shafts belonging to internal combustion engines with powers greater than 80 kW and variable working load. The differential equations of torsion vibrations are deduced and solved using the programming environment named MathCAD.

The results of numerical integration are presented as graphics from which are deduces the optimal characteristics of rotary dampers attached to cranked shafts. These are used in such a manner in order to reduce the amplitudes of the torsion forced vibrations to limits accepted by technical standards specific to different types and sizes of internal combustion engines.

Session 9
Thursday, March 30, 13:30 - 15:30

Room: H 2033

Diskrete und nichtlineare Schwinger

Chair:

E. Brommundt
P.C. Mueller

13:30	Müller	H 2033

Natural Frequencies Of A Multi-degree-of-freedom Vibration System

Peter C. Müller, Sicherheitstechnische Regelungs- und Messtechnik, Bergische Universität Wuppertal
Metin Gürgöze, Mechanical Engineering, Technical University of Istanbul, Turkey

Mikota [1] considered a chain structured mass-spring vibration system with N degrees of freedom where masses $m_k = m/k$ and spring stiffness $c_k = (N+1-k)c$, $k = 1, \ldots, N$, have been applied. He supposed that the natural frequencies are given by $\Omega_k = k\Omega$, $k = 1, \ldots, N$, where Ω is the first natural frequency according to $\Omega^2 = c/m$. In this contribution this and other related eigenvalue problems are discussed showing that the supposition is true.

[1] MIKOTA, J.: Frequency tuning of chain structure multi-body oscillators to place the natural frequencies at Ω_1 and $N-1$ integer multiples $\Omega_2, \ldots, \Omega_N$. Z. Angew. Math. Mech. 81 (2001), S 2, pp. S 201-202.

13:50	Zwiers	H 2033

Vibration Analysis Of Gyroscopic Systems

Ulrike Zwiers, Manfred Baun, Institut für Mechatronik und Systemdynamik, Universität Duisburg-Essen

Continuous mechanical structures which can vibrate about a state of mean rotation or translation may be classified as gyroscopic dynamic systems that are related by the mathematical similarity of their governing equations of motion. Considering as examples a rotating circular ring and an axially travelling string, the analogy of those systems is demonstrated. The linear vibrations obtained by superposing small perturbations on the stationary solution are analyzed. Assuming time-varying speeds, the effect of non-constant stress resultants on the dynamic stability of gyroscopic systems is investigated and the results are compared to those found in literature where the stress resultants of axially moving continua are commonly taken as constant.

14:10	Weichert	H 2033

OPTIMIZATION OF MULTI BODY SYSTEMS WITH INTEGRATED MEASURING DATA

Florian Weichert, Markus Merkel, HTW Aalen
Johannes Fauser, ZF Lenksysteme

Hybrid multi body simulation with coupled MBS/FEA has proved to be a useful tool when dealing with noise, vibration and harshness (NVH). These oscillation problems are quite common for rotating machines. However excitations are often due to forces that can not be easily modeled in conventional or hybrid multi body systems or are even unknown. Examples are Lorentz forces acting on windings in electric motors or hydraulic forces in pumps. Those forces could be taken into account in holistic models using co-simulation, but only at the expense of complexity and time-consumption in calculation.

A simple way of integrating the forces that can be determined by independent simulations or measurements is the modeling by Fourier series. Thus the model is kept small and incomplex and can therefore well be used for stochastic optimization, a strategy in which only values of a user-defined quality function are evaluated. An example shows the application of a genetic algorithm for the optimization of a suchlike simplified mechanical system.

14:30	Brommundt	H 2033

TILTING ANGLES FOR CYLINDER COORDINATES

Eberhard Brommundt, Institut für Dynamik und Schwingungen, TU Braunschweig

In many kinematically nonlinear oscillators arise the relevant coordinates from not-so-small angular inclinations between the constituent parts of the system. Frequently, these parts are round bodies (e.g. in disk brakes, gear couplings etc.), for the formulation of the model one would prefer to apply a couple of cylinder coordinates which tilt with respect to each other. In this paper the reciprocal inclination of the two bodies are measured by suitably defined “tilting angles” ($<$ 90 deg.). They permit the explicit transformation of the cylinder coordinates from one system to the other.

14:50	Manucharyan	H 2033

Determination Of The Chaos Onset In Nonlinear Systems

Gayane Manucharyan, National Technical University "KhPI", Ukraine

Formation of homo- or heteroclinic trajectories (HT) is a criterion of the chaos onset in nonlinear systems. New approach for the closed HT construction is proposed. Padé approximants and quasi-Padé approximants are used for the construction. Necessary condition of the approximants convergence is used. The convergence condition as well conditions at infinity made possible to solve the boundary-value problem formulated for the HT and determine initial values.

Other approach is based on some consequence of the classical Lyapunov stability definition. Mutual instability of phase trajectories is used as criterion of chaotic behavior. One compares trajectories that are initially very close. Calculations permit to observe an appearance of the chaotic behavior regions if some selected parameters of the dynamical systems are changing.

Specific results were obtained for the nonautonomous Duffing equation, a parametrically excited pendulum, a system with discontinuous friction characteristic, an equation describing the snap-through truss motion etc.

[1] Yu. Mikhlin and G. Manucharyan. Construction of homoclinic and heteroclinic trajectories in mechanical systems with several equilibrium positions. Chaos, Solitons and Fractals, 2003, 16, 299-309.
[2] Yu. Mikhlin, T. Shmatko and G. Manucharyan. Lyapunov definition and stability of regular or chaotic vibration modes in systems with several equilibrium positions. Computer and Structures, 2004, 82, 2733-2742.

15:10	Manevich	H 2033

Subharmonic Resonance In 2dof Cubic Systems With Closed Eige

Arkadiy Manevich, Dniepropetrovsk National University, Ukraine

In our presentation on the Fifth EUROMECH Nonlinear Dynamics Conference (ENOC-2005) the interaction o f 1:1 internal resonance with subharmonic external resonance under harmonic excitation in 2DOF nonlinear cubic symmetric systems was studied. Coupled, or two-mode, subharmonic oscillations have been investigated in undamped systems.

In this work the analysis is extended to the general case of damped systems. A detailed analysis of steady-state subharmonic oscillations is presented with taking into account all significant parameters, in particular, the internal and external detuning parameters.

Equations of motion are written for the case when generalized displacements are principal coordinates (the linear link between the variables is absent), and the external force (of O(1)) is applied to the first degree of freedom. The complex representation of equations of motion is used to lower the order of differential equations and to simplify the solution by the multiple scales method.

Equations of the amplitude-frequencies modulation have been obtained, and steady-state solutions of these equations are studied with special attention to coupled subharmonic modes. The number of these modes, conditions of their existence, frequency response curves and their stability have been investigated, as well as configuration of the coupled subharmonic mode paths in 3D space (with amplitudes of linear modes and excitation frequency as coordinates).

Session 10
Thursday, March 30, 13:30 - 15:30

Room: H 106

Div. Anwendungen

Chair:

A. Khentov
A. Bobylov

13:30	Bobylov	H 106

Numerical Modelling Of Forced Vibrations Of Viscoelastic Solids ..

Alexandr Bobylov, Eugene Suturin, Dniepropetrovsk National University, Ukraine

The problems of forced vibrations of deformable solids under unilateral constraints are nonlinear problems with boundary conditions expressed in the form of inequalities. As a rule, capabilities of analytical methods for solving this type of problems are limited to discrete systems with a small number of freedoms. In this study the stabilization method for solving problems of forced vibrations of deformable solids under unilateral constraints was suggested. It is well known, that if dumping is present in a system then initial conditions have considerable effect on forced vibrations of the deformable solids only during a limited period of time after which the system moves to a steady-motion state. Therefore, the main idea of the suggested approach is that the T-periodical solution of the original problem can be found as a solution of the Kochi's problem for t-> *(unknown character)* when either natural or artificial dumping is present in the system. In this case initial conditions can be chosen arbitrarily.

The problems of forced vibrations of a system of deformable solids under unilateral contacts between bodies as well as with a rigid punch or with the Winkler foundation were considered. Variational formulations of the problems were found. The finite-element method was used for discretization of the problem with respect to spatial coordinates. Explicit schemes were used for numerical integration with respect to the time coordinate. The model of reduced viscosity and the Voigt's model of a viscoelastic solids were used in order to take into account energy dissipation.

A software package based on the described computational algorithm was developed. Specifics of contact interactions and amplitude-frequency dependencies of stresses and displacements in a system of deformable solids under unilateral constraints were researched. Performed computational experiments confirmed effectiveness of the stabilization method for solving problems of forced vibrations of deformable solids under unilateral constraints.

13:50	Chistilina	H 106

Research Of Layered Shells With Complex Form By R-function Method

Anna Chistilina, Galina Timchenko, Kharkov Polytechnical Institute, National Technical University, Ukraine

Wide application of the structural components that have laminated structure results in necessity to create new methods of their dynamic behavior investigation. The shape of such elements and boundary conditions become increasingly complicated that leads to problems connected with necessity to solve the systems of differential equation in the domains with complex form. It can be realized only by approximate methods. The method of R-functions has proved itself as alternative method to MFE and has been used for solution of different static and dynamics problems.

In given article algorithm for investigation of natural vibrations of multi-layered shallow shells and plates with complex form, which are made of different number of layers, is presented. This algorithm is based on R-function method and variational Ritz method. At that mathematical statement of the problem was realized in the framework of three theories of multi-layered shells: classical and refined theories of the first and second order. It allows to consider both thin and moderately thick shells. Conducted researches permit to study influence of the mechanical (boundary conditions, anisotropy of the layer material, angle of their rotation) and geometrical (shape, radius of the shell curvature) factors on the values of natural frequencies.

14:10	Khentov	H 106

On The Dynamics Of Pendulum With Vibrating Fastener's Point

Anatoli Khentov, State University of Nizhni Novgorod, Russia

The solutions of equation which is describing a pendulum,s motion in homogeneous field of weight was analysed. It was assumed that a point of fastener for this pendulum was accomplished the horizontal and vertical oscillations simultaneously with small amplitude (in comparison with the pendulum's length) and big frequency (in comparison with the pendulum's frequency of own oscillations). The transformation of variables which is allowing to reform a motion pendulum,s equation to the system of equations in the Bogolubov,s standart form was found. Full study of this system,s solutions which during of the big (asymptotically) interval of time can approximate the exact solutions was received. Like that the principal peculiarities of the solutions in a dependence from the parameters was discovered.

14:30	Myslinski	H 106

Rolling Contact Problem With Slip Rate Dependent Friction

Andrzej Myslinski, Systems Research Institute, Poland
Andrzej Chudzikiewicz, Warsaw University of Technology, Poland

This paper deals with the numerical solution of the wheel - rail rolling contact problems. The unilateral dynamic contact problem between a rigid wheel and a viscoelastic rail lying on a rigid foundation is considered. The contact with Coulomb friction is assumed to occur at a portion of the boundary of the body. The contact condition is described in velocities. The friction coefficient is assumed to be bounded and Lipschitz continuous with respect to a slip velocity. Moreover Archard's law of wear in the contact zone is assumed. The equlibrium state of this dynamic viscoelastic contact problem is described by a hemivariational inequality of the second order governing a displacement field. The existence of solutions to this contact problem is shown. Finite difference and finite element methods are used to discretize this contact problem. Augmented Lagrangian method with active set strategy is used to solve auxiliary optimization problem. Numerical examples are provided and discussed.

14:50	Yuan	H 106

On Paper Machine Roll Contact With Beating Vibrations

Lihong Yuan, V. M. Järvenpää, Tampere University of Technology, Finland

The test roll installation in the Tampere University of Technology includes two horizontal and nearly identical metal rolls with one roll having a polymer cover layer. The test installation is half scale of the real paper calendering units used in paper machines. The rolls are hydraulically compressed against each other and this roll contact is used to pull the paper web through the contact due to the rolling motion of the rolls.

Vibration problems can exist during rolling operation. The paper web and the cover layer of a roll act as external and internal excitations sources. The theory explaining these vibration behaviors is based on the literature on rolling-chatter dynamics [Johnson]. In this work, the vertical vibrations of the rolls are considered. The 2-DOF mass-spring model is used to describe the motion of the rolls. The analytical expressions for the natural frequencies are derived. The mathematical model consists of both a squeezing mode and a motion of the mass-center. When the mass-center frequency is close to the squeezing mode frequency and damping is negligible, the beating phenomena may be possible. The numerical results are carried out in case studies. Finally, the real beating resonances which are determined during the measurement of the test installation are presented as well.

R. Johnson, H. Cherukuri, "Chatter Dynamics in Sheet-rolling Process", Dynamics and Chaos in Manufacturing Processes, Editor F. Moon, John Wiley & Sons, Inc., 1998.

Session 11
Thursday, March 30, 16:00 - 18:00

Room: H 2033

Kontinuierliche Schwingerssysteme

Chair:

R. Heuer
C. Adam

16:00	Adam	H 2033

Nonlinear Flexural Vibrations Of Composite Shallow Open Shells

Christoph Adam, Institut für Hochbau und Technologie, TU Wien

This presentation addresses nonlinear flexural vibrations of shallow shells composed of three thick layers with different shear flexibility, which are symmetrically arranged with respect to the middle surface. The considered shell structures of polygonal planform are hard hinged supported with the edges fully restraint against displacements in any direction. The kinematic field equations are formulated by layerwise application of a first order shear deformation theory. A modification of Berger's theory is employed to model the nonlinear characteristics of the structural response. The continuity of the transverse shear stress across the interfaces is specified according to Hooke's law, and subsequently the equations of motion of this higher order problem can be derived in analogy to a homogeneous single-layer shear deformable shallow shell. Numerical results of rectangular shallow shells in nonlinear steady state vibration are presented for various ratios of shell rise to thickness, and non-dimensional load amplitude.

16:20	Holl	H 2033

Efficient Series Solutions For Vibrating Thin Rectangular Plates

Helmut J. Holl, Johannes Kepler Universität Linz

Simply supported rectangular Kirchhoff-plates with two-parametric Pasternak-type foundation are studied under the action of a transient temperature moment, which is span-wise constant. The classical analytical series solution for the shear-forces and corner-forces are known to be not convergent in this problem. It is shown that an excellent convergence of the series solutions can be achieved by means of Kummer's transformation and Cesaro's generalized C1-Summation. The dynamic solution for the deflection and section forces is computed using an efficient solution for the quasi-static case with fast convergent Fourier series. Modal expansion is applied for the computation of the vibrations about this quasi-static part. Results are compared to FE computations. The influence of the Pasternak-foundation is studied in detail.

16:40	Yan-Zhu	H 2033

On Formulation And Analysis In Dynamics Of Kirchhiff's Rod

Liu Yan-Zhu, Shen Li-Wei, Department of Engineering Mechanics, Shanghai Jiao Tong University
Xue Yun, Department of Mechanical Engineering, Shanghai Institute of Technology

The present paper includes two parts. In the first part the method of analytic mechanics are applied to formulate the dynamics of Kirchhoff's elastic rod. The Lagrange equations and Boltzman-Hamel equations for a discrete dynamical system with arc-coordinate s and time t as dual independent variables are proposed, from which the dynamical equations can be derived to describe the motion of a thin elastic rod. In the second part the stability and vibration of a helical elastic rod with circular cross section under the action of axial force and torque is discussed. The dynamical equations of the rod with Euler's angles are established in the Frenet coordinates of the centerline. The difference and relationship between Lypunov's and Euler's stability concepts of equilibrium of the rod are analyzed. It is shown that the Euler's critical load is the axial force of the elastic rod when the Lyapunov's stability and the ends constraints are satisfied. Furthermore, the Euler's stability conditions of the helical rod in the space domain are the necessary conditions of Lyapunov's stability in the time domain. The three-dimensional flexural vibration of the helical rod is studied, and the analytical formula of free frequency can be obtained.

17:00	Machina	H 2033

Spatial Random Material Property Model For Vibration Of Composites

Gangadhar Machina, Manfred W. Zehn, Institut für Mechanik, Otto-von-Guericke Universität

Investigation of vibration and buckling of thin walled composite structures is very sensitive to parameters like uncertain material properties and thickness imperfections. Because of the manufacturing process and others, thin walled composite

and other structures show uncertainties in material properties, and other parameters which cannot be reduced by refined discretization. These parameters are mostly spatial distributed in nature. Here I introduce a semivariogram type material property model to predict the spatial distributed material property (like young's modulus) over the structure. The computation of semivariogram parameters needs the local material properties over a prespecified gird. The material properties at each grid have been obtained by considering a statistically homogeneous representative volume element (RVE) at each gird. According to random nature of the spatial arrangement of fibers, the statistically homogeneous RVE is obtained using image processing. The effective material properties of the RVE have been obtained numerically with the help of periodic boundary condition. The methodology is applied to a composite panel model and modal analysis has been carried. The results of the modal analysis (eigen values and mode shapes) are compared with experimental modal analysis results which are in good agreement. Using the presented material property model we can better predict the vibration characteristics of the thin walled composite structures with the inherent uncertainties.

17:20	**Buchacz**	**H 2033**

New Branched Vibration Systems As Result Of Synthesis Of Mobility

Andrzej Buchacz, Silesian University of Technology Gliwice, Poland

The requirements concerning mechanical systems, for example their working velocity, exact positioning, control and dimensions are challenging tasks for scientific research. These tasks, however, cannot always be approached from the point of view of traditional principles of mechanics. Therefore, it is necessary to investigate new possible methods of designing the mechanical systems. The basic principles of such a method are provided by the use of graphs and structural numbers. The synthesis consists in investigating the structure of a system with the discrete parameters and specific requirements set for the realization of the desired mechanical phenomena. The first attempt at the solution to this problem, that means synthesis of continuous bar system and selected class of discrete mechanical systems concerning the frequency spectrum has been made in the Gliwice research centre. In these works the distribution of selected characteristics by using the continued fraction expansion method, recurrent cascade method when the level of the numerator was higher than the level of denominator and distribution of immobility function into partial fraction has been presented and used to continuous systems. However in this papers according to other cases the problem has been just signalized.

In the paper the realization of the characteristics by means the distribution of this class of the function – that means mobility – into partial fraction has been presented.

The approach enables the expansion of synthesis characteristics of discrete systems, both immobility and mobility. In this way we obtained new discrete vibration mechanical system with branched structure.

Acknowledgements: This work has been conducted as a part of the research project No. 4 TO7C 018 27 supported by the Committee of Scientific Research in 2004-2007.

17:40	Heuer	H 2033

Vibrations Of Linear Structures With Spatial Local Nonlinearities

Rudolf Heuer, Zentrum für Allgemeine Mechanik und Baudynamik, TU Wien

Classical Modal Analysis can be applied to linear systems if the corresponding damping matrix is proportional to the mass or/and stiffness matrices. Otherwise, e.g. in case of structures with single external damping devices, an alternative or approximate solution procedure for determining the dynamic response has to be chosen. Vibration problems of linear structures with spatially localized nonlinearities are related to those non-classically damped systems. Such systems are characterized by the fact that their nonlinear behavior is largely restricted to a limited number of single points in the structure. The objective of this paper is to present and discuss approximate semi-analytical procedures for analyzing the steady-state harmonic response of those local nonlinear structures, where special emphasis is laid on systems with single nonlinear damping devices.

6 Material models in solids

Organizers:

Paul Steinmann, TU Kaiserslautern
Albrecht Bertram, Universität Magdeburg

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 107

Plasticity I

Chair:

Albrecht Bertram

13:30	Mahnken	H 107

SIMULATION OF ASYMMETRIC EFFECTS IN PLASTICITY

Rolf Mahnken, Lehrstuhl für Technische Mechanik, Universität Paderborn

Many materials experimentally exhibit different behavior in different loading scenarios, such as tension, compression and shear, respectively. To this end a constitutive framework is presented in the framework of plasticity.

An additive decomposition of the yield function and the plastic potential, respectively, is assumed into a sum of weighted stress mode related quantities.

The characterization of the stress modes is obtained in the octahedral plane of the deviatoric stress space in terms of the Lode angle, such that stress mode dependent scalar weighting functions can be constructed. For two specific prototype models thermodynamic consistency of the constitutive equations is shown, and we briefly address the numerical implementation for both sets of constitutive equations into a finite element program.

Verification of the proposed approach is succeeded for a polycarbonate (PC).

In a finite element example the asymmetric inelastic behavior of a short cantilever with hole is investigated.

13:50	Le	H 107

Dislocation Nucleation And Workhardening In Anti-plane Constraine

Khanh Chau Le, Victor Berdichevsky, Lehrstuhl für Allgemeine Mechanik, Ruhr-Universität Bochum

The paper aims at studying the dislocation nucleation, the corresponding workhardening and the influence of resistance to the dislocation motion within the framework of continuum theory of dislocations. We consider an anti-plane constrained shear problem which admits an analytical solution. The interesting features of this solution are the energy and dissipation thresholds for dislocation nucleation, the Bauschinger translational workhardening, and the size effect.

14:10	Schurig	H 107

A Model For The Vertex Effect In Polycrystal Plasticity

Michael Schurig, BAM Berlin
Albrecht Bertram, Otto-von-Guericke-Universität Magdeburg

Interaction of a multitude of plastic mechanisms raises the vertex effect in plasticity. Accordingly, the direction of plastic flow is changed if a process is continued on a non-proportional path.

The proposed material model based on a process dependend plastic potential is founded on micro-macro-simulation.

Its structure ensures the existence of an incremental rate potential that is important for stability considerations based on the convexity properties of an incremental variational problem (Petryk, 2003).

It is applied to the torsional buckling analysis of a thin-walled cruciform column (Gerard and Becker 1957).

14:50	Ekhlakov	H 107

Molecular Dynamics Modell Of The Texture Formation In Cfc

Alexander Ekhlakov, S. Dimitrov, Tom-Alexander Langhoff, Eckart Schnack, Instituts für Technische Mechanik, Universität Karslruhe

The mechanical behaviour of isotropic carbon reinforced carbon fiber (CFC) composites obtained by chemical vapour infiltration (CVI) not only remains controversial but strongly depends on the formation and evolution of material's nano- and micro structure during the production process (V. de Pauw et.al. 2003). Although, the experiments shows that the intrinsic deformation behaviour of this

kind carbon based composites is strongly influenced by the textural degree of material, little is known about the exact character of this influence.

We assume that the texture is described by the distribution of orientations of so called turbostratic domains (V. de Pauw et.al. 2003) which can be observed on the nanometer scale. We use molecular dynamics (MD) simulation that is performed on the base of the macroscopic phase-field diffuse-interface model (Ekhlakov et.al. 2005) in order to elucidate the texture formation and evolution in the solid carbon phase. The polyaromatic hydrocarbon molecules are assumed as elliptical particles. The molecular systems governed by an anisotropic potential (Gay-Berne) and an empirical deposition potential. From the MD simulations (Ilnytskyi et.al. 2002) a discrete time dependent distribution function of orientations of the turbostratic domains is obtained in account for evolution of the material texture.

15:10	Shneider	H 107

Complex Cyclic Loading In The Micro Deformation Plasticity Theory

Vladimir Shneider, Yuri Chernyakov, Dnipropetrovsk National University, Ukraine

Within the limits of the theory of microdeformations (Novozhilov, Kadashevich, Chernyakov “Theory of plasticity taking into account micro deformations”, Reports of USSR AS, 1985, v.284, n.4, p. 821-823) by more detailed analysis of the structural microheterogeneity arising due to various directions of plastic deformation and yield loci of particles, making representative macro volume, at the description of complex cyclic loading authors succeeded in consider in addition some effects arising at it. In particular, opportunities of the theory under the ratcheting description have been expanded. Also by the account of volumetric plastic deformation influence of plastic loosening of material on its cyclic durability is considered, and shown, that the kind of loading trajectory essentially influences durability.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: H 106

Phase Transitions I

Chair:

Wolfgang Müller

13:30	Kuhl	H 106

Simulation Of Mineral Growth With The Cahn-hilliard Equation

Ellen Kuhl, Lehrstuhl für Technische Mechanik, TU Kaiserslautern
Daniel W. Schmid, Physics of Geological Processes, University of Oslo, Norway

A finite element based simulation technique for mineral growth governed by the classical Cahn-Hilliard equation is presented. The particular format of the underlying Flory-Huggins free energy for non-ideal mixtures is characterized through a double-well potential. It allows for uphill diffusion driven by gradients in the chemical potential and thus provides the appropriate framework to simulate phase separation typically encountered in mineral growth. For the finite element discretization, the governing fourth order diffusion equation is reformulated in terms of a system of two coupled second order equations. The basic features of the Cahn-Hilliard equation are elaborated by means of selected geologically relevant examples. In particular, isotropic and anisotropic mineral growth and symplectite formation are studied and the long term response in the sense of Ostwald ripening is elaborated.

13:50	Christ	H 106

On The Necessity Of Modelling Sma In Range Of Large Deformations

Daniel Christ, Stefanie Reese, Institut für Festkörpermechanik, TU Braunschweig

Shape memory alloys (SMA) can undergo phase transformations between a higher-ordered austenite phase and a lower-ordered martensite phase as a result of changes in temperature and the state of stress. Consequently, SMA exhibits several macroscopic phenomena not present in traditional materials. Three significant phenomena are the shape memory effect, the external two way effect as well as the phenomenon of pseudoelasticity. These unique features of SMA have found numerous

applications in mechanical, automotive, aerospace and electronic industries as well as in the field of medical technology. The increasing use in commercially valuable applications has motivated a vivid interest in the development of accurate constitutive models to describe the thermomechanical behaviour of SMA. Meanwhile, many three-dimensional material models have been developed to describe the behaviour within the frame of small deformations. Some of these describe only the effect of pseudoelasticity whereas others consider also the shape memory effect. However, there is still a lack of material models which are developed in the scope of large strains.

In this contribution we present a thermomechanically coupled material model for SMA which includes the effect of pseudoelasticity as well as the shape memory effect and the external two way effect. Experiments show that SMA materials exhibit deformations up to 20 % strain if one takes into account the plastification phase which follows the austenite-martensite transformation. For this reason we extend the latter model within the scope of large strains. Subsequently, the model is implemented into a FE code by using an innovative implicit time integration scheme. The final aim of the research work is to investigate whether FE simulations of SMA applications, e.g. NiTI-stents and medical foot staples, should be based on large strain formulations. If this was not the case the computational cost of such numerical investigations could be reduced significantly.

14:10	**Grabe**	**H 106**

Multidimensional Isothermal Tests Of Superelastic Niti

Christian Grabe, Otto Timme Bruhns, Lehrstuhl für Technische Mechanik, Ruhr-Universität Bochum

Different tension/torsion tests are conducted on hourglass shaped superelastic NiTi specimens. A new measurement device based on inductive displacement transducers is presented allowing for a directly decoupled measurement of twist and elongation at the same measuring points within the gage length. Thus not only measuring but also controlling the deformation of the specimen is possible. This is particularly important for pseudoelastic materials exhibiting a distinct plateau almost without any non-zero slope in the stress/strain diagram. The temperature is actively controlled to keep the temperature deviation as low as possible and to be able to react immediately to sudden changes in the temperature field due to latent heat generation/absorption during phase transition. Cooling is realized using atomized liquid nitrogen spray whereas heating is achieved by energizing the specimen. This allows for higher dynamics than passive temperature control where a fluid surrounding the specimen is kept at constant temperature.

14:30	**Lyeshchuk**	**H 106**

Computer-aided Modeling Of Diamond Crystallization Zones In Hpa

Oleksandr Lyeshchuk, V. N. Bakul Institute for Superhard Materials of the NAS of Ukraine

A problem on determination of temperature, stresses and concentration fields in the reaction cell of high pressure apparatus (HPA) and in the local diamond-melt-graphite system under diamond synthesis conditions has been solved. The results demonstrate: a significant coupling of these fields; an interrelation of the solutions for the reaction mixture and for the local diamond-melt-graphite system; the effect of self-regulation of pressure in the HPA reaction zone consisting in pressure oscillation with respect to graphite-diamond phase transition line.

Computer-aided modelling allow us to determine crystallization volumes of cubic, cubooctahedral and octahedral diamond crystals in the reaction cell. Calculated and experimental dependences of crystallization volumes of various habit diamond crystals on heating current power have been found. Influence of pressure value, heat sink, peculiarities of reaction cell heating scheme and graphite and solvent-metal positions, density variations in diamond crystallization have been taken into account. Differences in crystallization volumes of diamond crystals of various habits with regard to HPA and reaction cell design have been defined. The design of the reaction cell has been optimized so that diamond crystallization occurs in the greatest possible volume.

14:50	Kokoshyn	H 106

Microstructure Approach To The Description Of Shape Memory Effect

Olexandr Kokoshyn, Yuri Chernyakov, Dniepropetrovsk National University, Ukraine

A model based on the plasticity theory taking microstrains into account [1, 2] is proposed for the behavior of polycrystalline shape memory alloys (SMA). A distinctive feature of the present work is the assumption that phase transition according to microstrain theory (MT) occurs as a result of a crystal lattice twinning. Within the MT theory framework this assumption allows to essentially simplify the mechanical model and describe the behavior of the material by defining its properties on micro level only on twinning planes, taking into account their interference. Thus, within the MT theory it is possible to describe the behavior of SMA by superposing the shape memory effects calculated along different directions of twinning microplanes, which makes it possible to accurately reproduce the actual physical behavior of the material.

15:10	Pecherski	H 106

Modelling Of Plastic Softening Conditioned By Cyclic Loading

Ryszard Pecherski, Institute of Structural Mechanics, Cracow University of Technology, Poland

Since early works of cyclic plasticity, it was observed that stress-strain cycles of large amplitude imposed on the cold-worked metallic specimens produce cyclic softening. Plastic softening conditioned by cyclic loading is also widely observed in ductile as well as in hard deformable metals and alloys. This phenomenon plays an important role in designing efficient metal forming operations. The experimental observations show that shear banding is the basic mechanism responsible for the plastic softening. Application of the theory of plasticity with Huber-Mises yield condition accounting for shear banding as well as the theory with Burzynski yield condition accounting for the strength differential effect (SDE) and shear banding is proposed to model numerically the mentioned plastic softening on the example of elongated axially thin walled tube subjected to reverse torsion. Confrontation of the results of calculations and experimental tests is presented and further studies on material models describing the mentioned phenomena are discussed.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: H 107

Granular Media and Non-Standard Continua

Chair:

Paul Steinmann

16:00	Avci	H 107

Modelling Of Granular Materials Applied To Localization Problems

Okan Avci, Wolfgang Ehlers, Institut für Angewandte Mechanik, Universität Stuttgart

The examination of landslide processes are of high interest for geotechnical engineers. The material behaviour, which has to be considered, can be described by a triphasic porous media model based on the *Theory of Porous Media* (TPM), where the single constituents are a deformable solid skeleton and two pore fluids, i. e., pore water and pore air. Thereby, one of the main difficulties is the modelling of the complex material behaviour of the solid skeleton.

In this contribution, the solid skeleton is represented by Hostun sand is considered as a granular material. Therefore, an elastoplastic material law with isotropic hardening is presented, where the elastic domain is limited by a single surface yield criterion and the non-associated plastic flow is taken into account by an additional plastic potential. The respective material parameters are determined via optimization procedures from triaxial experiments. Finally, an initial boundary value problem is presented, where the developed model is applied to the simulation of a natural slope failure problem.

16:20	Meier	H 107

Failure Of Granular Materials At Different Scales

Holger Meier, Ellen Kuhl, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

In recent years there has been an increase in interest in granular and discontinuous media. We apply a computational homogenizationmethod in order to complete the task of modelling this kind of media in three dimensions. Two scales are to be considered: First, the macro scale assuming continuous media, second, the micro scale which represents granular and discontinuous media, see e.g. Miehe and

Dettmar [1]. The finite element method is applied on the macro scale. Three dimensional discrete elements are employed on the micro scale. On the micro level a boundary value problem is considered which is driven by the macro scale deformation gradient. Static condensation of the micro scale stiffness matrix and the use of the averaging theorems are utilized to obtain the macro scale constitutive operator.

[1] Miehe, C. and Dettmar, J., "A framework for micro-macro transitions in periodic particle aggregates of granular materials", Comp. Meth. Appl. Mech. Eng., Vol. 193, pp. 225-256, [2004].

16:40	Grammenoudis	H 107

Classical Limits Of A Micropolar Plasticity Model

Paschalis Grammenoudis, Charalampos Tsakmakis, Institut für Mechanik, Universität Darmstadt

We focus attention on finite deformation micropolar plasticity theories developed previously, which deal with a second-order non-symmetric micropolar strain tensor and a second-order curvature tensor. The aim of the paper is to investigate the classical limiting plasticity models, which may be approached by these theories. The differences compared with a standard classical plasticity model consist in the constitutive equations governing kinematic hardening. With reference to torsional loading, this causes different responses essentially only in the so-called second-order effects.

17:00	Hirschberger	H 107

Computational Material Forces In Micromorphic Continua

C. Britta Hirschberger, Ellen Kuhl, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

The micromorphic continuum theory (see e. g. [1]) is characterised as a continuum which is endowed at each physical point with a micro-continuum that may undergo arbitrary affine deformations. The macro-continuum kinematics is described by the macro mapping $\boldsymbol{x} = \boldsymbol{\varphi}(\boldsymbol{X})$ and the macro tangent map $\mathrm{d}\boldsymbol{x} = \boldsymbol{F} \cdot \mathrm{d}\boldsymbol{X}$, whereas the relation $\bar{\boldsymbol{x}} = \bar{\boldsymbol{F}} \cdot \bar{\boldsymbol{X}}$ accounts for the affine micro-mapping, and the third-order tensor $\bar{\boldsymbol{G}} = \nabla_X \bar{\boldsymbol{F}}$ provides a link between the two scales. The Dirichlet principle is exploited towards the balance of momentum relations for both macro- and micro-continuum in the weak and the strong formulation (cf. [2]). Therein the assumption of hyperelasticity with the internal stored energy density $W_0(\boldsymbol{F}, \bar{\boldsymbol{F}}, \bar{\boldsymbol{G}})$ allows to derive the Piola-type stresses $\boldsymbol{P}$, $\bar{\boldsymbol{P}}$

and $\bar{\boldsymbol{Q}}$ which are energetically conjugate to the above deformation measures. Via Piola transforms and push-forward/pull-back operations between the spatial and the material motion problem description, one may obtain different stress formats which may be used for the evaluation of material forces at finite element nodes as discussed in [3] and [4].

[1] Eringen, A. C. (1999) *Microcontinuum Field Theories: I. Foundations and Solids*. Springer, New York.
[2] Kirchner, N., Steinmann, P. (2005) A unified treatise on variational principles for gradient and micro-morphic continua. *Philosophical Magazine*, accepted for publication.
[3] Maugin, G. A.(2005) *Material Inhomogeneities in Elasticity (Techniques in Visible and Ultraviolet Spectrometry)*. Chapman & Hall.
[4] Steinmann, P. (2000) Application of material forces to hyperelastostatic fracture mechanics. I. Continuum mechanical setting. *International Journal of Solids and Structures*, 37:7371-7391.

17:20	Gawinecki	H 107

Global Solution Of Cauchy Problem In Nonlinear Non-simple Material

Jerzy August Gawinecki, Jaroslaw Lazuka, Institute of Mathematics and Cryptology, Military University of Technology, Poland

We prove a theorem about global existence (in time) of the solution to the initial-value problem for a nonlinear hyperbolic-parabolic system of coupled partial differential equations of **fourth order** describing the thermoelasticity of non-simple materials. We consider such the case of this system in which some nonlinear coefficients can depent not only on the temperature and the gradient of displacement and also on the second derivative of displacement. The corresponding global existence theorem has been proved using the $L^p - L^q$ time decay estimates for the solution of the associated linearized problem. Next, we proved the energy estimate in the Sobolev space with constant independent of time. Such an energy estimate allows up to apply the standard continuation argument and to continue the local solution to one defined for all $t \in \infty$.

17:40	Svanadze	H 107

Boundary Value Problems In The Theory Of Micromorphic Solids

Merab Svanadze, I. Vekua Institute of Applied Mathematics, Tbilisi State University, Georgia

The general theory micromorphic continua was constructed by Eringen (1967). The linear theory of micromorphic elastic solids with microtemperatures was constructed by Iesan (2001). In this theory, in addition to the classical displacement and temperature fields, possess microtemperatures and stretch and contract their translations independently. The same author proved the uniqueness and existence theorems in the dynamical theory of anisotropic materials. The fundamental solutions of equations of the theory of micromorphic elastic solids with microtemperatures are constructed by means of elementary functions by Svanadze (2004). The basic results and extensive review of the theory of elastic materials with microstructure are given in the book of Eringen (1999).

In this paper the linear theory of micromorphic elastic solids with microtemperatures is considered. The fundamental solution of the system of the equations of steady oscillations is constructed in terms of elementary functions. The Sommerfeld-Kupradze type radiation conditions are established. The uniqueness and existence theorems of solutions of the boundary value problems by means Boundary Integral Method and multidimensional singular integral equations are proved. The existence of eigenfrequencies of the interior homogeneous boundary value problem of steady oscillations is studied.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: H 106

Phase Transitions II

Chair:

Ellen Kuhl

16:00	Böl	H 106

Simulation Of Shape Memory Polymers By Means Of The Finite Element

Markus Böl, Daniel Christ, Stefanie Reese, Institut für Festkörpermechanik, TU Braunschweig

Shape memory polymers belong to the group of smart materials that can be easily formed into complex shapes, retaining memory of their original shape even after undergoing large deformations. For the simulation of such material behaviour under varying thermal and mechanical conditions while the polymer undergoes large deformations we present an innovative finite element model which bases on micro-mechanical behaviour of rubber-like material.

The proposed approach is based on a so-called unit cell consisting of one tetrahedral element and six truss elements. On each edge of the tetrahedron one truss element is attached which models the force-stretch behaviour of a bundle of polymer chains. Connecting this elastic behaviour of rubber-like material with the thermal one, the proposed method provides the possibility to observe how changes at the microscopic level influence the macroscopic material behaviour also under varying thermal conditions.

The main focus of this work is the influence of both, the material constants and heat transfer boundary conditions on the response of shape memory polymers. Therefore we illustrate different examples of application.

16:40	Wolff	H 106

Transformation-induced Plasticity: Modelling And Analysis In 3-d

Michael Wolff, Michael Böhm, FB3, Universität Bremen

Phase transformations in steel occurring under non-vanishing deviatoric stress lead to a permanent anisotropic deformation, which cannot be described by classical plasticity (CP) at the macroscopic level. This phenomenon is called transformation-induced plasticity (TRIP). Its modelling contains some open questions, in particular in case of varying loads and of interaction with CP. We deal with TRIP models involving backstress generated by TRIP itself and by CP. In our talk we present models for transformation-induced plasticity (TRIP) in steel in the multi-phase case for more than two phases. These models are suitable to be incorporated into the bulk model of material behaviour. Furthermore, we obtain formulas expressing the 3-d TRIP stain through stress tensor, thermoelastic and CP strain tensors. These formulas are applicable in mathematical investigations and numerical simulations of the bulk model. Finally, we derive estimates of the TRIP strain by stresses and thermoelastic and CP strains. For a relevant class of phase transformations, the final amount of TRIP can be estimated by bounds that do not contain explicitely the phase fractions.

17:00	**Müller**	**H 106**

MODELLING PHASE SEPARATION AND COARSENING IN AG-CU

Wolfgang H. Müller, Thomas Böhme, TU Berlin

The ongoing miniaturization and environmental trends in microelectronics recently turn the attention to new materials the properties of which still have to be studied. One of the most interesting material behaviours is the temporal development of the microstructure experimentally observed in several alloys. In order to estimate the reliability and the lifetime of microelectronics it is important to predict the rate of these microstructural changes. Starting with a detailed overview on coarsening phenomena and intermetallic growth as observed in lead-free solder alloys this talk concentrates on the description of nucleation and spinodal decomposition as well as subsequent phase growth that occurs in various solder alloys below a critical temperature. An extended diffusion equation of the phase field type is presented, which can be interpreted as a generalization of the well known Cahn-Hilliard equation. This equation takes diffusion of the Fickean type, surface tensions along the phase boundaries as well as local mechanical stresses into account. Moreover it represents a non-linear partial differential equation of 4th order that describes the temporal development of so called alpha- and beta-phases in a binary alloy A-B. Furthermore all required material parameters of the diffusion equation, i.e., the mass density of the homogeneous mixture, the mobility, the Gibbs free energy density and the higher gradient coefficients are determined either from the literature / databases or from calculations based on the embedded atom method which is suitable to describe atomic interactions in metals. We will restrict to the one dimensional case and consider as an example the FCC-structured lead-free solder alloy AgCu. After the determination of all required material parameters we calculate the numerical solution of the 1D extended diffusion equation to arrive at a quantitative description of temporal micromorphological development. Finally exemplary results of the simulation are presented and compared with experimental investigations.

17:40	Berezovski	H 106

Velocity Of Moving Phase-transition Front In Solids

Arkadi Berezovski, Centre for Nonlinear Studies, Institute of Cybernetics at Tallinn University of Technology, Estonia
Gerard Maugin, Laboratoire de Modelisation en Mecanique, Université Pierre et Marie Curie, France

It is well known that the conventional theory of nonlinear thermoelasticity fails to fully determine the mechanical response to dynamic loading of a phase transforming thermoelastic material because of a constitutive deficiency. The governing equations do not completely determine the propagation of phase boundaries. Additional constitutive information is usually provided in the form of a kinetic relation between the driving force and the velocity of the phase boundary. The kinetic relation relating the driving force to its conjugate flux is a manifestation of the irreversibility of the phase transformation. That is why we apply the non-equilibrium jump relations at the moving phase boundary. The non-equilibrium jump relations are formulated in terms of contact quantities. These relations allow us to determine the jump of the contact stress across the moving phase boundary, but it is still not sufficient to determine the velocity of the phase-transition front completely. Therefore, we need to introduce an additional assumption concerning the entropy production at the phase boundary. The simplest assumption of the continuity of the contact stress across the phase boundary is applied. This assumption can be a subject of further modifications or generalizations. The derived relationship can be reduced to a known kinetic relation.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: H 107

Identification, Fractional Derivatives

Chair:

Rolf Mahnken

13:30	**Hohl**	**H 107**

Identifikation Von Materialparametern Anhand Inhomogener Versuche

Carsten Hohl, D. Besdo, J. Ihlemann, Institut für Kontinuumsmechanik, Universität Hannover

Sowohl für die Entwicklung von Stoffgesetzen, als auch für die Ermittlung der zugehörigen Materialparameter werden aussagekräftige Versuche benötigt. Normalerweise werden dazu Experimente durchgeführt, die einen möglichst homogenen Belastungszustand erzeugen. Obwohl dies oft nur näherungsweise gelingt, wird bei der Identifikation der Parameter die Homogenität der Spannungen und Dehnungen angenommen.

Für die Entwicklung von Stoffgesetzen haben diese annähernd homogenen Experimente den signifikanten Vorteil, dass das reine Materialverhalten direkt beobachtet werden kann. Auf diesem Weg liefern die Messungen wertvolle Hinweise, um ein passendes Materialmodell zu finden. Aus diesem Grund sind homogene Verformungen für diesen Anwendungsfall von Vorteil.

Bei der Verwendung eines Stoffgesetzes ergeben sich andere Anforderungen an die Experimente. In diesem Fall steht die zuverlässige und präzise Identifikation der Stoffgesetzparameter im Vordergrund. Eine Notwendigkeit sich auf homogene Verformungen zu beschränken, besteht hingegen nicht mehr. Vielmehr bieten sich für diese Aufgabe Versuche an, die klare und einfache Randbedingungen aufweisen sowie einfache und leicht herzustellende Probekörperformen zulassen.

Der Nachteil dieser Vorgehensweise liegt in der aufwendigeren Parameteridentifikation, die sich zur Berechnung der inhomogenen Belastungsprozesse auf Finite Elemente Simulationen stützt.

13:50	**Kleuter**	**H 107**

Parameter Identification For The Fe Analysis Of Elastomers

Bernd Kleuter, Paul Steinmann, TU Kaiserslautern

Viscoelastic materials like elastomers are applied in various fields of civil and mechanical engineering. In this contribution the parameter identification for a finite viscoelastic constitutive law for different materials is shown.

First the the direct problem within the finite element method and its integration method is presented. It is a finite viscoelastic constitutive law in principal directions which is based on the multiplicative decomposition of the deformation gradient into elastic and viscous parts.

In the following we focus on the identification algorithm and the associated sensitivity analysis needed to analyze inhomogenous displacement fields. A gradient based optimization algorithm, the Levenberg Marquardt method, is applied for a least squares type objective function.

The results of the identification of the 7 parameters of the constitutive law for a polyurethane adhesive, a polyurethane foam and a filled rubber like polymer is then presented. In the different cyclic and quasistatic tensile and pressure tests digital image correlation in 3d was used as field measurement technique.

14:10	Lindner	H 107

Different Methods Of Sensitivity Analysis In Parameter Estimation

Mario Lindner, Reiner Kreißig, Institut für Mechanik, TU Chemnitz

As a rule the material behavior in the simulation of technical processes is described phenomenologically characterized by a certain set of material parameters which usually cannot be measured directly. Normally the identification of these parameters is based on the minimization of an objective function in terms of a least squares functional containing differences of measurements and related numerically calculated comparison values.

For the minimization of the least squares functional, nonlinear in the parameters, the trust-region methods especially the Levenberg-Marquardt algorithm have been proved as very efficient. Therefore the determination of the optimal set of parameters requires the calculation of the derivatives of the objective function with respect to the material parameters.

In this talk we present a comparison of the numerical and semianalytical sensitivity analysis of the objective function, containing local and global quantities, with respect to the material parameters. The advantages and drawbacks of the different approaches are shown.

14:30	Johansson	H 107

Error Computation For Parameter Identification Problems

Håkan Johansson, Kenneth Runesson, Dept. Applied Mechanics, Chalmers University of Technology, Sweden

The parameter identification (calibration) of constitutive models, i.e. to find the values of the material parameters from experiments, is an important issue in computational mechanics. In the general case it is difficult, or even impossible, to obtain situations where the parameters can be determined directly. Instead, one has to resort to optimization methods, where the parameter values are sought such that optimal correspondence (in a least-squares sense) between measured and predicted response is achieved.

This optimization problem is usually solved using a gradient-based method, where essentially two methods are employed for the computation of the gradient, the "direct differentiation method" and the "adjoint state method". Although the exact Hessian of the objective function can be computed in both methods, a Gauss-Newton type approximation is often used in the direct differentiation method to obtain an efficient solution scheme, whereas the adjoint method usually does not involve any approximation of the Hessian.

As the measurement data are often contaminated with measurement noise, it is of great interest to investigate how this noise propagates and give rise to an error in the optimal solution, which is estimated by a sensitivity assessment of the calibration problem. Moreover, as the prediction is generally performed by solving an equation of state using a finite element method, the resulting discretization errors may also influence the parameters.

A strategy for computing the sensitivity and the discretization error estimations using the adjoint formulation involves the (exact) Hessian of the objective function. In this presentation, we will try to combine the "direct differentiation" and the "adjoint state" in order to take advantage of the error estimation involved in the adjoint formulation with the computationally inexpensive approximation of the Hessian in the direct differentiation approach.

14:50	**Pfitzenreiter**	**H 107**

Thermodynamic Models For Fractional Derivatives

Tim Pfitzenreiter, Helmut-Schmidt-Universität

In this talk a model for the explanation of fractional derivatives in constitutive equations for viscoelastic materials (especially polymers) will be presented. This model bases on the ideas of cinetic gas theory and the tube model of Doi, Edwards and de Gennes.

15:10	**Schäfer**	**H 107**

Uniqueness Of Solutions Of Linear Fractional Partial Differential

Ingo Schäfer, *Siegmar Kempfle, Bodo Nolte, Helmut-Schmidt-Universität*

Fractional derivatives are used to describe viscoelastic materials. In this talk we treat the question of existence and uniqueness of solutions of linear fractional partial differential equations. Along examples we show that, due to the global definition of fractional derivatives, uniqueness is only sure in case of global initial conditions.

Session 6
Wednesday, March 29, 13:30 - 15:30

Room: H 106

Polymers

Chair:

Dirk Helm

13:30	**Dal**	**H 106**

Approaches To The Modelling Of Physical Ageing In Rubbery Polymers

Hüsnü Dal, Michael Kaliske, Institut für Statik und Dynamik der Tragstrukturen, Universität Leipzig

In this contribution, the aspects of physical (oxidative) ageing of rubbery polymers will be discussed. The oxidative ageing reactions end in cross-link formation similar to vulcanization process in most elastomers. The material is very brittle due to cross-link dominance. The aged specimens of elastomers show cracks in the stretch direction at relatively small stretch levels. In this work, we will present the formulation of mechanisms describing physical ageing in rubbery polymers. The alteration of chain network due to cross-linking will be incorporated into anisotropic damage formulation of micro-mechanically based network theories of rubbery polymers.

13:50	**Méndez**	**H 106**

Experiments And Identifications For Finite Polymer Inelasticity

Joel Méndez, Serdar Göktepe, Christian Miehe, Institut für Mechanik (Bauwesen), Universität Stuttgart

Polymers exhibit a non-linear rate-dependent inelastic behavior when subjected to finite deformations. The constant increase in the use of polymeric materials in many industrial fields suggests the need for constitutive material theories that are able to quantitatively acquaint for the complicated material response. Generally, the constitutive models aiming at resembling the experimentally observed phenomena contain some adjustable material parameters. Identification of these parameters based on experimental results is not a trivial task but rather defines an optimization problem that is subjected to some constraint conditions. Parameter identification as an optimization problem is generally not well-posed. It is tackled by means of methods that can be roughly classified as gradient-based or gradient-free. This contribution presents the complete procedure studying the behavior of a filled rubber (*HNBR50*) and a glassy polymer (*Polycarbonate*) in three basic steps. These are: *i*) Accomplishment of homogeneous and 3-D inhomogeneous experiments under different deformation conditions. *ii*) Identification of the material parameters of a constitutive model by means of gradient-based optimization methods with respect to the homogeneous experimental data and *iii*) validation of the identified material parameters by comparing 3-D FE simulations to the inhomogeneous experimental data.

14:10	Shaban	H 106

Simulation Of Rate Dependent Plasticity Of Polymers

Ahmed Shaban, Rolf Mahnken, Lehrstuhl für Technische Mechanik (LTM), Universität Paderborn

Polycarbonate is an amorphous polymer which exhibits nonlinear deformation before failure. It shows a pronounced strength-differential effect between compression and tension. Strain rate influences the mechanical response of the polycarbonate. In particular, the yield stress is increased with increasing strain rate. The concept of stress mode dependent weighting function is used in the proposed model to simulate the asymmetric effects for different loading speeds. In this concept, an additive decomposition of the flow rule is assumed into a sum of weighted stress mode related quantities. The characterization of the stress modes is obtained in the octahedral plane of the deviatoric stress space in terms of the mode angle, such that stress mode dependent scalar weighting functions can be constructed. The resulting evolution equations are updated using backward Euler scheme and the algorithmic tangent operator is derived for the finite element equilibrium iteration. The numerical implementation of the resulting set of constitutive equations is used in a finite element program for parameter identification. The proposed model is verified by showing a good agreement with the experimental data.

14:30	Itskov	H 106

A Constitutive Model For The Anisotropic Mullins Effect In Rubber

Mikhail Itskov, Alexander Ehret, RWTH Aachen

Deformation induced softening in filled rubbers which arises beneath the maximal stretch of the previous loading history is widely known as the Mullins effect. Latest experimental data show that the Mullins effect is of a strongly anisotropic nature. It also becomes apparent that residual strains always accompanying the Mullins

effect play an important role in the stress-softening and may not be neglected. In the present contribution we propose a phenomenological constitutive model taking into account both these phenomena. The model is thermodynamically consistent and based on a scalar damage function which is evaluated by means of uniaxial tension tests. Numerical implementations of the model show its ability to describe the anisotropic softening behavior of filled elastomers in the case of a complex loading history.

14:50	**Ehret**	**H 106**

A Generalized Polyconvex Hyperelastic Model For Anisotropic Solids

Alexander Ehret, Mikhail Itskov, Institut für Kontinuumsmechanik, RWTH Aachen

There are a great number of materials which are characterized by strong anisotropy and the ability to undergo large elastic deformations. Representative examples are soft biological tissues such as skin or arteries but also many engineering materials as calendered or fiber-reinforced elastomers. In the constitutive modeling, these characteristics should be taken into account. In the present contribution, hyperelastic anisotropic constitutive models will be discussed with a focus on the polyconvexity aspect. Polyconvexity ensures ellipticity or the so-called Legendre-Hadamard condition. It implies positive definiteness of the acoustic tensor so that the speed of displacement waves is always real for any direction of propagation. Furthermore, in combination with coercivity, polyconvexity guarantees the existence of the global minimizer of the total elastic energy of the body which is of decisive importance in the context of a boundary value problem. To benefit from these positive features we propose a class of polyconvex anisotropic strain energy functions which are given by a series. Each term of this series satisfies a priori the condition of the energy and stress free natural state without imposing additional restrictions. Special cases of the generalized model show very accurate agreement with experiments on various materials.

Session 7
Wednesday, March 29, 16:00 - 18:00

Room: H 107

Plasticity II

Chair:

Chau Le

16:00	Kayser	H 107

Modeling And Simulation Of Aluminum Alloys During Extrusion

Tobias Kayser, Christian Hortig, Bob Svendsen, Lehrstuhl für Mechanik, Universität Dortmund

The purpose of this work is the modeling and simulation of the material behavior of aluminum alloys during extrusion processes. In particular, attention is focused here on aluminum alloys of the 6000 series (Al-Mg-Si) and 7000 series (Al-Zn-Mg). Alloys of the 6000 series are especially designed to provide maximum ductility, whereas members of the 7000 series are less ductile but show better hardness properties. The material behavior of these alloys during extrusion is governed mainly by dynamic recovery and static re-crystallization during cooling. Experimental results regarding the developing microstructure (e.g., texture, dislocation structures, etc.) provide information on how the process conditions such as extrusion rate and temperature affect its development. The current material model is based on the role of energy stored in the material during deformation as the driving force for microstructural development. The concept of internal variables is used to describe state quantities such as dislocation density, average grain size and average grain orientation. Constitutive equations for these quantities are formulated in a thermodynamically-consistent fashion as part of a thermo-elastic, visco-plastic model with heat conduction. Implementation of the material model and use of adaptive mesh refinement facilitates its application in the simulation of effective microstructural development during extrusion and cooling.

16:20	Kainz	H 107

Inconsistencies In Plane-strain Elasto-plastic Rolling Simulations

Alexander Kainz, Klaus Zeman, Johannes Kepler Universität Linz
Konrad Krimpelstetter, VOEST-ALPINE Industrieanlagenbau

Plane strain conditions are frequently used as model assumptions for the approximate calculation of flat rolling processes for sufficiently wide strips. This means that during the entire forming process, the strain rate in strip width direction (z-direction) remains zero. In the case of elasto-plastic material, the transitions from elastic to plastic states and vice versa are of particular interest. If we accept the flow rule of Levy-Mises, the normal stress sig_zz equals the average value of the normal stresses sig_xx and sig_yy inside plastic domains. Using Hooke's law we obtain a different relation for sig_zz in elastic domains. At transition points from elastic to plastic domains and vice versa, above relations for sig_zz have to be fulfilled simultaneously. Generally, this yields a discontinuous behaviour of sig_zz at the transition points and consequently to discontinuities of the stress sig_yy as well as the strains eps_zz and eps_yy, provided a continuous behaviour of sig_xx in rolling direction is postulated.

The resulting discontinuity of eps_zz indicates therefore an inconsistency of such a plane strain model. Some key aspects of the underlying theory and consequences of such model assumptions will be pointed out in detail.

Key words: Plane strain conditions, Elasto-plasticity, Model inconsistency, Stress and Strain discontinuities.

16:40	**Vladimirov**	**H 107**

Modelling The Springback Of Sheet Metals At Large Deformations

Ivaylo Vladimirov, Stefanie Reese, Institut für Festkörpermechanik, TU Braunschweig

Sheet metal forming simulations are increasingly replacing traditional build-and-break prototyping because they provide a less expensive and more rapid way to speed up product design time while improving quality and performance. Sheet metal is subjected to stretching, bending and unbending during forming, and an accurate prediction of the formability and springback of the sheet necessitates the use of an appropriate constitutive model.

Isotropic hardening has been identified as a source of inaccurate springback prediction. In order to describe the cyclic hardening behaviour and the Bauschinger effect, a large-deformation elasto-plastic material model with non-linear kinematic hardening is discussed in the present work. The model is derived from a thermodynamical framework and is based on the multiplicative split of the deformation gradient. Its applicability for the case of springback prediction has been illustrated by a simulation of the draw-bend process.

17:00	**Alexandrov**	**H 107**

Maximum Friction Law In Plasticity

Sergei Alexandrov, Institute for Problems in Mechanics, Russia

The maximum friction law has a property that the corresponding friction stress is equal or larger than the actual friction stress. This law leads to special mathematical features of solutions. The paper concerns with a variety of constitutive equations applicable to metal forming. In rigid perfectly plastic solids, the solutions are singular in the vicinity of maximum friction surfaces (the equivalent strain rate approaches infinity and follows an inverse square root rule) and, usually, sliding must occur for the solution to exist. Viscoplastic models with unbounded yield stress at infinite equivalent strain rate require sticking and no singularity occurs. However, many classical solutions in plasticity cannot be generalized on such models. The qualitative behavior of solutions changes when a saturation stress is introduced and strongly depends on the behavior of the equivalent stress as it approaches its saturation value. Sticking or sliding may occur and different kinds of singularities are possible. In pressure-dependent plasticity, the behavior of solutions depends on the relation between stress and strain rate and the sign of the hydrostatic stress. It appears that an essential property is the coincidence of stress and velocity characteristics. Damage evolution equations included in the formulation may significantly change the solution behavior.

17:20	Czyz	H 107

Boundary Element Method For Dynamic Inelastic Analysis

Tomasz Czyz, Piotr Fedelinski, Silesian University of Technology, Poland

The boundary element formulation for dynamic analysis of inelastic two-dimensional structures subjected to impact loads is presented. The integral equation of the problem includes not only boundary integrals but also domain integrals, due to inelastic and inertial terms. The problem is solved by using simultaneously the displacement and stress equation. The numerical solution requires discretization of the boundary displacements and tractions, and stresses in the interior of the body. The boundary is divided into quadratic elements and the domain, where plastic zone is expected, into quadratic quadrilateral cells. The number of unknowns in the resultant algebraic system of equations depends only on the boundary discretization. The unknown stresses in the coupled system of equations are computed using an iterative procedure. The mass matrix of the structure is formulated by using the dual reciprocity method. The matrix equation of motion is solved step-by-step by using the Houbolt direct integration method. Several numerical examples show the accuracy and applications of the method. The results of computations are compared to the results obtained by other boundary and finite element solutions.

17:40	Lyamina	H 107

Flow Of Pressure-dependent Plastic Materials Between Two Cones

Elena Lyamina, Sergei Alexandrov, Gennady Mishuris, Institute for Problems in Mechanics, Russia

Yield criteria of several modern metallic materials reveal some pressure-dependence though the property of incompressibility remains to be valid with a high accuracy. For such materials, models developed for soil and granular materials can be adopted though the formulations of boundary value problems of interest may be different. In particular, in the case of metallic material high friction can appear on contact surfaces in course of metal forming processes, including the maximum possible friction stress (maximum friction law). Applications of the maximum friction law often lead to singular velocity fields. In the case of pressure-dependent materials such singular fields have been found for plane strain deformations and axisymmetric flow through an infinite channel. In the present paper, another example of axisymmetric singular velocity fields is given considering the converging flow between two concentric, rough cones. A distinguished feature of this solution is that there are two maximum friction surfaces and, thus, the velocity field has two singularities. A special numerical method accounting for these singularities is developed to get the solution in the plastic zone. The strain rate intensity coefficients are calculated at each friction surface. The solution can be used for approximate analysis of extrusion and drawing of tubes.

Session 8
Wednesday, March 29, 16:00 - 18:00

Room: H 106

Instabilities, Numerics

Chair:

Kerstin Weinberg

16:00	Brüggemann	H 106

Modeling And Simulation Of The Portevin-le Chatelier Effect

Carina Brüggemann, Thomas Böhlke, Otto-von-Guericke Universität Magdeburg

During deformation processes of Al-Mg alloys dynamic strain aging occurs in a certain range of temperature and strain-rate. The effect is usually called Portevin-Le Chatelier (PLC) effect. The PLC effect is produced by strongly discontinuous dislocation motion, which is the result of a negative strain-rate sensitivity. The appearance of the PLC effect reduces the surface quality of sheet metals significantly and also affects the ductility of the material. Since the appearance of the effect strongly depends on the triaxiality of the stress state, three-dimensional finite element simulations are necessary in order to optimize metal forming operations. We present a geometrical nonlinear material model which reproduces the main features of the PLC effect. The material parameters have been identified based on experimental data from tensile tests. Special emphasis is given to the statistical characteristics of the distribution of stress drops and the inverse behavior of the critical strain vs strain-rate.

16:20	Flatten	H 106

Non-local Modeling Of Thermomechanical Localization In Metals

Arnd Flatten, Dietmar Klingbeil, Bob Svendsen, BAM Berlin

The modeling of dynamic, high-speed loading of metallic materials, encountered for example in crash or drop tests, as well as in high-speed forming and cutting processes, involves in general a variety of processes and effects such as high strain-rates, hardening behaviour, heating due to plastic dissipation, friction and contact, thermal softening, damage, thermomechanical localization and shear-band development. In particular, the latter process represents an instability of the original uniform deformation field due to, *e.g.*, inhomogeneous material behaviour and/or geometrical effects, resulting metallurgically in extreme grain stretching over a finite, narrow domain in the structure. Rate-dependent "local" models according to Johnson & Cook (1983, 1985) do not generally result in a physically correct shear-band development, *e.g.*, involving a finite (non-vanishing) shear-band thickness.

In the current work, an extension of such local models is presented as based on a corresponding extension of the *rate-dependence* to one on the gradient of the accumulated inelastic deformation *rate* for high-speed processes. This results in a coupled field problem involving the accumulated equivalent inelastic deformation as an additional field variable next to total deformations. On this basis, we compare and contrast local and non-local approaches in the context of their application to the modeling and simulation of dynamic shear-banding in the alloy Inconel 718. This will include the solution strategies for each kind of model in the context of the finite-element method and simulation.

16:40	**Ban**	**H 106**

On Separately Convex Potentials And Their Applications

Michael Ban, Dieter Weichert, Institut für Allgemeine Mechanik, RWTH Aachen

In this paper, we present the main properties of separately convex functionals, a variational formulation, and some applications to the modeling of coupled and non-associated constitutive laws. Such models belong to the class of Implicit Standard Materials (ISM), introduced by de Saxcé as an extension of the Generalized Standard Material model. The ISM model is based on a particular kind of separately convex functions, called bipotentials, which satisfy a Fenchel-Young-type inequality.

17:00	**Rosato**	**H 106**

Non-isothermal Shear Band Localization In Crystal Plasticity

Daniele Rosato, Christian Miehe, Institut für Mechanik im Bauwesen, Universität Stuttgart

We analyze the formation of shear bands in plastically deforming single crystals under non-isothermal quasi-static loading conditions. A key feature of the present work is to motivate the constitutive coupled thermomechanical equations for the slip resistance and the slip evolution by micromechanical investigations of defects in crystals. Here, we put particular emphasis on comparative investigations of hardening–softening effects of crystals under non-isothermal conditions, including a quantification of the latent energy storage. Furthermore, we analyze a numerical solution algorithm for the coupled thermomechanical problem and we test the

performance on a typical benchmark example of finite-strain single-crystal thermoplasticity: the localization of deformation into a shear band for the case of a rectangular strip. Experimental evidence for this problem is well documented. We analyze the deformation of the specimen, the temperature distribution within the deformed specimen and investigate problems associated with the quantification of the temperature evolution.

17:20	Jäger	H 106

Modelling And Computation Of 3d Discontinuities In Solids

Philippe Jäger, Julia Mergheim, Ellen Kuhl, Paul Steinmann, Lehrstuhl für Technische Mechanik, TU Kaiserslautern

Strong and weak discontiniuties can appear in different fields of mechanics. Some obvious examples where strong discontinuities arise are stationary and propagating cracks. This presentation will thus discuss a geometrically nonlinear, mesh-independent finite element framework for the modelling of stationary and propagating cracks in three dimensional continua. By essentially doubling the degrees of freedom in the discontinuous elements, this algorithm allows for arbitrary strong discontinuities which are not restricted to inter-element boundaries. The deformation field is interpolated independently on both sides of the discontinuity according to [1]. Rather than following the classical X-FEM approach and introducing jumps in the deformation field as additional unknowns, our formulation is based exclusively on deformation degrees of freedom. While the X-FEM requires additional transition elements, our modifications are strictly local and only affect the discontinuous elements themselves, see [2].

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17:40	Zimmermann	H 106

Material-force-based Refinement Indicators In Adaptive Strategies

Dominik Zimmermann, Christian Miehe, Institut für Mechanik (Bauwesen), Universität Stuttgart

We investigate the application of material-force-based refinement indicators to adaptive finite element strategies for problems of finite elasto-plasticity. Starting from the local format of the spatial balance of linear momentum, a dual material counterpart in terms of Eshelbys energy-momentum tensor is derived. For inelastic problems, this material balance law additionally depends on the material gradient of the generalized internal variable vector. In a weak format the material balance equation coincides with an equilibrium condition of material forces. For a homogeneous body, this equilibrium condition corresponds to vanishing discrete material nodal forces. However, due to insufficient discretization, spurious material forces at the interior nodes of the finite element mesh occur. These nodal forces can be used as mesh refinement indicator. For elastic problems, material forces have a clear energetic interpretation. Here, the magnitude of the discrete material nodal forces may be interpreted as an energetic misfit of the current discretization. The same argumentation is assigned to problems of finite inelasticity. Utilizing this idea, we first define a relative global criterion which is used for the decision on mesh refinement. Following the same reasoning, in a second step a criterion on the element level is computed which governs the local refinement procedure within a h-adaptive strategy. The mesh refinement is documented for a spectrum of representative numerical examples of finite elasticity and finite plasticity.

Session 9
Thursday, March 30, 13:30 - 15:30

Room: H 107

Coupled Problems, Numerics

Chair:

Thomas Böhlke

13:30	Helm	H 107

Modellierung Und Simulation Thermomechanischer Kopplungsphänomene

Dirk Helm, Institut für Mechanik, Universität Kassel

Metallische Werkstoffe zeigen insbesondere bei großen Deformationen und hohen Deformationsgeschwindigkeiten stark ausgeprägte thermomechanische Kopplungsphänomene. In dem Vortrag wird ein Materialmodell der finiten Thermoviskoplastizität vorgestellt: Das Modell besteht aus einer Funktion für die Freie Energie sowie aus Evolutionsgleichungen für innere Variable. In dem Modell wird die Annahme verwendet, dass die viskoplastischen Deformationen isochor sind. Insgesamt ist das Modell in der Lage, die wesentlichen thermomechanischen Kopplungsphänomene zu beschreiben. Dies wird abschließend anhand numerischer Beispiele demonstriert: Die Lösung thermomechanisch gekoppelter Anfangs-Randwertaufgaben erfolgt mit Hilfe der Methode der finiten Elemente. Zur numerischen Integration der Konstitutivgleichungen wird ein Integrationsoperator auf der Basis des impliziten Euler Verfahrens vorgestellt. Dieser Integrationsoperator besitzt die Eigenschaft, dass die Unimodularität der Integrationsvariablen für beliebige Zeitinkremente erhalten bleibt. Infolgedessen wird die in dem Materialmodell angenommene Inkompressibilität der viskoplastischen Deformationen im Rahmen des numerischen Verfahrens stets eingehalten.

14:10	Linnemann	H 107

A Constitutive Model For Magnetostrictive Materials

Konrad Linnemann, Sven Klinkel, Universität Karlsruhe (TH)

A 3D macroscopic constitutive law for hysteresis effects in magnetostrictive materials is presented and a finite element implementation is provided.

The novel aspect of the thermodynamically consistent model is an additive decomposition of the magnetic and the strain field in a reversible and an irreversible part. Employing the irreversible magnetic field is advantageous for a finite element implementation, where the displacements and magnetic scalar potential are the nodal degrees of freedom. To consider the correlation between the irreversible magnetic field and the irreversible strains a one-to-one relation is assumed. The irreversible magnetic field determines as internal variable the movement of the center of a switching surface. The switching surface controls the motion of the domain walls during the magnetization process. The evolution of the internal variables is derived from the magnetic enthalpy function by the postulate of maximum dissipation, where the switching surface serves as constraint. The evolution equations are integrated using the backward Euler implicit integration scheme.

The constitutive model is implemented in a 3D hexahedral element which provides an algorithmic consistent tangent stiffness matrix. A numerical example demonstrates the capability of the proposed model to reproduce the ferromagnetic hysteresis loops of a Terfenol-D sample.

14:30	**Pop**	**H 107**

Approximation Of The Contact Problems In Elasticity With Mixed Fin

Nicolae Pop, Department of Mathematic and Computer Science, North University of Baia Mare, Romania

The aim of the paper is to give an efficient numerical algorithms for a mixed hybrid variational formulation of a quasi-static contact problem with friction, using the Uzawa type algorithm. This problem is considered as a saddle point problem for the Lagrangian which is approximated with the mixed finite element, where the stress, displacement and tangential displacement on the contact boundary will be simultaneously computed. The static contact problem with friction cannot describe the evolutive state of the contact conditions. Out of this reason, the quasi-static formulation of the contact problem with friction is preferred, because contains a dynamic formulation of the contact conditions and the inertial term is no longer used. Through the temporal discretization of the quasi-static contact problem, the so called incremental problem is obtained, equivalent with a sequence of static contact problems. Therefore, the quasi-static problem is solved step by step. At each time small deformations and displacements are calculated and are added at those calculated previously, as a result of a few small modifications of the applied forces, of the contact zone and of the contact conditions. Although, at each increment the dependence of the load-way is neglected, this hypothesis takes into account the way the applied forces change (modify themselves). From a mathematical point of view, the problem obtained at each step is similar with a static problem. Using the mixed finite element method and an augmented Lagrangian formulation [3] for modelling the quasi-static contact problem, an efficient numerical algorithms are performed by an Uzawa type algorithm.

The mixed formulation of the quasi-static contact problem in elasticity is the following: Find $u(x,t) \in V$, $u(0) = 0$, $\sigma \in K$ such that

$$(C\sigma, \tau - \sigma) + (\dot{u}, \operatorname{div} \tau - \operatorname{div} \sigma) \geq 0,\ \forall\, \sigma \in K$$

$$-\operatorname{div}\sigma = f,\ \text{in}\,\Omega.$$

We consider a hybrid formulation [1] where the constrain in $K(\equiv \Lambda_1 \times \Lambda_2)$ is taken into account with a Lagrange multiplier. We denote by Λ_1 the space $H^{1/2}(\Gamma_C)^2$ and we introduce the following closed convex cone

$$\Lambda_2 = \left\{ \mu \in H^{1/2}\Gamma_c \,|; \mu \geq 0\ a.e \right\},$$

the space of *virtual displacements*

$$V = \left\{ v \in (H^1(\Omega))^2 | v = 0 \text{ on } \Gamma_1 \right\}$$

and the space

$$X = \left\{ \sigma = \{\sigma_{ij}\} \in (L^2(\Omega))^4 : \operatorname{div} \sigma \in (L^2(\Omega))^2 \right\}$$

equipped with the norm

$$\|\sigma\|_X = \left(\|\sigma\|^2_{(L^2(\Omega))^4} + \|\operatorname{div} \tau\|^2_{(L^2(\Omega)^2)} \right)^{1/2}.$$

We define the functional $\mathcal{L}_h$ on $V \times X \times \Lambda_1 \times \Lambda_2$ and the problem can be formulated equivalent to the minimization over $V \times X \times \Lambda_1 \times \Lambda_2$ of the Lagrangian:

(P_2) Find $(v, \tau, \mu_T, \mu_N) \in V \times X \times \Lambda_1 \times \Lambda_2$

$$\mathcal{L}_h(v, \tau, \mu_T, \mu_N) = \mathcal{L}(v, \tau) + \ll \tau_T, \mu_T \gg_{1/2,\Gamma_C} + \langle \tau_N, \mu_N \rangle_{1/2,\Gamma_C}$$

where

$$\mathcal{L}(v,\tau) = \frac{1}{2}\,(C\tau, \tau) + (\dot{v}, \operatorname{div} \tau + f) + \frac{r}{2}\, \|\operatorname{div} \tau + f\|^2_{(L^2(\Omega))^2},\ \text{with } r > 0.$$

Here $\langle \cdot, \cdot \rangle_{1/2,\Gamma_c}$ denotes the duality product between $(H^{1/2}(\Gamma_c))$ and its dual space, and $\ll \cdot, \cdot \gg_{1/2,\Gamma_C}$ is duality product defined by:

$$\ll \tau_T, \phi \gg_{1/2,\Gamma_C} = \langle \tau_{T_1}, \phi_1 \rangle_{1/2,\Gamma_C} + \langle \tau_{T_2}, \phi_2 \rangle_{1/2,\Gamma_C},\ \forall\, \phi = (\phi_1, \phi_2) \in \Lambda_1$$

By full discrete approximations, of the temporal variables with backward Euler scheme and of the spatial variables with mixed finite element, using a Uzawa type algorithm, we obtain the numerical solution of this problem.

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14:50	**Vesenjak**	**H 107**

Homogenisation Of Cellular Structures In Dynamic Fe Analyses

Matej Vesenjak, Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Slovenia
Andreas Oechsner, Campus Univ. de Santiago, University of Aveiro, Portugal

This research work is concerned with the homogenisation procedure of regular closed- an open-cell cellular structures. The cellular structures behaviour under dynamic loading has been analysed with computational simulations of the representative volume element, where influences of different relative densities, strain rates and base material parameters (metal and non-metal) have been considered. The explicit finite element code LS-DYNA has been used for this purpose. Quasi-static and dynamic tensile and compression tests of the base materials have been carried out to assure precise modelling of the cellular structure. The simulation results of the representative volume element have then been used to define homogenised material parameters of the cellular structure. Homogenised material parameters were subsequently applied to regular solid finite elements, which resulted in equivalent macroscopic behaviour of simulated cellular structure under dynamic loading. Analysed examples prove that homogenised models are very precise and stable in comparison with fully detailed models of cellular structures. Their main advantage is much shorter computational time and higher pre-processing efficiency at minimal loss of accuracy.

15:10	**Dziatkiewicz**	**H 107**

Dual Reciprocity Bem For Dynamic Piezoelectricity

Grzegorz Dziatkiewicz, Piotr Fedelinski, Faculty of Mechanical Engineering, Silesian University of Technology, Poland

Piezoelectric materials generate an electric field when they are subjected to strain fields and they deform when an electric field is applied. This phenomenon is widely uitilized in many devices, for example, sensors and actuators, micro-electromechanical systems (MEMS) and transducers. An analysis of piezoelectric devices requires a solution of coupled mechanical and electrical partial differential equations. In this paper the boundary element method (BEM) is implemented to solve the transient dynamic and eigenvalue two-dimensional problem of linear piezoelectricity. The piezoelectric material is modelled as: homogenous, transversal isotropic, linear elastic and dielectric. The numerical solution by the BEM requires fundamental solutions, which have rather complicated forms even for a simplified transversal isotropic model of piezoelectric material. In the present work the Stroh formalism is used to obtain fundamental solutions. The mass matrix of piezoelectric is computed by the dual reciprocity BEM. The radial basis functions are used for interpolation of displacement field. The matrix equation of motion is solved by using the numerical Laplace transform method. Numerical examples will be presented and they will show that the dual reciprocity BEM formulation allows to analyze efficiently dynamic problems of linear piezoelectricity.

Session 11
Thursday, March 30, 16:00 - 18:00

Room: H 107

Composites

Chair:

Markus Böl

16:00	Szczesniak	H 107

Numerical Modelling Of A Heterogeneous Composite Material

Michal Szczesniak, Wroclaw University of Technology
Piotr Konderla, Wroclaw University of Technology, Poland

The objective of the study reported on in this paper is the numerical modelling of a cement-based composite. The components of interest are aggregates, water, voids and cement paste. The connections between the components are assumed to be rigid, and the cement paste is considered as a homogeneous material with no distinction between areas of different density. The constitutive model used for the description of the cement paste is quasi-linear. The voids are modelled at the macroscopic level. Water is treated as a incompressible material. The aggregate is represented by selected diameters of glass or polyurethane spheres. The study is carried out with the aim to examine the behaviour of a composite with perfectly rigid and perfectly soft inclusions. The numerical algorithms used are verified by laboratory tests.

16:20	Nazarenko	H 107

Nonlinear Deformation Of Three-component Composites

Lidija Nazarenko, Institut für Mechanik, TU Berlin

In the present paper the model of nonlinear deformation of stochastic composites under microdamaging is developed for the case of three-component composite, when the microdamages are accumulated in the matrix. The composite is treated as isotropic matrix strengthened by two different types of spheroidal inclusions with transversally-isotropic symmetry of elastic properties. It is assumed that the loading process leads to accumulation of damages in matrix. Fractured microvolumes are modelled by a system of randomly distributed quasispherical pores. The porosity balance equation and relations for determining the effective elastic modules for the case of transversally-isotropic components are taken as basic relations.

The fracture criterion is assumed to be given as the limit value of the intensity of average shear stresses occurring in the undamaged part of the material. Basing on the analytical and numerical approach the algorithm for determination of nonlinear deformative properties of such a material is constructed. The nonlinearity of composite deformations is caused by finiteness of components deformations. Using the numerical solution the nonlinear stress-strain diagrams for three-component concrete for the case of uniaxial tension are obtained.

16:40	Jedrysiak	H 107

The Elastic Response For Microlayered Functionally Graded Media

Jaroslaw Jedrysiak, Department of Structural Mechanics, Lodz University of Technology, Poland
Ewaryst Wierzbicki, Czeslaw Woźniak, Institute for Mathematics and Informatics, Technical University of Częstochowa, Poland

The main objects of considerations are laminates having macroscopic properties continuously varying across laminas, i. e. laminated media with a functionally graded microstructure. Dynamic problems of such composites are analysed by using different methods, similar those used for macroscopically homogeneous composites as periodic composites, [2]. However, these methods neglect the effect of the microstructure size.

The aim of this contribution is to propose an averaged microstructural model describing the elastic response of these composites, based on the concepts introduced in the tolerance averaging technique, cf. [3]. Employing these concepts and certain heuristic assumptions model equations with slowly-varying continuous coefficients will be derived. A similar approach was also proposed to functionally graded laminated plates in [1].

1. Jędrysiak J., Rychlewska J., Woźniak C., Microstructural 2D-models of functionally graded laminated plates, Shell Structures: Theory and Applications, ed. W. Pietraszkiewicz, C. Szymczak, series: Balkema - Proceedings and Monographs in Engineering, Water and Earth Science, Taylor and Francis, London - Leiden 2005, 119-123.
2. Suresh S., Mortensen A., Fundamentals of functionally graded materials, The University Press, Cambridge, 1998.
3. Woźniak C., Wierzbicki E., Averaging techniques in thermomechanics of composite solids, Wydawnictwo Politechniki Częstochowskiej, Częstochowa, 2000.

17:00	Rychlewska	H 107

On The Modelling Of Functionally Graded Laminates With Microcracks

Jowita Rychlewska, Czeslaw Wozniak, Institute of Mathematics and Computer Science, Czestochowa University of Technology, Poland

Functionally graded materials (FGM) are a class of material structures having gradually varying properties in a certain direction. In this contribution the object of analysis is a special class of FGM which on the microstructural level are made of two kinds of very thin laminae and will be referred to as the functionally graded laminates (FGL). The aim of this contribution is to formulate and apply a certain averaged mathematical model for the analysis of the effect of interlaminar microcracks on the macroscopic dynamic behaviour of FGL. To this end we shall adapt some concepts of the tolerance averaging technique which so far has been used to the modelling of periodic composites. It will be assumed that the distribution of microcracks is represented by its mean density per unit area of every interface between adjacent laminae. Although the considerations are restricted to the linear elasticity theory the obtained model equations are nonlinear due to the existence of the free boundary separating regions with open and closed microcracks. An application of the formulated model to the analysis of free longitudinal vibrations in FGL will be shown.

17:20	Szymczyk	H 107

SUCCESSIVE APPROXIMATIONS IN DYNAMICS OF LAMINATED MEDIA

Jolanta Szymczyk, Czeslaw Wozniak, Institute of Mathematics and Computer Science, Czestochowa University of Technology, Poland

The object of analysis is a behaviour of micro-laminated linear elastic solids. The considerations are restricted to laminates with a weak transversal inhomogeneity. Roughly speaking this kind of inhomogeneity takes place for laminae reinforced by long high-strength fibres. The aim of this contribution is to formulate a mathematical models which describe both micro- and macro-dynamics of laminate. The main result of this contribution is that for laminate with a weak transversal inhomogeneity the model equations can be decomposed into two successive approximations equations describing behaviour of a laminate independently on a macro- and micro-level. The obtained equations make it possible to analyse the effect of microstructure size of micro laminated solid on its overall behaviour. The proposed modelling technique will be illustrated by the analysis of a certain benchmark problem.

17:40	Burlayenko	H 107

CREEP DAMAGE ANALYSIS OF PLATES USING AN ANISOTROPIC DAMAGE MODEL

Vyacheslav Burlayenko, Oleg Morachkovski, Polytechnical Institute, National Technical University Kharkov, Ukraine

An anisotropic (transversally-isotropic) damage model for characterization of creep damage processes in metals is applied to estimation of creep rupture times and analysis of kinetic stress strain states of thin plates. A symmetric second rank damage tensor was introduced for description both of initial and damage induced of material anisotropy. The framework of the thermodynamics of irreversible processes on the basis of Helmholtz free energy with state variables and effective stress associated to damage variable has been used to derive fully coupled creep damage constitutive equations. To illustrate the validity of the proposed model computational simulations of tensile creep tests are carried out and compared with known experimental data obtained by other authors. The non-linear initial and boundary value problem (IBVP) has been formulated using the basic equations of the thin plate theory taking into account the anisotropic evolution of material damage. The related numerical aspects concerning the global strategy of finite element simulation of the IBVP and integration scheme of the constitutive equations are discussed and the in-house finite element codes are created. The influence of damage anisotropy on creep strain rates, stress distributions and creep rupture times of thin rectangular plates in case of plane stress are analyzed.

Session 12
Thursday, March 30, 16:00 - 18:00

Room: H 106

Miscellaneous

Chair:

Michael Schurig

16:00	Chiroiu	H 106

On The Solitonic Behavior Of Carbon Nanotubes Fracture

Veturia Chiroiu, Institute of Solid Mechanics, Romania

Since their discovery in 1991, the carbon nanotubes have attracted much interest because of their ability to sustain large deformations and their great stiffness and strength.In this contribution, the fracture of carbon nanotubes is studied by solitonic simulations. nanotubes are attractive for studying fracture because they are single molecules with all atoms joined by identical bonds. The major defects are the Stone-Wales type that are of the order of several bond lengths.Our results show an interesting dependence of fracture strength on chirality, dissociation energies and separation energy. The fracture strength strongly depends on the inflection point in the interatomic potential. Various nanotube are studied. Theory of solitons is an efficient instrument to study the behavior of carbon nanotubes.

16:20	Munteanu	H 106

The Pseudospherical Reduction Of The Uniaxial Deformation Of Carbo

Ligia Munteanu, Institute of Solid Mechanics, Romanian Academy

The paper tackles the uniaxial deformation problem for carbon nanotubes. The aim is to determine a parametrical representation for a class of constitutive laws for which the motion equations attached to a material system can be associated to a pseudospherical surface (with negative Gaussian curvature). A subclass of the constitutive laws can be associated to a Tzitzeica surface, for which the ratio between the curvature and the distance from the origin to the tangent plane at an arbitrary point to the fourth power, is constant. A genetic algorithm is performed to study several inverse problems associated to some experimental results for uniaxial deformation of the carbon nanotubes.

16:40	Teodorescu	H 106

On The Solitonic Mechanism Of Bending For Carbon Nanotubes

Petre Teodorescu, Dept. of Mathematics, University of Bucharest, Romania

In this paper, we analyse the bending of single- and multi-walled nanotube of carbon. By coupling the continuum theory with molecular dynamic theory we model a deformation solitonic mechanism, to explain the high strength of nanotubes in bending. When the external bending moment increases, the axial compression in the tube increases too, and when the compressive stress reaches a critical value, the tube will locally buckle at the critical value of the bending angle as 25.58 deg. For the above values of the critical angle, a solitonic deformation mechanism is starting and a portion of the nanotube becomes to rotate about a central hinge line. For large distances, the van der Waals force is attractive, but when the separation between the atoms is below the equilibrium distance of 3.42 Å, it becomes strongly repulsive. Upon complete unloading from angles below 110° the nanotube completely recovers. At a very large bending angle of 120 deg, atomic bonds break and the deformation of the nanotube becomes irreversible.

17:00	Böhme	H 106

Cavities In An Elasto-plastic Material: A Mesoscopic Concept

Thomas Böhme, Kerstin Weinberg, TU Berlin

Structured materials seems to be omnipresent and show different forms of appearance. Examples are micro cracked, multiphase or porous materials. The question is: How can the additional information about the microstructure be included in the framework of continuum mechanics. One possibility is the use of a general mesoscopic concept, firstly introduced by Muschik and his co-workers (see [1] and cited works) to describe a certain microstructure with continuum mechanical methods. The basic idea is the extension of the space-time domain by a set of mesoscopic variables. Additionally, a mesoscopic distribution function is introduced, which describes the distribution of the mesoscopic variables at each time and position. In this way a statistical element enters the classical continuum theory.

Here we apply the mesoscopic theory to model a general solid material with a certain porosity. We assume the material (with typical properties of metals) to be a conglomerate of spherical pores of arbitrary size each surrounded by elasto-plastic material. In this way it is possible to link the mechanism of pore expansion and global softening of the material to parameters which describe the micro mechanical mechanisms in elasto-plastic solids. The mesoscopic framework enables us in particular to study the temporal development of porosity under different loading regimes. We will see, that this approach shows the same structure as well known LSW-theories, but has a different constitutive law for the change-velocity of the additional variables.

[1] W. Muschik, H. Ehrentraut, C. Papenfuss: Mesoscopic continuum mechanics, in: G.A. Maugin (Ed.): Geometry, Continua, and Microstructure. ISBN 2 7056 6399 1, 49-60, 1999.

17:20	**Bontcheva**	**H 106**

Simulation Of Strain Induced Austenite - Martensite Transformation

Nikolina Bontcheva, P. Petrov, G. Petzov, L. Parashkevova, Institute of Mechanics, Bulgarian Academy of Sciences

Grain refinement due to phase transformation is an effective method for improving the mechanical properties of steel. The strain induced austenite - martensite transformation in stainless steel with metastable austenite leads to formatting of new smaller grains. The martensite, as well as the dislocation density, are unstable at thermal effects and reverse diffusional into finer-grained austenite. The entire cycle of austenite - martensite-austenite transformation provides considerable elevation of the plasticity of the austenitic steel type 304 at warm forming. The grain refinement can be supplied by preliminary controlled rolling of the steel.

The aim of this work is elaborating of approaches, based on the FE method, for numerical simulation of the microstructure evolution as a result of hot rolling and consequent cold torsion, with evaluating of the aggregate austenite-martensite flow stress.

17:40	**Malag**	**H 106**

Analysis Of Stress And Strain In Spread Cylindrical Sample

Leszek Malag, Leon Kukielka, Technical Univesrity of Koszalin, Poland

One of the basic engineering problem occurrences during the numerical analysis is define the function yield stresses of material in the real conditions of process. These properties are necessary to calculate deformation and state of stress and strain of object. Inappropriate selection of mechanical property of material is the reason of rise the errors of numerical calculations of continuous object, considered as a boundary and initial problem. The scientific investigations be guided in aim of study of datum feature data relating yield stresses for different metals, depends on complex conditions of thermodynamical loads, i.e. temperature, equivalent of strain and strain rate. The article presents a method of determination this dependence using experimental and numerical analysis. During the model investigations on the INSTRON machine the force of elongation of the sample is measured and then calculate displacement of nodes of finite elements, plotted on outside surface of sample. The process is considered as a multi non-linear problem and the incremental method of motion and deformation of solid in updated Lagrange formulation is used.

Session 13
Thursday, March 30, 18:00 - 20:00

Room: H 107

Thermal Problems

Chair:

Mikhail Itskov

18:00	**Zhuk**	**H 107**

Vibrations And Heating Of Inelastic Solids Under Harmonic Loading

Yaroslav Zhuk, Timoshenko Institute of Mechanics, Ukraine

An approximate problem statement for the case of steady-state vibrations of elastic-viscoplastic solids under harmonic loading is obtained. The “rigorous” problem statement is formulated first. It consists of universal balance equations of thermodynamics and constitutive equations derived from the general thermodynamic theory of viscoplastic bodies with internal state variables. The theory version that corresponds to the Bodner-Partom generalized flow theory is used.

Then the approximate problem statement is derived by the application of modified harmonic linearizing technique to the rigorous system of equations. Thereby the subsystem of mechanical equations is formulated in the complex-value form and material properties are described by means of amplitude-dependent complex-value moduli.

Numerical technique for the solution of the problems of vibrations and dissipative heating of spatial and thin-wall structurally inhomogeneous bodies are elaborated.

Next types of problems were investigated: axisymmetric vibrations and dissipative heating of layered viscoplastic disc and rectangle; resonant vibrations and heating of the thin-wall layered members. The regularities of the main spatial field variable distributions as well as temperature- and amplitude-frequency characteristics of viscoplastic structurally inhomogeneous members under harmonic load are studied. Comparing the solutions obtained in the frame of rigorous and approximate problems demonstrates high accuracy of the approximate model.

18:20	**Lacinski**	**H 107**

Heat Conduction In Laminates With A Weak Transversal Inhomogeneity

Lukasz Lacinski, Czeslaw Wozniak, Czestochowa University of Technology

Heat transfer problems in composites with a dense periodic structure are usually investigated in the framework of certain averaged (macroscopic) mathematical models. The best known are asymptotic models of periodic heat conductors. The heuristic tolerance models take into account the effect of period lengths on the overall behavior of a conductor. The purpose of this contribution is to formulate a tolerance model for periodically laminated media with a weak transversal inhomogeneity. Laminates in which layers are of the same material but one of them is reinforced by thin fibers in parallel to the interfaces are this kind of media. Taking into account the weak transversal inhomogeneity makes possible to separate equations for the averaged temperature and the temperature fluctuations. Using proposed model selected initial-boundary value problems were solved. Results were verified by direct numerical solutions obtained in the framework of the Fourier model.

18:40	Wozniak	H 107

Heat Conduction In Certain Functionally Graded Material

Czeslaw Wozniak, Institute of Mathematics and Computer Science, Czestochowa University of Technology, Poland
Bohdan Michalak, Department of Structural Mechanics, Lodz University of Technology, Poland
Margaret Wozniak, Dep. of Road and Traffic Engng., Kielce University of Technology, Poland

A conjunction of local apparent properties with a global design of structural elements is a motivation for applying composites which have a space-varying effective properties. A new approach to the modelling and analysis of both macro- and micro-response of such composites is the subject of this contribution. Considerations are restricted to the heat conduction problem. The main attention is focused on a description of the microstructure size effect on the overall composite behavior. This effect is neglected in commonly used locally homogenized models of composites.

19:00	Svanadze	H 107

On The Problems Of Heat Propagation In A Binary Mixture

Maia Svanadze, Faculty Pure and Natural Sciences, Tbilisi State University, Georgia

The linear theory of heat propagation in a binary mixture is presented by Gurtin and De La Penha (1970), Khoroshun and Soltanov (1984), Iesan (1997).

In this paper the boundary value problems of steady oscillations of the linear theory of heat propagation in a binary mixture are investigated. The fundamental solution of the system of the equations of steady oscillations is constructed in terms of elementary functions. A solution of Galerkin type is established. The integral representation of Somigliana type for the regular vectors is presented. The basic properties of single-layer, double-layer and volume potentials are studied. The uniqueness and existence theorems of solutions of the interior and exterior boundary value problems by means boundary integral method (potential method) are proved.

19:20	**Hortig**	**H 107**

Adaptivity In The Context Of High Speed Cutting

Christian Hortig, Bob Svendsen, Lehrstuhl für Mechanik, Universität Dortmund

High speed cutting is a process of high interest in modern production engineering. Besides the advantage of high productivity as a result of the increase of cutting speed, a decrease of cutting forces can be observed. In order to take advantage of the potential of the high speed cutting process, the knowledge of the working mechanisms in combination with the material behavior is essential. Observations detect the occurrence of localized adiabatic shear bands as the main mechanism of deformation of chip formation. These shear bands develop in localized areas of temperature dependent softening, surrounded by material in a process of strain and strain rate dependent hardening. The fact of high deformation speed and the mechanism of localized shear bands forces the implementation of a temperature and rate dependent material model which will be discussed. The strong mesh dependence of the phenomenon of localized shear banding is one of the key problems in the context of FE simulation of the high speed cutting process, as orientation and characteristic length of the mesh force direction respectively expansion of localization. The influence of the orientation of the mesh can be reduced by using adaptive procedures with the aim to reduce the characteristic element length locally. The pathological mesh dependence can then be eliminated with a non-local material model. Results of calculations will be presented.

7 Coupled problems

Organizers:

Stefan Diebels, Universität des Saarlandes
Stefanie Reese,

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 2036

Electromechanical coupling

Chair:

Tim Ricken

13:30	Romanowski	H 2036

Aspects Of The Simulation Of Electro-mechanical Coupling Effects

Holger Romanowski, Jörg Schröder, Institut für Mechanik, Universität Duisburg-Essen

The challenge in the field of ferroelectric ceramics is the modeling of complicated interactions between electrical and mechanical properties of the material on the macro scale, caused by switching processes on the micro scale. In this paper we present a thermodynamically consistent phenomenological model for an assumed transversely isotropic ferroelectric crystal and mainly focus on the hysteresis loops exhibited by such materials. This hysteresis phenomena occur in the ferroelectric phase, within a certain range of temperature, where the material becomes spontaneously polarized. On the macro scale a remanent polarization and remanent strains, due to the reorientation of the polarization, are observed, if an electric field above the so-called coercive field is applied. In this context the influence of mechanical loadings on the shape of the hysteresis loops is discussed. The anisotropic behavior is governed by isotropic tensor functions, which satisfy automatically the symmetry relationships of the considered body and which are formulated in terms of a finite set of invariants.

13:50	Kurzhöfer	H 2036

A Hybrid Finite Element Formulation For Electromechanical Problems

Ingo Kurzhöfer, Jörg Schröder, Institut für Mechanik, Universität Duisburg-Essen

Ferroelectric materials are to be found in a wide range of applications in smart materials, e.g. vibration reducing sensors or fuel injection systems. A special characteristic feature of these materials is the appearance of a spontaneous polarization in a certain temperature range. This polarization can be reversed by an applied electric field of sufficient magnitude. The resulting nonlinear material behavior is expressed by characteristic dielectric and butterfly hysteresis loops. In the present work we present an electric hybrid element formulation where the stresses and the electric fields are derived by constitutive relations. Therefore the displacements, the electric potential and the electric displacements are approximated by bilinear ansatz functions. Applying a static condensation procedure we obtain a modified finite element formulation governed by the degrees of freedoms associated to the displacements and the electric potential. The anisotropic material behavior is modeled within a coordinate-invariant formulation for an assumed transversely isotropic material. In this context a general return algorithm is applied to compute the remanent quantities (remanent strains and remanent polarization) at the actual timestep. Resulting hysteresis loops for the ferroelectric ceramics are discussed and some numerical examples are presented.

14:10	Schrade	H 2036

Phase Field Simulations Of Ferroelectric Materials

David Schrade, Ralf Müller, Dietmar Gross, Institut für Mechanik, TU Darmstadt

The hindering of domain wall movement by defects in ferroelectric materials is closely connected to electric fatigue. A movable domain wall in a ferroelectric material in most cases is modelled as a singular surface which allows the use of configurational forces. In contrast, the present approach treats the polarization as an order parameter, extending the total energy by a phase separation energy and a domain wall energy. The polarization then no longer has a discontinuity at the domain wall but is a continuous vector field (phase field).

Examples of numerical simulations of domain evolution under various boundary and initial conditions are given. It is found that in the presence of an electric field a single domain wall can be set into motion. The velocity of the domain is proportional to the applied electric field. These results are in good agreement with experimental studies.

14:30	Unger	H 2036

On The Influence Of Electric Currents On Plastic Deformation

Jaan Unger, Marcus Stiemer, Bob Svendsen, Heribert Blum, Universität Dortmund

Electromagnetic sheet metal forming (EMF) is an example of a high-speed forming process driven by the dynamics of a coupled electromagnetic-mechanical system. Principle physical effects of this forming operation, such as, e.g., inertia, visco-inelastic deformation and Lorentz-Force coupling, are considered in previous works of the authors. The present work is now focused on the relevance of further, more specific physical effects. Here, in particular, the development of the temperature and the reduction of the yieldstress due to electric currents are considered. While the thermo-elasto-viscoplastic effects are thoroughly understood, the influence of the electric current on the dislocation motion, generally referred to as the electroplastic effect, is still an unresolved issue. Of particular interest is the question whether such an effect would be an indirect result of the electric Joule heating or if there exits a direct and significant interaction between the electron movement and the dislocation dynamics. For all experiments and modeling situations, orders of magnitude for relevant physical variables are chosen similar to the ones obtained for the industrial EMF operation.

14:50	Svendsen	H 2036

Ale-based 3d Fe Simulation Of Electromagnetic Forming

Bob Svendsen, Marcus Stiemer, Heribert Blum, Jaan Unger, Lehrstuhl für Mechanik, Universität Dortmund

Electromagnetic forming is a contact-free high-speed forming process in which strain rates of over $10^3/s$ are achieved. The deformation of the work piece is driven by a material body force, the Lorentz force, that results from the interaction of a pulsed magnetic field with eddy currents induced in the work piece by the magnetic field itself.

The purpose of this work is to present a fully-coupled three-dimensional simulation of the process. For the mechanical structure, a thermoelastic, viscoplastic, electromagnetic material model is relevant, which is incorporated in a large-deformation dynamic formulation. The evolution of the electromagnetic fields is governed by Maxwell's equations under quasistatic conditions. Their numerical solution in 3D requires particular arrangements due to a reduced regularity at material interfaces. Hence, Nédélec elements are employed. Coupling between the thermomechanical and electromagnetic subsystems takes the form of the Lorentz force, the electromotive intensity, and the current geometry of the workpiece. A staggered solution scheme based on a Lagrangian mesh for the workpiece and an ALE formulation for the electromagnetic field is utilized to solve the coupled system. This approach guarantees both the efficiency and accuracy of the data transfer between the two meshes.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 2036

Piezo ceramics and ferro electrics

Chair:

Ralf Müller

16:00	Dienerowitz	H 2036

Pretwisted Beam With Piezoelectric Structures

Frank Dienerowitz, Wolfgang Seemann, Institut für Technische Mechanik, Universität Karlsruhe

Straight beams made of piezoelectric and/or elastic layers, denoted bimorphs, are well-known. A bimorph takes advantage of both piezoelectricity and kinematics of beams – i.e. (1) direct and fast transformation of electric energy into mechanical energy without causing significant magnetic fields and (2) to be capable of turning small strain modifications into large changes of curvature, provided the cross-section is rather flat. Unfortunately the latter commonly implies that bimorphs have just one direction of large deflection.

Imagine a bimorph being pretwisted, similar to a helicoid. Subdivide the active elements along the beam axis and control them independently; hence allowing independent control of the curvature of each section. Thanks to the pretwist, this bimorph could provide not only one but two directions of deflection.

For a slender pretwisted bimorph the problems emerging are presented and discussed, covering analytical calculation of the multi-field problem and some finite element analysis. In addition first steps towards an experimental setup are presented.

16:20	Klinkel	H 2036

A 1d Constitutive Law For Hysteresis Effects In Piezoceramics

Sven Klinkel, Institut für Baustatik, Universität Karlsruhe

This paper is concerned with a macroscopic constitutive law for domain switching effects, which occur in piezoelectric ceramics. The thermodynamical framework of the law is based on two scalar valued functions: the Helmholtz free energy and a switching surface. In common usage, the remanent polarization and the remanent strain are employed as internal variables. The novel aspect of the present work is to introduce an irreversible electric field, which serves besides the irreversible strain as internal variable. The irreversible electric field has only theoretical meaning, but leads to advantages within the finite element implementation, where displacement and the electric potential are the nodal degrees of freedoms. A common assumption is a one-to-one relation between the irreversible strain and the polarization. This simplification is not employed in the present paper. To accomplish enough space for the polarization, resulting from an applied electric field, the irreversible strains are additively split and a special hardening function is introduced. This balances the amount of space and the domain switching due to polarization. The constitutive model reproduces the ferroelastic and the ferroelectric hysteresis as well as the butterfly hysteresis for piezoelectric ceramics and it accounts for the mechanical depolarization effect.

16:40	Bossong	H 2036

Characterisation And Modelling Of Piezoceramic Actuator Hystereses

Heiko Bossong, Sven Lentzen, Rüdiger Schmidt, RWTH Aachen

Piezoelectric ceramics are often used as actuators in smart structures technology. In the vast majority of papers dealing with this topic only linear constitutive relations are used. However, the electric field-strain relations of such actuators show hysteretic behaviour, which means that the piezoelectric coupling coefficient is not constant.

In this study the hysteresis of a mechanically unconstrained actuator is determined using the Michelson Interferometry. The hysteretic behaviour is modelled by a Preisach Model. Using these experimental data, for the modelling of an active structure with embedded piezoelectric actuators the actual coupling coefficient can then be determined with the help of the Preisach Model. With this procedure the actuation strain of an embedded actuator, including the physical nonlinearities, can be calculated using the material characteristics obtained for an unconstrained actuator.

For an experimental validation of the method outlined above, a Lead Zirkonate Titanate (PZT) actuator is characterised experimentally and then glued to a cantilever beam. Then, the tip displacement of the actuated beam is determined experimentally and simulated numerically using the above method. The experimental and numerical results agree reasonably well if the shear lag due to the bonding layer between the actuator and the structure is taken into consideration.

17:00	Goy	H 2036

3D SIMULATION OF POINT DEFECT MIGRATION IN FERROELECTRICS

Oliver Goy, Ralf Müller, Dietmar Gross, FG Elastomechanik, TU Darmstadt

Electric fatigue in functional materials involves a set of phenomena which lead to the degradation of materials with an increasing number of electrical cycles. Ionic and electronic charge carriers, later modeled as point defects, interact with each other and with microstructural elements in the bulk and with interfaces, which can lead to degradation, or finally to mechanical damage and dissociation reactions.

With this in mind, efforts are made to calculate the fields caused by point defects to simulate their interaction as well as to verify the used parameters. Ferroelectrics mostly exhibit orthotropic or transversely isotropic material properties. Here, a material with linear electro mechanical coupling is used. The applied methods are integral transforms (Radon Transform) and a combination of Difference Methods and a Fast Fourier Transform to obtain solutions in infinite space and under periodic boundary conditions, respectively.

The investigation of point defect interaction is done by means of material or configurational forces. Configurational forces are used in combination with reasonable kinetic laws to simulate defect migration. The aim is to improve the understanding of defect agglomeration in ferroelectrics.

17:20	**Mehling**	**H 2036**

CONSISTENT MODELING OF FERROELECTRIC MATERIAL BEHAVIOR

Volkmar Mehling, Charalampos Tsakmakis, Dietmar Gross, Fachbereich Mechanik, TU Darmstadt

Ferroelectric materials under high electrical and mechanical loading exhibit irreversible deformations and polarizations.

A simple model, which accounts for three-dimensional electromechanical loading and multi-axial domain switching is presented. It is based on a microscopically motivated choice of internal variables which describe the irreversible parts of strain and polarization. It involves the assumption of an orientation distribution function for the crystal unit cells.

By satisfying the second law of thermodynamics in the form of the Clausius-Duhem inequality, driving forces for the internal variables are derived. Using techniques from classical rate-independent metal plasticity theory a convex switching function combined with a normality rule is introduced. Saturation of strain and polarization is modelled by appropriately defined energy barrier functions. The reversible, linearly piezoelectric part of the constitutive model, utilizes an invariant formulation for the electric enthalpy function, modified by the dependence on the magnitude of polarization.

The finite element method is used for numerical simulations. Time-integration of evolution equations is performed by implicit Euler integration. The constitutive equations are solved by the operator split method involving a piezoelectric predictor step and a ferroelectric general return algorithm. Numerical results illustrate the capabilities of the model.

17:40	Dashko	H 2036

An Analytical Solution Of A 3d Problem Of Magnetoelasticity

Olga Dashko, S. P. Timoshenko Institute of Mechanics, NAS of Ukraine

A behavior of the soft ferromagnetic solid in magnetic field is conventionally investigated with the framework of the developed by Brown, Pao and Yeh linear theory of magnetoelasticity. Magnetoelastic interaction results in coupling of variables in governing equations and boundary conditions. Although the general two-dimensional problems of magnetoelasticity have been successfully studied by Shindo and other researchers, the three-dimensional problems have not been explored with some exceptions. For example the case of infinite solid with an ellipsoidal inclusion then its shape is essentially compressed in the direction of magnetic field propagation is considered using the series of simplifying assumption. In the present report a new approach to find the solution for the solid with an inclusion of arbitrary ellipsoidal shape is offered. The problem is solved using a general method of constructing the exact analytical solutions for the static problems, which has been developed by Podil'chuk on the basis of Fourier method. This method implies the using of curvilinear coordinates and separating of variables in the governing equations. As a result magnetoelastic stresses are obtained in the closed form and their distributions are studied. The influence of magnetic properties of the material and the boundary surface geometry is investigated.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 2036

Thermomechanical coupling

Chair:

Paul Steinmann

13:30	Bargmann	H 2036

Modeling Of Non-classical Thermoelasticity

Swantje Bargmann, Paul Steinmann, Lehrstuhl für Technische Mechanik, Universität Kaiserslautern

Due to experimental observations of thermal waves in solids non-classical theories of thermoelasticity were developed in recent years. A very promising theory was developed by Green and Naghdi. The classcial theory (type I) is fully embedded in their approach. An outstanding property of their thermal theory of type II besides the modeling of thermal wave propagation at finite speed is that it conserves energy. We investigate type III, a combination of type I and II, as well. The natural extension of a rigid heat conductor leads to deformable elastic continua. Consequently each of the three heat equations is coupled with the balance of momentum. We suggest a discretization based on Galerkin finite elements for the spatial as well as for the temporal discretization of the equations. The linear theory of thermoelasticity is applied to an isotropic and homogeneous elastic-deformable continuum. The numerical example is compared to the experimental results of Jackson et al. in order to underline the performance of the method.

13:50	Gross	H 2036

Stable Time Integration Of Nonlinear Thermomechanical Problems

Michael Gross, Peter Betsch, Institut für Mechanik und Regelungstechnik, Universität Siegen

In computational dynamics, a spatial discretisation using finite elements is a standard procedure in mechanical engineering. The time discretisation, however, has been still often carried out by finite differences, although finite element methods in time have some advantages over finite differences. One advantage is that one obtains a higher order accurate time approximation in a natural way. A further

advantage is that continuous finite element methods in time inherit conservation laws of dynamical systems. These methods were therefore a natural starting point to construct higher order conserving time integrators which turned out to be well suited for computing long time runs in nonlinear elastodynamics.

An energy consistent time integration of dissipative continuum dynamics has also advantages over standard temporal discretisations. For instance, balance laws are fulfilled as well as the physical dissipation is guaranteed independent of the material parameters and the chosen time step size. In this lecture, we present an energy consistent time discretisation for thermomechanical coupled continuum dynamics. In comparison to standard Galerkin time approximations, we obtain numerical stability and time step size independent balance laws as well as qualitative solutions.

14:10	Feng	H 2036

Experimental And Theoretical Investigation Of Plc Deformation Band

Xiaoqun Feng, H.-A. Crostack, G. Fischer, Bob Svendsen, Universität Dortmund

The basis of plastic deformation of metals is the formation and motion of dislocations. One of the methods to reduce the ductility and improve the strength of pure metals is to introduce foreign atoms in metallic solid solutions in order to obstruct the dislocation motion. In some regimes of temperature and loading rate, the interaction of such foreign atoms with dislocations can result in a negative strain-rate sensitivity, dynamic instability and deformation localization, leading to the nucleation and propagation of so-called Portevin-Le Châtelier (PLC) bands. From a technological point of view, the development of such bands results in a reduction of surface quality and strength, and therefore is undesirable.

In this paper, the nucleation and propagation of PLC deformation bands in Al alloys are studied experimentally and theoretically. The morphology and kinematics of PLC bands are investigated using both mechanical and thermal measurement methods. The latter is based on the use of a thermal camera which captures the temperature changes resulting from mechanical dissipation and heating produced during nucleation and propagation of PLC bands. The experiment results are illustrated in spatiotemporal figures to explain the nucleation and propagation of PLC bands, in addition to the analysis of stress and strain. On the modeling side, two models are investigated via finite element and finite difference methods. Here, attention is focused on the influence of model parameters and the geometry of specimen as well as on the thermomechanical coupling. A comparison of experimental and simulation results will be presented.

14:30	Göktepe	H 2036

Coupled Finite Thermoviscoplasticity Of Glassy Polymers

Serdar Göktepe, Christian Miehe, Institut für Mechanik, Universität Stuttgart

The lecture is concerned with the constitutive modeling and algorithmic implementation of the temperature and thermomechanical coupling effects on the rate-dependent finite plastic behavior of glassy polymers. Isothermal experiments conducted at different temperature levels point three distinct phenomena for increasing temperature values: *i*) The softening in the post-yield kinematical hardening phase, *ii*) the drop in the yield stress and *iii*) the decrease in the amount of stress softening. Therefore, the considerable temperature increase accompanying the deformations at moderate and high rates results in the softened material response.

In contrast to existing kinematic approaches to finite plasticity of glassy polymers, we propose a distinct kinematic framework constructed in the logarithmic strain space. The logarithmic framework is extremely attractive due to the fact that it allows a very efficient algorithmic treatment of the finite plasticity akin to geometrically linear theory. The evolution law of plastic strains is adopted from Argon's double kink theory. Temperature-induced softening is incorporated by thermal disassociation of the secondary bonds in the polymer network. For the FE analysis of the coupled BVPs, the staggered scheme is employed in order to circumvent the drawbacks of monolithic solution schemes.

The proposed formulation is validated by simulating various experimental data.

14:50	**Chekurin**	**H 2036**

Inverse Problems For Tensor Fields Optical Tomography

Vasyl Chekurin, Pidstryhach Institute for Applied Problems of Mechanics and Mathematics of Academy of Science, Ukraine

The techniques of the polarized-optical measurement are well elaborated to date thus the photo-elasticity effects coupled with polarized-optical technique can be applied to create new effective methods and means for nondestructive determination of non-uniform strain and stress fields in solids and material characterization. In this connection three inverse problems for tensor field tomography are considered in the paper. For all of them the polarized-optical data, obtained for some set of directions crossing the body, are used as input information. These are the problems of a body stress-strained state restoration, its material properties (elastic, thermo-elastic and photo-elastic) nondestructive determination, and inclusions identification.

Variational formulations are given for these problems. The functionals for them are built using three components - mathematical model for strain-stressed state of the object, polarized-optical ray integrals, accounted light beams with strained solid media interaction, and data of polarized-optical measurements.

To solve the variational problems several approach have been developed - representation of the solution in a functional space of eigen-function of suitable boundary-value problem of the theory of elasticity, boundary and finite element methods application. To illustrate the effectiveness of the developed approaches and methods some problems for residual stresses in piece-wise structures are considered.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 2036

Multiphase continua

Chair:

Bernd Markert
Markus Böl

16:00	Graf	H 2036

Phase Transition Processes Of Pore Fluids In Porous Materials

Tobias Graf, Wolfgang Ehlers, Institut für Angewandte Mechanik, Universität Stuttgart

Taking a closer look on, e. g., storage processes of greenhouse gases in deep geological aquifers or pressure decreases in dilatant shear bands, the observation can be made that pressure and temperature changes in porous materials can induce phase transition processes of the respective pore fluids.

For a numerical simulation of this behaviour, a continuum mechanical model based on a multiphasic formulation embedded in the well-founded framework of the *Theory of Porous Media* is presented in this contribution. The single phases are an elasto-viscoplastic solid skeleton, a materially compressible pore gas consisting of pore air and the gaseous pore water (water vapour) and a materially incompressible pore liquid, i. e., liquid pore water. The numerical treatment is based on the weak formulations of the governing equations, whereas the primary variables are the temperature of the mixture, the displacement of the solid skeleton and the effective pressures of the pore-fluids.

Several initial boundary-value problems are discussed in detail, where the resulting system of strongly coupled differential-algebraic equations is solved by the FE tool PANDAS.

16:20	Bluhm	H 2036

Modeling Of Phase Interfaces During Freezing And Thawing Processes

Joachim Bluhm, FB Bauwissenschaften, Universität Duisburg-Essen

Frost damages of porous building materials like road pavements, masonries and concrete in regions with periodical or permanent freezing are well known. On the other hand, artificial freezing techniques are used, e.g., for tunneling in non-cohesive soils and other underground constructions, for protection of excavation and for compartmentalization of contaminated regions.

In order to describe the volumetric deformation behavior of saturated porous media due to the anomaly of water, it is necessary to model both the phase interface and the motion of the interface. Furthermore, due to the phase transitions inside the porous body one has to consider the latent heat, here the heat of fusion.

Taking into account the aforementioned effects of ice formation in porous materials, a simplified macroscopic model for the description of freezing and thawing processes of saturated porous solids is presented. Thereby, the main focus of the current work is on the modeling of phase interfaces. With respect to the model, the Theory of Porous Media (TPM) is used.

16:40	Chen	H 2036

Wave Propagation In Fluid-saturated Porous Media

Zhiyun Chen, Holger Steeb, Stefan Diebels, Universität des Saarlandes

The numerical analysis of wave propagation in fluid-saturated porous materials like soil or granulates is of relevant importance in geology, seismologic engineering, petroleum engineering and geotechnical engineering. Besides the well investigated theory of Biot, the mechanical behavior of multi-phase media can also be described by the more rational andthermodynamically consistent Theory of Porous Media (TPM). In the current work, we investigate wave propagation problems within a so called hybrid two-phase model, i. e. a mixture consisting of a materially incompressible solid skeleton and a compressible pore fluid.

Biot [1956] has demonstrated that within a two-phase model, there exist two compressible waves: The compressible wave of the first kind and the compressible wave of the second kind, which is the so-called Biot slow wave. In addition, there exists one shear wave.The initial consideration of Biot was concentrated on a mixture of compressible constituents. However, in a gas or a bubble-fluid-filled porous skeleton, the compressibility of the solid material itself can be neglected in comparison with the volume changes of the pores, whereas the compressibility of the highly compressible fluid or gas can be very dominant. Such a model composed of a compressible fluid phase and an incompressible solid skeleton is denoted as a by hybrid model in the terminology of the TPM.

According to the saturation condition $n^{\mathfrak{s}} + n^{\mathfrak{f}} = 1$,$\mathfrak{s}$: solid, $\mathfrak{f}$: fluid), the volume fraction of the fluid constituent is instantaneously varified due to the deformation in the solid phase ($n^{\mathfrak{s}} = n_0^{\mathfrak{s}} J_{\mathfrak{s}}^{-1}$). In the present contribution, a non-linear gas low according to Muskat [1937] is employed to describe the behavior of the compressible fluid phase.

We employ a discontinuous space-time Galerkin method to solve the governing set of PDEs.Numerical experiments have confirmed the existence of both compressible waves and the shear wave.

17:00	Johlitz	H 2036

Size Effects Due To The Formation Of Interphases In Polymer Joints

Michael Johlitz, Holger Steeb, Stefan Diebels, Universität des Saarlandes

In this contribution, we investigate the numerical modelling of polymer bonds among quasi-static and isothermal conditions. From experimental investigations we know that polymers form interphases in contact to substrates. This interphases influence the macroscopic material behaviour in form of a size effect. Dependent on the substrate both effects “Smaller is Stiffer” and “Smaller is Weaker” are possible. To take the formation of a microstructure into account, we postulate an aditional balance equation based on an abstract scalar-valued order parameter which offers us a way to describe the interaction between the macro- and microscopic scale through a coupling on the level of the constitutive equations which we obtain after the typically analyses of the entropy principle. According to the macro-and microscopic balances which we received from this procedure, we investigate the coupled model by finite element analysis. Different numerical examples are shown and compared to experimental investigations.

Session 5
Thursday, March 30, 13:30 - 15:30

Room: H 2036

Surface coupling

Chair:

Stefan Diebels

13:30	Niekamp	H 2036

A Framework For The Coupling Of Simulations

Rainer Niekamp, Hermann G. Matthies, TU Braunschweig

Nowadays there is a large number of projects concerning the coupling of different simulation codes. This presentation describes a framework for the coupling of simulations like fluid-structure interaction or micro-macr o formulations as well as for the coupling of simulations with Monte Carlo and Optimisation methods. This framewor k consists of a C++ component template library supporting remote method calls using various protocols like pvm, mp i or tcpip together with an interface definition for simulations-codes serving as an standartisation for such cod es. We will show some example applications based on this framework in the fields of multi-physics, micro-macro-int eraction and high dimensional integration methods applied to structures with stochastic material properties genera ted by a Poisson process. Some computations will show the potential of this framework and also the practicability and limits of the investigated high dimensional integration methods.

13:50	Müller	H 2036

Beschreibung Der Zeitskalenproblematik Bei Bremsvorgängen

Michael Müller, Georg-Peter Ostermeyer, Institut für Dynamik und Schwingungen, TU Braunschweig

Die Dynamik in der Grenzschicht von Bremssystemen ist im Wesentlichen determiniert durch charakteristische Wechselwirkungen von Reibung und Verschleiß. Diese sind durch ein Fließgleichgewicht zwischen dem Auf- und Abbau typischer Oberflächenstrukturen auf dem Bremsbelag gegeben [1].

In vergangenen Arbeiten sind unter der Berücksichtigung des Wärmeflusses und der Verschleißpartikeldynamik in einem neuartigen dynamischen Reibgesetz, sowie darauf aufbauend einer Grenzschichtdiskretisierung mit Hilfe von Zellulären Automaten [2] die Topographiedynamik und einzelne Phänomene beschrieben worden.

Das tribologische Verhalten ist hierbei an ein Multiskalenproblem gekoppelt, dessen Beschreibung mit Hilfe der Zellulären Automaten durch eine Auftrennung der Zeitskalen in Sekunden und Mikrosekunden implementiert wird.

In dieser Arbeit soll vorgestellt werden, wie dabei die algorithmische Formulierung der Regeln für die zur jeweiligen Zeitskala zugehörigen stationären und instationären Zustandsgrößen erfolgen kann. Dabei soll im Speziellen auf die Problematik der Temperaturfelder eingegangen werden.

[1] Ostermeyer, G.P.:, "On the dynamics of the friction coefficient" WEAR 254 (2003), 852-858
[2] Ostermeyer, G.P., Mueller, M.: "New developments of friction models in brake systems" Proceedings of the 23rd SAE Brake Colloquium and Exhibition 2005, Orlando

14:10	Helmich	H 2036

Numerical Simulation Of Surface Scanning In An Afm Environment

Tobias Helmich, Udo Nackenhorst, Institut für Baumechanik und Numerische Mechanik; Universität Hannover

In this contribution a model for the numerical simulation of an atomic force microscope (AFM) is presented. A challenge of this goal is the treatment of the multiphysics phenomena on the microscopic lengthscale. Hence, a coupled strategy is required to incorporate the different physical aspects and their interactions. The strategy is embedded into a nonlinear finite element formulation, where the different aspects are tackled by direct and weak coupling. The following aspects will be presented in this talk.

The contact between the tip of the AFM and the surface of the sample is modeled by a potential formulation of the van der Waals force with a repulsive and attractive component. In contrast to classical contact formulations the contact conditions are continuous, normal and tangential contact are coupled consistently.

The multiscale problem of the system is treated by a dimensional adaptive approach of contact, continuum and beam elements. These elements are joined by transitions elements with different degrees of freedom.

The cantilever bending can be influenced through forces from an external electrostatic field. Therefore a coupling strategy with an external FEM-BEM formulation for the electric field is shown. Numerical examples and results from the introduced coupling strategy are presented for typical AFM setups.

14:30	Altenbach	H 2036

Ausrichtung Von Partikeln In Stationären Strömungsfeldern

Holm Altenbach, Barbara Renner, Konstantin Naumenko, Martin-Luther-Universität Halle-Wittenberg

Die Problematik wird bei der Analyse der Verarbeitung partikelverstärkter Kunststoffe breit diskutiert. Das Ziel ist die Voraussage der Partikelausrichtung für gegebene Strömungsfelder während der Füllphase beim Spritzgießen oder bei der Extrusion. Im Rahmen des Vortrages werden Bewegungsgleichungen für Translation und Rotation eines zylindrischen Partikels in einem stationären Strömungsfeld vorgestellt. Die Modellierung der Wechselwirkung mit dem Fluid erfolgt durch Konstitutivannahmen für die Reibungs- sowie für die Widerstandskräfte und -momente. Das resultierende nichtlineare Gleichungssystem wird bezüglich der Gleichgewichtszustände analysiert. Die stabilen Zustände liefern Aussagen über die Partikelausrichtung. Ferner werden für ausgewählte Strömungen numerische Lösungen vorgestellt und mit experimentellen Daten aus der Literatur verglichen. Zusätzlich erfolgt eine Gegenüberstellung mit der konventionellen Vorgehensweise, in der die rotatorische Trägheit des Partikels vernachlässigt wird.

14:50	Schrape	H 2036

Fsi Of A Simplified Aero Engine Compressor Cascade Configuration

Sven Schrape, Arnold Kühhorn, Lehrstuhl Strukturmechanik und Fahrzeugschwingungen, BTU Cottbus

Aero engines of the next generation are faced to requests for an increased power as well as reductions of emissions, weight and costs for maintenance and fuel. To achieve these goals the application of integrally constructed bladed disks (Blisks) plays an essential role. The main disadvantage of these blisks is the slight structural damping compared to the conventional system, where disk and blades are connected with complex and weighty constructions.

Primarily relevant for the service life of these structures are stresses caused by aerodynamic excitation. An estimation of these stresses close to reality requires an accurate knowledge of the complex and unsteady interaction between fluid and structure. A corresponding simulation is realised applying an explicit, partitioned coupling approach (MpCCI) between established CFD- and FEM-codes.

Aiming at a validation of this recently integrated coupling a plate exposed to a transverse flow is considered as a first example. In this case the structure responds in a decaying vibration induced by the flow. The theoretical background, the steps of modelling on principle and numerical results compared to the literature are introduced. Furthermore a two dimensional model of a compressor cascade configuration will be shown concerning a fully coupled computation of compressor blade vibration. Initially considering an inviscid, subsonic flow a numerical parameter study in terms of the vibration behaviour with quantification of aerodynamical damping, oscillating air mass as well as reinforcement due to compressible air flow will be discussed.

8 Multiscales and homogenization

Organizers:

Alexander Mielke, WIAS Berlin
Christian Miehe, Universität Stuttgart

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 112

Energy Minimization and Relaxation

Chair:

Alexander Mielke

13:30	Conti	H 112

ENERGY SCALING AND MICROSTRUCTURE FORMATION IN PAPER CRUMPLING

Sergio Conti, Fachbereich Mathematik, Universität Duisburg-Essen
Francesco Maggi, Università di Firenze, Italy

Crumpling a sheet of paper leads to the formation of complex folding patterns over several length scales. This can be understood on the basis of the interplay of a nonconvex elastic energy, which favors locally isometric deformations, and a small singular perturbation, which penalizes high curvature.

Based on three-dimensional nonlinear elasticity and by using a combination of explicit constructions and general results from differential geometry, we prove that, in agreement with previous heuristic results in the physics literature, the total energy per unit thickness of such folding patterns scales at most as the thickness of the sheet to the power 5/3. For the case of a "single fold" we also obtain a corresponding lower bound.

13:50	Hornung	H 112

Asymptotic Analysis Of Thin Martensitic Films

Peter Hornung, Max Planck Institut für Mathematik in den Naturwissenschaften

In 1999 Bhattacharya and James observed that thin films of martensitic (two-well) materials show a much richer structural variety than bulk samples made of the same material. Recently, Chaudhuri and Müller proved a scaling law for such thin films in the nonlinearly elastic setting which suggests that the Γ-limit (as the plate thickness tends to zero) of the 3D energy functional might be of the form

$$\int_J k(\nu(x))dH^1(x),$$

where J denotes the interface between the austenite and the martensite phase, ν is the interface normal and $k : S^2 \to R$.

Using a recent result by Conti and Schweizer we prove this for the case of linearized elasticity.

14:10	Orlando	H 112

On The Numerical Relaxation Of Single-slip Plasticity

Antonio Orlando, Carsten Carstensen, Institut für Mathematik, Humboldt-Universität zu Berlin
Sergio Conti, Fachbereich Mathematik, Universität Duisburg-Essen

The modeling of the elastoplastic behavior of single crystals with infinite latent hardening leads to a nonconvex energy density, whose minimization produces fine structures. The effective macroscopic behaviour can be characterised by means of the quasiconvex envelope of the energy density; unfortunately a closed form expression for the latter is known only in few very simplified cases. One is therefore lead to a new computational challenge, namely numerical relaxation. This is faced with huge numerical difficulties because of the minimization of a nonconvex function with clusters of local minima.

With the objective of gaining better insight in the type of microstructure that can develop, and in the type of numerical minimization algorithm that can be used for the relaxation, we study a simplified model problem in two-dimensional, geometrically nonlinear plasticity, with a single slip system and a linear hardening law.

First, we consider an elastically rigid problem, i.e. assume that the elastic part of the deformation is a rotation, and neglect dissipation. For this case, the quasiconvexification of the energy density can be determined in closed form.

A more refined model is obtained by assuming the microstructure to have the form of a laminate of second order, which is supported either on rigid-plastic deformations or on purely elastic ones. In this case the relaxation can be reduced to the minimization of a function of only one variable.

Finally, we use the above results for the numerical minimization of the full energy density, including dissipation, and removing the kinematic constraint, and compare with results in the literature.

14:30	Kühn	H 112

ANALYSIS OF MAGNETIC NANOWIRES

Katharina Kühn, Max Planck Institut für Mathematik in den Naturwissenschaften, Leipzig

In numeric simulations of the magnetic reversal process of nanowires several groups (e.g. [1], [2], [3]) have observed two different types of reversal modes, which correspond to very different switching speeds. These modes depend on the wire thickness. Forster et al. [1] suggest that the reversal modes correspond to minimizers of the static energy functional.

In this talk I will present results about energy minimizers in different regimes of thickness. Moreover I will show a theorem on the Γ-limit as the diameter tends to zero.

[1] H. Forster et al., Domain wall motion in nanowires using moving grids, *J. Appl. Phys.* **91**, 69 14-6919, 2002
[2] R. Hertel, J. Kirschner, Magnetization reversal dynamics in nickel nanowires, *Physica B* **343**, 206-210, 2004
[3] R. Wieser, U. Nowak, K.D. Usadel, Domain wall mobility in nanowires: Transverse versus vortex walls, *Physical Review B* **69 064401, 2004**

14:50	Münch	H 112

CONSTITUTIVE MODELING AND FEM FOR A NONLINEAR COSSERAT CONTINUUM

Ingo Münch, Werner Wagner, Patrizio Neff, Universität Karlsruhe (TH)

Many materials show an inner structure influencing the mechanical behaviour. In this context we develop a geometrically nonlinear Cosserat continuum of micropolar type, including an additional strain measure of second order (curvature), penalizing an independent rotation field $\mathbf{R}$.

Besides the strain measure of first order (stretch), the curvature energy leads to comparatively small additional inner energy terms. On the positive side, the continuum model can benefit from the additional field $\mathbf{R}$ by a better description of lower energy modes.

Depending on material constants, it is possible to simulate classical infinitesimal elasticity under small loads while length scale effects arise under higher loads. In the proposed framework the linearized Cauchy-stress tensor remain symmetric in contrast to traditional Cosserat-type models. This corresponds to setting the traditional Cosserat couple modulus to zero. This result is only possible in a nonlinear treatment.

The problem is mathematically well posed (existence of minimizers) as it has been shown by P. Neff; notice that the problem is uniformly Legendre-Hadamard elliptic at prescribed rotations w.r.t. the deformation. However, since we deal with an overall nonlinear, non-convex two-field problem, computed equilibrium solutions may loose their stability since a highly complicated energy landscape occur. The pseudo-homogenization achieved through the micropolar continuum theory does not represent a real physical material. By considering an imperfection field critical states of stability can be excluded.

In our numerical tests we observe size effects. For the same internal length, great sample geometries behave weaker than small ones. The presented mechanical model offers weaker response than either the classical linear elastic model or the elastic model based on Neo-Hooke energy with similar elastic moduli when subjected to larger loads.

15:10	Neff	H 112

Local Minimization On So(3) And Relaxation

Patrizio Neff, FB Mathematik, Universität Duisburg-Essen

In this talk I exhibit the interrelation between a geometrically exact Cosserat bulk model, the local minimization problem on SO(3) and the distance to rotations in three dimensions. The convex and quasiconvex hull of the distance function is computed for two space dimensions with a simple argument. The extension to three space dimensions is open.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 112

Multiscale Modeling

Chair:

Johannes Giannoulis

16:00	Uecker	H 112

A Model Problem For Inclined Film Flow Over Wavy Bottoms

Hannes Uecker, Andreas Wierschem, Universität Karlsruhe

The spatially periodic Kuramoto–Sivashinsky equation (pKS)

$$\partial_t u = -\partial_x^4 u - c_3\partial_x^3 u - c_2\partial_x^2 u + 2\delta\partial_x(\cos(x)u) - \partial_x(u^2), u(t,x) \in \mathbb{R},\ t \geq 0,\ x \in \mathbb{R},$$

can be considered as a model problem for the flow of a viscous liquid film down an inclined wavy plane. For given $c_2, c_3 \in \mathbb{R}$ and $\delta \geq 0$ it has a one dimensional family of spatially periodic stationary solutions $u_s(\cdot; c_2, c_3, \delta, u_0)$, parametrized by the mass $u_0 = \frac{1}{2\pi}\int_0^{2\pi} u_s(x)\,\mathrm{d}x$. Depending on the parameters these stationary solutions can be linearly stable, or unstable due to a long wave instability. Using Bloch wave analysis we separate the long scale from the short scale coming from the bottom profile. Then, using renormalization group methods, we show that in the stable case localized perturbations decay with a polynomial rate and in a universal self-similar way: the limiting profile is determined by a Burgers equation in Bloch wave space. We also discuss wave patterns in the linearly unstable case.

16:20	Koprucki	H 112

Upscaling Of Quantum Calculations To Macroscopic State Equations

Thomas Koprucki, WIAS Berlin

Multi-band kp-Hamiltonians are detailed models for the calculation of quantum-confined electronic states in semiconductor quantum-well structures. They consistently include band mixing, spin-orbit interaction and strain effects. Quantities such as carrier densities or the optical response can be efficiently obtained in terms of the quantum states. To utilize such microscopically calculated data for device simulation, e.g., with drift-diffusion-type models, a suitable upscaling to macroscopic state equations is required. We demonstrate upscaling schemes for the carrier densities and the peak gain characteristics calculated for an example quantum-well structure.

16:40	Kaiser	H 112

Coupled Models In Semiconductor Device Simulation

Hans-Christoph Kaiser, WIAS Berlin

We investigate extensions of van Roosbroeck's model for a semiconductor device which describes the flow of electrons and holes in a self-consistent electrical field due to drift and diffusion. In real-world modeling of semiconducter devices van Roosbroeck's system often serves as a component in a compound model of the device. Then the superordinated system – for instance a circuit model – may exercise a control on van Roosbroeck's system. Apart of a superordinated circuit model, compound models comprising in addition to van Roosbroeck's system equations for the lattice temperature or the power of lasing modes play an important role in device simulation. But the concept of external control also comes to bear in segmentation of the simulation domain, in particular in connection with multiscale modelling.

17:00	Chatzouridou	H 112

From Microscopic Investigations To Macroscopic Models Of Foams

Anthippi Chatzouridou, Stefan Diebels, Tobias Ebinger, Lehrstuhl für Technische Mechanik, Universität des Saarlandes

Certain materials like foams, sponges and hard biological tissues feature a lattice-like microstructure which affects their overall macroscopic behavior. In these materials an interaction between the microstructure and the macroscopic response leads to size effects, i.e. effective material properties depending on the size of the specimen. As a consequence a continuum approach which takes into consideration the microstructural mechanism is required, e.g. an extended continuum theory. The formulation of extended constitutive models requires a number of material parameters whose determination demands a parameter identification analysis. The interpretation of these parameters and their direct association with the microstructure is not obvious/trivial in the most cases. In order to understand these parameters and relate them to the microscopical mechanism one can use an alternative approach of including the microscale information in such a sense that no macroscopic constitutive equations are necessary. This can be done by using a numerical homogenisation procedure, often called FE^2, where a direct scale bridging takes place, in the sense that a microstructure is attached to each integration point of the macroscopic finite element formulation. In this case the constitutive equations are formulated on the microscale.

The purpose of this work is to discuss the different modelling approaches of materials with lattice-like microstructure and investigate the relation between the parameters of the macroscopic model and those of the FE^2 aproach to the numerical results obtained by a microscopic beam model.

17:20	**Demiray**	**H 112**

Homogenization Of Elasto-plastic Open-celled Foams

Serkan Demiray, Wilfried Becker, Institut für Mechanik, TU Darmstadt
J. Hohe, Fraunhofer Institut für Werkstoffmechanik

Subject of the numerical study is the effective yield behaviour of open-celled metal foams. As a surrogate model, a three-dimensional elasto-plastic lattice of tetrakaidecahedral cells is considered. Each strut of a cell is discretized by structural beam elements. The applied homogenization scheme is based directly on the Hill principle, so that the energetically and mechanically defined effective properties are compatible. In a first step, the initial yield surfaces are analysed in both strain space and stress space. The initial yield surface in the normal strain space is similar to a polyhedron with sharp corners. Parametric studies are carried out to investigate the effect of different imperfections. In the second part of the study, the further evolution of the yield surfaces is obtained by considering complex loading histories. It is found that the change of the micro-structure under large deformations influences significantly the macroscopic hardening behaviour. Although, the struts are elastic/ideal-plastic, both kinematic and isotropic hardening effects are observed. In addition, the stress yield surface may rotate under certain loading conditions.

17:40	**Ilic**	**H 112**

Multiscale Fem In Modelling Of Solution-precipitation Creep

Sandra Ilic, Klaus Hackl, Ruhr Universität Bochum

In previous work we proposed a mechanical model for solution-precipitation creep based on the minimization of a Lagrangian consisting of elastic power and dissipation. Elastic energy is chosen to be in a standard form but dissipation is strongly adapted to the solution-precipitation process by introducing two new quantities: the velocity of material transport within the crystallite-interfaces and the normal velocity of precipitation or solution respectively. Until now only the results for a Voigt-Sachs model and very simple specimens discretized by FEM were available.

Here, our intention is to show results for more realistic examples obtained by using multiscale FEM adapted to the limit case where the ratio between macro and microlevel tends to infinity. In that method the deformation gradient is provided on the macroscale and on the microscale one calculates microfluctuations satisfying periodic boundary conditions. Further calculation yields the effective first Piola-Kirchhoff stress tensor whose derivative gives the elasticity tensor on the macrolevel. Our particular model for solution-precipitation creep is implemented at the microscale of the multiscale method. The orientation of the representative volume element in each Gauss point is arbitrary, which enables us to simulate randomly inhomogeneous media.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 112

Multiple Scales in Phase Transformations and Transitions

Chair:

Klaus Hackl

13:30	Bartel	H 112

Energy-barriers Due To Nucleation In Solid/solid Phase-transitions

Thorsten Bartel, Klaus Hackl, Institut für Mechanik, Ruhr-Universität Bochum

Within the framework of a micromechanical model for multiphase materials, a numerical method for the prediction of additional energy barriers due to nucleation is presented. It is a well known issue that the stress-strain-relationship of such materials reveals a stress-drop when a phase-transition is initiated. A possible physical interpretation for this phenomenon is the need to overcome an additional energetic barrier in order to form a nucleus which is large enough to enforce the growth of the new phase. The classical theory of nucleation provides formulae to determine the critical radius of the nucleus and an energy barrier respectively, where the shape of the nucleus is assumed to be a sphere. For the purpose of extending these theories by means of being applicable to solid-to-solid phase-transitions we explore the effect of an ellipsoidal inhomogeneity with specified volume and known eigenstrains within a solid matrix. Therefore, a representative volume element (RVE) is discretized spatially by finite elements and the mechanical problem is solved by a multiscale approach. An energy minimization process yields the optimal geometry of the inhomogeneity. The comparison of the total energy of the RVE with and without nucleus lets us draw conclusions about the critical volume of the nucleus and the energy barrier which needs to be overcome in order to initialize the phase-transition.

13:50	Heinen	H 112

A Lamination Upper Bound To The Free Energy Of Shape Memory Alloys

Rainer Heinen, Klaus Hackl, Gregor Kotucha, Thorsten Bartel, Insitut für Mechanik, Ruhr-Universität Bochum

Modeling of the energetic behavior of materials showing martensitic phase transformations usually leads to non-convex energy formulations. In most models based on quasi-convex analysis, the Reuß lower bound, which neglects the compatibility constraint for the deformation fluctuations, is used as an estimate for the so-called energy of mixing.

We present an upper bound that is on the one hand based on the *lamination mixture formula*, which gives an estimate of the free energy of two-variant materials and is extended to the n-variant case in our work. On the other hand, we rely on experimentally well established assumptions about the type of microstructure that forms in such alloys. More precisely, we restrict the set of physically admissible microstructures to the subset of second order laminated microstructres consisting of austenite and twinned martensites. We further refine our upper bound by taking into account the notion of twin-compatibility.

For the physically relevant examples of 13- and 7-variant Cu-Al-Ni shape memory alloys, striking congruence is obtained in the comparison of the Reuß lower and our upper bound for fixed volume fractions. Furthermore, we show different algorithms and their application to the minimization of the energy obtained by each bound over the volume fractions of the variants. Similarities and differences in the energy-minimizing volume fractions are discussed.

14:10	Langhoff	H 112

Energetic Modelling Of Multiphase Materials With Microstructure

Tom-Alexander Langhoff, Eckart Schnack, Universität Karlsruhe (TH)

In recent years, computational mechanics has focused on properties and structures on microscopic length scales. In many materials phase transitions occur as a consequence of thermomechanical loading changing the microstructure and also the macroscopic properties. Energetic models have been developed for a wide range of problems in many of which the energy functionals are no longer convex [Miehe & Lambrecht 2004, Bartels et al. 2004]. Recently the notion of Γ-convergence in connection with problems of homogenisation for multi-scale materials has been used in engineering [Mora & Müller 2003]. For rate independent problems incremental variational formulations have been proposed [Mainik & Mielke 2005]. In this contribution an energetic model for multi-phase materials is developed describing the influence of microstructure on different length scales as well as the evolution of phase changes. Restrictions on this energy functional are discussed. In such a non-convex framework, interfacial contributions serve for relaxing the total energy. Such models can be applied to describe the macroscopic material properties of carbon fibre reinforced carbon where phase transitions between regions of different texture of the carbon matrix are observed on nanoscale as well as columnar microstructures on microscale [de Pauw et al. 2003].

14:30	Schlömerkemper	H 112

About Phase Transformations In Polycrystalline Shape-memory Alloys

Anja Schlömerkemper, Max-Planck-Institut für Mathematik in den Naturwissenschaften

The mathematical modelling of polycrystalline shape-memory alloys faces two major difficulties. One is related to the quasiconvex hull of stress-free minimizers of the free energy in single crystals. The other deals with the passage from single crystalline grains to a complex pattern of polycrystals, which is done by homogenization.

To circumvent the determination of quasiconvex hulls, the geometrically linear theory of elasticity can be used as is done in [1,2]. The mathematical problem of homogenization is replaced by studying bounds, in particular the Sachs bound and the Taylor bound, cf. [1,2].

In this talk I will present examples for stress-induced transformations in polycrystalline shape-memory alloys which are studied on the basis of this approach.

[1] K. Bhattacharya and A. Schlömerkemper, Transformation yield surface of shape-memory alloys, *J. Phys. IV France* **115**, 115-162, 2004
[2] K. Bhattacharya and R. V. Kohn, Elastic Energy Minimization and the Recoverable Strains of Polycrystalline Shape-Memory Materials, *Arch. Rational Mech. Anal.* **139**, 99-180, 1997

14:50	Lenz	H 112

Model And Simulation Of Magnetic Shape-memory Polymer Composites

Martin Lenz, Sergio Conti, Martin Rumpf, Universität Bonn

Ferromagnetic shape-memory materials exhibit comparably large strains in response to an applied magnetic field. For single crystals one can achieve strains of order of magnitude 10%, but in case of polycrystals the effectivity drops significantly as a consequence of the rigidity of interacting grains.

A recently-proposed alternative is that of small single crystal shape-memory particles embedded in a soft polymer matrix. This approach gives a large freedom in the material development, which includes the type of polymer, the density of particles, their shape, and their orientation. The optimization of all these microstructural parameters is still at a preliminary stage, and we aim at providing criteria based on theory and simulation.

We consider a continuous model for such a configuration describing the full range of interactions between elastic and magnetic effects. Aiming for a homogenization approach we study the affine-periodic cell problem.

We develop and use a numerical method for the study of the cell problem in two dimensions. The main ingredients are (i) the boundary element method to compute the elastic and magnetic field energies; (ii) a combinatorial component reflecting the phase transition in the individual particles (which are assumed to be single-domain); (iii) a gradient descent approach for the actual energy minimization. Simulations demonstrate the behavior of the macroscopic material properties for different possible microstructures and give suggestions for the optimization of the composite.

15:10	Nestler	H 112

From Dendritic And Eutectic Solidification To Grain Growth

Britta Nestler, Frank Wendler, Hochschule Karlsruhe Technik und Wirtschaft

Phase transformations in multicomponent and multiphase systems play a major role during solidification processes of a variety of alloys. Using a recently developed phase-field model for multicomponent and multiphase systems, we apply our 3D parallel simulator to numerically investigate dendritic and eutectic phase transitions in Ni- and Al- alloys. In our computations, we show both, the solidification processes leading to the formation of a polycrystalline grain structure and the subsequent process of grain growth.

Concerning dendritic growth into untercooled melts, we compare the simulated dynamics and velocity-undercooling relation for pure nickel with recent experimental measurements and theoretical predictions. Further, we consider the binary dendritic phase tranisition in a Ni-Zr alloy and discuss a comparison between molecular dynamics and phase-field simulations on the scale of nanometers. In ternary Ni-Cu-Cr alloys, a morphological transition from dendritic to globular growth is found by varying the alloy composition at a fixed undercooling. The dependence of the growth velocity and of the impurity segregation in the solid phase on the composition is analyzed and indicates a smooth type of transition between the dendritic and globular structures.

The stability of lamellar eutectic structures in Al-Cu alloys is investigated in 2D and 3D. The possible types of the growth structures: Regular lamellae, rod stuctures and oscillatory patterns are discussed depending on the lamellar spacing, the undercooling and the off-eutectic composition of the melt. On the scale of polycrystals, we present results of grain coarsening and of remelting processes for superheated grain structures.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 112

Effective Constitutive Laws

Chair:

Sergio Conti

16:00	Emmerich	H 112

Improved Constitutional Relations By And For Multiscale Models

Heike Emmerich, RWTH Aachen

Constitutional relations are of great impact in materials modeling: Their accuracy determines to a large extend the accuracy at which the macroscopic behaviour of a material can be described in a respective continuum model approach. Since these constitutional relations themselves are usually determined at the micro- or even nanoscale, they can be understood as a "natural" link between the different scales relevant in materials modelling. In spite of this undeniable impact today's theoretical materials scientists encounter quite often the situation, that 'classical' constitutive relations do longer match our precise understanding of a materials microstructure dynamics, since the latter has increased dramatically due to increased experimental accessibility over the last decade. This contribution reviews this situation in terms of mathematical approaches for several phase transition problems in complex materials. Moreover we demonstrate, how homogenization techniques can be employed to derive improved constitutional relations and use them in turn for improved macroscopic continuum model approaches.

16:20	Eck	H 112

Multiscale Models For Phase Transitions With Microstructures

Christof Eck, Institut für Angewandte Mathematik, Universität Erlangen

Several phase transition problems of technical significance exhibit microstructures; examples are dendritic and eutectic microstructures in alloy solidification and microstructures of spiral or pyramidal shape in epitaxial growth processes for semiconductors. The scale of these microstructures is typically too small to be resolved by a computational grid in a simulation for a sample of a technically relevant macroscopic length scale. In the lecture we review recently obtained homogenized models for applications in alloy solidification and liquid phase epitaxy. In these applications the microstructure is not given a priori but evolves with time; and it is typically different at different macroscopic observation points. The obtained homogenized model typically consists of averaged macroscopic equations and of local microscopic problems for the computation of the microstructure evolution; the latter are given for every macroscopic observation point. The lecture adresses the derivation of the models, their analysis and their numerical realization.

16:40	Biwanski	H 112

Flow Structure In A Technical Scale Reactor With Internal Reboiler

Tomasz Biwanski, Albert Baars, Wojciech Kowalczyk, Antonio Delgado, LFP TU München

In this contribution, results of numerical and optical (LDV) flow investigations in a technical scale cylindrical reactor with internal reboiler are presented. The fluid motion in the kettle is induced by natural circulation. Hereby, the process medium (water) is partially evaporated in the centrally located evaporator. Two different geometrical configurations are considered. First, the liquid level is set above the evaporator outlet. Thus, liquid phase penetrates the liquid surface. The second configuration is characterized by direct injection of the two phase mixture in the bulk liquid. In both cases, the liquid leaves the reboiler radially and horizontally towards the cylindrical wall. At the wall, the jet moves downward. Gathered results reveal a presence of toroidal vortex in the annulus of the kettle due to momentum transfer between jet and bulk liquid. Independently on the implemented boundary conditions, self similarity of the velocity profiles in the near wall region is observed. In contrast, investigations of the momentum transfer between jet and bulk liquid reveal a strong dependency on the geometrical configuration of the setup. This results from the different turbulent flow structures for injection of two phase flow and one phase flow respectively.

17:00	Timofte	H 112

Homogenization Results For Enzymatic Dispersion Processes

Claudia Timofte, Department of Mathematics, University of Bucharest, Romania

The general question which will make the object of this talk is the homogenization of some nonlinear problems arising in the modelling of enzymatic reactions through the exterior of a domain containing periodically distributed reactive obstacles.

The asymptotic behavior of the solution of such a problem is governed by a new elliptic boundary-value problem, with an extra zero-order term that captures the effect of the enzymatic reactions.

17:20	Kaßbohm	H 112

Fourier Series For Continua With Microstructure

Sven Kaßbohm, Wolfgang H. Müller, G. Silber, R. Feßler, Institut für Mechanik, TU Berlin

Based on the idea of the Cosserats at the beginning of the 20th century, Mindlin, Tiersten, Toupin, Rivlin, Green, Trostel et al. developed theories for generalized continua in the 1960s.

Currently, such theories for continua with microstructure are extended in micromechanics, fluid mechanics etc. by various scientists. All such theories follow the same purpose of a more precise material description embedded in a continuum theory.

In the following article, the well-known Cosserat-continuum is used for the calulation of strains and stresses in Representative Volume Elements with arbitrary stiffness distribution and periodic boundary conditions.

Restricting the problem to small displacements and linear elasticity results in linear equations of motion, which can be solved iteratively by means of Fourier Series. It is pointed out, that other types of generalized continua can be analyzed in the same manner.

Results of example problems are presented, and some differences between the classical Boltzmann-continuum and the Cosserat-continuum are pointed out.

17:40	Orlik	H 112

Homogenization For Contact Problems For Hypprosthesis With Periodi

Julia Orlik, Fraunhofer ITWM

We consider the contact of two elastic bodies with rough surfaces in the interface. The size of the micro-peaks and -valleys is very small compared with the macrosize of the bodies' domaines. This makes the direct application of the FEM for the calculation of the contact problem prohibitively costly. A method is developed that allows deriving a macrocontact condition on the interface. The method involves an asymptotic homogenization procedure that takes into account the microgeometry of the interface layer and the stiffnesses of materials of both domaines. The macrocontact condition is then used in a FEM model for the contact problem on the macrolevel. The averaged contact stiffness obtained allows the replacement of the interface layer in the macromodel by the macrocontact condition. The approach is illustrated by the application to the hip-prosthesis-bone contact.

Session 5
Wednesday, March 29, 16:00 - 18:00

Room: H 111

Foundations of Homogenization

Chair:

Patrizio Neff

16:00	Jenny	H 111

Multi-scale Finite-volume Method For Stiff Elliptic Problems

Patrick Jenny, Ivan Lunati, ETH Zürich

Simulation of sub-surface flow in geologically complex formations is just one example in computational science, where efficient and accurate solutions of heterogeneous elliptic problems are of great interest. Often it is not feasible to resolve the whole range of relevant length scales associated with the spatial distribution of the highly varying coefficients, which often are non-linear functions of evolving scalar fields. Recently, we developed a multi-scale finite-volume (MSFV) scheme for multi-phase flow in porous media and applied for many difficult cases. It was demonstrated that the number of degrees of freedom can be reduced dramatically without compromising the accuracy of the solution significantly. The method is based on locally computed basis functions, from which a coarse-scale system is derived. Important properties of the MSFV algorithm are its adaptivity and the ability to reconstruct a high fidelity fine-scale solution.

Here we present the MSFV method in a more general form and show that it can be employed for a broader range of multi-scale problems. We also present its extension for elliptic equations with source terms and show numerical results for gravity driven multi-phase flow in a sub-surface reservoir.

16:20	Schmidt	H 111

Effektive Steifigkeit Von Polymeren Mit Kohlenstoff-nanoröhrchen

Ina Schmidt, Institut für Mechanik, Helmut-Schmidt-Universität

Eine extreme Steifigkeit und Zugfestigkeiten, die das 20-fache der Werte von hochfesten Stählen betragen, prädestinieren Kohlenstoff-Nanoröhrchen für den Einsatz zur Verstärkung von Kunststoffen. Bei gleichem Volumengehalt haben Kohlenstoff-Nanoröhrchen im Vergleich zu Fasern, deren Durchmesser im Mikrometerbereich liegen, wesentlich größere Grenzflächen mit der Matrix. Außerdem sind sie zum Teil in der Lage, die Eigenschaften der sie umgebenden Polymere zu verändern. Dieses führt zu einer weit größeren Beeinflussung der mechanischen Eigenschaften der Verbundwerkstoffe als sich durch gegenwärtig verfügbare mikromechanische Modelle darstellen lässt. Im Vortrag sollen verschiedene Ansätze zur Bestimmung der effektiven Eigenschaften von Kohlenstoff-Nanoröhrchen, die in eine Polymermatrix eingebettet sind, verglichen werden. Ausgehend von in der Literatur verfügbaren Modellen werden die Geometrie der Einschlüsse sowie deren Materialtensor variiert. Die so ermittelten Eigenschaften werden in einem mikromechanischen Modell verwendet, um nach der Mori-Tanaka Methode die effektive Steifigkeit der Verbundwerkstoffe zu berechnen.

16:40	**Schanz**	**H 111**

Effective Frequency Dependent Properties Of Cellular Materials

Martin Schanz, TU Graz
Steffen Alvermann, Institut für Angewandte Mechanik, TU Graz

A numerical homogenization procedure is proposed for the determination of effective properties of cellular structures such as foams or sandwich cores. In the procedure, the unit cell of a periodic microstructure is calculated in frequency domain, taking into account inerta. The frequency response of the cell is used to determine effective properties of the microstructure. Due to inertia, the response of the unit cell is frequency dependent, requiring a freqency dependent macroscopic constitutive equation. Thus, a viscoelastic behavior is assumed on the macroscale. The sought material parameters are found using an optimization procedure, i.e., “find macroscopic material parameters which approximate the microstructure behavior as good as possible”. Since gradient-based optimization procedures can run into local minima, an Evolutionary Strategy is used to solve the optimization problem. A number of microstructures are considered which are modelled as plane truss structures.

17:00	**Miara**	**H 111**

Shape Optimization Of Heterogeneous Phononic Materials

Bernadette Miara, Eduard Rohan, ESIEE, France

We consider the problem of wave propagation in strongly heterogeneous elastic medium, i.e. with large sifferences between the stiffness of the matrix (hard) and that of periodically distributed inclusions (soft). When the size of the inclusions goes to zero we obtain an homogenized model which depends on the frequency of the incident wave. For some values of this incident frequency near to resonance, we show that the so-called homogenized mass density matrix becomes negative.

This implies the existence of band gaps (intervals in which there is no propagating waves) [1]. Numerical simulations in two-dimensional elasticity are presented, they show the influence of the geometry of the microstructure (the shape of the inclusions) and of the mass density of the composite [2]. Based on these observations, we consider the problem of designing a “smart material” as a device which allows for suppressing, or guiding the wave propagation in a (macroscopic) domain of interest. The desired properties of such a material are approached by optimisation of the shape of the inclusion in the reference microscopic cell which determines the microstructure. The sensitivity formulae are given along with the optimality conditions. In particular, we discus the problem of sensitivity of multiple eigenvalues which feature the band gap bounds for a class of symmetric microstructures.

[1] A. Avila, G. Griso, B. Miara. Bandes phononiques interdites en élasticité linéarisée. C. R. Acad. Sci. Paris, Ser. I 340 (2005) 933-938.
[2] A. Avila, G. Griso, B. Miara, E. Rohan. Multi-scale modelling of elastic waves. Theoretical justification and numerical simulation of band gaps. In preparation.

17:20	Timofte	H 111

Homogenization For Rate-independent Systems

Aida-Mirela Timofte, Alexander Mielke, WIAS Berlin

This talk is devoted to the homogenization for a class of rate-independent systems described by the *energetic formulation*. The associated nonlinear partial differential system has periodically oscillating coefficients, but has the form of a standard evolutionary variational inequality. Thus, the model applies to standard linearized elastoplasticity with hardening.

Using the recently developed method of *two-scale convergence* and *periodic unfolding*, we show that the homogenized problem can be represented as a two-scale limit which is again an energetic formulation, but now involving the macroscopic variable in the physical domain as well as the microscopic variable in the periodicity cell.

17:40	Scholz	H 111

From Particle Dynamics To Micropolar Media: A Localization Study

Bernd Scholz, Wolfgang Ehlers, Institut für Angewandte Mechanik, Universität Stuttgart

Granular materials show a complex stress-strain behavior depending on the stress state and the load history. Furthermore, e. g. in biaxial tests, the occurrence of localization phenomena can be observed. For the description of such materials there are two possibilities. On the microscopic level, a mechanical model for the motion of the single grains can be applied in the framework of the *Molecular Dynamics* based on constitutive assumptions for the interaction forces between the single grains. By use of homogenization methods, it is shown that, on the macroscopic level, this corresponds to a micropolar continuum approach (*Cosserat* theory) including the consideration of micro-mechanical grain rotations. This procedure yields additional terms in the balance equations, which are connected with new material parameters.

The intent of the macroscopic model is the solution of real geotechnic boundary-value problems, whereas microscopic particle models are inappropriate for the application of such problems due to the vast number of degrees of freedom.

Session 6
Thursday, March 30, 13:30 - 15:30

Room: H 112

Multiscale Modeling in Metals

Chair:

Christian Miehe

13:30	Levkovitch	H 112

Homogenization Modeling Of Induced Anisotropy In Sheet Metals

Vladislav Levkovitch, Bob Svendsen, Jian Wang, Lehrstuhl für Mechanik, Universität Dortmund

Sheet metal forming involves large strains and severe strain path changes. Large plastic strains lead in many metals to the development of persistent dislocation structures resulting in strong flow anisotropy. This induced anisotropic behavior manifests itself in the case of a strain path change by very different stress-strain responses depending on the mode of the strain path change. While many metals exhibit a drop of the yield stress (Bauschinger effect) after a load reversal, some metals show an increase of the yield stress after an orthogonal strain path change (i.e., so-called cross hardening). To model the Bauschinger effect, kinematic hardening has been successfully used for years. However, the usage of kinematic hardening leads automatically to a drop of the yield stress after an orthogonal strain path change contradicting tests exhibiting the cross hardening effect. So already this example demonstrates that the concept of the combined isotropic-kinematic hardening used in the conventional plasticity has to be extended in order to better simulate processes with complex strain path changes. To this end, texture-based homogenization modeling of the development of polarized dislocation structures on the grain level is proposed in this work. The development and evolution of these structures represent the main cause of the induced flow anisotropy on the macroscopic level. With the help of such micromechanical models, one is able in particular to predict the evolution of the yield surface and in particular its shape (i.e., distortional hardening) at the polycrystalline macroscopic level. This can be used to calibrate effective phenomenological models for use in structure simulations. The capability of the model is demonstrated on sheet forming processes with complex strain path changes.

13:50	Becker	H 112

Micromechanically Motivated Gradient Crystal Plasticity

Martin Becker, *Christian Miehe, Institut für Mechanik im Bauwesen, Universität Stuttgart*

Within crystal plasticity the incorporation of plastic strain gradients into the constitutive relations has a sound micromechanical motivation. However, modern formulations which rely on a continuum theoretical dislocation basis still reveal an ambiguity with respect to the specific incorporation of the gradient measure. While the gradient measure is most commonly related to an incompatibility of the elastic or plastic deformation and thus to the storage of geometrically necessary dislocations, also the precise form of the employed incompatibility measure is not allways congruent. In this contribution first a classification of some recent approaches to strain gradient crystal plasticity will be given which highlights the respective key constitutive assumptions. Thereafter we point out a unified viewpoint of the dislocation density tensor as a mapping. This framework covers various dislocation density tensors, or equivalently incompatibility measures, employed throughout the models in literature and thus aims to direct the choice of the incompatibility measure. Subsequently the dislocation density tensor is equipped with a sound differential geometric as well as micromechanical basis. Finally these considerations are specified for a dislocation density based crystal plasticity formulation. This includes the numerical treatment in a finite element context and a demonstration of the modeling capabilities through comparison with theoretical and experimental observations.

14:10	**Glüge**	**H 112**

Texture Evolution And Swift Effect In Nial

Rainer Glüge, *Thomas Böhlke, Albrecht Bertram, Otto von Guericke Universität*

The texture evolution and the Swift effect in the intermetallic compound NiAl are investigated under free-end torsion at 727 degree Celsius. The material behavior is modeled by an elastic-viscoplastic model. Homogenization has been carried out based on a full-constrained Taylor approach at the Gauss-points of the finite element mesh. In order to overcome the well-known shortcomings of Taylor's approach, the texture evolution is also investigated by a representative volume element with periodic microstructure and periodic boundary conditions. Such a representative volume element takes into account the grain morphology and the grain interaction. The experimental data are provided by Skrotzki et al. [Mater. Sci. Forum., 408-412, 161-167, 2002]. It is shown that the two-scale approach based on the Taylor model describes the texture evolution, the deformation induced anisotropy and the Swift effect in NiAl qualitatively. The modeling of a finite element based RVE leads to a better prediction of the final texture components.

14:30	Hochrainer	H 112

A Self-consistent Theory Of 3d-dislocation Based Plasticity

Thomas Hochrainer, Michael Zaiser, Stefan Sandfeld, Universität Karlsruhe (TH)

The need for physically based continuum theories of plasticity led to a revival of continuum theories of dislocations during the last decade. For simplified systems of straight edge dislocations in a single slip configuration there is a two-dimensional theory available derived by rigorous averaging procedures adapted from the statistical mechanics of interaction particle systems (see e.g.: *Groma et al.* Acta Mater 51 (2003) 1271-1281). Attempts to transfer this method to three-dimensional systems of curved dislocations yet failed due to the lack of a dislcoation density measure able to reflect all dislocations – and not only the geometrically necessary ones – as line like objects.

We define such a dislocation density measure as a differential form on the tangent bundle to the crystal and derive an evolution equation for it as a conservation law. A self-comsistent theory accounting for the long range interactions of dislocations is deduced by assuming overdamped dislocation motion and will be combined with a line tension approximation for the short-range self-interactions. Small numerical examples will illustrate the results.

14:50	Trondl	H 112

3d Fea Of Size Effects In Deformation Of Thin Metallic Films

Andreas Trondl, Dietmar Gross, Leon Mishnaevsky, Norbert Huber, FB Mechanik, TU Darmstadt

The purpose of this work is to analyze size effects in the deformation occurring during nanoindentation-tests of thin metallic films on ceramic substrates.

It is well known that classical phenomenological theories of plasticity are hardly applicable in cases of very small dimensions of a body [1]. Thus, the dependency of the mechanical behavior of thin films on the thickness can not be studied in the framework of classical theories. In order to simulate numerically the deformation, a specific material model has been chosen which is able to account for size effects. It bases on the theory of “Mechanism Strain Gradient” (MSG) plasticity [2] in conjunction with the deformation theory of plasticity. The material model has been implemented via the user defined element subroutine (UEL) in the commercial FE code ABAQUS/Standard as a ten-node tetrahedron-element. With the developed subroutine the deformation of thin copper films on Si substrates during nanoindentation-tests has been simulated. Different material models of the indentor (rigid and elastic) as well as different friction conditions between the film and the pyramidal indentor were tested. Furthermore, the influence of an additional oxide layer on the films surface has been analysed.

In order to verify the numerical investigations, results from nanoindentation experiments have been used for comparison [3]. The FE simulations for different thicknesses in the range of 100-600nm showed a very good agreement with the experiments. In particular, the size dependency of the force-displacement curves, calculated by using the developed subroutine, is in rather good agreement with experiments.

[1] L. Mishnaevsky J, D. Gross, Micromechanisms and Mechanics of Damage and Fracture in Thin Film/Substrate Systems, *International Applied Mechanics*, Vol. 40, No. 2, pp.33-51
[2] H. Gao, Y. Huang, W.D. Nix, J.W. Hutchinson, Mechanism-based strain gradient plasticity I. Theory, *J. Mech. Phys. Solids (1999)*, Vol. 47, pp. 1239-1263
[3] N. Huber, W. Schwan, Ermittlung der mechanischen Eigenschaften von Cu-Schichten auf Si-Substrat, Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft, *Bericht IMF II (35008679)*, 2004

15:10	Chen	H 112

Local Deformation Behavior And Crystallographic Texture Evolution

Yanling Chen, Thomas Böhlke, Albrecht Bertram, Institut für Mechanik, Otto-von-Guericke-Universität

We consider two-phase composites consisting of polycrystalline iron and copper particles. The composites under consideration are produced from mixtures of iron and copper powders. The phase volume fractions vary between zero and one. Due to the large difference of the yield stress of the two phases - which also have a different slip system geometry - the deformation field is highly heterogeneous. For example for a high volume fraction of copper the soft copper phase flows around the iron particles, which are much less deformed compared to the copper phase. Due to the high heterogeneity of the deformation field the Taylor model is generally unable to predict any variation of the texture evolution with the phase volume fraction. In order to obtain better numerical predictions of the crystallographic texture evolution, a finite element based representative volume element with periodic boundary conditions is used for the texture simulation. The microstructure is modeled as a Poisson-Voronoi mosaic. The material parameters are determined based on data from an experimental compression test. Both the crystallographic and the morphological texture evolution are discussed. Special emphasis is given to the prediction of the strain distribution in both phases. The correspondence of the numerical and the experimental data is shown.

Session 7
Thursday, March 30, 13:30 - 15:30

Room: H 111

Passage from Discrete to Continuum Models

Chair:

Hannes Uecker

13:30	Giannoulis	H 111

Three-wave Interaction In Discrete Lattices

Johannes Giannoulis, WIAS Berlin

We consider the interaction of three pulses in a multidimensional monoatomic lattice $\mathbb{Z}^d$, $d \in \mathbb{N}$. The scalar displacement $x_\gamma \in \mathbb{R}$ of each atom $\gamma \in \mathbb{Z}^d$ is described by Newtons equations of motion

$$\ddot{x}_\gamma = \sum_{\alpha \in \mathbb{Z}^d} V'_\alpha(x_{\gamma+\alpha} - x_\gamma) - W'(x_\gamma), \tag{1}$$

where V_α is a general pairwise-interaction potential between atoms at a mutual distance $\alpha \in \mathbb{Z}^d$ and W is a general external potential.

We model the pulses as macroscopic (small-)amplitude modulations of three plane-wave solutions to the linearization of (1)

$$\begin{aligned} x_\gamma(t) =& \varepsilon \sum_{j=1}^{3} A_j(\varepsilon t, \varepsilon\gamma) \mathrm{e}^{\mathrm{i}(\omega_j t + \vartheta_j \cdot \gamma)} \\ & + \text{complex conjugate} + \mathcal{O}(\varepsilon^2), \end{aligned}$$

with $0 < \varepsilon \ll 1$, which are in resonance: $\omega_1 + \omega_2 + \omega_3 = 0$ and $\vartheta_1 + \vartheta_2 + \vartheta_3 = 0$. In this case, we formally derive as a macroscopic limit a system of three nonlinearly coupled equations *(three-wave-interaction equations)*, which describe the macroscopic evolution of the amplitudes A_j, $j = 1, 2, 3$. Our main objective is the mathematically rigorous justification of the validity of this macroscopic limit.

13:50	Schmidt	H 111

On The Passage From Atomic To Continuum Theory For Thin Films

Bernd Schmidt, Max-Planck-Institut für Mathematik in den Naturwissenschaften

We give a rigorous derivation of continuum theory from atomic models for thin films as proposed by Friesecke and James in [JMPS 48 (2000)]. The resulting continuum energy expression is obtained by integrating a stored energy density which not only depends on the deformation gradient but also on $\nu - 1$ director fields when ν is the (fixed) number of atomic film layers.

14:10	**Patz**	**H 111**

Dispersive And Long-time Behavior Of Oscillations In Lattices

Carsten Patz, CERMICS, France
Alexander Mielke, WIAS Berlin

We study the long-time dynamics of oscillations in lattices of infinitely many particles interacting via harmonic springs. After recapitulating the results of an infinite chain with nearest-neighbour interaction, we highlight the differences to the case of next-nearest-neighbour interaction.

Given compactly supported initial conditions, the energy distribution is explained using numerical simulations. Decay rates for the displacements and velocities are proved analytically applying methods for oscillatory integrals. Using different scalings the asymptotic energy distribution is described globally as well as resolved locally near the wave fronts.

Finally we will also discuss the two dimensional lattice with nearest-neigbour interaction where more complicated singularities occur.

14:30	**Rademacher**	**H 111**

Towards Macro-limits Of Riemann Problems In Atomic Chains

Jens Rademacher, Michael Herrmann, Wolfgang Dreyer, WIAS Berlin

We consider Riemann problems for hyperbolic macroscopic limits of chains of nearest neighbor coupled particles in a convex non-harmonic potential. For shock initial conditions, the arising oscillations can be described formally by modulated travelling waves. Motivated by numerical experiments, we discuss the shock structure in terms of the geometry of these waves and differences to the case of harmonic potentials.

14:50	**Andrianov**	**H 111**

Continuous Models For Discrete Media For Higher-frequency Domain

Igor Andrianov, RWTH Aachen

The paper focuses on 1D and 2D continuous models derived from a discrete microstructure. A new continualization procedure that takes into account the non-local interaction between variables of the discrete media and of the continuous model is proposed [1, 2]. The proposed procedure mainly contains an application of two-point Padé approximants and allows obtaining continuous models suitable to analyze 1D and 2D lattice vibrations with arbitrary frequencies.

[1] I.V. Andrianov, The special feature of limiting transition from a discrete elastic media to a continuous one. PMM, J. Appl. Math. Mech., 2002, vol. 66, No 2, 261-265.
[2] I.V. Andrianov, J. Awrejcewicz, Continuous models for chain of inertially linked masses, Eur. J. Mech A/Solids, 2005, vol. 24, 532-536.

15:10	Mielke	H 111

Lagrangian And Hamiltonian Structures For Modulation Equations

Alexander Mielke, Johannes Giannoulis, WIAS Berlin

We consider Hamiltonian wave equations as well as discrete lattice systems with Hamiltonian structure. Modulation equations are usually derived by inserting an ansatz of the form

$$u(t,x) = \varepsilon^{\alpha} U(\varepsilon^{\beta} t, \varepsilon(x+ct)) \mathrm{e}^{\mathrm{i}(\omega t+\theta x)} + \text{c.c.}$$

into the original equation and equating to 0 terms of equal powers of ε and $\mathrm{e}^{\mathrm{i}(\omega t+\theta x)}$. The arising modulation equations for U may be seen as macroscopic evolution equations on the slow time scale $\tau = \varepsilon^{\alpha} t$ and the large spatial scale $\xi = \varepsilon(x+ct)$. Typical equations are the Korteweg-de Vries equation, the nonlinear Schrödinger equation or nonlinear transport equations. The justification of this procedure is a very active area of ongoing research, but will not be addressed here.

Instead we ask the question in what sense the modulation equations inherit the Hamiltonian and Lagrangian structures from the original problem. It turns out that in many cases the Lagrangian reduction works nicely but the Hamiltonian reduction is more involved and leads to a different conserved quantity.

Session 8
Thursday, March 30, 16:00 - 18:00

Room: H 112

Homogenization of Composites

Chair:

Martin Becker

16:00	Kästner	H 112

Homogenisation Of Fibre Composites Using X-fem

Markus Kästner, Volker Ulbricht, Institut für Festkörpermechanik, TU Dresden

A successful material design process for novel textile reinforced composites requires an integrated simulation of the material behaviour and the estimation of the effective properties used in a macroscopic structural analysis.

In this context the Extended Finite Element Method (X-FEM) is used to model the behavior of materials that show a complex structure on the mesoscale efficiently. Here the focus is set on composites made of glass fibres and thermoplastic matrices and on the application to commingled thermoplastic and glass fibres. Homogenisation techniques are applied to compute effective macroscopic stiffness parameters.

Starting with the choice of a suitable enrichment function the first part of this contribution gives an outline of the implementation of the X-FEM for complex multi-material structures. A modelling procedure is presented that allows for the automated generation of an extended finite element model for a specific representative volume element.

Furthermore, the problem of branching material interfaces arising from complex textile reinforcement architectures, e.g. bi- or multi-axial or woven fabrics, in combination with high fibre volume fractions will be addressed and appropriate solutions are proposed.

Finally, the obtained results are verified and critically evaluated.

16:20	Birkle	H 112

On Variational Based Scale-bridging Of Inelastic Composites

Manuel Birkle, Ercan Gürses, Christian Miehe, Institut für Mechanik, Universität Stuttgart

The lecture discusses a theoretical and numerical framework of the homogenization for composites with possible development of discontinuities. We focus on multi-phase microstructures of heterogeneous materials, where discontinuities may occur in the form of debonding mechanisms as well as matrix cracking. The approach developed provides a basis for understanding the micromechanical mechanisms of macroscopic damage in composites. The definition of overall properties of discontinuous microstructures critically depends on the developing discontinuities. Thus, we extended recently developed incremental variational formulations of homogenization for continuous microstructures to microstructures with discontinuities. The basic underlying structure is a canonical variational setting in the fully nonlinear range based on incremental energy minimization. We develop algorithms for numerical homogenization of composite solids in a deformation-driven context with non-trivial formulations of boundary conditions for (i) linear deformation, (ii) uniform tractions and (iii) periodic deformations. Finally, overall stability problems of the microstructures due to the development of discontinuities are investigated.

16:40	Köster	H 112

A Micromechanical Damage Model For Fibre Reinforced Composites

Benjamin Köster, Anton Matzenmiller, Universität Kassel

The numerical analysis of engineering structures is usually based upon the assumption of a homogeneous as well as a continuous medium. The supposition of the macroscopic homogeneity is maintained for fibre reinforced composite structures which possess by definition a heterogeneous finescale architecture. The constitutive behaviour is described in terms of volume averaged quantities that smear the heterogeneities of the microscale. The evolution of the non-isotropic damage within the different layers of laminated structures is microscopically caused by void nucleations like the debonding of the embedded fibres, the growth of microcracks inside the matrix phase or the breakage of the fibres. Since the development of damage depends on the local loading history, the effective tangential stiffness tensor varies in time for different material points on the macroscale. The analysis of composite structures is executed by applying a twoscale approach. The average material properties, needed for the macroscale finite element simulations, are obtained by modelling the discontinuous and damaged microstructure based on the concept of the representative volume element. The *Generalized Method of Cells* (GMC) is used in order to discretise the representative volume element and to compute the process depending tangential constitutive tensor as well as the average stress response in a closed form manner for each integration point individually. The homogenization algorithm of the GMC is run simultaneously to the nonlinear finite element analysis.

17:00	Danishevskyy	H 112

Effects Of Interphases In Fibre-reinforced Composite Materials

Vladyslav Danishevskyy, Vladimir Bolshakov, Prydniprovska State Academy of Civil Engineering and Architecture, Ukraine

Interphases represented by thin coating layers between constitutive components play an important role in functionality and reliability of composite materials. The optimal utilization of the strength and stiffness of composites primary depends on efficient load transfers from a matrix to inclusions undergoing through these interphases. In many instances the interphases appear to be the regions of the highest concentration of local stresses. Then the interphases' strength and properties become the crucial factors determining the overall behaviour of the material. We propose a new asymptotic approach for prediction of effective elastic moduli and for determination of local stresses in periodic composite materials taking into account the micromechanical effects of interphases. Problems of the longitudinal tension and of the longitudinal shear of fibre-reinforced composites with square and hexagonal arrays of cylindrical inclusions are considered. Performed analysis is based on the asymptotic homogenization method; cell problems are solved using the underlying principles of the boundary shape perturbation technique. Obtained approximate analytical solutions are valid for all values of the components' volume fractions and properties. In particular, they work well in cases of rapid oscillations of the stress field on micro level, while many of other commonly used methods may face computational difficulties.

17:20	Haasemann	H 112

On The Simulation Of Textile Reinforced Composites And Structures

Georg Haasemann, Volker Ulbricht, Institut für Festkörpermechanik, TU Dresden

This contribution presents experimental and numerical methods to perform simulations of the mechanical behavior of textile reinforced composites and structures. For these investigations the focus is set on materials composed of multiaxial weft-knitted glass fibers and thermoset matrix.

The first aspect considered refers to the meso-to-macro transition in the frame work of the finite element method. Regarding an effective modeling strategy the Binary Model is used to represent the discretized complex architecture of the composite. To simulate the locale response and to compute the macroscopic stress and stiffness undergoing small strain a user routine is developed. The results are transfered to the macroscopic model during the solution process.

The second aspect concerns the configuration of the fiber orientation and textile shear deformation in complex structural components. These deformations are affected by e.g. the manufacturing process. A three-dimensional optical measurement system is used to determine the surface geometry and the configuration of a textile preform. The data are assigned to the macroscopic finite element model to define the mechanical properties.

17:40	Kreikemeier	H 112

Investigation, Modelling And Analysis Of Stiffened Gfrp-samples

Janko Kreikemeier, Karl-Heinz Gröbel, Harald Berger, Ulrich Gabbert, Otto-von-Guericke-Universität

The paper deals with the experimental estimation as well as the numerical calculation of overall material properties of special types of glass fibre composite (GFC) samples reinforced with stiffeners and manufactured by autoclave technology. At first the effective properties of the GFC were calculated analytically as well as numerically by applying three different types of representative volume elements and compared with measurements. The properties of the commercially available stiffeners in form of thin glass fibre rods were taken from the technical data sheets of the manufacturer and evaluated as well with experimental results from tension and bending tests. Finally, the effective material properties are used in the finite element modelling and analysis of the reinforced samples. The numerical results were again compared with measurements, e.g. with three point bending tests. In the paper the results will be presented in detail and the advantage of the special reinforcing technique with single rod type stiffeners is discussed.

9 Turbulence and reactive flows

Organizers:

Christian O. Paschereit, TU Berlin
Dominique Thevenin, Otto-von-Guericke-Universität Magdeburg

Frank Thiele, Hermann-Föttinger-Institut für Strömungsmechanik

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 2035

Chemical Engineering and Applications

Chair:

C. O. Paschereit

13:30	Donescu	H 2035

The Motion Of A Micropolar Fluid In Inclined Open Channels

Stefania Donescu, Technical University of Civil Engineering, Romania

In a micropolar fluid the motion is described not only by a deformation but also by a micro-rotation giving six degree of freedom. The interaction between parts of the fluid is transmitted not only by a force but also by a torque, resulting in asymmetric stresses and couple stresses. The theory of hydro-dynamic turbulence is still lacking a fundamental theory from which the physical phenomena can be predicted and understood. The micropolar theory is employed in this contribution to obtain solutions which are periodic with respect to distance, describing the phenomenon called "roll-waves" for water flow along a wide inclined channel and to discuss the behavior of the solutions. In this work we study the turbulent flow of a micropolar fluid in a wide channel inclined at different angles below the horizontal, by using the theory of solitons. The wave profile moves downstream as a linear superposition of solitons at a constant speed and without distortion. The model parameters are determined by using a genetic algorithm.

13:50	Javurek	H 2035

Oscillation Of Confined Jets In Continuous Casting Mold Flow

Mirko Javurek, Institut für Strömungslehre und Wärmeübertragung, Universität Linz
Raimund Wincor, Markus Brummayer, voestalpine Linz

In continuous slab casting, the liquid steel is introduced into the mold via a submergered entry nozzle. This nozzle usually has two opposed orifices on its side walls, generating two diametrically opposed turbulent jets that are declined about 20° to the horizontal axis. These jets interact with the surrounding walls of the mold, which leads to an unstable flow situation and a self induced oscillation of the jets. Although both mold and nozzle geometry have two perpendicular symmetry planes, the oscillations are asymmetric. The fluid flow inside the mold is calculated with a 3D finite volume solver using turbulence models based on Reynolds-averaging. The massflow of the jets and the mould extensions are varied, and the numerical results are partially compared with PIV-measurements at a 1:1 scaled watermodel of the mould.

14:10	Schlauch	H 2035

Numerical Simulation Of Stirred Liquid-liquid Systems

Sonja Schlauch, Institut für Mathematik, TU Berlin

The numerical simulation of drop size distributions in stirred liquid-liquid systems requires on the one hand the simulation of the flow field in a stirred tank and on the other hand the calculation of population dynamical processes. These processes, in the considered application coalescence and breakage, describe how the number and the sizes of the drops in the dispersed phase change with time.

In the presented approach, the (Reynolds-averaged) Navier-Stokes equations (with k-ε turbulence model), describing the turbulent flow in the stirred tank, are solved with a CFD code and the population balance equation, accounting for coalescence and breakage of the drops, is simulated with a population balance solver. The coupling of the two solvers is realized as a one-way coupling, i. e. the results of the CFD simulation are used for the calculation of the population dynamical processes.

In this talk, we will explain how the coupling is realized, motivate why this type of coupling was chosen, and present simulation results. However, we will also discuss arising problems and risks of simulator coupling.

14:30	Schumacher	H 2035

Statistics And Geometry In High-schmidt Number Scalar Mixing

Jörg Schumacher, Fakultät für Maschinenbau, TU Ilmenau
Dan Kushnir, Achi Brandt, Weizmann Inst. of Science, Israel
Katepalli R. Sreenivasan, Int. Centre of Theoretical Physics, Italy

Using well resolved direct numerical simulations (DNS) with grid sizes of up to 1024^3 points, we explore geometrical and statistical properties of passive scalar fields. The advecting turbulence is homogeneous and isotropic and is maintained stationary by stochastic forcing at low wavenumbers. The passive scalars are maintained stationary by a mean scalar gradient in one direction. The strong resolution requirements results in rather low Taylor microscale Reynolds numbers ($R_\lambda \leq 63$) of the advecting flow. The Schmidt numbers vary between 2, 8 and 32.

We report results on the probability density function (PDF), the conditional probability density function and the multifractal properties of the scalar dissipation rate. A result of primary interest is that the scalar dissipation shows considerable deviations from lognormality, which exceed those previously reported. The tails of the PDF can be fit with a stretched exponential for all Schmidt numbers studied here. We also study the effects of coarse-graining on the probability density to simulate the effects of poor probe-resolution in measurements.

Regions of the most intensive scalar dissipation are organized in thin and curved sheets. Their shape and internal structure is analysed by a fast multiscale clustering algorithm. The algorithm allows to separate the structures of each other and to apply a local principal component analysis. The resulting cross-section thickness is distributed over the whole viscous-convective Batchelor range. Only a small number of the sheets have a thickness that comes close to the Batchelor scale, which is the finest scale in the turbulent mixing process. The most probable sheet thickness is found to scale with $Sc^{-1/2}$ for fixed Reynolds number and with $R_\lambda^{-3/2}$ for fixed Schmidt number. We relate the thickness distribution to the statistics of the contraction rates of the flow which is measured by the smallest finite-time Lyapunov exponent.

14:50	Shalaby	H 2035

Particle-laden Flow Simulation In A Cyclone Separator

Hemdan Shalaby, K. Wozniak, G. Wozniak, Universität Magdeburg

The gas flow of a cyclone separator for industrial applications at a Reynolds number of Re = 140000 has been calculated numerically. Due to the nature of cyclone flows, which exhibit highly curved streamlines and anisotropic turbulence, we used the advanced turbulence model Large Eddy Simulation (LES). LES reveals qualitative agreement with the experimental data, however, it requires higher computer capacity and longer running times compared to other turbulence models. The results of the continuous phase flow computations were first generated and served as a basis for modeling the behavior of the solid particles in the separator. The modeling of the solid particle motion in the cyclone is based on a one-way coupling between the gas flow field and the particles. The cyclone separation efficiency and particle trajectories have been studied in detail. The separation efficiency results show satisfying agreement between LES data and experimental results. It turned out that the particle cut-off diameter for a particle material density of 2500 kg/m3 is about 1.3 micro meter.

15:10	Streng	H 2035

Analyse Eines Flotationsprozesses

Mario Streng, Olaf Wünsch, Universität Kassel

Der Flotationsprozess ist ein mechanischer Trennvorgang, der v. a. in der Verfahrenstechnik Anwendung findet. Seine Aufgabe besteht darin, Feststoffpartikel aus einer wässrigen Lösung abzutrennen. Dazu werden diese chemisch aufbereitet, damit sie sich an Gasblasen anlagern und in der Suspension aufsteigen. Der Vorgang erfolgt i. d. R. in Rührapparaten mit integriertem Rotor-Stator-System. Zur Optimierung des Prozesses ist die Analyse der instationären, mehrdimensionalen und turbulenten Strömungsvorgänge in Abhängigkeit verschiedener Einflußparameter wie Geometrie, *Re*-Zahl oder Partikelbeladung notwendig.

Die numerische Berechnung des Geschwindigkeitsfelds erfolgt anhand bewegter Netze mit einem kommerziellen CFD-Programm auf Basis einer Finite-Volumen-Methode. Unter Annahme eines geringen Volumenanteils der diskreten Phase lassen sich deren Bahnlinien relativ leicht verfolgen.

In diesem Vortrag werden das numerische Modell sowie erste Ergebnisse in Form von ausgewählten Konturplots für das Druck- und Geschwindigkeitsfeld präsentiert. Weiterhin wird die Abhängigkeit des Prozesses von den Einflussgrößen mittels typischer Bahnlinien und Kennzahlen diskutiert.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 2035

RANS and boundary layer

Chair:

F. Thiele

16:00	Chernykh	H 2035

Swirling Turbulent Wake Behind A Self-propelled Body

Gennadi Chernykh, A. Demenkov, V. Kostomakha, Institute of Computational Technologies, Russia

The development of the swirling turbulent axisymmetric wake of a self-propelled body is modeled numerically. The flow pattern is calculated within the framework of the thin shear layer approach for nonclosed system of the motion and continuity equations. The closed system of equations is written for two different formulations of the closure relations, based on Rodi's nonequilibrium relationships. The numerical solution of the problem is performed with the use of the finite-difference algorithm realised on moving grids. The algorithm is conservative with respect to the laws of conservation of the momentum and the angular momentum. The experimentally measured distributions are used as the initial conditions. Both the models described agree well with the experimental data of Gavrilov et al. (2000). It is demonstrated that at the large distances downstream from the body the solution of the problem approaches the self-similar one. The simplified mathematical flow models were constructed.

1.Gavrilov, N., Demenkov, A., Kostomakha, V. and Chernykh, G. (2000) Experimental and numerical modelling of turbulent wake behind self-propelled body, J. of Appl. Mech. and Tech. Phys., No. 4, 619-627.
2.Vasiliev O.F., Demenkov A.G., Kostomakha V.A.,Chernykh G.G. Numerical simulation of swirling turbulent wake behind self-propelled body. Physics- Doklady of Russian Academy of Sciences ,2001, No. 1, pp. 52-55.
3. Chernykh G.G., Demenkov A.G., Kostomakha V.A. Numerical modelling of swirling turbulent wake past self-propelled body, Russ. J. Numer. Anal. Math. Modelling, VSP, Netherlands, 2001, Vol. 16, No. 1, pp. 19-32.
4. Chernykh G.G, Demenkov A.G., Kostomakha V.A. Swirling turbulent wake behind a self-propelled body. Int. J. of Computational Fluid Dynamics. 2005 (in press).

16:20	Hölling	H 2035

Using Laser-cantilever Anemometry Under Various Flow Condition

Michael Hölling, Stephan Barth, Joachim Peinke, Jean-Daniel Rüedi, Carl von Ossietzky Universität Oldenburg

We present measurements executed with the new laser-cantilever anemometer (LCA) under various flow conditions. Previously, the basic principles and characteristics of the LCA were investigated. Measurements led to results comparable to common measurement techniques for turbulent flows, such as hot-wire anemometry for air and hot-film anemometry for water. Here we present further experiments under various flow conditions. The LCA was used in a snow wind tunnel to investigate the behavior of the cantilever under particle impact. In comparison to data collected with a hot-film anemometer under same conditions the times series of the LCA showed less pronounced impact characteristics than that of the hot-film, namely a shorter and easier to identify recovery time. In addition the behavior of the LCA at low velocities in air was investigated to determine the threshold velocity for measurements.

16:40	Kudinov	H 2035

Compressible Flows Simulation On Multiblock Unstructured Grids

Pavel Kudinov, Valentyna Yericheva, Dnepropetrovsk National University, Ukraine

In the work numerical methods for simulation of heat and mass transfer problems on multiblock unstructured grids are presented. For simulation of turbulent flows Reynolds averaged Navier-Stokes equations are used. The equations are enclosed by one-equation turbulence model of Spallart-Almaras or two-equation SST model of F.Menter.

The combination of frontal methods and domain triangulation algorithms for hybrid unstructured grids generation in complex domains is presented and discussed.

Validation of numerical algorithms was carried out on a series of test problems with known experimental data (interaction of laminar and turbulent boundary layers with a oblique shock wave). Detailed comparison of turbulence models was carried out on problems about flow around profile RAE2822 and NACA0012.

Numerical simulation of flow in compressor's and turbine's cascades was done. The satisfactory coincidence of computational and experimental data is shown. Analysis of three dimensional flow structures was carried out. Unsteady interection of several compressor stages with moving rotors was studied.

Behavior of aerodynamics characteristics and flow structure for the high speed transport vehicle was studied for the wide range of heights above the ground surface and Mach numbers. Strong non-linear and non-monotone influence of ground effect was obtained.

17:00	Schwarze	H 2035

Performance And Limitations Of The Unsteady Rans Approach

Rüdiger Schwarze, Frank Obermeier, Institut für Mechanik und Fluiddynamik, TU Bergakademie Freiberg

Turbulent flows in complex geometries often exhibit an oscillating behavior of large coherent structures, even in the case of steady state boundary conditions. Recently, numerous efforts have been made to resolve these oscillations by means of numerical simulations. Unfortunately, large-eddy simulations are often very time- and memory-consuming in the case of complex flows. Therefore, the unsteady RANS (URANS) approach is an attractive alternative, especially when numerical simulations are used as a design and optimization tool.

Here, three complex flow situations are presented: (i) a jet in a crossflow, (ii) the tundish flow, and (iii) the mold flow. For these flows, relationships between the Strouhal number and important flow parameters are known from experiments. In the paper, URANS models are applied to resolve those relationships also numerically. The evaluation of the numerical results demonstrates the abilities and the limitations of the URANS approach when resolving the dynamics of large coherent structures in complex flows.

17:20	Vigdorovich	H 2035

Turbulent Boundary Layer On A Flat Plate With Suction

Igor Vigdorovich, Central Institute of Aviation Motors, Moscow, Russia

A closure condition is derived for turbulent boundary layer flow over a flat plate with suction in the form of a universal relation between shear stress and mean velocity gradient. This relation is determined by using only one empirical function: the velocity profile in the turbulent boundary layer flow over an impermeable flat plate.

As a result, the distributions of velocity, shear stress, and skin friction are calculated in the entire range of parameters under very general physical assumptions without invoking any special closure hypotheses.

The developed theory permits to calculate the rms velocity fluctuation which can be performed by using only the corresponding distributions for the flow over an impermeable plate.

Universal distributions of mean velocity, shear stress, and rms transverse velocity fluctuation are obtained for the near-wall region of the boundary layer. The distributions of these quantities outside the viscous sublayer represented in terms of scaling variables are described by a one-parameter family of curves.

The Reynolds stress components associated with streamwise and spanwise velocity fluctuations also obey one-parameter scaling laws in the outer region of the boundary layer. There exists a near-wall region where both square root of shear stress and rms transverse velocity fluctuation are proportional to the logarithm of the distance from the wall, while the rms streamwise and spanwise velocity fluctuations scale with the logarithm to the power 3/2.

The skin-friction distribution is described by a single scaling curve for flows with arbitrary suction velocities at various Reynolds numbers.

17:40	Zanoun	H 2035

Mean Flow Properties In Smooth Pipe Flow Experiment

El-Sayed Zanoun, Franz Durst, Christoph Egbers, Lothar Jehring, BTU Cottbus

Recently, a number of publications resulted out of investigating fully developed turbulent pipe flows, yielding a conviction that the mean flow properties of such flows are fully understood. This is not the case, since a controversy discussion regarding the pipe friction factor and normalized form of the mean velocity distribution of such flows still exists. The main aim of the present paper is therefore to provide good basis to assess the validity of the functional form of the law of the wall and its parameters dependence on both Reynolds number (Re) and wall friction data. It is concluded that to obtain reliable wall friction and mean velocity data to remedy the unsatisfactory information available, the following requirements must be fulfilled:

- Choosing pipe test section with highly smooth surface to avoid the transitional roughness effect, in particular, at high Re for hydrodynamically smooth pipe flow experiments.
- Velocity measurements have to be performed with measuring techniques that provide high spatial resolutions to yield local flow information.
- Shear stress measurements must be carried out with high care independently from the mean velocity and the data must be averaged over high enough number of statistically independent measurements.
- Precise wall-distance measuring approach is of big importance to minimize wall distance uncertainty.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 2035

Turbulence and two-phase flows

Chair:

D. Thevenin

13:30	Henniger	H 2035

Les Of Particle Settling In Homogeneous Turbulence

Rolf Henniger, Thorsten Bosse, Leonhard Kleiser, Institut für Fluiddynamik, ETH Zürich

The dynamics of small particles in a turbulent flow is important for the understanding of a variety of natural phenomena and engineering applications involving two-phase flows, e.g. in the chemical and pharmaceutical industries. The focus of our investigation is on the prediction of the mean settling velocity of microparticles in homogeneous turbulence using a large-eddy simulation (LES) approach. As our previous direct numerical simulations (DNS) and recent experimental findings (Aliseda et al., JFM 468, 2002; Yang and Shy, JFM 526, 2005) have shown, this issue is still unresolved. We intend to perform direct comparisons of our LES study with the experimental data at microscale Reynolds numbers of a few hundred. The particulate phase is modeled in a Lagrangian way using the point-particle approximation. The interaction between particles and fluid is ensured by assuming two-way coupling, i.e. a mutual exchange of momentum. The fluid equations are solved by a pseudo-spectral method. Different subgrid-scale models will be employed to account for the unresolved part of the small-scale fluid motion. The LES results for the preferential accumulation and the settling velocity of the particles will be assessed in comparison with both DNS at lower Reynolds number and experimental results.

13:50	Jocksch	H 2035

Exergetic Aspects Of Turbulent High-speed Boundary Layers

Andreas Jocksch, Leonhard Kleiser, Institut für Fluiddynamik, ETH Zürich

Exergy is classically defined as the maximum available work in equilibrium systems and its destruction is proportional to the entropy production. The extension to systems with local equilibrium (S. Karlsson. Energy, Entropy and Exergy in the Atmosphere. PhD Thesis, Chalmers University of Technology, Göteborg, 1990) is used here to analyse the energy budgets of laminar and turbulent high-speed boundary layers. In addition, turbulent spots in a laminar boundary layer are considered. The dissipation of kinetic energy heats up the flow close to the wall. For high-speed boundary layers an appreciable amount of the thermal energy generated is exergy and possibly can be reconverted into kinetic energy in accordance with the second law. We quantify the loss of kinetic energy and exergy destruction by the corresponding dissipation and exergy thicknesses which depend on Mach number. The region in which entropy is generated is identified and the corresponding turbulent exchange processes are described.

14:10	Kubik	H 2035

Influence Of Mass Loading On Particle-laden Turbulent Channel Flow

Anna Kubik, Leonhard Kleiser, Institut für Fluiddynamik, ETH Zürich

The behavior of particle-laden gases in a channel flow is studied at moderate Reynolds number. Effects of the mass loading on the dispersion and velocity statistics of the particles are investigated by direct numerical simulations that include the effects of particle feedback on the gas phase. The resolution of the simulation is comparable to the smallest scales in the corresponding particle-free flow and the grid spacings are much larger than the particle size. Both elastic and inelastic collisions at the wall, deposition, and influence of the wall on the particle forces are taken into account. In this study only dilute flows (low volume fraction of the particles) are considered. Particle-particle collisions for this kind of flows are generally not significant and can be neglected.

Besides the influence of the mass loading parameter on the results, the impact of the employed model for wall-particle interaction is shown to be crucial to particle dispersion and to the concentration in the channel which is highly anisotropic. The tendency of particles to accumulate near the wall and in regions of lower turbulence intensity gives rise to regions of particle concentration vastly higher than the average. Besides statistical data, local and instantaneous quantities are examined. It could be shown that the local increase in particle number does not invalidate the assumption of low incidence of particle-particle collisions.

14:30	Marheineke	H 2035

Fiber Dynamics In Turbulent Flows – Mathematical Modeling Concept

Nicole Marheineke, Raimund Wegener, Fraunhofer-Institut für Techno- und Wirtschaftsmathematik

This work deals with the modeling of turbulence effects on the dynamics of a long slender elastic fiber. Independent of the choice of the drag model, a general aerodynamic force concept is derived on the basis of the velocity field for the randomly fluctuating component of the flow. Its construction as centered differentiable Gaussian field complies thereby with the requirements of the stochastic k-ϵ turbulence model and Kolmogorov's universal equilibrium theory on local isotropy. The turbulence effects on the fiber motion are particularly modeled by a correlated random Gaussian force and in its asymptotic limit on a macroscopic fiber scale by Gaussian white noise with flow-dependent amplitude. Quantitative similiarity estimates and numerical comparisons of the correlated and uncorrelated force effects on the fiber are provided for the concrete choice of a Taylor drag model in the application of a melt-spinning process of nonwoven materials. The simulation of the melt-spinning process by using the developed aerodynamic force model yields very promising results in comparison to the experimental data.

14:50	Stresing	H 2035

Longitudinal And Transversal Two-point Correlations In Turbulence

Robert Stresing, Stephan Barth, Joachim Peinke, Institut für Physik, Universität Oldenburg

Based on measurements with x-wire anemometers in a fully developed turbulent flow we investigate different aspects of longitudinal and transversal two-point correlations. In particular we use the Taylor hypothesis of "frozen turbulence" as well as simultaneous measurements with two x-wires, and investigate how the correlations change with the relative orientation of their distance vector with respect to the mean flow direction. These experiments are designed to find evidence of anisotropy and/or deviations from the Taylor hypothesis in fully developed turbulent flows. We analyze the data using increment statistics and perform a stochastic analysis which will give us a Focker-Planck equation for the cascade process. Therefore we estimate Kramers-Moyal coefficients directly from the experimental data.

15:10	Weller	H 2035

Dns Of A Turb. Rotating Channel Flow: Study Of The Reverse Effect

Tanja Weller, Martin Oberlack, TU Darmstadt

Modeling of rotating turbulent flows is a major issue in engineering applications. In this work a turbulent channel flow rotating about the streamwise direction is presented. The theory is based on the investigations of [1] employing the Lie group analysis. It was found that a cross flow in spanwise direction is induced. A series of direct numerical simulations (DNS) has been conducted for both different rotation rates and different Reynolds numbers to validate this effect. The cross flow could be verified [2]. It was also found out that for small rotation rates up to Ro=10 the spanwise mean velocity profiles increase. At rotation number Ro=14 this effect appears to reverse. This reverse effect is also observed at different Reynolds numbers. Further details can be presented in the final paper.

[1] Oberlack M., Cabot W., Rogers M. M. (1998): Group analysis, DNS and modeling of a turbulent channel flow with streamwise rotation. Center for Turbulence Research, Stanford Univ., Proceed. of the Summer Program 1998, 221-242.
[2] Weller, T., Oberlack, M.(2005): DNS of a Turbulent Channel Flow with Streamwise Rotation - Investigation on the Cross Flow Phenomena, accepted for publication in Proc. of DLES6.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 2035

Reacting flow computations

Chair:

D. Thevenin

16:00	**Kurenkov**	**H 2035**

LES OF PREMIXED COMBUSTION USING THE LEVEL SET APPROACH

Oleksiy Kurenkov, Martin Oberlack, FB Bauingenieurwesen und Geodäsie, TU Darmstadt

LES of premixed turbulent combustion is presented based on the level set approach. The level set method is a technique which is especially designed for the tracking of propagating interfaces with complex topology changing in free-surface flows, geodesics, grid generation. In the context of premixed combustion it is called G-equation approach which we use in or simulations. The G-equation is notably advantageous for premixed combustion because it does not require the detailed chemistry treatment of the combustion process. The model involves one parameter only, the local turbulent flame speed s_t.

Our previous work [1] which was performed in RANS-context contains the level set approach with reinitialisation scheme of Sussman et al. [2]. Contrary to this we have developed for LES a completely new algorithm based on the Fast Marching method. It does not need the iterative reinitialisation schemes, and, therefore, it quarantees more accurate solution and drastical speed-up of the computation. We implement our algorithm in FASTEST 3D which is a flow solver for a non-carthesian, block-structured grid, so we can treat the geometry with arbitrary complexity.

[1] Kurenkov, A, Oberlack, M. Modelling turbulent premixed combustion using the level set approach for Reynolds averaged models. To appear in *Flow, Turbulence, Combustion.*
[2] Sussman, M., Smereka, P., Osher, S. A level set approach for computing solutions to incompressible two-phase flow. *J. Comp. Phys.* **114** (1994) 146-159.

16:20	**Meyer**	**H 2035**

Parameterized Scalar Profile Mixing Model For Turbulent Combustion

<u>Daniel W. Meyer</u>, Patrick Jenny, Institut für Fluidmechanik, ETH Zürich

For turbulent reactive flow simulations joint probability density function (JPDF) methods have the advantage that the mean source terms and macro-mixing appear in closed form. Molecular (or micro-mixing) on the other hand requires modeling, which is one of the major challenges in numerical turbulent combustion. Recently, a new mixing model based on parameterized scalar profiles (PSP) was developed. For different test cases it was shown that predictions of joint scalar PDFs and conditional scalar diffusion rates are in almost perfect agreement with the corresponding DNS data. This is very encouraging for simulations of non-premixed turbulent flames.

Now the PSP mixing model was implemented in a hybrid (finite-volume/particle) PDF solution algorithm and was combined with a flamelet approach based on mixture fractions. By comparison with PDF simulations using other mixing models it can be shown that the accuracy of the joint distribution of scalars and scalar dissipation rates is of major importance. With regard to efficiency it is also discussed, how the bias and statistical errors for a given number of particles can be reduced.

16:40	Hegetschweiler	H 2035

Model Of Partially Premixed Turbulent Combustion With Pdf Methods

<u>Michael Hegetschweiler</u>, Patrick Jenny, Institut für Fluiddynamik, ETH Zürich

In turbulent combustion one distinguishes between premixed, non-premixed and partially premixed combustion. While laminar flamelet models proved to be extremely valuable for a wide range of non-premixed flame simulations, similar approaches are more problematic in the premixed and partially premixed regimes. Here the laminar flamelet concept for non-premixed turbulent combustion simulations is generalized for the premixed and partially premixed regimes. Similar as in the unsteady flamelet approach, the joint statistics of a progress variable, mixture fraction and scalar dissipation rate is used to obtain the joint statistics of the compositions from pre-computed flame tables. The required distribution is computed with a joint PDF method and the main differences between the new approach and previous ones are the pre-computed tables and the way the evolution of the progress variable is calculated. Instead of evolving 1D flamelets, steady 2D solutions of burning flamelets propagating into unburned mixtures with varying mixture fraction are considered. Like a premixed flame, the propagating non-premixed flamelet can be stabilized in a moving frame of reference, such that one obtains a steady solution for a specified scalar dissipation rate. The location of a fluid particle in this 2D laminar flame is defined by its mixture fraction and a burning time, which are modeled for each computational particle used in the PDF method. Numerical experiments of turbulent lifted diffusion flames and premixed Bunsen flames demonstrate that this approach can be employed for a wide range of applications.

17:00	**Rembold**	**H 2035**

A Lagrangian Joint Pdf Approach For Turbulent Premixed Combustion

Benjamin Rembold, Patrick Jenny, Institut für Fluidmechanik, ETH Zürich

Turbulent combustion is central for many engineering applications. Whereas the modelling approach based on mixture fraction and laminar flamelets proofed to be very successful for non-premixed combustion, currently there exists no general approach for premixed flames. In the Eulerian context a common model is the one by Bray, Moss and Libby (BML).[1]

They assume an infinitely thin flame and use a progress variable $c \in \{0, 1\}$ to describe, whether the gas is burned or or unburned. The difficulty is to close the transport equation for the Favre average of c, *i.e.* to model the turbulent transport and mean source terms. Another modeling approach for premixed combustion is based on laminar flamelets and a level set equation to determine the flame position. For turbulent flames, however, it is not straight forward to achieve closure. The advantage of using joint probability density function (PDF) methods [2] is that reaction source term and turbulent convection appear in closed form. On the other hand, modeling molecular mixing remains a major challenge.

Here we propose a new model for premixed turbulent combustion. It is based on a joint PDF method [3, 4, 5] and combines ideas used in both, the BML and the flamelet approach. Each particle has a progress variable $c^* \in \{0, 1\}$ and it is a crucial advantage compared with the BML model that turbulent transport of c^* requires no modeling. Moreover, this Lagrangian framework allows to assign an individual flame-residence-time to each particle, which allows to resolve the laminar flame profile. Closure of the source term is achieved by specifying the probability with which a particle with $c^* = 0$ switches to $c^* = 1$. At this point this is done consistently with the BML model. Finally, simulations of turbulent Bunsen flames clearly demonstrate that the new model can be employed for a wide range of applications.

[1] K.N. C. Bray and J. B. Moss. A unified statistical model of the premixed turbulent flame. *Acta Astronautica*, 4:291-319, 1977.
[2] S. B. Pope. *Turbulent Flows.* Cambridge University Press, 2000.
[3] P. Jenny, M. Muradoglu, K. Liu, S. B. Pope, and D. A. Caughey. PDF simulations of a bluff-body stabilized flow. *J. Comp. Phys*, 169-1:1-23, 2001.
[4] P. Jenny, S. B. Pope, M. Muradoglu and D. A. Caughey. A hybrid algorithm for the joint PDF equation of turbulent reactive flows. *J. Comp. Phys*, 166-2:218-252, 2001.

[5] B. Rembold and P. Jenny. A multiblock joint pdf finite-volume hybrid algorithm for the computation of turbulent flows in complex *J. Comp. Phys.*, 2005. submitted.

17:20	Thevenin	H 2035

Influence Of The Propagation Direction For An Acoustic Wave Intera

Dominique Thevenin, Hemdan Shalaby, Institut für Strömungstechnik und Thermodynamik, Otto-von-Guericke-Universität Magdeburg

We investigate in this work the conditions leading to amplification or damping of a planar, Gaussian acoustic wave interacting with a CO/H2/Air turbulent premixed flame. We examine in particular the influence of the direction of propagation. In a first case the acoustic wave is coming from the right direction (starting in burnt gas zone), while it propagates from the left direction (starting in fresh gas zone) in the second case. This investigation is based on fully compressible Direct Numerical Simulation (DNS) results. Chemical processes are computed using a complete reaction scheme and accurate transport properties are taken into account. A local version of the classical Rayleigh's criterion is used to analyze the results, based on the single assumption that the celerity of sound is independent of time and only function of the spatial coordinates. We observe that, after the interaction, the wave is wrinkled leading to a non-planar geometry, similar to that of the initial flame front. For both cases the heat release fluctuation is concentrated in very small zones, associated either with positive or negative values. Rayleigh's criterion is then used to localize large positive and negative values (amplification resp. damping conditions). This criterion shows that wave amplification occurs only inside well-located small zones in the two cases. The propagation direction has no influence on these results, confirming that amplification or damping is controlled by a coupling process between pressure and heat release fluctuations through the chemical reactions.

Session 5
Thursday, March 30, 13:30 - 15:30

Room: H 2035

Fundamental considerations

Chair:

F. Thiele

13:30	Aripov	H 2035

Self Similar Approach For Visualisation Of Nonlinear Processes

Mersaid Aripov, Abdugappar Khaydarov, National University of Uzbekistan

In [1] was offered one method of construction of the self similar, an approximately self similar equations. This method allows to construct the self similar, approximately self similar equations for many classes of nonlinear differential equations of parabolic, hyperbolic, elliptic types that are basis for modeling different nonlinear processes. This method allows also to study properties of some class of the second order reaction-diffusion system, the high order differential equations and system.

In this paper we demonstrate the possibilities of the self similar, approximately self similar approaches to the studying of properties of nonlinear reaction- diffusion systems under action of a convective transfer. It is supposed that the speed of convective transfer is a function of time. An influence of parameters of the reaction- diffusion systems to an evolution of the process is studied. It is shown how the parameters of the nonlinearity and moving media reduce to the new nonlinear effects such as localisation of solution, finite velocity of perturbation, blow up. It is proved that there exist some values of parameters when the effect of finite velocity of a perturbations, localization of solution, onside localization, the effect of "wall", blow up, blow up localization.

The estimates of different type solutions, the numerical analysis and visualization of nonlinear reaction- diffusion system for different value of parameters were carried out. The results of numerical experiments showes the affectivity of self similar approaches for studying of the nonlinear processes.

[1] Aripov M. Asymptotics of the Solutions of the Non-Newton Polytrophic Filtration equation. ZAMM 2000, vol. 80, Supp. 3, 767-768.

13:50	Grebenev	H 2035

Integration Of Infinite Chain Of Transport Equations For Cumulants

Vladimir Grebenev, Russian Academy of Sciences
Martin Oberlack, TU Darmstadt

We apply the so-called direct method of symmetry analysis (method of differential constraints) for formulating integrability properties of an infinite chain of transport equations for the cumulants which appear in modeling the dynamics of a momentumless turbulent planar wake. We expose the conditions of compatibility of the original infinite system of partial differential equations for cumulants with the gradient-type algebraic relation suggested by Launder and Hanjalick for the so-called triple correlations (the differential constraint). The compatibility conditions obtained make it possible to realize a reduction of the original infinite chain of transport equations for the cumulants and to present an algorithm for calculating cumulants of arbitrary order. This algorithm is based on a recursion relation. An illustrative example of applying the compatibility conditions obtained for examining a third-order closure model of turbulence is given.

We show that the method of differential constraints is an effective tool to analyze parametric turbulent models that enables us, in particular, to find new reductions of the model under consideration, and then in turn to construct explicit solutions. Equations, which appears in the reduced chain, can be analyzed by the standard Lie group method for finding group-invariant solutions. An important application of the approach presented is obtaining functional and algebraic relationships between various flow characteristics in the exact analytic form. Moreover, it is turned out that some model constants may be calculated and their values obtained are sufficiently close to the standard data.

This work was partially supported by RFBR (proposal no. 04-01-00209).

14:10	**Yasuda**	**H 2035**

Evaporation And Condensation Of A Binary Mixture Of Vapors

Shugo Yasuda, FB Mathematik, TU Kaiserslautern
Shigeru Takata, Kazuo Aoki, Graduate School of Engineering, Kyoto University, Japan

Half-space problem of evaporation and condensation of a binary mixture of vapors is investigated on the basis of the linearized Boltzmann equation for hard-sphere molecules with the complete condensation condition. The problem is analyzed numerically by a finite-difference method, in which the complicated collision integrals are computed by the extension of the method proposed by Y. Sone, T. Ohwada, and K. Aoki [Phys. Fluids A **1**, 363 (1989)] to the case of a gas mixture. As a result, the behavior of the mixture is clarified not only at the level of the macroscopic quantities but also at the level of the velocity distribution function.

In addition, accurate formulas of the temperature, pressure, and concentration jumps caused by the evaporation and condensation are constructed for arbitrary values of the concentration of the background reference state by the use of the Chebyshev polynomial approximation.

10 Viscous flows

Organizers:

Nuri Aksel, Universität Bayreuth
Dieter Hänel, Gerhard-Mercator-Universität Duisburg
Gert Böhme, Universität der Bundeswehr Hamburg

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 1058

Interfaces and Films

Chair:

Michael Dreyer

13:30	Adler	H 1058

Modelling Free Surfaces In Oscillating Pipe Flows

Katrin Adler, Rüdiger Schwarze, H. Chaves, Frank Obermeier, Institut für Mechanik und Fluiddynamik, TU Bergakademie Freiberg

An oscillating pipe flow with a free surface is investigated numerically by means of a moving grid model combined with a VOF-model and experimentally by means of pictures which are taken of the flow field near the free surface. The pipe diameter is 12 mm. Due to this small diameter capillary forces play an important role. Therefore special attention has to be paid to the flow field near the free surface.

Inside the pipe the flow is characterized by the annular effect, the velocity profile can be calculated analytically. Near the free surface this analytical solution is not valid, therefore numerical and experimental investigations are necessary. This near surface flow is characterized by the superposition of two different vortices. One is easily identified by the velocity vector plots at the surface. The second vortex can only be visualized by tracers exhibiting a very slow rotation of the vortex which takes more than 10 periods of the imposed oscillation. The numerical simulations agree well with experimental data.

13:50	Afanasiev	H 1058

Thin Film Dynamics On Vertically Rotating Disks

Konstantin Afanasiev, Andreas Münch, Barbara Wagner, WIAS Berlin

The axisymmetric flow of a thin liquid film subject to surface tension, gravity and centrifugal forces is considered for the problem of a vertically rotating disk that is partially immersed in a liquid bath. This problem constitutes a generalization of the classic Landau-Levich drag-out problem to axisymmetric flow. A generalized lubrication model that includes the meniscus region connecting the thin film to the bath is derived. The resulting nonlinear fourth-order partial differential equation is solved numerically using a finite element scheme. For a range of parameters steady states are found. While the solutions for the height profile of the film near the drag-out region show excellent agreement with the asymptotic solutions to the corresponding classic Landau-Levich problem, they show novel patterns away from the meniscus region. The implications for possible industrial applications are discussed.

14:10	Grah	H 1058

Unsteady Modeling And Simulation Of Open Capillary Channel Flows

Aleksander Grah, Uwe Rosendahl, Dennis Haake, Michael Dreyer, ZARM, Universität Bremen

Capillary systems provide a passive means to control fluids and are widely used for space craft fuel management. With no moving parts capillary systems have the greatest potential for reliability.

In this study a forced unsteady liquid flow through an open capillary channel under reduced gravity conditions (microgravity) is investigated. The channel consists of two parallel plates with a free surface at one or two sides.

Due to convective and viscous momentum transports, the pressure along the flow path decreases and causes the free surface to bend inwards. The free surface has a high tendency to oscillate due to minor perturbations, e. g. experimental flow rate changes. The maximum flow rate is achieved when the free surface collapses and gas ingestion occurs. This critical flow rate depends on channel geometry and liquid properties.

The prediction of the different dynamical effects is obtained with an unsteady one dimensional model taking into account entrance and inlet pressure loss, frictional pressure loss and losses due to flow separation effects.

We present a comparison of the numerical and experimental surface contour dynamics. The experimental investigations were performed in the Bremen drop tower and on board of the sounding rocket TEXUS EML-1[1].

[1] Rosendahl, U.; Ohlhoff, A.; Dreyer, M. E.: Choked flows in open capillary channels: theory, experiment and computations, J. Fluid Mech. 518, 187-214, 2004

14:30	**Heining**	**H 1058**

Bistable Resonance In Gravity-driven Film Flows

Christian Heining, Andreas Wierschem, Nuri Aksel, Universität Bayreuth

We study the flow of a viscous liquid down an inclined plane with a sinusoidal bottom profile. Applying the integral boundary-layer method leads to a nonlinear ordinary differential equation for the film thickness. Linear resonance between the free surface and the bottom contour is observed via a regular perturbation approach. Considering nonlinear contributions, the resonance curve shows a foldover effect which is typical for nonlinear oscillators. In order to understand the origin of this bistable behaviour a simple model equation is derived and an analogy to the Duffing oscillator is shown.

14:50	**Rosendahl**	**H 1058**

Sounding Rocket Experiment On Capillary Channel Flow

Uwe Rosendahl, Michael Dreyer, Antje Ohlhoff, Aleksander Grah, ZARM, Universität Bremen

We will report on the experimental procedure and the results of a sounding rocket experiment (TEXUS) on open capillary channel flows which was launched from ESRANGE in North Sweden. The rocket provides 6 minutes of compensated gravity. The capillary channel consists of two parallel plates (25 mm breadth) mounted at a gap distance of 10 mm. The length of the open flow path, along which the test liquid (FC-72) is exposed to the ambient gas phase, is variable in-between 12 mm and 19 mm. Depending on the applied volumetric flow rate, the liquid pressure decreases in the flow direction due to flow losses. To achieve stationary flow conditions the difference between the liquid pressure and the ambient pressure has to be balanced by the capillary pressure of the free liquid surfaces. A steady flow is obtained only for a flow rate below a certain critical value. If this value is exceeded, the liquid surfaces collapse at the channel outlet and the flow changes from steady single-phase flow to unsteady two-phase flow. The aim of the experiment is to determine the profiles of the free liquid surfaces and to find the critical flow rate.

15:10	Peters	H 1058

Kräftegleichgewicht An Kleinen Bläschen In Einer Scherströmung

Franz Peters, Sven Biermann, Ruhr-Universität Bochum

Der freie Aufstieg von kleinen Luftbläschen in ruhendem Wasser ist ein klassisches Problem der Strömungsmechanik mit vielen offenen Fragen. Theoretische Ansätze stützen sich auf zweifelhafte Randbedingungen und Experimente haben mit der Reinheit des Wassers zu kämpfen und damit, einen stationären Zustand zu finden. Der Aufstiegsprozeß entpuppt sich nämlich bei genauerer Betrachtung als eher transient. Hinzu kommt, daß die Umströmung eines am Beobachter vorbeieilenden Bläschens schwierig zu untersuchen ist. Wir haben ein Experiment entworfen, das ein aufsteigendes Bläschen unter einem mm Durchmesser in einem Gleichgewicht von verschiedenen Kräften so fesselt, das es ortsfest steht und über viele Minuten beobachtet werden kann (hydrodynamische Levitation). Diese Methode erlaubt die genaue optische Größenbestimmung über ein Interferenzverfahren inklusive der Deformation des Bläschens. Sie gewährleistet die genaue Bestimmung der Geschwindigkeit und des Geschwindigkeitsgradienten der Anströmung. Aus diesen Größen läßt sich der Widerstandskoeffizient und der Auftriebsbeiwert des Bläschens errechnen. Ebenso läßt sich genau beobachten mit welcher Rate die Luft in das Wasser diffundiert. Die experimentellen Methoden und die Ergebnisse werden dargestellt.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 1058

Channel Flow

Chair:

Peter Erhard
Markus Scholle

16:00	Ehrhard	H 1058

Messung Des Strömungsfelds In Einem Mikromischer

Peter Ehrhard, Hamid Farangis Zadeh, Institut für Kern- und Energietechnik, Forschungszentrum Karlruhe

Auf integrierten Systemen für chemische oder biologische Analysen („lab on a chip“) spielt die Vermischung von Flüssigkeiten eine wichtige Rolle. Die Vermischung von Flüssigkeiten in Mikrokanälen bei kleiner Reynolds-Zahl ist hierbei nicht trivial, weil die Strömung laminar bleibt und keine Instabilitäten zur Erzeugung großer Austauschflächen vorhanden sind. Große Austauschflächen sind aber gerade für eine effiziente Diffusion notwendig. Meisel & Ehrhard [1] schlagen in diesem Kontext einen Mikromischer vor, der ein oszillierendes elektrisches Feld anwendet, um elektroosmotische Käfte in der elektrischen Doppelschicht zu induzieren. So kann über eine zeitabhängige Sekundärströmung eine Auffaltung der Austauschfläche erreicht werden, um auch bei kleinen Reynolds-Zahlen effektive Vermischung zu erreichen.

Wir stellen experimentelle Untersuchungen zur Strömung und zum Stofftransport in einem solchen, elektrisch erregten Mikromischer vor. Eine Zielsetzung ist die Validierung des Konzepts und des theoretischen Modells von Meisel & Ehrhard [1]. Nach einer Diskusion des Mikromischerkonzepts, wird das Strömungsfeld bei schwerkraftgetriebenem (stationärem) und elektrisch erregtem (zeitabhängigem) Betrieb des Mikromischers erläutert. Nebem dem Einfluss der Parameter (Reynolds-Zahl, elektrische Feldstärke, Frequenz) wird insbesondere die Strömungsstruktur (Wirbel, Sattelpunkte, etc.) diskutiert und Schlussfolgerungen für eine weitere Optimierung des Mikromischers werden gezogen.

[1] I. Meisel & P. Ehrhard (2005), Electrically-excited (electroosmotic) flows in microchannels for mixing applications, *Europ. J. Mechanics B/Fluids*, in press.

16:20	Barz	H 1058

3D Simulation And Experiment Of Flow In A Folded Microchannel

Dominik P. J. Barz, Hamid Farangis Zadeh, Peter Ehrhard, Forschungszentrum Karlsruhe GmbH

Mixing of liquids in microstructures, for example in lab on a chip devices or micro-reactors, usually turns out to be a challenging task. The flow within such devices typically is of strong laminar character as a result of the small length scales. To achieve effective and fast mixing, an increased interfacial area between the different liquids for enhanced molecular diffusion is required. In lab on a chip systems that are made of glass or plastics, mixing can be improved by means of electrokinetic effects. For that purpose an oscillating electrical field is superposed to a pressure-driven flow. The electrical excitation causes secondary flows and, hence, increases the interfacial area. With regard to electrokinetic mixing, it is obvious that folded channels are particulary beneficial. Additionally, curved channels, leaving aside electrokinetic effects, may lead to further secondary flows, even though the Reynolds number is small and the flow remains laminar. Due to centrifugal forces so-called Dean vortices are present within the curved channels and affect mass transport significantly.

The focus of the present study is on the investigation of the pressure-driven flow in a folded micro-channel that serves as electrokinetic mixer. Therefore, time-dependent, three-dimensional Finite Element (FEM) Simulations are performed. The governing equations of mass, momentum and species transport are non-dimensionalized by adequate scales. Several dimensionless groups arise, i.e. the Reynolds number and the Schmidt number control the problem. Significant 3D flow structures at a Reynolds-No. of $Re = 42$ are recognized. To validate the simulations, the results are compared with experiments within the real micro mixer. The comparison shows reasonable agreement.

16:40	Strein	H 1058

Stability Analysis For The Flow In A Wetting/dewetting (micro-)gap

Sabine Strein, Peter Ehrhard, Institut für Kern- und Energietechnik, Forschungszentrum Karlsruhe GmbH

Dynamic wetting or dewetting is important in many technical coating processes, like the production of photographical films or of liquid-crystal displays (LCDs). In these production processes it is important for economical reasons to get a fast and steady coating of a liquid onto a solid. In such processes an unstable contact line is observed beyond a critical coating velocity, causing air entrainment and, subsequently, a poor quality of the coating layer. In detail, the straight dynamic contact line takes a sawtooth form in this unstable regime. This instability of the contact line has its origin presumably in the flows of either the wetting or the dewetting fluid. For a prediction of the critical velocity, it appears desirable to evaluate the stability of these flows.

In this study we concentrate on the flow in the convergent gap between a moving solid wall and a free interface. The base flow is considered two-dimensional, steady and incompressible and has two basic pattern. In a first step we idealize the free interface as geometrically-fixed and plane, whereas the kinematic boundary conditions are approximated reasonably. This idealized base flow is subject to small disturbances which are (i) 2D and time-dependent or (ii) 3D and time–dependent. The governing equations are mass and momentum conservation in cylindrical coordinates. We discuss the stability results, obtained for this idealized base flow. Further, an outlook is given, how the idealized base flows will be modified towards a more realistic geometry.

17:00	Finck	H 1058

Simulation Of Nasal Flow By Lattice Boltzmann Methods

Markus Finck, Dieter Hänel, Irenäus Wlokas, Institut für Verbrennung und Gasdynamik, Universität Duisburg-Essen

The present study is concerned with the numerical simulation of the viscous and incompressible fluid flow through a human nose using a variant of the lattice Boltzmann method. The knowledge of the characteristics of nasal breathing is a significant contribution to the new concept of CAS (computer aided surgery). To increase the success of nose surgery, the prediction of nasal functions like climatization and filtering is desirable. This requires a fast and reliable method for flow prediction in complex geometries.

Our current studies document that the lattice Boltzmann method matches this postulate. The results show good agreement with a conventional finite-volume method. Essential advantages are seen in the fast grid generation (Cartesian grids with octree refinement) even in complex physiological geometries, the high granularity for parallelization and the second order accuracy in space and time. Besides the pure flow prediction we also investigate the nose's climatization functionality using a finite difference-scheme to simulate the transport of heat and water vapor in the air. Moreover we use a Lagrangian method to model particle and aerosol transport through the nose which is an indicator for the filtering functionality.

17:20	Prokop	H 1058

Numerical Solution Of Newtonian And Non-newtonian Flows

Vladimir Prokop, Radka Keslerova, Karel Kozel, Czech Technical University

The motivation for numerical solution of Newtonian and Non-Newtonian flows arises in many applications, e.g. in the biomedicine, the solution of blood flow in cardiovascular system. This paper deals with flows through a bypass connected to main channel and flows through branching channels. The flows are supposed to be incompressible, steady, laminar and viscous. The system of Navier-Stokes equations is used for description of this type of flow. Artificial compressibility method is used for numerical solution in combination with three stage Runge-Kutta method. The examples of flow in branching channel with some modifications are presented.

17:40	Jonás	H 1058

Pressure Distributions In A Channel With A Backward Facing Step

Pavel Jonás, Oton Mazur, Václav Uruba, Academy of Sciences of the Czech Republic

Pressure distributions and liquid film records were measured downstream from the step root on the channel bottom. Both, the width b and the height of the channel downstream the step, were 0.1 m and 0.275 m respectively. The input channel height, H and the step one, h were variable and allow to model various configurations h/H from 0.1 up to 1.04. The volume flow velocity in the step plane was controlled from 5 m/s to 55 m/s. Results following from the analysis: the investigated shear flows in the closed channel with sudden expansion of the rectangular cross section are well symmetrical towards the plane of geometric symmetry; 3D-vortex system arises in a region adjacent at the step root and a couple of contra-rotating vortices is passing to a single vortex with decreasing span of step, b/h; the reattachment position x_r is fast fluctuating in the strip of width about 15 millimetres; marked dependences of the investigated separated flow zone characteristics on Reynolds number were not observed if various length scales were chosen (h, H, $H+h$ or d_H) in the velocity range applied; some rules were derived for prediction of the re-attachment and location of 3D-vortex systems.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 1058

Heat and Mass Transfer

Chair:

Herbert Steinrück
Dieter Hänel

13:30	Conzen	H 1058

Experimentelle Untersuchung Des Temperaturfelds In Einem Extruder

Carsten Conzen, Olaf Wünsch, Universität Kassel

Extruder werden im Maschinenbau und in der Verfahrenstechnik zur Förderung und Homogenisierung von hochviskosen Flüssigkeiten, wie z.B. Kunststoffschmelzen verwendet. Diese besitzen neben der temperatur- und schergeschwindigkeitsabhängigen Viskosität eine sehr geringe thermische Leitfähigkeit. Damit sind die Reynoldszahlen im Strömungsfeld sehr klein ($Re \rightarrow 0$), die Pecletzahlen ($Pe = 10^4 - 10^6$) dagegen sehr groß. Die Entwicklung der Strömung und des Temperaturfelds finden also auf verschiedenen Ortsskalen statt. Numerische Berechnungen zeigen, dass in realen Maschinen die thermische Einlauflänge in der Regel sehr viel größer ist als deren Abmessungen. Dieser Vortrag handelt von der experimentellen Untersuchung der nicht-isothermen Strömung in einem Doppelschneckenextruder mit einer Modellflüssigkeit. Der verwendete Versuchsaufbau wird vorgestellt und die Ergebnisse werden in Form von Kennlinien und als lokale Feldinformationen in Abhängigkeit von Betriebsparametern gezeigt. Diese werden ersten numerischen Berechnungen gegenüber gestellt.

13:50	Steinrück	H 1058

Mixed Convection Flow Past A Horizontal Plate: The Global Flow

Herbert Steinrück, Ljubomir Savic, Institut für Strömungsmechanik und Wärmeübertragung, TU Wien

The mixed convection flow past a horizontal plate which is aligned under a small angle of attack to a uniform free stream will be considered in the limit of large Reynolds number and small Richardson number. Even a small angle of inclination of the wake is sufficient for the buoyancy force to accelerate the flow in the wake thus a velocity overshoot in the wake forms. Moreover a hydrostatic pressure difference across the wake induces a correction to the potential flow which influences the inclination of the wake. Thus the wake and the correction of the potential flow have to be determined simultaneously. However, it turns out that solutions exists only if the angle of attack is sufficiently large enough. Solutions are computed numerically and the influence of the buoyancy on the lift coefficient is determined.

14:10	Savic	H 1058

Mixed Convection Flow Past A Horizontal Plate: The Trailing Edge

Ljubomir Savic, Herbert Steinrück, Institut für Strömungsmechanik und Wärmeübertragung, TU Wien

The mixed convection flow past a horizontal plate in the limit of large Reynolds Re and Grashof number Gr is considered in the distinguished limit $\kappa = \mathrm{Gr}\mathrm{Re}^{-9/4} = O(1)$. Here the influence of the buoyancy forces onto the flow near the trailing edge is analyzed in the frame work of triple deck theory. The flow near the trailing edge can be decomposed into a symmetric part and an anti-symmetric part. The symmetric part can be described by the classical triple deck theory (Stewartson 1969, Messiter 1970) while for the anti-symmetric part a new (linear) triple deck problem is formulated. However, it turns out that the pressure of the anti-symmetric part is discontinuous at the trailing edge even on triple deck scales $(x = O(\mathrm{Re}^{-3/8}))$. Thus new sub-layers of size $x = O(\mathrm{Re}^{-4/8})$, $x = O(\mathrm{Re}^{-5/8})$ are introduced to resolve the discontinuity of the pressure.

14:30	Domesi	H 1058

Dynamics Of Spherical Particles In Thermocapillary Liquid Bridges

Stefano Domesi, Hendrik Kuhlmann, TU Wien

We numerically investigate the motion of small spherical particles suspended in a thermocapillary liquid bridge. Assuming one-way coupling, the motion of the particles is modeled by a modified Maxey-Riley equation which takes into account the viscous, pressure-gradient and buoyancy forces. The particle motion is considered for both the steady axisymmteric toroidal vortex flow (low thermocapillary Reynolds numbers) and the three-dimensional hydrothermal-wave flow (larger thermocapillary Reynolds numbers). In both cases, particles heavier than the fluid are attracted by periodic orbits. Since the basin of attraction is the whole volume of liquid, an initial random distribution of particles inside the half-zone segregates in the course of time. Particular attention must be paid to the error introduced by the interpolation scheme for the flow field, which is only known on a discrete grid, and to the modeling of the particle-wall and particle-free surface interactions. The final aim of this work is the analysis of the dynamics in the four- and six-dimensional, respectively, phase space for the particle motion. Thereby, we hope to contribute to a better understanding of the particle accumulation structures (PAS) observed experimentally.

14:50	**Scholle**	**H 1058**

Influence Of Eddies On Heat Transfer In Couette Flow

Markus Scholle, Nuri Aksel, Universität Bayreuth

Under creeping flow conditions, we consider the steady Couette flow of a Newtonian fluid between two plates, one of them planar, the other one with a sinusoidal profile. Recent analytical studies on the velocity field revealed the formation of kinematically induced eddies in the valleys of the plate topography and the influence of these eddies on drag force and flow rate.

The influence of these eddies on the convective heat transfer is the subject of our paper. We solve the problem in two steps: First, the velocity field for an isothermal flow is calculated analytically using Reynolds' lubrication approximation. It is shown that in case of small plate gaps eddies are induced even for weakly undulated plates due to the kinematical constraints. Next, we impose a temperature difference between upper and lower plate and solve the heat conduction equation with convection for the above–solved velocity field. Motivated by the lubrication solution for the velocity we make an analogous ansatz for the temperature field and reduce the field equation to a set of ordinary differential equations. Its solution is visualized and discussed.

15:10	**Stan**	**H 1058**

"hammer" Effect Of Surfactants On A Free Drop

Ioan-Raducan Stan, Maria Tomoaia-Cotisel, Babes-Bolyai University, Romania
Aurelia Stan, County School Department of Cluj, Romania

The forces, acting on a liquid drop immerged in an immiscible liquid, in microgravity conditions, are investigated. The liquids, considered Newtonian, incompressible and viscous, have the same densities. If the initial interfacial tension 0 is lowered to 1, an interfacial tension gradient appears, which is generated by injecting, on the drop surface, of a chosen quantity of surfactant. This gradient produces a real two-dimensional surface flow (the Marangoni flow) of the interfacial liquid, also considered Newtonian, incompressible and viscous, moving with a distinct front, noted f in spherical coordinate. As a consequence of the surface flow, a Fp hydrodynamic pressure will act on the drop in the injecting point. The

Fp depends on the f, namely on the extent to which the drop surface is covered with surfactant. For 0 - 680, the Fp force cancels. For a coverage degree 0 $f < 0$, the Fp force is negative, $Fp < 0$, and the Fp force exerted upon the drop is oriented toward the negative direction of the drop surface normal. This situation is similar with the application of a “hammer” knock on the drop in the injecting point of the surfactant and is the origin of the Marangoni driven instability.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 1058

Stability

Chair:

Christoph Egbers
Nuri Aksel

16:00	Stücke	H 1058

Über Die Exzentrische Zylinderspaltströmung Bei Engen Spaltweiten

Peter Stücke, Mike Schwarz, Christoph Egbers, Nicoleta Scurtu, Westsächsische Hochschule

Es werden die Strömungsverhältnisse im Ringspalt zweier koaxial angeordneter Zylinder mit den Mitteln der Strömungsvisualisierung untersucht. Dabei wird der Übergangsbereich von laminarer Couette-Strömung zu Taylor-Wirbel-Strömung bei konzentrischer und exzentrischer Anordnung der Zylinder und relativen Spaltweiten von unter 0,1 untersucht. Bei konzentrischer Zylinderanordnung kann die Stabilitätsgrenze der laminaren Couette-Strömung für Reynolds-Zahlen von 150 bis 400 bestätigt werden. Bei exzentrischer Anordnung der Zylinder ändern sich die Strömungsverhältnisse grundlegend. Mit zunehmender Exzentrizität verschiebt sich die Stabilitätsgrenze zu höheren Reynolds-Zahlen. In Abhängigkeit von der Reynolds-Zahl bilden sich Taylor-Wirbel bei bestimmten Exzentrizitäten nur im konvergenten Teil des Spaltes. Der Bereich um die engste Spaltweite ist dann frei von Taylor-Wirbeln.

16:20	Scurtu	H 1058

Numerical Simulation Of The Flow In Eccentric Cylindrical System

Nicoleta Scurtu, Peter Stücke, Christoph Egbers, BTU Cottbus

A numerical study on the flow of the eccentric Couette-Taylor system with rotating inner cylinder and fixed outer cylinder is presented. The unsteady, three-dimensional incompressible Navier-Stokes equations were solved using the θ-scheme time approximation and the finite-element spatial discretization method. The influence of the eccentricity on the formation of Taylor vortices was analyzed in the critical Reynolds number region. Approaching the flow in journal bearings the effect of a feed hole placed on the outer cylinder on the eccentric Taylor vortex flow pattern was also studied.

16:40	Smieszek	H 1058

Untersuchung Eines Scherverdünnenden Fluids Im Zylinderspalt

Marlene Smieszek, Christoph Egbers, Lehrstuhl für Aerodynamik und Strömungslehre, BTU Cottbus

Es wird die Strukturbildung und Stabilität eines viskoelastischen, scherverdünnenden Fluids im Taylor-Couette-System untersucht. Vorgestellt werden Ergebnisse aus Untersuchungen bei moderaten Aspektverhältnissen ($\Gamma = 4$ bis 10). Diese werden mit Messergebnissen aus Versuchen mit einem newtonschen Fluid verglichen.

17:00	Mayer	H 1058

Wavelets Generated By Stokes Potentials

Carsten Mayer, Geomathematics Group, TU Kaiserslautern

By means of the limit and jump relations of potential theory with respect to the Stokes equations the framework of a tensorial wavelet approach on a regular (Lyapunov-) surface is established. The setup of a multiresolution analysis is defined by interpreting the kernel functions of the limit and jump integral operators as scaling functions on the regular surfaces. The distance of the parallel surface to the surface under consideration thereby represents the scale level in the scaling function. Tensorial scaling functions and wavelets show space localizing properties. Thus, they can be used to represent vector fields locally on a regular surface. This fact will be demonstrated by an approximation of a (vectorial) wind field on the regular Earths surface given by the TerrainBase model. Furthermore, these functions can be used as ansatz functions for the discretization of Fredholm integral equations of the second kind which result from the Stokes boundary-value problems with respect to a regular surface. By this, scaling functions and wavelets enable us to give a multiscale representation of the solution of the Stokes problem. This representation will be demonstrated in a concrete example.

17:20	Schoisswohl	H 1058

Flow Instabilities In Buoyant-thermocapillary Liquid Pools

Ulrich Schoisswohl, Hendrik Kuhlmann, TU Wien

The instability of steady axisymmetric buoyant-thermocapillary flow in liquid pools heated or cooled from above is investigated numerically. The conditions for the onset of three-dimensional motion depend on the thermal conditions as well as on the geometrical constraints. The physical mechanisms leading to the hydrodynamic instabilities are explored by detailed analyses of the neutral modes of the system. Implications for application in crystal growth from the melt and for weld pools are pointed out.

17:40	Slavtchev	H 1058

Solute Transport By Radial Capillary Flow In A Hele-shaw Cell

Slavtcho Slavtchev, Institute of Mechanics, Bulgarian Academy of Sciences

The aim of the study is to model solute transport by water penetrating from a line source in artificial soils (substrates) used in Space greenhouses. The substrate granules are enriched by mineral nutrients used for feeding the plants. It is well known that two-dimensional flows in porous media can be modelled by viscous flows in Hele-Shaw cells.

Transport of a solute by radial capillary flow in a horizontal Hele-Shaw cell is studied. The solute is assumed to be deposited in advance on the cell walls. The liquid motion is governed by a nonlinear ordinary differential equation for the temporal position of the contact line. It expresses the balance between the viscous friction and the capillary force. As the latter depends on the surface tension and contact angle of the solution, the fluid motion is influenced by the solute concentration. On the other hand, the solute transport is described by a convection-diffusion equation that includes the unknown liquid velocity. The system of the conjugated equations is solved numerically. For large times, the motion equation admits an approximate solution for constant concentration on the liquid surface and then, the diffusion equation can be solved separately as Stefan problem.

Session 5
Thursday, March 30, 13:30 - 15:30

Room: H 1058

Non-Newtonian Fluid Flow

Chair:

Olaf Wünsch
Gert Böhme

13:30	Müllner	H 1058

Viscosity Characterisation For Rubber Blends From Die Swell Data

Herbert W. Müllner, Josef Eberhardsteiner, Karin Hofstetter, Institut für Mechanik der Werkstoffe und Strukturen, TU Wien

The goal of this presentation is the identification of the interaction of the typical swelling behaviour of viscoelastic fluids with the viscosity of the investigated rubber blends in the context of an extrusion process.

As basis serves an experimental investigation of different rubber blends by means of a capillary-viscometer. In addition to the extrusion pressure the die swell of the blends has been determined for all experiments. For the description of the shear rate dependent viscosity a power law is used. For the rheological characterisation a genetic algorithm can be used alternatively. It is well-known that the corresponding parameters depend on the geometry of the used capillary. Thus, the parameters change after the exit of the capillary, too. By adaptation the fitness equation of the used genetic algorithm it is possible to study the influence of the die swell on the viscous properties.

With this knowledge a more realistic simulation of the die swell phenomenon and its influence on the resulting profile geometry is possible. The research work is performed in cooperation with Semperit Technische Produkte Ges.m.b.H. & Co KG.

13:50	Rudert	H 1058

Simulation Of The Filling Behaviour Of A Non-newtonian Fluid

Alexander Rudert, Rüdiger Schwarze, Frank Obermeier, Institut für Mechanik und Fluiddynamik, TU Bergakademie Freiberg

A numerical model for free surface flows of non-newtonian liquids into a cavity is presented. These flows are regarded as a first model of injection molding, which is a widely used processing technology. Model experiments of the injection process are performed with a water-based gel. The filling process is visualized by tracing the free surface of the gel within the cavity. Filling times are deduced from the experimental observations and corresponding numerical simulations.

Here the flow equations are integrated according to the finite-volume-method. The Volume of Fluid method is employed in order to describe the free surface flow of two incompressible phases, the phase interface is resolved by the method of geometric reconstruction and a surface compression method. The Herschel-Bulkley-model is used in order to describe the shear-thinning behavior of the molding material and the effects of the yielding point. The governing equations of the flow are solved by means of the commercial code FLUENT as well as the Open Source code OpenFOAM. The results are compared and show good agreement.

Different patterns of the filling flow depending on the injection parameters are evident in the experiment and the simulation. They are characterized and arranged with respect to the similarity parameters of the flow. The results of the simulation are found to agree well with the experimental observations.

14:10	**Shahnazian**	**H 1058**

Controlled Shear Stressed Rheological Investigations Of Ferrofluid

Hamid Shahnazian, Stefan Odenbach, Institut für Strömungsmechanik, TU Dresden

Suspensions of magnetic nanoparticles with a mean diameter of about 10 nm in appropriate carrier liquids like oils or kerosene - called ferrofluids - show normal liquid behavior coupled with superparamagnetic properties. The magnetic particles are covered with a polymer shell to keep them stable against sedimentation and preventing agglomeration. The possibility of magnetic control of flow and properties of ferrofluids has led to the development of a variety of possible applications in various fields like in mechnical engineering and biomedicine. One of the major attributes of ferrofluids is the change of their viscosity caused by magnetic fields, the so called magnetoviscous effect. In order to explain the mechanism of the magnetoviscous effect, a model for quantitative comparison to experimental data has been developed. But this model is based the assumption that the investigations are made in the lower Newtonian regime of the flow curves, which cannot be reached with shear controlled rheometer. Therefore a special stress controlled rheometer for ferrofluids has been designed, with which appropriate shear rates can be achieved. Further the yield stress for different kind of suspensions can be investigated directly as a function of the applied magnetic field. The presentation introduces shortly ferrofluids and gives information about the stress controlled rheometer. Additionally preliminary experimental results are shown.

14:30	Pop	H 1058

Microstructure Of Co-based Ferrofluids And Its Influence On The Rh

Loredana Mirela Pop, Stefan Odenbach, TU Dresden
Albrecht Wiedenmann, Hahn-Meitner-Institut Berlin

Ferrofluids are suspensions of nanometer-sized magnetic particles in different carrier liquids. The particles are made of magnetite or cobalt, coated with a polymer shell to prevent agglomeration. Thus they are long term stable against sedimentation. In the presence of magnetic fields, ferrofluids show an increase of viscosity, the so called magnetoviscous effect, of several hundred percent compared to the viscosity without magnetic field. Due to a strong shear thinning in commercial ferrofluids, the viscosity changes diminish for technical useful shear rates to values not suitable for applications. In the last years, a lot of experimental and theoretical studies have been done in order to explain the microscopic mechanisms of the magnetoviscous effect. As a result of these efforts, a model, based on numerical and experimental data, has been established, which is able to explain the observed effects. Chain formation of magnetic particles with strong particle particle interaction as well as structure destruction by means of shear influence are the essential processes for the understanding of the magnetoviscous phenomena. By using a special designed rheometer, rheological measurements as well as investigation of the microstructure of ferrofluids using small angle neutron scattering (SANS) have been performed. The presentation will contain, after a general introduction of ferrofluids and a description of the experimental setup, the current results of the investigation of the microstructure using SANS. These results will be compared with the rheological data concerning measurements of the magnetoviscous effect and with the existent numerical simulations. The obtained experimental results will offer a starting point for theoretical approaches, leading to a detailed understanding of the magnetoviscous effect and opening the way to new technologically useful applications.

14:50	Matvienko	H 1058

Particles Separation In The Non-newtonian Suspensions

Oleg Matvienko, Eugeny Evtiushkin, Tomsk State University, Russia

Hydrocyclones are used extensively for particle separation and classification in mineral, powder processing, environmental and chemical engineering. The popularity of the hydrocyclone can be described to its simplicity, ease of operation, small physical size in proportion to the high volumetric throughputs that it can handle and the relatively low capital, operating and maintenance costs associated with its use. Many processing industries handle a number suspensions and slurries which show non-Newtonian behavior. A knowledge of the separation characteristics in these systems is required for process and design calculations.

This paper presents the results of the mathematical modelling separation in the hydrocyclone of the particles which contains in the Bingham slurry. The flow field within the hydrocyclone can be considered to be axisymmetrical with three velocity components in the radial axial and tangential directions. The 2D equations of rheodynamics were used for description of the flow field. An algebraic slip model will be used to represent the relative migration of particles in the liquid mixture. The present model will take into account the dependence of the density and viscosity of the slurry from particle concentration.

The set of the equations was solved with the use of an algorithm suggested by Patankar, where the finite difference equations where obtained by integrating the differential equations over scheduled volumes which incorporated points of a staggered finite-difference grids. The continuity equation was satisfied indirectly using an iterative method named PISO.

The calculations of the cut size in several hydrocyclone geometries for particles in the Bingham slurry was carried out and the results were quite reasonable. This results demonstrate that separation characteristics of the hydrocyclone are strongly affected by the rheological parameters, especially magnitude of the yield stress. The increasing of the magnitude of the yield stress leads to diminishing of the tangential velocity. Therefore coarse particles in the conical part of hydrocyclone cannot reach the vicinty of the wall and get with the upstream vortex in the overflow. This is mechanism for decrease in the sharpness of separation and the increase of the cut size with higher yield stress.

This research has been supported by the by the Alexander von Humboldt Foundation.

15:10	**Ivanovic**	**H 1058**

Control Of Unsteady Mhd Boundary Layer On Porous Surface

Decan Ivanovic, Vladan Ivanovic, Department of Mechanical Engineering, University of Montenegro, Serbia and montenegro

The fluid, flowing past the surface, is incompressible and its electro-conductivity is constant. The present magnetic field is homegenous and perpendicular to the surface and through the prose contour the fluid has been injected or ejected. In order to study this problem, a polyparametric method known as generalized similarity method has been established. The corresponding equations of unsteady boundary layer, by introducing the appropriate variable transformations, momentum and energy equations and three similarity parameters sets, being transformed into generalized form. So obtained generalized solutions are used to calculate the shear stress distribution in laminar-turbulent transition of unsteady boundary layer on porose high accelerating circular cylinder, whose center velocity changes in time as a degree functions. It's shown that for both in confuser and in diffuser regions the ejection of fluid postpones the boundary layer separation, and vice versa the fluid injection favours the separation. For both injection and ejection of fluid, the magnetic field increases the friction and postpones the laminar-turbulent transition. Magnetic field influences on postpone of boundary layer separation is stronger for high fluid acceleration, an also than for ejection in the same flow. Boundary layer characteristics are found directly, no further numerical integration of momentum equation.

Session 6
Thursday, March 30, 13:30 - 15:30

Room: H 1029

Miscellaneous

Chair:

Vitaly Vetlutsky
Natalia Lebedeva

13:30	Lebedeva	H 1029

Admixture Stratification In The Stagnation Region Of Two Streams

Natalia Lebedeva, A. Osiptsov, Lomonosov MSU, Russia

A self-similar 2D steady-state flow of two immiscible viscous fluids with inertial inclusions is considered. It is assumed that two viscous streams interact forming a flat interface with a stagnation point. The general case is discussed, when the fluids have different viscosities and densities and the streams are directed at arbitrary angles. The far field corresponds to inviscid vortex flow near an "oblique" stagnation point. The limiting case of viscous dusty flow near a rigid plane is studied in detail within one-way coupling and two-way coupling approximations.

The dispersed phase is decsribed using both the Eulerian and full Lagrangian approach, with the Stokes drag exerted on the particles. The problem is reduced to a boundary value problem for a high-order system of ODE, which is solved numerically for a wide range of governing parameters. It is shown that the spatial distribution of inertial particles near the stagnation point formed by two colliding streams is very nonuniform with the formation of layered structure of particle concentration and the appearance of thin zones of particle accumulation. Different qualitative flow patterns are demonstrated and the threshold parameters corresponding to the change of regime are found.

Work is supported by the RFBR grant 05-01-00502.

13:50	Yericheva	H 1029

Heat Transfer And Aeroelastic Oscillation Of Circular Cylinder

Valentyna Yericheva, Pavel Kudinov, Dnepropetrovsk National University, Ukraine

The problem of aeroelastic oscillations of the circular cylinder is topical for many technical applications. Resonance phenomena in aeroelastic systems are of special interest. Also aeroelastic oscillations can be used for the control of heat mass transfer.

The aim of the present paper is comparison of heat transfer in constantly accelerated flow of viscous fluid for the fixed and elastically mounted circular cylinder.

Navier-Stokes equations of viscous incompressible fluid are solved numerically by the SIMPLER algorithm. Semi-analytic method is developed for solving equations of dynamics on each time step. Usage of the semi-analytic method, instead of Runge-Kutta method allows to considerably decrease the time for calculation.

Verification of developed methods was carried out on a problem of fixed cylinder in a viscous fluid flow. The good coincidence of dependence of Strouhal and Nusselt numbers from a Reynolds number with experimental dependences is obtained. Also the vibrations of elastically mounted rigid cylinder in non-accelerated flow were studied. The dependence of cross flow displacement amplitude from the reduced damping coefficient, amplitude and aerodynamic forces response as a function of time are obtained. They are in a good agreement with known experimental data.

The effect of flow acceleration and of spring's rigidity on heat transfer intensification at the resonant oscillations of elastically mounted rigid cylinder in accelerated fluid flow is studied.

It was obtained that, when the frequency of oscillation of aerodynamic force is captured by the natural frequency of oscillations of the cylinder, there is almost constant heat flux. So one can obtain increasing or decreasing of heat flux as contrasted to the fixed cylinder.

14:10	Vetlutsky	H 1029

Partikelbeladene Strömung In Einer Überschalldüse

Vitaly Vetlutsky, V. L. Ganimedov, Institut für Theoretische und Angewandte Mechanik Novosibirsk, Russia

Zur Beschreibung des Problems einer partikelbeladenen Düsenströmung für große Reynolds- Zahl wird der Prandtl-Ansatz verwendet. Zur Berechnung der Partikelströmung im reibungsfreien Gebiet wird der Lagrange-Ansatz und der Euler-Ansatz in der Grenzschicht verwendet. Die Validierung des erstellten Codes für die reibungsfreie Strömung wird durch Vergleich mit Experimenten durchgeführt. Der Einfluß der drei Randbedingungen fur die Partikel wird untersucht: die Haftung, die nichtelastische Reflexion und die totale Reflexion. Die Berechnungen zeigen, daß die Partikel, die im Einströmquerschnitt der Düse eingeführt werden, sich vor dem kritischen Querschnitt von der Wand entfernen. Danach häufen sich die Partikel auf der Achse im Überschallteil der Düse an. Die Erhöhung der Partikelzahl verursacht eine Verzögerung des Gases in diesem Gebiet. Die Strömungsberechnungen in der Grenzschicht werden für konstante Wandtemperatur und die Randbedingungen am äußeren Rand durchgefuhrt, die aus den Berechnungen der reibungsfreien Strömung resultieren. Die Grenzschichtströmung mit

Bronze-Partikeln wird in einer konischen Düse betrachtet. Der Einfluß des Öffnungswinkels in Unterschallteil, des Füllungskoeffizients und des Partikeldurchmessers wird auf die Partikelströmung untersucht.

14:30	**Ivanova**	**H 1029**

Numerical Analysis Of Slow Steady Flows Of Nonlinear Viscous Fluid

Natalia Ivanova, S.P. Timoshenko Institute of Mechanics of National Academy of Sciences of Ukraine

A problem on steady flows of nonlinear viscous fluid with the viscosity function depended on the second invariant of the rate of strain tensor is stabilized under 'velocity-pressure' mixed formulation.

The equations of motion take the form of he Stokes approximation. We consides the mixed boundary conditions, the no-slip condition is prescribed on one portion of the boundary while on the other portion the surface forces are given.

The problem is reduced to finding a saddle point of some functional. Under some conditions on viscosity function, force function and surface forces are natural from the physical point of view, the existence and uniqueness of a weak solution of our problem are established. The augmented Lagrangian technique and finite element methods are applied to obtaining the approximate solutions and strong convergence of approximate velocity and pressure functions to exact ones is proved.

To solve finite dimensional nonlinear problems iterations and splitting approach are used. In this case we obtain uncoupling linear problems for the separate calculation of each component of the velocity vector and pressure.

The method under consideration was applied to numerical investigation of polymer fluid flow in the axi-symmetric and two-dimensional domains.

Session 7
Thursday, March 30, 16:00 - 18:00

Room: H 1058

Modelling/Rotating Systems

Chair:

Frank Obermeier
Venkatesa Vasanta Ram

16:00	Mausbach	H 1058

Scherviskosität Für Das „gaussian Core Model“-fluid

Peter Mausbach, Fachhochschule Köln
Helge-Otmar May, Fachhochschule Darmstadt

Molekulardynamische Methoden gelten als wichtige Verfahren zur Bestimmung von Materialeigenschaften viskoser Flüssigkeiten. Auf dieser Basis berechnen wir mit Hilfe des Green-Kubo-Formalismus die Scherviskosität für ein „Gaussian Core Model (GCM)“-Fluid. Das Wechselwirkungspotenzial für die Fluidteilchen ist beschränkt, daher ist eine gegenseitige Durchdringung der Teilchen möglich. Dies kann zu verschiedenen Flüssigkeitsanomalien, wie z.B. der anomalen Diffusion, führen. Die Kopplung der Viskosität mit der Diffusion wird durch die Stokes-Einstein-Relation beschrieben. Wegen dieses Zusammenhanges ist eine Untersuchung der Viskosität für das GCM von großem Interesse.

16:20	Obermeier	H 1058

Prandtl's Mixing Length Model - Revisited

Frank Obermeier, Institut für Mechanik und Fluiddynamik, TU Bergakademie Freiberg

The paper is concerned with a modification of Prandtl's mixing length model of Reynolds stresses in turbulent channel flows. Here it is well known that Prandtl's model fails to describe the main Reynolds stresses correctly very close to the wall, as it displays a quadratic instead of a cubic behavior with respect to the wall distance. Furthermore, the resulting solution of the x-component of the time averaged velocity fails to describe the channel flow correctly from the wall to its center. To evade this problem usually two different asymptotic solutions of the mean flow are presented in the literature, valid either very close to the wall or at some distances from the wall. To avoid this problem van Driest introduced a damping function. However, the resulting Reynolds stress still shows an incorrect behavior at the wall. In the present paper an alternative modification is discussed were only the correlation length of the velocity fluctuations normal to the wall is modified but the correlation length of the fluctuations parallel to the wall remains unchanged. The modified model describes the mean velocity, all Reynolds stresses, the production of these Reynolds stresses, and the functional dependence between Reynolds numbers based either on the mean velocity or on the stress velocity. The results agree well with experimental data and with data obtained by direct numerical simulations.

16:40	**Vimmr**	**H 1058**

Modelling Of Newtonian And Non-newtonian Incompressible Fluid Flow

Jan Vimmr, University of West Bohemia, Pilsen, Czech Republic

In this work, the isothermal turbulent flow of incompressible Newtonian fluid is investigated. The turbulent flow field is assumed to be statistically steady. The mathematical model is described by the non-linear conservative system of the Reynolds-averaged Navier-Stokes (RANS) equations with two different kinds of turbulence models, such as algebraic Baldwin-Lomax model and Spalart-Allmaras one-equation turbulence model. This system of equations is solved using the pseudo-compressibility method. The spatial discretization is performed by the cell-centred finite volume method on a structured quadrilateral grid.

Further, the non-Newtonian incompressible fluid flow is modelled. The governing equations are based on the Navier-Stokes equations for the Newtonian fluid flow, only a special constitutive equation for the viscosity is implemented.

The developed numerical code is tested on a incompressible flow in a test tube and all obtained results are compared.

17:00	**Bleier**	**H 1058**

Stability Of A Strongly Swirling Annular Flow

Nikolaus Bleier, V. Vasanta Ram, Ruhr-Universität Bochum

The subject of our contribution is the transition of the swirling flow in the annular space between concentric circular cylinders when the inner cylinder is set in rotation and a small axial pressure gradient is imposed. Besides the conventional parameters, viz. a Reynolds number and the transverse curvature, transition is affected by the further flow parameter S that characterises swirl. The parameter

S may be identified as the ratio of the characteristic velocities in the azimuthal and axial directions.

Our study focusses attention on the difference in the nature of propagation of small amplitude disturbances from the case $S = \infty$, when transition is by the classical Taylor mechanism. The main difference is seen to be that, in contradistinction to the classical Taylor instability, there is a propagating wave at the onset of transition. Results of our computations of the stability characteristics over a range of S within the framework of a linear theory will be presented.

17:20	Hussong	H 1058

The Critical Layer Of A Swirling Annular Flow In Transition

Jeanette Hussong, V. Vasanta Ram, Ruhr-Universität Bochum

Subject of our contribution is transition of the swirling flow in the annular gap between concentric circular cylinders one of which is set in rotation. The swirl generated is one caused by a combination of an imposed axial pressure gradient and pulling the inner cylinder axially. In this flow configuration, transition is affected by additional flow parameters characterising swirl and the axial wall velocity.

Our aim is to identify the outstanding features of propagation of small amplitude disturbances from a point of view of examining the possibility of transition control. Our primary interest centers around the differences from the classical case of zero swirl and axial wall velocity, when transition is brought about by the classical Tollmien-Schlichting mechanism. In particular, the focus of our attention lies in the dependence of the critical layer on the additional parameters. Results of our computations of the stability characteristics over a range of the additional parameters will be presented.

Session 8
Thursday, March 30, 16:00 - 18:00

Room: H 1029

Aerodynamics and Turbulence

Chair:

Dmytro Redchyts

16:00	Redchyts	H 1029

Numerical Modelling Of Aerodynamics Of Darrieus And Savonius

Dmytro Redchyts, Olexander Prykhodko, Dniepropetrovsk National University, Ukraine

In the report the most typical aspects of technology of numerical modeling of dynamics and aerodynamics vertical-axis wind turbines are surveyed: selection of initial mathematical model, the model of turbulence, selection of the numerical method, verification of initial mathematical model and testing of the numerical method, machining and visualization of the obtained results. The procedure offered in the present work is founded on the joint solution of the equation of wind turbine rotation and the equations describing a non-stationary incident airflow of a wind. Simultaneously with the problem of streamlining of wind turbines blades the equation of rotation of a rotor concerning fixed axis under the action of the incident airflow and the affixed loading for definition of the current angular rate of wind turbine rotation was decided. For calculation of aerodynamic characteristics algorithms are used on the basis of Reynolds average Navier-Stokes equations (RANS). The one-equation model of turbulence Spalart-Allmaras is used. In the capacity of the test problems streamline of the fixed and rotating circular cylinder; fixed, oscillating and rotating airfoil NACA 0012 are considered. The procedure is applied to calculation of aerodynamic characteristics of vertical-axis wind turbines. The results of Darrieus and Savonius rotors calculations with different quantity and geometrical performances of blades are submitted. Singularities of aerodynamics (boundary layer breakaway, interaction of blades, flow in a track and near to a wind turbine nacelle) are analyzed at the rotation of the windwheel.

16:20	Prykhodko	H 1029

Numerical Modeling Of Space Flows Using Navier-stokes Equations

Olexander Prykhodko, Dniepropetrovsk National University, Ukraine

A modelling methodology for three-dimensional flows is developed on the base of three-dimensional non-stationary full and reduced Navier-Stokes equations. The modern development trends of numerical algorithms of a solution of Navier-Stokes equations, and also methods of their closure by turbulence models are considered. All stages of numerical algorithm development for calculation of compressible and incompressible flows, in particular, formulation of initial equations, choice of turbulence model, creation of a difference analogue, grid generation, testing of developed algorithms are considered. Non-orthogonal coordinate systems are used in formulation of the initial non-stationary Navier-Stokes equations. Explicit and implicit difference schemes, method of finite difference and finite volumes methods on structured and not-structured grids are applied to build difference analogues. Scalar and vector sweep method, Gauss-Zeidel iteration method, conjugate gradient method are used for solution of algebraic equation systems. The used approach is presented as a package of applied codes. For verification and testing of the developed approach the following problems are solved: the Soda test, plate boundary layer problem, non-regular flow through a nozzle, interaction of a shock wave with a laminar and turbulent boundary layer, subsonic and supersonic flow around sphere, cylinder and cone under attack angle, transonic flow around a single airfoil, calculation of flow in a lattice of compressor and turbine airfoils, flow over a wedge and semi-cone installed on a plate. An analysis of calculation results concerning the structure and specific features of spatial turbulent separated supersonic flows under large attack angles around combination sphere-cylinder, angle from two wedges, conical concave wing, and also cylinder installed on a plate are presented.

16:40	Rasuo	H 1029

On Boundary Layer Control Using Suction In The Wind Tunnels

Bosko Rasuo, Faculty of Mechanical Engineering, University of Belgrade, Serbia and Montenegro

The establishment of exact two-dimensional conditions of flow in the wind tunnels is a very difficult problem. This is evident for the wind tunnels of all types and scales. In order to create correct two dimensional flow conditions and uniform spanwise loading of the airfoil model, it is necessary to apply side-wall suction, i.e. the control over the boundary layer along the side walls of the wind tunnel.

In this paper a closed-form analysis of flow in a two-dimensional transonic wind tunnel that uses the sidewall distributed suction around the model to reduce the sidewall boundary-layer effects is presented.

Some practical examples and experimental results are given for the NACA 0012 airfoil, tested at subsonic and supercritical flow conditions in perforated wall test sections of the Aeronautical Institute VTI's high Reynolds number trisonic wind tunnel. The VTI's wind tunnel is a blowdown type with a two-dimensional test section with a cross section dimensions $0.38 \times 1.5\,m$.

17:00	Dumitrache	H 1029

A Numerical Model For Two-dimensional Flow Of Flapping Airfoil

Alexandru Dumitrache, Statistical and Applied Mathematics Institute, University of Bucharest, Romania

Flapping flight has been suggested as a means of propulsion for micro-aerial vehicles flying machines.

The paper presents a computational study of the fluid physics of a heaving airfoil, to elucidate the important features of these flows and determine how the flow physics relate to important parameters such as power consumption and efficiency.

To study the physics of the flow, a numerical model for the two-dimensional flow around an airfoil undergoing prescribed oscillatory motions in a viscous flow is described. The model is used to examine the flow characteristics and power coefficients of a symmetric airfoil heaving sinusoidally over a range of frequencies and amplitudes.

Both periodic and aperiodic solutions are found. Additionally, some flows are asymmetric in that the up-stroke is not a mirror image of the down-stroke.

For a given Strouhal number, the maximum efficiency occurs at an intermediate heaving frequency (in contrast to ideal flow models).

Below a threshold frequency, the separation of the leading edge vortices early in each stroke reduces the force on the airfoil and leads to diminished thrust and efficiency. Above the optimum frequency, the efficiency decreases similarly to inviscid theory. For most cases, the efficiency can be correlated to interactions between leading and trailing edge vortices, with positive reinforcement leading to relatively low efficiency.

Additionally, the efficiency is related to the proximity of the heaving frequency to the frequency of the most spatially unstable mode of the average velocity of the wake; the greatest efficiency occurs when the two frequencies are nearly identical.

The importance of viscous effects for low Reynolds number flapping flight is discussed.

17:20	Dumitrescu	H 1029

Boundary Layer And Flow Field Structure On Wind Turbine Blades

Horia Dumitrescu, Vladimir Cardos, Statistical and Applied Mathematics Institute, Romania

Blade rotation routinely and significantly augments aerodynamic forces during zero yaw horizontal axis wind turbine operation. To better understand the flow physics underlying this phenomenon, three-dimensional and rotational viscous effects on wind turbine blades are investigated by means of a 3-D boundary layer model. The governing equations of the model are derived from 3-D primitive variable boundary-layer equations written in cylindrical coordinates in the rotating frame of reference. The latter are integrated along the peripheral direction with the radial distance as parameter for a particular external flow The skin friction coefficient is used to identify boundary layer separation and shear layer reattachment locations. Separation and reattachment kinematics shows at inboard locations that while the separation point location is not really affected and remains near the leading edge, the reattachment point advances forward rapidly on the blade chord from the trailing edge as radial distance decreases. It is concluded that the rotational augmentation is linked to specific separation and reattachment state strictly determined by the Coriolis forces.

12 Waves and acoustics

Organizers:

Alfred Kluwick, TU Wien
Franz Ziegler, TU Wien

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 2038

Acoustics

Chair:

Alfred Kluwick

13:30	Von Estorff	H 2038

Vibro-acoustic Investigations Using Finite And Infinite Elements

Otto Von Estorff, Steffen Petersen, Intsitut für Modellierung und Berechnung, TU Hamburg-Harburg

The prediction of vibro-acoustic phenomena of complex systems requires the use of numerical methods such as the Finite Element Method (FEM), which is generally well suited in the lower frequency range. In recent years, however, the focus of research with respect to acoustic simulations shifted to the range of higher wave numbers. This gave motivation for using higher order shape functions and related p-FEM concepts, which may be used in order to increase the accuracy and to control the so-called pollution effect.

With an increasing wave number, the problem size may increase significantly, rendering iterative solution procedures, such as Krylov subspace methods, particularly efficient. The performance of these methods, however, strongly depends on the spectrum of the resulting system matrices, which is affected by the polynomial approximation function space. The current work shows that finite elements based on Bernstein polynomials yield particularly good performance in combination with commonly employed Krylov solvers. Adapting the basis of Astley-Leis infinite elements, the Bernstein polynomials may also be used for exterior acoustic simulations. In this contribution, the efficiency of such elements for interior acoustic problems as well as for sound radiation analyses is assessed.

13:50	Obrist	H 2038

COMPUTATION OF ACOUSTIC FAR-FIELDS

Dominik Obrist, Felix Keiderling, Leonhard Kleiser, ETH Zürich

Accurate numerical investigations of aero-acoustic phenomena require well-resolved DNS or LES. On the one hand we need to keep the computational domains of these expensive simulations small. On the other hand we want to know the sound levels far from the acoustic sources (for instance, the noise of an aircraft at take-off as perceived by an observer on the ground). Therefore numerical investigations are split into (a) a DNS/LES of the generating flow and the acoustic near-field and (b) a solver which uses the DNS/LES results to compute the far-field acoustics.

The far-field solution is described by Lighthill's acoustic analogy (Lighthill, 1951). It is solved by evaluating volume integrals. Ffowcs Williams & Hawkings (1968) have used Lighthill's theory to formulate a surface integral method where the acoustic sources are concentrated on a control surface.

We will discuss a spectral formulation of Lighthill's analogy (Crighton, 1975) which gives insight into the mechanisms of sound generation. This formulation motivates an accurate yet efficient scheme for the computation of the acoustic far-field. We will present this scheme in detail and will discuss the differences to the Ffowcs Williams & Hawkings method in terms of accuracy, computational cost and numerical robustness on the basis of various examples.

14:10	Schmidt	H 2038

A ZERO MACH NUMBER PROJECTION METHOD COUPLED TO EXTERNAL ACOUSTICS

Heiko Schmidt, Matthias Münch, Rupert Klein, FB Mathematik und Informatik, FU Berlin
Michael Oevermann, Institut für Energietechnik, TU Berlin

Long wave acoustic play an important role for thermo-acoustic combustion instabilities of premixed flames in industrial gas turbines or boilers. Here we present a fully conservative projection method for variable density zero Mach number flow taking explicitly into account long wave number acoustical effects. The coupling between acoustics and hydrodynamics is achieved by a multiple scale asymptotic ansatz. This ansatz leads to a modification of the divergence constraint and the momentum equation in the zero Mach number limit. Information about the acoustic field can be provided by any external acoustic model. The objective of our development is the provision for long wavelength acoustical effects in an efficient scheme for low Mach number flow which usually does not support acoustic waves. The method is applied to the oscillatory flow through a diaphragm. Using the unsteady solutions of pressure and velocity at the boundaries of the computational domain we are able to construct characteristic acoustical information as transfer matrices, reduced length, and acoustic loss coefficients. Additionally the effect of varying background velocity is studied. The results agree well with experimental data.

14:30	**Cardos**	**H 2038**

Aerodynamic And Acoustic Radiation From An Airfoil In Arbitrary ..

Vladimir Cardos, Horia Dumitrescu, Statistics and Applied Mathematics Institute, Romania

The reduction of aircraft noise is an important consideration for current and future aircraft designs as environmental noise pollution becomes increasingly detrimental with increased air traffic. The phenomena of interest are inherently unsteady and cover a wide range of frequencies and amplitudes. Nonetheless, with appropriate simplifications and special care to resolve specific phenomena, currently available methods can be used to solve important acoustic problems. Our method determines far field acoustics from near field unsteadiness and has greatly reduced the computational requirements. Using the time-dependent circulation hypothesis, the present paper calculates the components of aerodynamic forces for the airfoil performs arbitrary unsteady motions in fluid. In the same time, the field of speed is calculated in entire region of fluid and that determines acoustic radiation. The given diagrams show a good agreement which another theoretical and experimental results.

14:50	**Russkikh**	**H 2038**

To The Calculation Of The Acoustic Field Of Wind Turbine

Dmytro Russkikh, Galyna Sokol, Dniepropetrovsk National University, Ukraine

Therefore the environmental analysis of the noise which was generated by the wind turbines is needed. Actuality of problem of decline of noises does not cause any questions. In wind turbines WE 250 and WE 500 made by The State Design Office “Youzhnoe” (Ukraine) basic knots are the typical emitters of infrasound. So, frequency of rotation of wind turbine makes 47,6 turns per minute. The same wind turbines WE generate in an environment infrasound with frequency of 2,4 Hz. Creation of calculation method of the acoustic field descriptions wind turbines WE 500 is the purpose of this work. The method is based on work of L. J. Gutyn, which describes of the sound pressure calculation method, radiated powers and descriptions of orientation for a two-blades rotor. Two forces operate on every element of rotor: aerodynamic force and resistance to rotator motion. This element also affects an environment with equal on a size and the oppositely directed forces. Lays out these periodically repetitive forces in the Fourier row. Authors calculate sound pressure in the distant field of wind turbines. The results of calculations are represented as the graphs representing dependence of sound pressure in the distant field of wind turbines at powers of options 100...500 kWt, at speed of wind 3...10 m/s. Calculations are conducted in a software environment MathCAD.

15:10	Sokol	H 2038

Infrasound Is An Ecologically Harmful Factor In Wind Energy

Galyna Sokol, Dniepropetrovsk National University, Ukraine

Sources of infrasound in the wind energy are revealed. Features of general noise in the wind equipment (WE) are defined as sound radiation of its separate junctions. Sources of the sound are the following: the rotor of the wind turbine, machines and mechanisms placed in the WE small head, air cavities of the tower sections, fouling wind stream flowing around vanes of the wind turbine and interacting with their back edge and its turbulent boundary layer. Some WEs placed in the nearest vicinity from one another produce a general acoustic field around them, its features being defined by the noises from separate WEs and their interactions. The frequency range of WE acoustic radiation is rather wide. It contains the infrasound component. The urgency of solving WE noise reducing problems, namely in the infrasound range, is beyond any doubt. New methods for calculation of characteristics of acoustic fields produced by WE junctions are shown in this work. In particular, the methods of calculation of the noise pressure level in the far field of the wind propeller are applied to that of WE system the rotor of the wind turbine acoustic field. New methods for calculation of the acoustic medium resonance frequency in air cavities of the tower WE 500-C sections are offered. Appearance of non-linear waves in tower sections acoustic medium is investigated analytically. The program and the low-frequency We acoustic waves measurement is developed. This allows recommending some noise level reducing means.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 2038

Free surface and scalar dispersive waves

Chair:

Alfred Kluwick
A. Basmat

16:00	Kluwick	H 2038

The Effect Of Surface Topography On Weakly Nonlinear Roll Waves

Alfred Kluwick, Institut für Strömungsmechanik und Wärmeübertragung, TU Wien

The propagation of short waves in turbulent single layer flows forming on inclined surfaces has received considerable interest in the past. It is well known that such flows on flat surfaces are unstable if the Froude number of the unperturbed uniform state exceeds a critical value. In the initial linear stage disturbances grow exponentially with propagation distance but it has been shown that weakly nonlinear effects may limit the maximum wave amplitude under strictly periodic conditions leading in turn to a train of permanent roll waves. The present study investigates how the flow behaviour is affected if the slope of the bounding surface is no longer constant but changing slowly in the streamwise direction.

16:20	Basmat	H 2038

Interaction Of A Solitary Wave With A Porous Elliptical Cylinder

Oleksandr Basmat, ReneWave Ltd., Toronto, Canada

In this paper the diffraction of a plane first-order solitary wave by a vertical permeable elliptical breakwater with calculation of the wave loading is investigated. The interaction between long non-linear water waves and dissipative/absorbing breakwaters that are commonly used in ocean engineering is investigated using both analytical and numerical technique. The breakwater consists of a vertical permeable surface-piercing elliptical cylinder fixed in the ground. The analytical model herein is based on the application of Boussinesq equations to describe the diffraction of the first-order solitary wave by an elliptical cylinder. The method of solution is based on perturbation theory, using a perturbation parameter defined in terms of surface geometry of the cylinder. The analysis includes terms up to the first-order in this parameter, where the zeroth-order solution corresponds to a circular cylinder. The velocity potentials at the zeroth and first orders are expressed as eigenfunction expansion involving unknown coefficients that are determined through the boundary conditions on unperturbed cylinder. The flow through the porous cylinder is assumed to obey Darcy's law. The total force onto the elliptical cylinder is obtained by integration of the pressure over permeable cylindrical wall. The analytical solution is obtained by means of a Fourier transformation technique. The effects of porosity, relative wave length and the incident wave angle are discussed. Numerical results compare well with previous predictions for the limiting case of a permeable circular cylinder.

16:40	Selezov	H 2038

Pulse Propagation In Fluid-filled Cylindrical Shell With Insertion

Igor Selezov, Lidija Nazarenko, Institute of Hydromechanics, National Academy of Sciences of Ukraine

Pulse wave propagation from the end face of semi-infinite cylindrical shell with fluid in the presence of an insertion situated at some distance from the end face is investigated. The pressure pulse growing up to a maximum and exponentially decreasing is applied to the end face at initial instant. It is assumed that the shell material is viscoelastic and fluid is viscous. The motion of shell is described by the Kirchhoff-Love theory of shells, the fluid motion by the equations averaged over the cross-section. The corresponding initial boundary value problem is solved by using the Laplace transform in time with a consequent numerical inversion. The analysis of numerical results for the shell radial displacement and pressure in the presence of elastic insertion is carried out. It follows from calculations that in places of thickness cut break of 10% the strong concentration of shear and flexural stresses takes place, like in the case of vessel joint.

17:00	Boese	H 2038

On Impulse Distortion In Dispersive Media

Fritz G. Boese, Max-Planck-Institut für extraterrestrische Physik

Currently, superluminal impulse propagation in linear, active, transparent, anomalously dispersive optical media is a field of intensive research, cf. [1]-[3]. An electromagnetic impulse $E(z,t)$ propagating in z direction with (angular) carrier frequency ω_c, bandwidth Ω around ω_c, electrical field strength distribution $E(\omega)$, and the medial wave number $k(\omega)$,

$$E(z,t) := A(z,t) \cdot e^{-i[t \cdot \omega_c - z \cdot k(\omega_c)]}],$$

$$A(z,t) := \int_{\omega_c-\Omega/2}^{\omega_c+\Omega/2} E(\omega) e^{-i\{t\cdot[\omega-\omega_c]-z\cdot[k(\omega)-k(\omega_c)]\}} d\omega,$$

input at $z = 0$ in the medium experiences for a linear $k(\omega)$ no distortion. For the case of nonlinear wave numbers $k(\omega)$, a sequence of approximations $\{A_n(z,t)\}_{n\in\mathbf{N}}$ to $A(z,t)$ is set forth. The simplest of them exhibits a distortion growing linerarly with run length z,

$$A_2(z,t) := A[0, t - z \cdot k'(\omega_c)] - izk''(\omega_c) \cdot \ddot{A}[0, t - z \cdot k'(\omega_c)].$$

In the case of the important Gauss impulses $A(0,t) := A \cdot \exp[-(t/\tau)^2]$, $\tau > 0$, a concise representation of the $A_n(z,t)$ is achieved. Open problems in fast-light will be mentioned.

[1] A. Dogariu, A. Kuzmich, L.J. Wang: Transparent anomalous and superluminal light-pulse propagation at negative group velocity, Phys. Rev. A **63**(2001), 53806-53812.
[2] L.J. Wang: Causal all-pass filters and Kramers-Kronig relations, Optics Communications, **213**(2002), 27-32.
[3] H. Cao, A. Dogariu, L.J. Wang: Negative Group Delay and Pulse Compression in Superluminal Pulse propagation, IEEE J. Sel. Top. Quant. Electr. **9**(2003), 52-58.

17:20	Rudnev	H 2038

Small Oscillations Of Inviscid Fluid In Vessels With Perforated ..

Yuri Rudnev, *Dmitriy Borisov, V.N. Karazin Kharkov National University, Ukraine*

Small oscillations of inviscid fluid in a partially filled vessel with rigid perforated bafflers were considered. The presence of rigid perforated bafflers leads to a significant complication in finding of frequencies and modes of a wave motion. But for thin-walled bafflers with large number of small holes exact formulation of a problem can be replaced by a simpler problem with averaged conjugation conditions on bafflers.

Full mathematical statement of limiting problem was given. Solution of this problem is asymptotic limit of initial problem solutions if the hole number increases simultaneously with decreasing of hole sizes. Variational and operator statement of this problem was given as well. It was shown that for the limiting problem fundamental qualitative properties of frequency spectrum and modes of free normal oscillations are conserved.

Oscillations of ideal fluid in rectangular and cylindrical vessel with different types of perforated bafflers was considered as examples illustrating common conclusions.

Numerical method of determining frequencies and modes of normal oscillations in arbitrary shape vessels was offered. Proposed method is based on the variational

formulation of the problem under consideration.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 2038

Elastic waves 1

Chair:

Rudolf Heuer
Christoph Adam

13:30	Ellermeier	H 2038

Waves In Active Media

Wolfgang Ellermeier, Fachbereich Mechanik, TU Darmstadt

Hyperbolic and dispersive wave propagation in active media is considered. In particular discrete systems and continua examples taken from mechanics and electrodynamics (Chua and van-der-Pol continua) are investigated.

13:50	Von Ende	H 2038

Simulation Von Lamb-wellen Zur Schadensdetektion In Platten

Sven Von Ende, Rolf Lammering, Helmut-Schmidt-Universität

Versteckte Strukturschäden von Flächenbauteilen schnell und effizient zu detektieren ist Gegenstand dieses Forschungsprojekts. Mit Hilfe der Ausbreitungseigenschaften von hochfrequenten elastischen Wellen in dünnwandigen Bauteilen können Rückschlüsse auf vorhandene Defekte gezogen werden. Als besonders geeignet haben sich die über die komplette Bauteildicke wirkenden Lamb-Wellen erwiesen.

Im Sinne des Konzepts adaptiver Strukturen erfolgt die Generierung der Wellen mit Hilfe piezoelektrischer Keramiken. Die Erzeugung und Ausbreitung der Wellen in komplexen Strukturen wird mit der Methode der Finiten Elemente simuliert. Dazu werden 2D- und 3D-Berechnungen durchgeführt. Unter Zugrundelegung idealisierender Annahmen werden die Berechnungen für einfache Konfigurationen unter Verwendung der Fourier-Transformation analytisch verifiziert.

14:10	Sofronov	H 2038

Non-reflecting Boundary Conditions For Anisotropic Media

Ivan Sofronov, Nikolai Zaitsev, Keldysh Institute of Applied Mathematics RAS, Russia

Our method is based on conceptions of both analytical [1] and discrete [2] transparent boundary conditions. We improved the approach [3] towards drastic reduction of computational costs of exploring TBC; in particular unlike [2], [3] it does not require additional massive auxiliary calculations while changing grid parameters in the computational domain. The elastic wave propagation in 2D orthotropic media is considered to show strong transparency of open boundaries with proposed NRBC for all tested cases (unlike PML that fails in some cases [4]).

The work is supported by the RFBR grant No. 04-01-00567.

[1] *I.L. Sofronov.* Artificial boundary conditions of absolute transparency for two- and three-dimensional external time-dependent scattering problems. Euro. J. Appl. Math., **9**, No.6 (1998), 561-588.
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[3] *I.L. Sofronov, O. Podgornova.* A spectral approach to generate non-reflecting boundary conditions for external problems in inhomogeneous media. J. Scien. Comp., to appear (ICOSAHOM-2004 proceedings).
[4] *E. Becache, S. Fauqueux, P. Joly.* Stability of perfectly matched layers group velocities and anisotropic waves, JCP, **188** (2003), 399-433.

14:30	Symchuk	H 2038

To Evolution Of The Profile Of Hyperelastic Cylindrical Waves

Iaroslav Symchuk, C. Cattani, J. Rushchitsky, S.P. Timoshenko Institute of Mechanics, Ukraine

Evolution of the initial profile of hyperelastic plane waves is quite well studied for different models. The significant part of results was based on using the Murnaghan elastic potential as permitting the adequate description of waves in materials. This lecture shows the recent steps in studying the cylindrical waves, when nonlinearity is described by Murnaghan potential and the quadratic nonlinearity only is saved. The starting point is deriving the nonlinear wave equation corresponding to the axisymmetric state which depends on the radial coordinate only. This state is characteristic for the propagating in direction perpendicularly to the symmetry axis and harmonic in time cylindrical waves arising in the hyperelastic medium with a cylindrical cavity. Obtained within the framework of the second approximation analytical solution consists of the sum of "the first" and "the second" harmonics. For some fibrous composite materials with nanolevel fibers, the primary computer analysis of distortion of an initial wave profile is carried out and transformation of the first harmonics of the cylindrical wave into the second one is demonstrated graphically. The matrix of composites is the mixture of epoxy rosin EPON 828 and polystyrene. As the arming fibers the zig-zag and chiral carbon nanotubes are chosen.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 2038

Elastic waves 2

Chair:

Christoph Adam
Rudolf Heuer

16:00	Zakharov	H 2038

Bending Waves Of Rayleigh Type In Anisotropic Layered Plates

Dmitry Zakharov, Terralife Comm, Moscow, Russia

Everybody knows what is a Rayleigh wave. However, in plates the bending waves propagating along the stress-free edge and having the exponential decay when going away from this edge also exist and known since the late 60-th. In the present paper such waves in anisotropic and possibly layered plates are investigated. Both symmetrical and asymmetrical layup is taken into account. The dispersion properties are considered. New physical effects and differences from the case of isotropic material are discussed. For the latter case the possibility to use asymptotics of high order is shown with a good agreement with experimental data.

16:20	Dobovsek	H 2038

Wave Dispersion Decoupling In Micropolar Thermoelasticity

Igor Dobovsek, Faculty of Mathematics and Physics, University of Ljubljana, Slovenia

For a system of field equations of micropolar thermoelasticity we derive a propagation condition for thermoelastic disturbance in a form of monochromatic plane wave in deformation, micro rotation and temperature. The corresponding dispersion relation is given in an explicit form, together with dependence of characteristic coefficients on principal material constants forming the constitutive tensor of isothermal macro and micro elasticity, phenomenological heat conductivity and coupled macroscopic thermoelasticity. It is shown that due to the centrosymmetric nature of microelasticity and particular form of temperature coupling in free energy function, the separation between the optical and acoustical branch of dispersion relation is inherent. For such systems dispersion relations due to the micropolar fields on one side and macroscopic thermoelastic fields on the other side are completely independent without any cross-coupling.

16:40	**Simionescu-Panait**	**H 2038**

Attenuated Wave Propagation In Cubic Crystals Under Biasing Fields

Olivian Simionescu-Panait, Dept. of Geometry, Bucharest University, Romania

Last decades, the problems related to electroelastic materials subject to incremental fields superposed on initial mechanical and electric fields has gain considerable extension, due their complexity and to multiple applications in electro-mechanical engineering.

In this domain we studied the effects of the interactions between initial elastic deformation and electric fields applied to a solid continuum material, regarding the progressive waves propagation in such media. We started with the simpler case, the isotropic material subject to initial mechanical and electric fields, and we obtained the electrostrictive effect on wave propagation.The next step was to investigate the conditions of plane waves propagation in cubic crystals subject to initial deformations and electric fields. We showed the influence of the electrostrictive and piezoelectric effects on wave propagation in such media. In a more complex case, of a 6mm-type crystal, we find the conditions for propagation of progressive waves along the symmetry axis, in the plane normal to the symmetry axis, and in the meridian plane containing the symmetry axis. We investigated the influence of the initial fields on the shape of slowness surfaces, respectively on the values of generalized electromechanical coupling coefficients.

In the present work we find the conditions of propagation of attenuated plane waves in cubic crystals, subject to initial mechanical deformations and initial electric fields. For initial longitudinal and transverse electric fields, we derive the velocities of propagation, the displacements, and the attenuation coefficients, as closed form solutions, and we analyze the polarization of the obtained waves in two main cases: (i) propagation along a cube edge; (ii) propagation along a cube face. We show the influence of the electrostrictive and piezoelectric effects on attenuated wave propagation in such media. We find approximate expressions of the previous solutions, that generalize known results, and could be useful in various applications. For particular choice of the initial electric field, we obtain and analyze the generalized anisotropy factor.

Session 5
Thursday, March 30, 13:30 - 15:30

Room: H 2038

Impact

Chair:

A. Basmat

13:30	Teufel	H 2038

Rotating Stick-slip-separation Waves In A Shaft-bush Configuration

Andreas Teufel, Alois Steindl, Hans Troger, TU Wien

The problem of a rotating rigid shaft fitted into an elastic annular bush by means of a diameter mismatch is studied as a vivid example for the generation of stick, slip and separation waves on the contact surface. This configuration may be regarded as a coarse model for a drum-brake system, where the explanation of break squeal is of great engineering importance. With regard to this goal, we numerically calculate the loci of several non-smooth bifurcations in the parameter space and discuss respectively the occurence of rotating slip, stick-slip, slip-separation and stick-slip-separation waves on the contact surface. We make use of a general friction law accounting for both, a decreasing and increasing dynamic coefficient of friction depending on the local relative velocity between the shaft and the bush.

13:50	Rossikhin	H 2038

Dynamic Stability Of A Pre-stressed Elastic Orthotropic Plate

Yuriy Rossikhin, Marina Shitikova, Voronezh State University, Russia

The problem on impact of a rigid body upon a buffer embedded into a pre-stressed orthotropic plate possessing cylindrical anisotropy is considered. The buffer is modelled by a linear elastic helical spring. The plate's dynamical behaviour is described by equations taking the rotary inertia and transverse shear deformations into account. Longitudinal compression forces are uniformly distributed along the plate's median surface. During the shock interaction of the body with the buffer and, hence, with the plate, the waves which are surfaces of strong discontinuity are generated in the plate and begin to propagate. Behind the wave fronts, the solution is constructed in terms of ray series, which coefficients are the different order discontinuities in partial time-derivatives of the desired functions, and a variable is the time elapsed after the wave arrival at the plate's point under consideration. The analysis of the solution obtained enables one to make the inference that under a certain critical compression force the orthotropic plate goes over into a critical state, what is characterized by 'locking' the shear wave within the contact region.

14:10	Shitikova	H 2038

Fractional Derivative Viscoelastic Model Of The Shock Interaction

Marina Shitikova, Yuriy Rossikhin, Voronezh State University, Russia

Impact of a rigid body upon an elastic isotropic plate, whose equations of motion take the rotary inertia and shear deformations into account, is investigated. The impactor is considered as a mass point, and its contact with the plate is established trough a buffer involving a linear spring-fractional derivative dashpot combination, i.e. buffer's viscoelastic features are described by the fractional derivative Maxwell model. It is assumed that transient wave of transverse shear generates in the plate. To determine the desired values behind the transverse shear wave front, one-term ray expansions are used, as well as the equations of motion of the impactor and the contact region. As a result, we are led to a set of two linear differential equations in the displacements of the spring's upper and lower points. The solution is found analytically by Laplace transform method, and the time-dependence of the contact force is obtained.

14:30	Kubenko	H 2038

Plain Problem Of Impact By A Blunted Rigid Body Against A Thick

Veniamin Kubenko, National Academy of Scienses of Ukraine, Ukraine

The next problem is considered. A blunted rigid body moves sheer to surface of thick elastic plate and meets with it with given velocity and then it begins to penetrate into the plate and deforms it. A mixed initually-boundary problem with moving unknown boundary is formulated. It includes equations of elasicity (plate) and equation of motion of the body; boundary conditions on the plate's frontal surface (body 's and plate's velocities are equal one another at the contact domain, normal stress is absent out of it, shear stress is absent everywhere) and on the backside of it; zero initially conditions for the plate and given initially velocity for the body; criterion to determine the contact domain. Solution of the problem is constructed with help of Forier serios expansions and after boundary conditions' satisfaction it reduced to infinite system of 2-nd kind Volterra integral equation that must be solved together with equation of of the body motion. Numerical solution of the system provides determination of stresses, displacements and velocities with provision for wave diffraction on the backside. Some examples are included.

14:50	Gavrilova	H 2038

Forced Stationary Gas-structure Interaction Vibrations In A Tank

Elena Gavrilova, St. Ivan Rilski University of Mining and Geology, Bulgaria

A closed rigid rectangular parallelepiped tank is filled with gas and a part of one of its walls is a thin linearly elastic rectangular plate. The problem of the determination of the forced stationary vibrations of the obtained gas-structure interaction system under the action of a point source is under consideration. The method of the crossed strips of Warburton and the Bubnov-Galerkin method are used to create a method of investigation of the dynamic behavior of the considered gas-structure interaction system in the cases of arbitrary supporting conditions of the plate. An approximate solution is made based on the ignoring the diffracted by the elastic plate waves. Some numerical examples are made and they are represented graphically.

15:10	Marchenko	H 2038

Non-symmetric Shock Of Different Elastic Cylindrical Bodies

Tetiana Marchenko, S.P. Timoshenko Institute of Mechanics, Ukraine

The approach to the investigation of non-central shock interaction process for two different cylindrical elastic bodies has been developed. At the initial moment of contact interaction occurs along common cylinders' generatrix. The size of contact area changes while impacting and is directly determined during the solution. Different statements of the problem are realized depending on the way of definition of the border of contact area. Impact is considered on a small time interval, during which indignation, reflected from back and lateral surfaces has not time to come back to contact area.

During the solution Laplase transformation with the subsequent division of variables in space of images is used. As a result of satisfaction of the mixed boundary conditions, two infinite resolving systems of the second kind Volterra integral equations are received. These systems are solved numerically.

Presented approach allows to define all process characteristics (as rate of movement, force and moment of interaction, angle of rotation, development of normal pressure on the frontal surfaces, change of the border of contact area) at each moment of chock and their dependency on physic-mechanical properties of bodies. Numerical results illustrate the shock of two circular cylinders.

13 Applied analysis

Organizers:

Andreas Münch, Humboldt-Universität zu Berlin
Guido Schneider, Universität Karlsruhe

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: MA 141

Multiple scales

Chair:

Guido Schneider
Andreas Münch

13:30	Teufel	MA 141

Effective Quantum Dynamics In Slowly Perturbed Periodic Media

Stefan Teufel, Gianluca Panati, Herbert Spohn, Christof Sparber, Mathematisches Institut, Universität Tübingen

I review recent result on the Schrödinger equation with a perturbed periodic potential based on adiabatic perturbation theory. Applications include the Piezo- and the Quantum-Hall-Effect.

14:10	Pesetskaya	MA 141

The Effective Conductivity Of Composite Materials

Ekaterina Pesetskaya, Thomas Fiedler, Andreas Oechsner, Jose Grasio, University of Aveiro, Portugal

The effective conductivity of composite materials with cylindrical reinforcements is investigated on the base of two approaches: constructive (or analytical) and numerical. For constructive investigations, the method of potentials is applied to receive analytical representations of the effective conductivity. Furthermore, this analytical approach allows for the consideration of perturbations of the regular reinforcement arrangement. The finite element method as a representative method for a numerical approximation of the effective properties is used. The results obtained by using two approaches are compared for periodic structures and an excellent correlation is found.

14:30	Düll	MA 141

Phase Dynamics In Modulation Equations For Pattern Forming System

Wolf-Patrick Düll, Guido Schneider, Universität Karlsruhe

We analyse the phase dynamics in modulation equations for pattern forming systems close to the boundaries of the Eckhaus-stable domain. For this purpose we approximate the modulation equations by so-called phase-diffusion equations. The solutions of these equations are expected to describe the qualitative properties of the evolution of the pattern. We explain the extent to which the phase-diffusion equations are valid by proving estimates for these approximations.

14:50	Meier	MA 141

Two-scale Models Of Diffusion And Reaction In Porous Media

Sebastian Meier, Michael Böhm, Universität Bremen

Diffusion-reaction processes in porous media usually involve two or more spatial scales of highly different magnitude. In many applications, averaging out the small scales leads to insufficient results. One way of resolving these scales is the solution of local cell problems at discrete points of the medium. For the mathematical analysis of such models, we introduce a continuum framework in appropriate Sobolev spaces. The construction modifies the *Distributed-Microstructure* concept by Showalter et al., introduced for *flow* in fissured media. The formulation is strongly related to the mathematical homogenisation method, but allows also for heterogeneous, in particular non-periodic media.

In our model we consider diffusion, interfacial exchange, and chemical reaction of a gas in an unsaturated porous medium. The scenario is typical for the degradation of concrete due to the attack of chemical substances. From a mathematical point of view, the problem leads to a coupled system of semilinear or quasilinear parabolic equations. We formulate assumptions under which the abstract PDE problem is wellposed.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: MA 144

Eigenvalue problems

Chair:

Andreas Münch
Guido Schneider

13:30	**Trunk**	**MA 144**

Minimum-phase Infinite-dimensional Second-order Systems

Carsten Trunk, Birgit Jacob, Institut für Mathematik, TU Berlin
Kirsten Morris, University of Waterloo, Canada

We study second-order systems of the form

$$\ddot{z}(t) + A_o z(t) + D\dot{z}(t) = B_o u(t),$$

equipped either with velocity measurements

$$y(t) = B_o^* \dot{z}(t).$$

or position measurements

$$y(t) = B_o^* z(t).$$

Here the stiffness operator A_o is a self-adjoint, positive definite, invertible linear operator on a Hilbert space $\mathcal{H}$ and the control operator B_o is a bounded operator acting from $\mathbb{C}^k$ to $\mathcal{H}_{-\frac{1}{2}}$, where $\mathcal{H}_\alpha$, $\alpha \in \mathbb{R}$, is the scale of Hilbert spaces with respect to A_o. Moreover the damping operator $D : \mathcal{H}_{\frac{1}{2}} \to \mathcal{H}_{-\frac{1}{2}}$ is a bounded operator such that $A_o^{-1/2} D A_o^{-1/2}$ is a non-negative operator in $\mathcal{H}$.

The transfer function $G(s) = B_0^*(s^2 I + sD + A_o)^{-1} B_o$ describes the behaviour of the system in the frequency domain. In the case $\mathcal{H}$ equals $\mathbb{C}^n$ a system is called *minimum-phase* if its transfer function G is defined and has no zeros in the right-half-plane. A more general definition of minimum-phase systems exists for infinite-dimensional systems.

As for finite-dimensional systems, it is desirable that the system is minimum-phase. It is therefore advantageous to establish conditions under which infinite-dimensional systems are minimum-phase.

We will show that with this choice of output, and some additional assumptions on the damping operator D, these systems are well-posed and have a minimum-phase transfer function G.

The results are illustrated by an example.

13:50	Behrndt	MA 144

An Operator Theoretic Approach To Elliptic Boundary Value Problems

Jussi Behrndt, Matthias Langer, Institut für Mathematik, TU Berlin

We describe a family of self-adjoint extensions of symmetric second order elliptic partial differential operators on a smooth bounded domain with the help of boundary conditions on the functions and their derivatives from the domain of the maximal operator. We discuss the connection between the spectra of these self-adjoint differential operators and the solvability of a class of associated boundary value problems. Moreover a linearization procedure for certain types of boundary value problems involving partial differential expressions with boundary conditions depending nonlinearly on the spectral parameter will be presented.

14:10	Kirillov	MA 144

Krein Space Related Perturbation Theory For MHD α^2-dynamos

Oleg Kirillov, Uwe Guenther, FB Maschinenbau, TU Darmstadt

The mean field α^2-dynamo of magnetohydrodynamics (MHD) [1, 2, 3] plays a similarly paradigmatic role in MHD dynamo theory like the harmonic oscillator in quantum mechanics. In its kinematic regime this dynamo is described by a *linear* induction equation for the magnetic field. For spherically symmetric $\alpha-$profiles $\alpha(r)$ the vector of the magnetic field can be decomposed into poloidal and toroidal components and expanded in spherical harmonics. In the present contribution the spectrum of the spherically symmetric α^2-dynamo is studied in the case of idealized boundary conditions. Starting from the exact analytical solutions of models with constant $\alpha-$profiles a perturbation theory and a Galerkin technique are developed in a Krein-space approach. With the help of these tools a very pronounced $\alpha-$resonance pattern is found in the deformations of the spectral mesh as well as in the unfolding of the diabolical points located at the nodes of this mesh. Non-oscillatory as well as oscillatory dynamo regimes are obtained. Finally, Fréchet derivative (gradient) based methods are developed, suitable for further numerical investigations of Krein-space related setups like MHD α^2-dynamos or models of $PT-$symmetric quantum mechanics.

[1] H. K. Moffatt, *Magnetic field generation in electrically conducting fluids*, (Cambridge University Press, Cambridge, 1978).

[2] F. Krause and K.-H. Rädler, *Mean-field magnetohydrodynamics and dynamo theory*, (Akademie-Verlag, Berlin and Pergamon Press, Oxford, 1980), chapter 14.
[3] Ya. B. Zeldovich, A. A. Ruzmaikin and D. D. Sokoloff, *Magnetic fields in astrophysics*, (Gordon & Breach Science Publishers, New York, 1983).

14:30	Karabash	MA 144

Indefinite Sturm-liouville Operators And Parabolic Equations

Illya Karabash, Department of Mathematics, Donetsk National University, Ukraine

We consider the operator

$$(Ay)(x) = (sgn\, x)(Ly)(x) \quad \text{in} \quad L^2(\mathbb{R}), \tag{1}$$

where $L = L^* = -d^2/dx^2 + q(x)$, and the corresponding forward-backward parabolic equation.

Such problems arise in transport theory, statistical physics and hydrodynamics. They leads to the similarity problem for the nonselfadjoint operator $\frac{1}{r(x)}L$ with an indefinite weight $r(x)$. Operators with a discrete spectrum have been considered by Beals, Kaper *et al* and Pyatkov. For definitisable operators Ćurgus and Langer have developed another method.

We present the new approach to spectral analysis of the operator A, which allows to remove assumptions mentioned above. It is based on Naboko-Malamud similarity criterion. Several effective conditions of similarity of A to a selfadjoint operator are obtained. We construct an example of a nondefinitizable operator of type [(1) that is similar to a normal operator. Eigenvalues in the essential spectrum of A are studied. Geometric and algebraic multiplicities of eigenvalues are given. An operator of type (1) with an eigenvalue of infinite algebraic multiplicity is constructed.

It is proved that if L is a nonnegative Sturm-Liouville operator with a finite-zone potential, then the corresponding forward-backward parabolic problems have a unique solution.

Joint work with Mark Malamud (Donetsk National University)

14:50	Bulatovic	MA 144

On The Perfectly Matched Gyroscopic Systems

Ranislav Bulatovic, Mila Kazic, Department of Mechanical Engineering, University of Montenegro, Serbia and Montenegro

A linear n-dimensional gyroscopic system described in modal coordinates is called perfectly matched if the gyroscopic matrix contains one and only one non-zero element in each row and column. The neccessary and sufficient conditions under which it is possible to find a real congruence transformation which reduce a gyroscopic system to the perfectly matched system are formulated. The conditions are expressed directly in terms of the coeffitient matrices of the original system.

15:10	Loginov	MA 144

Pseudoperturbation Method For Computation Of E. Schmidt Eigenvalue

Boris Loginov, O. Makeeva, E. Foliadova, Ulyanovsk State Technical University, Russia

E. Schmidt had introduced (1908) for integral operators the systems of eigenvalues λ_n, counted with their multiplicity, and eigenelements $\{\varphi_k\}_1^\infty$, $\{\psi_k\}_1^\infty$ satisfying the relations $B\varphi_k = \lambda_k\psi_k$, $B^*\psi_k = \lambda_k\varphi_k$ and allowing to generalize Hilbert-Schmidt theory on non-selfadjoint completely continuous operators in abstract separable Hilbert space H. As s-numbers these systems have found many applications in computational mathematics and ill-posed problems theory.

Here for a pair of linear, bounded for simplicity, operators $B,\ A \in \mathcal{L}(H)$ the generalized E. Schmidt eigenvalues and eigenelements are introduced by the following equalities [1] $B\varphi = \lambda A\psi,\ B^*\psi = \lambda A^*\varphi$, where λ can be chosen real. The last system for the non-symmetric operator A is non-selfadjoint, and E. Schmidt's eigenelements can have generalized Jordan chains.

In this communication for approximately given n-multiple E. Schmidt eigenvalue λ and relevant Jordan chains of eigenelements the perturbation operator is constructed such that these approximations would be exact for the perturbed operators. Then on the base of branching theory applications in perturbation theory Newton-Kantorovich iterational process is suggested for the computation of exact values of E. Schmidt λ and relevant eigenelements with Jordan chains.

[1] Loginov B.V., Pospeev V.E. On eigenvalues and eigenelements of perturbed operator. Izvestya Acad. Sci. Uzbek SSR, No. 6, 29–35 (1967) (Russian).

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: MA 141

Multiple scales

Chair:

Guido Schneider
Andreas Münch

16:00	Lasser	MA 141

Resonances Generated By A Conical Intersection Of Energy Levels

Caroline Lasser, Setsuro Fujiie, Laurence Nedelec, FU Berlin

We present an explicit asymptotic description of the resonant set of a matrix-valued Schrödinger operator with conically intersecting eigenvalues.

16:20	Swart	MA 141

The Non-crossing-rule

Torben Swart, Institut fuer Mathematik, FU Berlin

We discuss the so-called Non-Crossing-Rule of theoretical chemistry, which makes a basic statement about the electronic spectra of diatomic molecules.

We motivate the importance of degeneracies in the electronic spectrum by the time-dependent Born-Oppenheimer-Approximation. Afterwards we present the concept of symmetry groups and give a discussion on the conditions for a spectral degeneracy.

We show that these conditions cannot be met by arbitrary electronic states, unless one imposes certain restrictions on their symmetry properties.

16:40	Zeitlin	MA 141

Pattern Formation In Collective Quantum Dynamics

Michael Zeitlin, Antonina Fedorova, Russian Academy of Sciences, Russia

We demonstrate the appearance of nontrivial localized (stable) states/patterns in a number of collective models covered by the (quantum) hierarchy of quasiclassical

Wigner-von Neumann equations and present the explicit constructions for exact analytical/numerical computations. Our fast and efficient approach is based on variational and multiresolution representations in the bases of polynomial tensor algebras of generalized coherent states/wavelets (fast convergent variational-wavelet representation). We construct the representations for hierarchy/algebra of observables/distribution functions via the complete multiscale decompositions, which allow to consider the polynomial type of nonlinearities. Numerical modeling shows the creation of different internal structures from localized modes, which are related to the localized, entangled and chaotic-like type of behaviour and the corresponding patterns (waveletons) formation. Applications to the modeling of quantum computer are considered.

17:00	Fedorova	MA 141

Fusion Modeling In Complex Vlasov-maxwell-poisson Dynamics

Antonina Fedorova, Michael Zeitlin, Institute of Problems of Mechanical Engineering, Russia

An exact variational/projection approach is proposed for modeling the complex collective behaviour in plasma physics models described by different forms of Vlasov-Maxwell-Poisson equations. We give representations for partition functions and physical fields via the multiscale/multiresolution decomposition corresponding to exact expansions into the slow and fast nonlinear high-localized eigenmodes providing the full information about stochastic dynamical process. Numerical modeling shows the creation of different internal structures from localized modes, which are related to stable/unstable type of behaviour and the corresponding patterns (waveletons) formation. Reduced algebraical structure provides the pure algebraical control and realization of localized fusion states with energy confinement.

17:20	Kazic	MA 141

On The Accumulation Resonance Of Systems

Nenad Kazic, University of Montenegro, Serbia and Montenegro

In this paper, the influence of the accumulation effect on the switch frequency of the machine, is analyzed. Under some conditions, some kind of resonance appears in the system. In this situation, increasing of the accumulation does not reduced the switch frequency of the machine controlled by ON/OFF regulation. Presented approach can be applied through the analogy on many problems: in hydraulic, operational research, data processing etc.

17:40	Fiedler	MA 141

How Are Vibrating Beams Damped?

Bernard Fiedler,

he intention of this presentation is to obtain competent feedback on the issue of real damping of vibrating beams, even in the linear case.

We consider a "one-dimensional" metal blade with one free end and the other end clamped to a vibrating support of adjustable frequency and amplitude. We compare measured resonant frequencies of several spatial modes with standard (and rather naive) mathematical assumptions on appropriate damping terms. The resulting discrepancies call for proper modelling, perhaps even on a micro-scale, which remains elusive at the present stage, however.

This is joint work with Mohamed Belhaq (Lab. de Mecanique, Univ. Hassan II, Casablanca), supported by DFG and GTZ.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: MA 144

Thin liquid films and thin membranes

Chair:

Andreas Münch
Guido Schneider

16:00	Evans	MA 144

Asymptotic Structure Of A Dewetting Thin Liquid Film

Peter Evans, Andreas Münch, Institut für Mathematik, HU Berlin
J. R. King, University of Nottingham, United Kingdom

When a thin liquid film dewets, it forms a rim which spreads outwards leaving behind a growing dry region. The structure of such a rim, formed by a viscous liquid in the limit of strong slip on a planar substrate, can be modelled by two coupled partial differential equations (PDEs) describing the film thickness and velocity. Using asymptotic methods, we describe the structure of the rim as it evolves in time. This description is compared with numerical solutions of the full system of PDEs.

16:20	Rump	MA 144

Coarsening In A Droplet Model: The Role Of Migration

Tobias Rump, Institut für angewandte Mathematik, Universität Bonn

A configuration of droplets connected by a precursor layer, which wets the entire substrate, coarsens in time: The average droplet size increases while the number of droplets decreases. We consider an evolution equation for the film height $h > 0$ on the substrate:
$$\partial_t h + \nabla \cdot (m(h)\nabla(\Delta h - U'(h))) = 0,$$
where m is the mobility function given by $m(h) = h^q$ for $q > 0$. U stands for the intermolecular potential.

As was shown by Glasner and Witelski for $q = 3$ in case of a one-dimensional substrate, there are two competing pathways of coarsening: *collapse* and *collision* of droplets.

- *Collapse* relies on mass exchange through the precursor layer: The larger droplets grow at the expense of the smaller ones. This is known as Ostwald ripening.
- Droplets migrate on the precursor layer, which can lead to coarsening by *collision*. According to the choice of m, the mobility of the droplets strongly increases with height.

We study the role of migration in the coarsening process for the whole range of mobility exponents $q > 0$ in case of a two-dimensional substrate. In particular, we show that the migration factor of a droplet depends on q.

This is a joint work with Felix Otto and Dejan Slepčev.

16:40	**Bock**	**MA 144**

ON A PSEUDOPARABOLIC SYSTEM FOR A VISCOELASTIC SHALLOW SHELL

Igor Bock, FEI Slovak University of Technology, Bratislava, Slovak

We deal with the system describing moderately large deflections of thin viscoelastic shallow shells. The nonlinear strain-displacement relations due to von Kármán-Donnell theory is considered. In the short memory case the system consists of an pseudoparabolic partial differential equation for a deflection and an equation with the biharmonic left-hand side and the pseudoparabolic right-hand side for the Airy stress function. The existence and uniqueness of a solution is verified by transforming the problem into the sequence of stationary canonical equations of von Kármán elastic type. We assume the shell made of an isotropic material. It is clamped on the boundary and subjected to the perpendicular load $f(t,x),\ t > 0,\ x \in \Omega$, where Ω is a middle surface. The following pseudoparabolic von Kármán-Donnell system for the deflection and the Airy stress function describes its behaviour:

$$\begin{aligned}
&\Delta^2(D_0\partial_t w + \beta D_1 w) - [\Phi, w] - \Delta_k\Phi = \partial_t f(t,x) + \beta f(t,x) \text{ on } [0,T]\times\Omega,\\
&\Delta^2\Phi = -hE_0\partial_t(\frac{1}{2}[w,w] + \Delta_k w) - h\beta E_1(\frac{1}{2}[w,w] + \Delta_k w) \text{ on } [0,T]\times\Omega,\\
&\Delta_k w = k_{11}\partial_{22}w + k_{22}\partial_{11}w,\ k_{11} > 0,\ k_{22} > 0,\\
&w = \frac{\partial w}{\partial\nu} = \Phi = \frac{\partial\Phi}{\partial\bar{\nu}} = 0 \text{ on } [0,T]\times\Gamma, \quad w(0,x) = w_0(x) \text{ on } \Omega.
\end{aligned}$$

We transform the system into one canonical initial value problem in a Hilbert space and solve it by the semidiscrete approximation.

17:00	**Rajter-Ciric**	**MA 144**

On Stochastic Wave Equation

Danijela Rajter-Ciric, Marko Nedeljkov, Department for Mathematics and Informatics, University of Novi Sad, Serbia and Montenegro

In modern analysis, stochastic differential equations are generally very interesting for studying. In this paper, the authors consider stochastic wave equation and construct the solution as Colombeau generalized stochastic process. Also, in some cases, the limiting behavior of that solution is considered.

17:20	Ivasishina	MA 144

Calculation Of Temperature Field In Non-asymptotically Thin Layers

Darya Ivasishina, Dniepropetrovsk National University, Ukraine

The problem of temperature field determination in a body covered by thin layer of other substance is very actual at the moment, because practically all industrial products have protective severing layer. If the layer is asymptotically thin, its thermal effect is negligibly small and it only changes heat transfer condition parameters on outer surface. However, if the layer is non-asymptotically thin, for example, layers of thermal insulation, it can have a significant thermal effect. A numerical calculation of the mentioned effect is rather difficult, because it leads to multiscale problem with all specific difficulties of such kind of problems. Its analytical investigation is restricted by cases, when analytical methods are effective. Thus a specific approach must be developed for the considered problem. An asymptotic analysis is applied to the problem. The temperature field in non-asymptotically thin layer is represented as a series with respect to small parameter, constructed as relation of the reference size of the layer thickness to the reference size of main body. It is shown that the time derivative term and the tangential heat conduction terms have a next smallness order in comparison with the term describing heat conduction across the layer. Then main heat conduction process on every approximation step in the layer is described by boundary-value problem for ordinary differential equation, which can be easy to solve analytically. Correspondent approximation terms for temperature distribution in the main body can by constructed by any known numerical (or analytical) method. In particular, boundary element method is used for case of infinite main body in the present work and finite difference method is used for main body of finite size. Special attention is paid to one-dimensioned in space case, which gives an opportunity to easy show specific features of the proposed approach. The developed algorithm is illustrated by several examples of numerical calculations.

17:40	Voigt	MA 144

Strong Anisotropies In Geometric Evolution Laws

Axel Voigt, Crystal Growth group, caesar

Surface anisotropies for crystalline materials often show a negative stiffness for certain orientations.

These lead to backward parabolic equations if mean curvature or surface diffusion is considered.

Recent experimental evidence on a nanometer length scale and theoretical predictions from ab initio calculations provide a physically based way to regularize these equations.

Higher order terms in the surface free energy, depending not only on orientation but also on curvature or derivatives of the curvature can be used to define well posed higher order problems. We discuss through regularity arguments the necessity of such terms and introduce sixth and eighth order equations for strong anisotropic mean curvature flow and surface diffusion, respectively.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: MA 141

Elasticity, energy methods

Chair:

Guido Schneider
Andreas Münch

13:30	Krejcí	MA 141

Hysteresis In Temperature-driven Phase Transitions

Pavel Krejcí, WIAS Berlin

We consider a class of models for multiphase evolution, where the phase transition process is driven by the energy balance, and by a phase dynamics equation (a so-called phase-field system). Such systems are irreversible and exhibit a strong *rate-dependent* entropy production due to heat conduction and phase relaxation. Additional *rate-independent* dissipation effects occur due to the latent heat storage and release, as well as at the contact with the boundary of the admissible phase domain. A third possible source of hysteresis arises in systems with a free energy of double well/double obstacle type, where phase transition only takes place if a potential barrier is overcome. The aim of this contribution is to demonstrate that using hysteresis operators to model the rate-independent components of the system may become useful for the mathematical analysis of the whole evolution problem. Furthermore, in the double well case, perfect hysteretic phase separation patterns arise in the long-time limit as a result of the time scale doubling between the global slow heat evolution and the local fast phase dynamics.

14:10	Schmid	MA 141

An Evolution Model In Contact Mechanics With Dry Friction

Florian Schmid, Alexander Mielke, WIAS Berlin

We present an existence result in contact mechanics with friction.

Our model consists of an elastic system whose shape is determined by the position of a single particle, thus leaving only three degrees of freedom. Further we assume that the external forces driving the system vary slowly in time. This allows us to neglect inertia terms, so the model will be rate-independent.

The main difficulty in such evolution problems is caused by the friction term which is physically modelled by Coulomb's law. Mathematically the friction term is usually modelled by a multi-valued subdifferential. We present a different approach, introduced by Mielke, which is based on an energetic formulation of the problem and may be applied to general rate-independent evolution problems.

14:30	**Ricker**	**MA 141**

Existence Of Solutions To The Linearized Spinning Wheel Problem

Sarah Ricker, Nina Kirchner, Andreas Menzel, Paul Steinmann, Lehrstuhl für Technische Mechanik, Universität Kaiserslautern

Spinning wheels, or rather steady rolling cylinder-like deformable bodies occur in many mechanical (contact) problems, e.g. car- or aircraft-tires, gears or grinding processes. In order to avoid transient calculation for such problems and in order to obtain a steady-state formulation we make use of a model -advocated by Oden and Lin in [1]- based on a spinning reference coordinate system. After developing the kinematics and deriving the weak formulation we will show the existence of a weak solution for the linearized spinning wheel problem by applying the Lax Milgram Lemma. The presented contribution will be concluded by some numerical examples.

[1] J.T. Oden and T.L. Lin. On the general rolling contact problem for finite deformations of a viscoelastic cylinder. Computer Methods in Applied Mechanics and Engineering. 57, 297-367, 1986.

14:50	**Knees**	**MA 141**

Energy Release Rate For Cracks In Finite-strain Elasticity

Dorothee Knees, Alexander Mielke, WIAS Berlin

Griffith's fracture criterion describes in a quasistatic setting whether or not a preexisting crack in an elastic body is stationary for given external forces. In terms of the energy release rate (ERR), which is the derivative of the deformation energy of the body with respect to a virtual crack extension, this criterion reads: If the ERR is less than a specific constant, then the crack is stationary, otherwise it will grow.

In linear elasticity the ERR for a straight crack can be expressed e.g.,by the J-integral or stress intensity factors. Regularity results for weak solutions of the corresponding field equations are essential for the derivation of these formulas. In nonlinear elasticity similar formulas for the ERR are also given in literature. These formulas are derived assuming that weak solutions have a certain higher regularity. In general, however, such regularity results have not been proved yet and, to our knowledge, a rigorous derivation of these formulas taking into account the known regularity of weak solutions is not done yet in the nonlinear case.

In this talk, we consider geometrically nonlinear elastic models with polyconvex energy densities and prove that the ERR is well defined. Moreover, without making any assumption on the smoothness of minimizers, we derive rigorously the well-known Griffith formula and the J-integral, from which the ERR can be calculated. The proofs are based on a convergence result for Eshelby tensors.

15:10	Glitzky	MA 141

Energy Models Where The Equations Are Defined On Different Domains

Annegret Glitzky, WIAS Berlin

We introduce a stationary energy model for semiconductor devices. Thereby we accept the more realistic assumption that the continuity equations for electrons and holes have to be considered only in a subdomain Ω_0 of the domain of definition Ω of the energy balance equation and of the Poisson equation. Here Ω_0 corresponds to the region of semiconducting material, $\Omega \setminus \Omega_0$ represents passive layers. Equations for the contacts are substituted by Dirichlet boundary conditions. The resulting nonlinear system of model equations is strongly coupled and has to be considered in heterostructures and with mixed boundary conditions.

For space dimension two we prove a local existence and uniqueness result for the stationary energy model. For this purpose we derive a $W^{1,p}$-regularity result for solutions of systems of linear elliptic equations with different regions of definition and use the Implicit Function Theorem.

Session 6
Wednesday, March 29, 16:00 - 18:00

Room: MA 141

Fluid mechanics, conservation laws

Chair:

Andreas Münch
Guido Schneider

16:00	Rohde	MA 141

Mathematical Models For Liquid-vapour Flows

Christian Rohde, Fakultät für Mathematik, Universität Bielefeld

A standard approach to model the dynamics of liquid-vapour flows is the coupling of incompressible models for the liquid phase with compressible models for the vapour phase using a free boundary at the position of the phase transition. However there are many examples of phase-transition phenomena that require the fully compressible modeling of both phases (e.g. cavitation problems or bubble oscillation). The class of Navier-Stokes-Korteweg systems offers the possibility of a such a model. We reviews these models, present the basic analytical results, and a number of numerical experiments. In the final part of the talk we consider the sharp-interface limit of vanishing viscosity and capillarity which leads to first-order systems of mixed hyperbolic-elliptic type.

16:40	Langemann	MA 141

Harmonical Analysis Of The Total Ponderomotive Force

Dirk Langemann, Institut für Mathematik, Universität zu Lübeck

In the investigation of droplets on outdoor high-voltage equipment occurs the problem of determining the ponderomotive force density acting on a comparatively small, uncharged test body. In general, it results in a non-vanishing total force. For instance, rainwater droplets move under its effect and leave water films.

Here, we present the total ponderomotive force as a series of inhomogeneity indicators which are computed by derivatives of the undisturbed electric field in absence of the test body. That enables us to calculate the total force for arbitrary positions of the test body with a single computation of the electromagnetic field equation on the basic geometry. The proposed method is much less time-expensive than the repeated numerical solution of the Poisson's equation for the electric field in the changing geometry including different local scales or even the simulation of a full time-dependent model.

The series expansions are proven for the two-dimensional case by standard Fourier techniques and by the use of spherical harmonics in the three-dimensional case. The order of magnitude of the terms are shown in an example. Finally, a droplet on a realistically shaped insulator is presented.

17:20	Brazaluk	MA 141

Dynamics Of Bubble Motion Under Buoyancy Force

Yuliya Brazaluk, Mykola Polyakov, Dmytro Yevdokymov, Dniepropetrovsk National University, Ukraine

Bubble motions under buoyancy force are widespread effect in manufacturing technologies and environment. The specific feature of such motions is growing size of bubble and then growing apparent additional mass of the bubble. The present paper is devoted to a bubble moving due to only buoyancy force in enough deep fluid without mass exchange with environment. The only effective way of solution of the problem is numerical investigation on base of simplified engineering approaches. The model is based on decomposition of the process into ideal fluid one and viscous one. The shape of bubble is assumed spherical. Since quite accurate experimental and theoretical data for drug coefficient of ball are known in wide range of Reynolds numbers, a consideration of viscous effects can be replaced by empirical formula for drug coefficient. This formula is enough for steady motion, but there is an additional drug force due to fluid acceleration in accelerated motion. The considered problem is reduced to the problem of apparent additional mass determination. Since the physical mass of bubble is small in comparison with apparent additional mass, it can be neglected. The case of single bubble is investigated enough well. More complex situation takes place in the case of several bubbles in the flow, because there are interaction forces and determination of apparent additional masses is quite difficult problem. The boundary element method is used for determination of apparent additional masses and calculation of flow to determine an interaction force. The bubble motions are calculated by Runge-Cutta method.

17:40	Polyakov	MA 141

Calculation Of Spraying Process

Mykola Polyakov, Dniepropetrovsk National University, Ukraine

A spraying process is the best way to obtain thin coating. However it requires a very precise technology and correspondingly a very accurate design to obtain a

uniform thin layer. The main aim of the present work is to develop an effective method of spraying calculation. It is easy to show that the flow can be considered as an ideal fluid flow. Beside of that the flow is enough slow, that Mach number is quite small and therefore the fluid can be considered as incompressible. Thus the gas flow is modelled by potential flow of incompressible ideal fluid in unbounded domain. The drops of spraying liquid substance move in the flow without mutual interaction. The main problem is to determine the point, where a drop touches the body, what requires to know velocity field near the body. Regular boundary element method algorithm with integration along real boundary and improved known and unknown function approximations is used for velocity field calculation. This approach provides high accuracy for points, situated near the body. The motion of the drops is described by Cauchy problem for a system of ordinary differential equations (obtained by using engineering approach), which is solved by Euler method or forth order Runge-Kutta method. To check an accuracy, a motion of liquid particle is used as a test problem. The test shows quite good results. Another test problem is a comparison of numerical results with similar one of the drop motion in analytically determined main flow. This test shows well accuracy too. Dependencies of geometrical parameters of spraying layer on parameters of spraying equipment are obtained.

Session 7
Thursday, March 30, 13:30 - 15:30

Room: MA 141

Phase separation, phase transformation

Chair:

Guido Schneider
Andreas Münch

13:30	Griepentrog	MA 141

Nonlocal Phase Separation Processes

Jens A. Griepentrog, WIAS Berlin

In our talk we give an overview of nonlocal phase separation processes in multicomponent systems of particles. These processes are driven by the minimization of the free energy under the constraint of mass conservation. The free energy functional contains both a convex logarithmic part describing the Fermi-type behaviour of the particles and a nonconvex quadratic part taking into account nonlocal particle interaction. This leads to an evolution system of second order parabolic equations for the mass densities including nonlinear drift terms.

The assumptions on the interaction operator, which ensure both unique solvability and regularity of the problem in suitable function spaces, are quite general. The key quantity to study the asymptotic behaviour is the free energy which turns out to be a Lyapunov functional for the system. Together with a Łojasiewicz-Simon gradient inequality this leads to strong convergence results for the whole trajectory to a stationary point. At the end of the talk we show some numerical simulations to illustrate the results.

14:10	Herrmann	MA 141

On Cluster Formation In Becker-doering Processes

Michael Herrmann, Barbara Niethammer, Institut für Mathematik, Humboldt-Universität zu Berlin

The Becker-Doering equations are a model for cluster formation in a set of identical particles. The main assumption in this model is that clusters can grow or shrink only by gaining or loosing a single atom, respectively. Despite its simplicity the Becker-Doering system can describe the relavant features in a first order phase transition as nucleation, metastability and coarsening. Recently, Dreyer and Duderstadt have proposed a modifified Becker-Doering equation, which leads in some aspects to a different long time behaviour. We focus on the mathematical properties of the modified model as well as on the comparison with the standard model.

14:30	Muntean	MA 141

A Two-reaction-zones Model: Global Existence Of Solutions

Adrian Muntean, Michael Böhm, ZeTeM, Universität Bremen

This talk is motivated by the macroscopic modeling, analysis and simulation of the concrete carbonation process where the carbonation reaction is localized on two distinct internal reaction zones. The zone, which separates reacted from unreacted parts, advances from the outside boundary inwards the material. The balance of diffusion and chemical reaction is the driving force for the motion of the reaction zones. We show the existence of local and global weak solutions and analyze some of their properties. Useful bounds on the penetration speed and final time of the process are presented. FEM approximation of the solution is employed to confirm numerically some of the analytic results: Upper and lower bounds on the active concentrations, monotonicity of the reaction front position, and the effect of secondary carbonation on the penetration depth. The numerical solution is compared with experimental data to illustrate a real-world application.

14:50	Serbichenko	MA 141

Numerical Solution Of Stefan Problem In Leybenzon Approximation

Darya Serbichenko, Mykola Polyakov, Dmytro Yevdokymov, Dniepropetrovsk National University, Ukraine

Slow phase transitions are wide-spread as in industrial technologies, as in natural process, taking place in environment. An asymptotic analysis give an opportunity to reduced a Stefan problem for slow phase transition to a series of elliptic boundary-value problems and the first term of the built series (zero approximation with respect to Stefan number) coincides with well-known Leybenzon approximation (quasi-stationary approximation). Thus the Stefan problem in Leybenzon approximation is reduced to solution of Laplace equations in two domains with moving boundary between them. The position of the interface boundary is determined as a result of solution of correspondent Cauchy problem in every boundary point. Laplace equation is solved numerically by boundary element method at every time step of numerical solution of Cauchy problem. The simplest algorithm of boundary element method with straight line elements in plane case and plane triangular elements in space case is used in the present work. Since the temperature on the phase transition boundary is constant, it is suitable to approximate of known and unknown values on a boundary element by constants. Euler scheme is used for numerical solution of Cauchy problem. A note point displacement is determined by linear interpolation of correspondent values on the connected elements. An accuracy of the proposed algorithms is checked by comparison with known analytical solutions. Beside of that, it is checked indirectly comparing with calculations with half time step and half boundary element length. The proposed approach is illustrated by several examples of numerical calculations.

15:10	Kochubey	MA 141

Boundary Instability Of Slow Phase Transformation

Olexander Kochubey, Tetyana Smolenska, Dniepropetrovsk National University, Ukraine

An instability of phase transition boundary takes place under so-called non-equilibrium phase transformation, for example, evaporation of overheated liquid or solidification of overcooled liquid. It can be prescribed such boundary conditions corresponding to real physical conditions, that the process would accelerate. And more than that, small disturbance of phase transformation boundary under such boundary conditions doesn't decay with time, but it grows. This growth of any small disturbance is evident feature of physical instability.

Slow phase transitions are widespread in natural and technological processes. There are a lot of specific features of the slow phase transitions, which lead to some difficulties in calculations of such processes. To overcome the mentioned difficulties the author of the present work and his colleagues developed a special approach based on small parameter and boundary integral equation methods. Since the effective and accurate algorithm for slow phase transitions exists, the process can be investigated numerically. However the algorithm must be slightly modified to check error accumulation during the calculations. In contrast to conventional phase transformations the considered process is especially interesting when there are several phase transition boundaries in the domain. This case is considered too. The motion of phase transition front decelerates in direction to the nearest phase transition front and accelerates in opposite direction.

To illustrate the proposed approach several examples of the problems described above are solved numerically.

Session 8
Thursday, March 30, 13:30 - 15:30

Room: MA 144

Fixed point theorems, bifurcations

Chair:

Andreas Münch
Guido Schneider

13:30	Schäfer	MA 144

A Fixed Point Theorem In Infinite-dimensional Spaces

Uwe Schäfer, Institut für Angewandte Mathematik, Universität Karlsruhe

In 1940 Miranda published a theorem that guaranteed a zero of a function from R^n to R^n under certain conditions.

Recently, many generalizations of this theorem have been given, but less in real infinite-dimensional spaces.

It is well-known that extending the techniques from finite-dimensional to the infinite-dimensional spaces presents a serious problem. The basic reason for this is that the unit sphere in the finite-dimensional case is compact while the unit sphere in the infinite-dimensional case is not compact.

Therefore, we only get a fixed-point version of Miranda'theorem, and only a special class of mappings which have a compactness property can be considered.

13:50	Marko	MA 144

Global Solutions Of Nonlinear Problem In Hilbert Space.

Lubomir Marko, Department of Mathematics, Slovak University of Technology, Slovakia

We deal with the nonlinear bifurcation problem $u - \lambda Lu + N(u) = 0$ in Hilbert space, where λ is the real parameter, $L : H \to H$ is linear operator and $N : H \to H$ is nonlinear operator of odd degree. We suppose that $\{\lambda_i\}_{i=1}^{\infty}$ be the set of simple eigenvalues of linearized problem $u - \lambda Lu = 0$ in H. We show the properties of solutions, the results describe local and nonlocal behaviour of nontrivial solutions bifurcating from the trivial solution at the point $(0, \lambda_i)$. The interesting result is that for $\lambda \in (\lambda_n, \lambda_{n+1})$, there exists exactly $2n + 1$ solutions without secondary bifurcation.

14:10	Seidel	MA 144

Breaking The Symmetry In A Car-following Model

Tilman Seidel, Bodo Werner, Universität Hamburg

A wide class of microscopic car-following traffic models deals with a system of ODEs describing N cars driving on a circular highway. The symmetry of the road naturally leads to (quasi-)stationary solutions and to an analysis of their stability. Breaking this symmetry with small perturbations we show the existence of a branch of some special solutions that occur instead of the stationary points.

Those solutions can be interpreted in reality, they describe the behavior of the cars on the road as expected.

14:30	Konopleva	MA 144

Application Of Cosymmetric Identity In Branching Theory

Irina Konopleva, Boris Loginov, Y. Rousak, Ulyanovsk State Technical University, Russia

The notion of cosymmetry was introduced in branching theory by V. I. Yudovich (1971) in connection with some nonlinear problems of filtration theory. Then in his scientific school many applications of this notion in nonlinear functional analysis and mechanics were given. Here as the generalization of N. N. Makarenko results (1996,2002) cosymmetry is used for the proof of Lyapounov and Schmidt bifurcation equations (BEq) reduction at their pseudopotential formulation.

In real Banach spaces E_1 and E_2 it is considered general nonlinear equation of branching theory $F(x,\varepsilon) = 0$, $F(x_0, 0) = 0$, $B = B_{x_0} = -F'_x(x_0, 0)$, equivariant with respect to continuous group symmetry $K_g F(x,\varepsilon) = F(L_g x, \varepsilon)$, $K_g F'_x(x_0,\varepsilon) = F'_x(L_g x_0, \varepsilon) L_g$, $g = g(a_1, \ldots, a_r) \subset G_r(a)$, L_g and K_g are representations of Lie group $G_r(a)$ in E_1 and E_2. Under additional assumptions relatively nonlinear operator F, Fredholm operator F'_x and group $G_r(a)$ the group symmetry inheritance theorems for relevant BEqs are proved.

The main result of this communication is cosymmetric identity for pseudopotential branching equations expressing as some type of orthogonality relation of the BEq left-hand-side and Lie algebra infinitesimal operators on its solutions. It allows to investigate BEqs reduction possibilities, and to give for the case of L_g-invariant zero-subspace $N(B)$ of the operator B new approach for the construction of their general forms on admitted group symmetry.

14:50	Iglin	MA 144

Research Of Hyperelastic Orthotropic Elliptical Membranes

Sergiy Iglin, National Technical University “KhPI”, Ukraine
Artem Kulachenko, Mid Sweden University, Sweden
Atanass Sjarrow, University of Economics, Bulgaria

The geometrical relations describing the stress-strain and bifurcation state of hyperelastic pressurized elliptical membranes are formulated.

A non-linear approximation of the constitutive equations for hyperelastic membranes is proposed. The approximation is based on orthotropic relations between true stresses and logarithmic strains.

The system of governing deferential equations describing the equilibrium state of a hyperelastic pressurized elliptical membrane is derived. An efficient code is developed for solving the system of governing deferential equations by the method of initial parameters. The critical pressure at which the membrane reaches the bifurcation threshold and looses stability is determined.

The results of a test problem with a hyperelastic pressurized elliptical membrane “EOOM” are reported.

Suggestions as to enhancing of static computations of hyperelastic pressurized elliptical membranes are proposed.

Keywords: Pneumatic shock absorbers, elliptical membranes, geometrical nonlinearity, non-linear orthotropic materials, hyperelasticity, bifurcation threshold.

15:10	Takaci	MA 144

On The Equation Of Viscoelastic Bar

Arpad Takaci, Department of Mathematics and Informatics, Serbia and Montenegro

We consider mathematical models of a shock between a solid body and a viscoelastic bar within the frames of the Mikusiński calculus. We construct the exact solution of the ordinary differential equation corresponding to the given problems in a form of infinite series. Moreover, we analyze the approximate solution determined as a finite sum, and estimate the error of approximation.

Session 9
Thursday, March 30, 16:00 - 18:00

Room: MA 141

Numerical methods

Chair:

Guido Schneider
Andreas Münch

16:00	Plum	MA 141

ENCLOSURE METHODS FOR ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS

Michael Plum, Mathematisches Institut I, Universität Karlsruhe

The lecture will be concerned with numerical enclosure methods for nonlinear elliptic boundary value problems. Here, analytical and numerical methods are combined to prove rigorously the existence of a solution in some "close" neighborhood of an approximate solution computed by numerical means. Thus, besides the existence proof, verified bounds for the error (i.e. the difference between exact and approximate solution) are provided.

For the first step, consisting of the computation of an approximate solution ω in some appropriate Sobolev space, no error control is needed, so a wide range of well-established numerical methods (including multigrid schemes) is at hand here. Using ω, the given problem is rewritten as a *fixed-point equation* for the error, and the goal is to apply a *fixed-point theorem* providing the desired error bound.

The conditions required by the chosen fixed-point theorem (e.g., compactness or contractivity, inclusion properties for a suitable subset etc.) are now verified by a combination of analytical arguments (e.g. explicit Sobolev embeddings, variational characterizations etc.) and verified computations of certain auxiliary terms, in particular of eigenvalue bounds for the linearization of the given problem at ω.

The method is illustrated by several examples (on bounded as well as on unbounded domains), where in particular it gives existence proofs in cases where no purely analytical proof is known.

16:40	Ruotsalainen	MA 141

BOUNDARY INTEGRAL OPERATORS FOR FRACTIONAL DIFFUSION EQUATION

Keijo Ruotsalainen, Jukka Kemppainen, Faculty of Technology, University of Oulu, Finland

In this paper we study the boundary integral formulation of the fractional diffusion equations. As a model problem we consider the initial-boundary value problem for a Volterra type integro-differential equation

$$\begin{aligned} \frac{\partial u(x,t)}{\partial t} - \int_0^t g(t-s)\Delta u(x,s)dxds &= 0, \text{ in } \Omega \\ B(u) &= f, \text{ on } \partial\Omega \\ u(x,0) &= 0, \end{aligned}$$

where $B(\cdot)$ is the boundary operator which spesifies the boundary data of the solution. The positive memory kernel $g(t)$ is assumed to be weakly singular at 0. In our concrete model problem the kernel is given by $g(t) = \frac{t^{\alpha-1}}{\Gamma(\alpha)}$, $0 < \alpha < 1$.

We present the boundary integral formulation of the problem by using the fundamental solution of the integro-differential operator in question. The mapping properties of the boundary integral operators in anisotropic Sobolev spaces will be given. Furthermore we show the validity of the Gårding inequality. These properties are needed in the analysis of the numerical approximation methods.

17:00	**Smolenska**	**MA 141**

Numerical Modelling Of Nonuniformity Of Biological Growth

Tetyana Smolenska, Dniepropetrovsk National University, Ukraine

The problem of biological growth and its mathematical description is one of the most serious problems of mathematical modelling in theoretical biology. The specific approach to the biological growth phenomena as a heat and mass transfer process is developed during last two decades. It gives an opportunity to apply the well-developed theory of heat and mass transfer in moving boundary domain to the considered problem, in particular, mathematical and numerical models of slow phase transitions are used because the biological growth is significantly slow process. Nonuniformity of biological growth is similar to nonuniformity of phase transition boundary, however it has completely another physical reasons. The growth process depends on a lot of environment parameters accelerating or decelerating the process, but the metabolism changes environment parameters. It leads to non-uniform growth conditions on the surface of biological system. A growth is directed to maximum of nutrient substances and minimum of excrement. There can be sufficient gradients of nutrient substances and excrement. As a rule, the growth increases these gradients, what leads to specific instability of local metabolism and then the growth itself. Such phenomena are often observed in nature. Since a biological growth is slow, the time asymptotic analysis is applied to build a mathematical model. Boundary element method is used for numerical solution of boundary-value problems obtained in asymptotic analysis. The considered problem is illustrated by several examples of numerical calculations.

Session 10
Thursday, March 30, 16:00 - 18:00

Room: MA 144

Miscellaneous

Chair:

Andreas Münch
Guido Schneider

16:00	Kähler	MA 144

Frames For The Continuous Spherical Wavelet Transform

Uwe Kähler, Universidade de Aveiro, Portugal

Over the last ten years there were several ways proposed to define a genuine continuous spherical wavelet transform, e.g. using series development by spherical harmonics, stereographic projection, or reproducing kernels. The most important are the ones which make use of the conformal group on the sphere. In this talk we want to construct frames for such a transform using the language of Clifford analysis, which gives the possibility to apply a geometric language in this context. In the end the best n-point approximation is studied

16:20	Cerejeiras	MA 144

Factorization Of The Non-stationary Heat Equation

Paula Cerejeiras, Univesidade de Aveiro, Portugal

In this talk we describe a factorization of the heat operator $\Delta_x - \partial_t$ based on methods of Clifford analysis, in order to reduce the non-stationary Schrödinger equation to a first order quaternionic equation, which is the direct spatial generalization of the ordinary differential Riccati equations.

Finally we describe the class of potentials $\nu = \nu(x, y)$ which admit a solution φ, of type $\varphi = e^u$, of the Laplacian equation with potential term $(\Delta_x - \nu)\varphi = 0$ where u is a solution of the Bitsadze equation $\partial_{\overline{z}}\partial_{\overline{z}} u = 0$.

16:40	Batra	MA 144

Necessary Stability Conditions For Differential-difference Systems

Prashant Batra, *Institut für Rechnertechnologie, TU Hamburg-Harburg*

Stability of a polynomial as well as a quasi-polynomial can be assessed by checking the principal minors of the Hurwitz matrix for non-negativity. This does not give rise to an equivalent finite test in the case of quasi-polynomials which are essentially infinite-dimensional. The question arises which criterion is suitable for stability tests especially if the system description needs to accommodate imprecisions and approximations. For time-delay systems with coefficients and (incommensurable) delays in finite intervals a new set of elementary four-term inequalities is given. The method of deduction is to construct a function with a specified mapping property, to use an integral representation of such analytic mappings, and then invoke the connection of Stieltjes' moment problem to the theory of non-negative definite forms. The new inequalities extend the well-known inequalities of Laguerre's for the coefficients of real entire functions of order less than two, and our method also covers precisely this class. In the case of polynomials, Newton's inequalities connecting three coefficients of real polynomials with real zeros are recovered, and extended for available coefficient information to an arbitrary number of coefficients. Our approach hence allows to deduce and improve on results derived recently for polynomials, as well as gives new results for differential-difference systems.

Batra, P., *Some Applications of Complex Analysis to Questions of Stability and Stabilizability*, Habilitationsschrift, Hamburg University of Technology, 2006.
Olshevsky, V.; Sakhnovich, L., A generalized Kharitonov theorem for quasi-polynomials, entire functions, and matrix polynomials, *Proc. of the 16th MTNS (MTNS 2004), Leuven*, Katholieke Universiteit Leuven, 2004.
Yang, X.,Some necessary conditions for Hurwitz stability, *Automatica*, vol. 40, pp.527-529, 2004.

17:00	**Dmitriyeva**	**MA 144**

On Some New Aspects Of Classical Riemann Problem

Irina Dmitriyeva, *Institute of Physics and Mathematics, South Ukrainian Ped University, Ukraine*

We look for the function $f(z)$ that is analytic everywhere on complex plane except the finite set of points that are the ramification points of $f(z)$. The functions' values undergo the corresponding permutations when passing round these points, and $f(z)$ is assumed to have a finite order at infinity.

Here we must stress the following important fact: in the classical statement of Riemann problem on the introduction of multivalued function all the ramification points had the permutations of one and the same dimension [1]. In our case to every ramification point corresponds the permutation of its own dimension, i.e. the permutations' dimensions are not equal to each other. Therefore, we obtain the new aspect of notion for multivalued function of one complex variable and, as a corollary, the generalization of Riemann surface in classical sense [1].

The given problem is solved explicitly in terms of the homogeneous vector boundary Riemann problem that is formulated in special way.

Proposed applications concern mostly the waves' theory.

[1] Riemann, B.: Gessamelte Mathematische Werke, 2: Aufl., Teubner, Leipzig 1892.

17:20	Milovanovic	MA 144

Some Mathematical Models In Forestry

Marina Milovanovic, University of Belgrade, Serbia and Montenegro

Mathematical models are fundamental for the rational management of forest, and especially for the intensive management of such plantations. Some examples and modelling issues will be presented in this talk.

17:40	Radnef	MA 144

Analytic Solution Of Non-autonomous Linear Ode

Sorin Radnef, National Institute of Aerospatial Research, Bucharest, Romania

The ordinary differential equation which is the subject of this paper is a linear one, having variable coefficients

$$\frac{dx}{dt} = A(t) \cdot x,$$

considering $x(t) \in \mathbb{R}^n$ and $A(t)$ an $n \times n$ real matrix. For the initial value problem, the solution is stated as a power series with coefficients $c_{k\in\mathbb{N}\cup\{0\}}(t) \in \mathbb{R}^n$.

Finally we arrive at a recurrence formula to obtain, step by step, these coefficients and we compare this result with the one for $n = 1$. The method is applied for a particular ODE of order $n = 2$.

14 Applied stochastics

Organizers:

Karl Sabelfeld, WIAS Berlin
Werner Römisch, Humboldt-Universität zu Berlin

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: H 1029

Chair:

Karl Sabelfeld
Werner Römisch

13:30	**Adamowski**	**H 1029**

SPECTRAL ANALYSIS OF DYNAMIC SYSTEMS WITH RANDOM PARAMETERS

Radoslaw Adamowski, *Pawel Sniady, Institute of Civil Engineering, Wroclaw University of Technology, Poland*

In this paper the problem of spectral analysis of bar systems with random geometrical and mechanical parameters under random loads is considered. There are presented solutions for beams with various support conditions and with known expected value and standard deviation of geometrical and mechanical parameters. The load is assumed as homogeneous stochastic process with Gauss distribution. Support conditions and definitions of loads are selected in the way, which enables to use obtained solutions for the vibration analysis of high engineering constructions (chimneys, towers and masts) under environmental loads (in this case wind loads).

13:50	**Heinz**	**H 1029**

STOCHASTIC MULTI-SCALE METHODS FOR TURBULENT FLOW SIMULATIONS

Stefan Heinz, Department of Mathematics, University of Wyoming, USA

The use of stochastic methods for turbulent flow simulations has significant advantages compared to the application of deterministic methods: the important effects of sources (chemical reactions) can be treated exactly, and the mechanism of turbulent fluctuation dynamics is explained (which is also helpful to develop consistent closures for correlations of turbulent variables that appear as unknowns in deterministic equations). However, stochastic methods developed previously are, basically, only applicable to certain scales: the molecular scale, small-scale turbulent motions (filter density function methods) and large-scale turbulent motions (probability density function methods). First, the paper illustrates these methods and their characteristic advantages and disadvantages by means of several examples. This discussion results in the conclusion that methods should be developed that have a broader range of applicability, this means we need methods which are applicable to a variety of scales. The second part of this paper shows how it is possible to develop such stochastic multi-scale methods. The capabilities of such multi-scale methods and some remaining challenges are described finally.

14:10	Mazur-Sniady	H 1029

Random Longitudinal Vibrations Of Composite Rod

Krystyna Mazur-Sniady, Pawel Sniady, Wroclaw University of Technology, Poland

In the paper the random longitudinal vibrations of a microperiodic composite rod are considered. The rod consists of a very large number of repeated line segments. It means that the dimensions of these segments along the axis of the rod are sufficiently small compered to the length of the rod. The approach is based on concepts of the tolerance-averaged model by Wozniak [3-4]. In this way it is possible to formulate the averaged equations of motion of the rod, which describe the lenght-scale effect. Using these equations we obtain the probabilistic characteristics of the response of the mocroperiodic rod. Obtained characteristics will be used to estimate the reliability of the rod with respect the fatique of the materials as the first crossing problem.

1. J. Fish, W. Chen, Higher-Order Homogenization of Initial/Boundary-Value Problem, J.of Eng. Mech. Dec., 2001, vol.127,12, 1223-1230.
2. K. Mazur-Sniady, A kinematic internal variable approach to dynamics of beams with a periodic-like structure, J. Theor. Appl. Mech., 2001, vol. 39, 175-194.
3. Cz. Wozniak, E. Wierzbicki, Averaging techniques in thermo-mechanics of composite solids. Tolerance averaging versus homogenisation, Wyd. Pol. Czest., Czestochowa 2000.
4. Cz. Wozniak, Micro-macro dynamics of periodic material structures, Eurodyn 93, Balkema, Rotterdam, 1993, 573-575.

5. T.T. Soong, M. Grigoriu, Random vibration of mechanical and structural systems, P T R Prentice-Hall Inc. New Jersey, 1993.

14:30	Proppe	H 1029

Computation Of Failure Probabilities Via Local Approximations

Carsten Proppe, Institut für Technische Mechanik, Universität Karlsruhe (TH)

For failure probability estimates of large structural systems, the numerical expensive evaluations of the limit state function have to be replaced by suitable approximations. Most of the methods proposed in the literature so far construct global approximations of the failure hypersurface. The global approximation of the failure hypersurface does not correspond to the local character of the most likely failure, which is often concentrated in one or several regions in the design space, and may therefore introduce a high approximation error for the probability of failure. Moreover, it is noted that global approximations are often constructed for parameter spaces that ignore constraints imposed by the physical nature of the problem.

In this study, a robust and efficient local approximation scheme of the limit state function for the estimation of failure probabilities is proposed. The major advantages of the proposed local approximation are that the limit state function is evaluated close to the region of most likely failure only and that it is not necessary to compute zeros of the limit state function. Moreover, an interaction between the importance sampling scheme and the limit state approximation scheme becomes possible.

14:50	Rystwej	H 1029

Dynamics Of An Infinite Beam Under Stochastic Moving Forces

Artur Rystwej, Wroclaw University of Technology, Poland

In this paper the problem regarding the dynamic response of an infinite beam resting on two-parametric foundation (Pasternack foundation) to the passage of a train of random forces is studied. This train of forces idealizes the flow of vehicles as having random weights and traveling at the same speed. It is assumed that the occurrence process is a Poisson process or a renewal (Erlang) process. Explicit expressions for the cumulants (semi-invariants) in the case of Poisson process and the expected value and the variance in the case of renewal process of the beam response are provided. Two different situations and solutions are presented. One for arbitrary locations of the forces on the beam and second when one of the forces is located in this point in which the response of the beam has maximum value. The first model can be used for estimate the reliability of the beam with respect

to fatigue, the second model can be useful in the reliability problem of the beam with respect to maximum response.

15:10	Tyagi	H 1029

Stochastic Particle Method For Nonlinear Hyperbolic Problems

Manav Tyagi, Patrick Jenny, Institut für Fluiddynamik, ETH Zürich

Particle methods have been investigated extensively for linear transport problems. However, these conventional particle methods are not suited to compute solutions of a hyperbolic system with non-linear flux functions. Here we present a new approach based on stochastic particles, which allows to compute solutions of a system of nonlinear hyperbolic PDEs arising in the modeling of immiscible displacement in porous pedia. In this approach, we use different particles for different phases and move them according to the stochastic rules for which the probability density function depends on the spatial distribution of the particles. Our motivation for such a method is a Lagrangian modeling approach in which one can describe certain physical phenomena more naturally than in an Eulerian framework. One of the major difficulties was local conservation; especially near discontinuities. It could be demonstrated for various test cases related to multi-phase transport in porous media that our method fulfills this important criterion statistically and that the particle distributions converge to the correct solutions. Moreover, it is demonstrated how this methodology allows to model non-equilibrium phenomena, trapping of phase particles in the porous network, dispersion and gravity effects in a very natural way. Note that such a multi-scale multi-physics framework allows to gain more insight into multi-phase physics in porous media and that the same approach offers similar modeling advantages for other applications.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: H 1029

Chair:

Evelyn Buckwar

16:00	**Kabysh**	**H 1029**

Boundary-layer Effects In Randomly Heterogeneous Materials

Yuriy Kabysh, S.P.Timoshenko Institute of Mechanics, Ukraine

Boundary-layer effects in composites with stochastic structure are analysed. The investigation is carried out on the base of new mathematical model describing the deformation of randomly heterogeneous media under static loading. This model improves well-known theory of effective properties of composites. The stress and strain fields inside of solid in these theories are identical, but in the vicinity of a boundary the stresses and strains in present one are differ from the values that would be predicted by the theory of effective properties. The model is constructed for granular composites and for fibre-reinforced composites which in plane strain state. The model includes fourth order equilibrium equations to the mean displacements and formulas for determining component-wise displacements, strains and stresses through the mean displacements. In a particular case, this model reduces to the theory of elastic mixtures.

The thick-walled fibre-reinforced infinite cylinder under internal and external pressure is presented as example. The cylinder is in plane strain state. The distribution of the fibres is assumed random.

16:20	**Schlather**	**H 1029**

Simulating Random Fields

Martin Schlather, Helmut-Schmidt-Universität Hamburg

Random fields are used to simulate stochastic variability of spatial material properties, such as surface roughness or fluctuations in material density.

Some newer techniques for simulating random fields are presented. The R extension package RandomFields includes these techniques as well as tools for the variogram estimation and kriging.

16:40	Sieniawska	H 1029

Influence Of Plastic Strength Randomness On Structure Reliability

Roza Sieniawska, Alina Wysocka, Stanislaw Zukowski, Wroclaw University of Technology, Poland

The problem of reliability estimation of structures made of an elastic-perfectly plastic material is considered. In order to calculate the reliability regarded as the reliability index, the shakedown limit conditions are used. For the limit conditions generation the kinematic approach is applied. In the calculations the random nature of the geometrical, physical and loading parameters are taken into account. The influence of the random character of the structure parameters on the velocity of plastic strength fields and the influence of the randomness of this fields on the reliability of structures is investigated. The problem analysed is interesting from the theoretical point of view and also has a practical value due to simplification of the calculations.

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Session 3
Wednesday, March 29, 13:30 - 15:30

Room: H 1029

Chair:

Werner Römisch
Kart Sabelfeld

13:30	Winkler	H 1029

Improved Linear Multi-step Schemes For Sdes

Renate Winkler, Evelyn Buckwar, Humboldt-Universität zu Berlin

In this talk the numerical approximation of solutions of Itô stochastic differential equations with small noise is considered. We discuss stochastic linear multi-step methods and their mean-square convergence. Including not only the increments of the driving Brownian motion, but also mixed classical stochastic integrals we derive methods with a mean-square global error of order $O(\epsilon^2 h^{1/2} + h^2)$, where h denotes the stepsize and ϵ quantifies the smallness of the noise. In case of additive noise the error is reduced nearly to that of the corresponding scheme in the deterministic setting. Simulation results using several explicit and implicit stochastic linear k-step schemes, $k = 1,\ 2$, illustrate the theoretical findings.

13:50	Buckwar	H 1029

Asymptotic Mean-square Stability Of Linear Multistep Methods For S

Evelyn Buckwar, Renate Winkler, Rozsa Horvath-Bokor, Otto-von-Guericke Universität, Magdeburg

In this talk we deal with linear multi-step methods for SDEs and study when the numerical approximation shares asymptotic properties of the exact solution in the mean-square sense. As in deterministic numerical analysis we use a linear time-invariant test equation and perform a linear stability analysis. Standard approaches used either to analyse deterministic multi-step methods or stochastic one-step methods do not carry over to stochastic multi-step schemes. In order to obtain sufficient conditions for asymptotic mean-square stability of stochastic linear two-step-Maruyama methods we construct and apply Lyapunov-type functionals.

14:10	Ellermann	H 1029

The Random Environment Of Offshore Systems

Katrin Ellermann, Institut für Fluiddynamik und Schiffstheorie, TU Hamburg-Harburg

The analysis of the dynamical behaviour of systems in ocean waves is an important part in offshore engineering. While a characterization of the response of a linearized model can be obtained in frequency domain, it has to be noted that offshore systems usually include components with nonlinear behaviour.

The systematic analysis of the nonlinear dynamics of floating structures is often facilitated by additional assumptions. One common example is the use of deterministic (harmonic) waves. Even though periodic waves may be a reasonable simplification for many applications, sea waves in general are usually better described by a spectral or probabilistic approach.

This talk addresses different methods of describing random waves for the analysis of floating structures. Examples show the effects of different wave models on the analysis of a simple floating structure.

14:30	Wagner	H 1029

Predicting Turnovers Of Cash Recycling Systems

Tim Wagner, Ute Günther, Fachbereich Mathematik, TU Darmstadt

Cash Recycling Systems (CRS) are Cash Points (CP) that dispense money but also are able to accept deposited money (bank notes and coins). So we analyse the outgoing (Automated Teller Machine (ATM) like) and the incoming cash flow and show that it is not satisfying to analyse the cumulated volume of turnovers.

The first component, highly correlated with the latter by the recycling effect, shows quite non stationary behaviour. We predict both cash flows separately by time series techniques (based on the historical data) and analyse the accuracy of the forecast.

Finally, we estimate security loadings to manage the uncertainty of the future turnovers and find optimal loading plans for large systems of CPs using Mixed Integer Programming (MIP).

14:50	Postelnicu	H 1029

Numerical Taxonomy For Statistical Data Processing

Tiberiu Postelnicu, Centre of Mathematical Statistics of the Romanian Academy, Romania

The purpose of Numerical Taxonomy can be briefly defined as the construction of objective clusters of units by means of a quantitative measure of their affinity. Its name comes from the fact that the first methods were proposed for, and essentially applied to, the biological classification. We emphasize that numerical taxonomy methods present a very powerful multiple comparison instrument insufficiently known or used in several disciplines, ranking from ecology to archaeology and from biostratigraphy to psychiatry. A numerical taxonomy analysis aims to construct clusters of particularly similar objects among a set of objects to be classified, termed as "Operational Taxonomic Units" (OTU). The substitution of the concept of "similarity" between two OTUs by the concept of "homogeneity" is considered. An important case for statistical data processing deals with OTUs described by "binary attributes". Homogeneities for binary and for ordered multistates data are presented.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: H 1029

Chair:

Renate Winkler

16:00	Gottschall	H 1029

Stochastic Modelling Of Wind Speed Power Production Correlations

Julia Gottschall, Edgar Anahua, Stephan Barth, Joachim Peinke, ForWind, Universität Oldenburg

Based on measurements we investigate the velocity-power characteristic of a 1MW wind turbine. We apply a stochastic analysis where we describe the evolution of the power output with a Langevin equation, with special respect to short-time fluctuations in wind speed.

Standard procedures, such as the IEC 61400-12 standard, are limited due to the fact that only mean values over several minutes of wind speed and power output are considered. According to this, short-time dynamics of wind and power fluctuations are usually not taken into account. We introduce an improved method which enables us to extract the requested dynamics of the power characteristic from the measured data.

In particular, we get the response dynamics of the power $L(u(t))$ via the estimation of Kramers-Moyal coefficients, describing its evolution in time $\dot{L}(t)$ with a Langevin equation where we separate the power output into a relaxation and a noise part. A fixed-point analysis provides the required power characteristic.

With this method we are also able to analyze measurement noise, distinguished from the dynamical noise of the stochastic process.

16:20	Bryja	H 1029

Suspension Bridge Response Due To Non-stationary Wind Action

Danuta Bryja, Wrocław University of Technology, Poland

The improved non-stationary wind model is formulated and the correlation analysis of suspension bridge response is presented in a time-domain by stochastic calculus approach. The wind speed consists of a steady part related to the mean speed and a time-varying part related to the gust speed that is composed of a periodic series of long-duration gusts and a superimposed random fluctuation occurred due to wind turbulence. The aerodynamic load of the bridge is assumed to consist of the time-and-space dependent buffeting forces and frequency dependent self-excited forces. The buffeting load acting on the bridge deck is divided on the sections (Cao et al [1]). The linear, global bridge response is calculated as the sum of component dynamic responses due to sectional excitations. To describe suspension bridge vibrations a continuum analytical approach (Bryja [2]) has been adopted.

1. Cao Y. et al, Simulation of stochastic wind velocity field on long-span bridges, Journ. of Engineering Mechanics, ASCE, 126(1), 2000, pp. 1-6.
2. Bryja D., Spatial vibrations of multi-span suspension bridges with large cable sags: continuum formulation, Proc. of 5th European Conference on Structural Dynamics: EURODYN '02, Munich, 2002, Vol. 2, pp. 1047-1052.

16:40	**Zajac**	**H 1029**

Die Kinematisch Erzwungenen Schwingungen Der Fussgängerbrücke

Tomasz Zajac, Wladyslaw Mironowicz, Wrocław University of Technology, Poland

In der Arbeit wird man die kinematisch erzwungene Stochastischschwingungen schwanker Konstruktionen behandelt, zu denen Fußgängerbrücke gehören. Solche Objekte sind empfindlich auf dynamische eingehende Wirkung, und darunter auf die Bewegung des Untergrundes z. B. das Erdbeben, der bergmännischen Gebirgsschlag. Aus praktischen Gründen wurde angenommen, dass die Nutzmasse des Objektes, und die kinematische Belastung die Schicksalsmerkmale haben.

Dargestellt wurde die allgemeine Problemlösung bei dem Gebrauch der Korrelation-Theorie. Die ausführliche numerische Analyse ist man für die Fußgängerbrücke durchgeführt, die in Gestalt von Raumrohrfachwerk. Man hat die verschiedenen Montageständе geprüft, und verschiedene Arten der Gerüste: aus Stahlbeton, Stahl und Holz.

Man analysierte verschiedene Varianten der kinematischen Belastung (die Schnelligkeit und die Richtung von Wellausbreitung, Schwingungen vertikal und horizontal).

15 Computer algebra and computer analysis

Organizers:

Werner Seiler, Universität Heidelberg
Bernd Tibken, Bergische Universität Wuppertal

Session 1
Wednesday, March 29, 13:30 - 15:30

Room: MA 144

Computer Algebra Applications

Chair:

Werner M. Seiler

13:30	Koepf	MA 144

Computer Algebra Algorithms For Orth. Polys. And Spec. Functs.

Wolfram Koepf, FB Mathematik/Informatik, Universität Kassel

In this talk we will show how computer algebra can be used in the study of orthogonal polynomials and special functions. In such computations the following algorithms are most often used: linear algebra techniques, multivariate polynomial factorization and the solution of nonlinear equations, e. g. by Groebner basis techniques.

The classical orthogonal polynomials named after Jacobi, Gegenbauer, Chebyshev, Legendre, Laguerre, Hermite and Bessel can be classified as the polynomial solutions of second order differential equations. Similarly the classical "discrete" orthogonal polynomials named after Hahn, Krawtchouk, Meixner and Charlier are classified as the polynomial solutions of second order difference equations.

Using computer algebra one can compute the recurrence equations and hypergeometric representations of these systems, one can convert this process by computing differential and difference equations from the hypergeometric representations automatically, and one can decide whether a recurrence equation has classical orthogonal polynomial solutions. We will discuss these and related algorithms, and give some on-line demonstrations with Maple.

14:10	Pillwein	MA 144

Hypergeometric Summation Techniques For High Order Finite Elements

Veronika Pillwein, Peter Paule, Joachim Schöberl, SFB013 Johannes Kepler Universität Linz

The goal of this talk is to discuss the application of computer algebra methods in the design of a high order finite element solver. The finite element method is nowadays the most popular method for the computer simulation of partial differential equations.

While low order finite elements are well established since half a century, in the last 10 years high order fem has become more and more attractive because of the higher accuracy achieved and other advantages.

High order finite elements are usually defined by means of certain orthogonal polynomials. The performance of iterative solution methods depends on the condition number of the system matrix, which itself depends on the chosen basis functions. A major goal is to design basis functions minimizing the condition number, and which can be implemented efficiently. A related goal is the application of symbolic summation techniques to derive cheap reccurence relations allowing a simple and efficient implementation of basis functions.

14:30	Zerz	MA 144

Linear Exact Modeling From Multivariate Data

Eva Zerz, RWTH Aachen

Given a finite set of vector-valued polynomial-exponential functions of several variables, we construct its closure in the class of solution sets of linear partial difererential equations with constant coefficients (that is, the smallest such set that contains the data, which is called the most powerful unfalsified model). Various explicit representations of this model are discussed, and we give both a direct and a recursive construction method. The problem has applications in multidimensional system identification (modeling from data), and can be reduced to manipulating multivariate polynomial matrices, which can be performed by computer algebra routines.

14:50	Gábor	MA 144

A Generalization Of Pascal's Triangle Using Powers Of Base Numbers

Kallós Gábor, Széchenyi University, Hungary

In this paper we consider generalizations of the famous Pascal triangle. While the binomial and multinomial coefficients show up in the expansions of $(X+Y)^n$ and $(X_0+X_1+\cdots+X_{m-1})^n$, we consider now expansions of the form $(a_0X_0+a_1X_1+\cdots+a_{m-1}X_{m-1})^n$. We examine the connections among the generalized triangles and powering integers, respectively polynomials.

Moreover, various classical problems of binomial coefficients are studied under generalization. We emphasize the relationship between the new triangles and the Pascal pyramids. Finally, we investigate some divisibility problems.

15:10	**Mladenov**	**MA 144**

Lorentz Force Via Exponential Mapping

Ivailo Mladenov, Georgi K. Dimitrov, Institute of Biophysics, Bulgarian Academy of Sciences

In this paper we present a few closed finite formulas for the exponential map connecting the Lorentz Lie algebra with its Lie group which are used for the description of the motion of charged particles in the static electromagnetic fields under the Lorentz force. These results are based on a theorem specifying all possible canonical forms of the Lie algebra elements. Besides the obvious physical interpretation of the electric and magnetic componets of the field as boost and spatial rotation generators of the Lorentz group our analytical expressions provide new global parametrizations of these transformations. This should be mentioned especially as usualy the exponential map appears in its infinitesimal form because one assumes that it holds only in a neighbourhood of the identity. Higher dimensional analogues and the role of computer algebra systems for solving such kind of problems are also discussed.

Session 2
Wednesday, March 29, 16:00 - 18:00

Room: MA 144

Interval Arithmetics

Chair:

Bernd Tibken

16:00	Decker	MA 144

ENCLOSING EIGENPAIRS OF THE QUADRATIC EIGENVALUE PROBLEM

Friederike Decker, Institut für Angewandte Mathematik, Universität Karlsruhe (TH)

The following quadratic eigenvalue problem is considered: For the matrix polynomial

$$P(\lambda) = A_2\lambda^2 + A_1\lambda + A_0\,, \quad \det A_2 \neq 0,$$

with real quadratic matrix coefficients, we seek real numbers λ^* (eigenvalues) and real non-zero vectors x^* (eigenvectors), such that $P(\lambda^*)x^* = 0$.

A method for verifying and enclosing simple eigenvalues λ^* and the associated eigenvectors x^* is presented.

This interval analytic method is based on a Taylor expansion and the Brouwer Fixed Point Theorem. It uses appropriate eigenvalue and eigenvector approximations.

16:20	Neher	MA 144

ON COMPLEX INCLUSION FUNCTIONS

Markus Neher, Institut für Angewandte Mathematik, Universität Karlsruhe

For a given real or complex-valued function f on some domain D, an *inclusion function* F of f is an interval function that encloses the range of f on all intervals $Z \subseteq D$. F is called *optimal*, if it computes the smallest interval containing the range of f for all Z.

In our talk, we discuss optimal complex inclusion functions for the set of standard functions that is usually available in modern programming languages: the exponential function, the trigonometric and hyperbolic functions, and their inverse functions.

Inclusion functions for all these functions have been implemented in a C++-library. Numerical examples are presented to demonstrate that high accuracy in computation has been achieved with our implementation.

16:40	**Schnurr**	**MA 144**

Some Supplements Concerning Automatic Slope Computation

Marco Schnurr, Institut für Angewandte Mathematik, Universität Karlsruhe (TH)

Slopes have become a useful tool in Numerical Analysis. Combining slope techniques with interval arithmetic and automatic differentiation leads to extensive applications, e.g. in Verified Global Optimization.

The author reports on some cases from the literature where the slope computation gives obviously wrong results. Furthermore, corrections of the algorithms are introduced.

17:00	**Markov**	**MA 144**

Towards An Axiomatisation Of Interval Arithmetic

Svetoslav Markov, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences

The paper is devoted to algebraic properties of the system of (one-dimensional) intervals with the corresponding arithmetic operations and the inclusion relation. An axiomatic approach is used similar to the approach used for real numbers and intervals are viewed as approximate real numbers. Clearly such a study is needed for any implementation of interval evaluations and computations within a computer algebra system. Opposite to similar existing studies, we consider generalised (Kaucher) interval arithmetic. In fact we reproduce a number of E. Kaucher's results in form suitable for computer algebra manipulations and give some new interpretations of this results.

17:20	**Krämer**	**MA 144**

Generalized Intervals And The Dependency Problem

Walter Krämer, Bergische Universität Wuppertal

Computing enclosures of the range of functions using interval arithmetic often leads to overestimations due to variables (parameters) appearing more than once within the expression to be evaluated (dependency problem).

We will present an experimental implementation of a generalized interval arithmetic [1, 3] which has been proposed by Hansen [2] in 1975.

In many cases generalized intervals are well suited to reduce the dependency problem and/or the so called wrapping effect. Numerical examples will be shown.

[1] Hassan El-Owny: A generalized interval arithmetic realized in C-XSC. Preprint WRSWT, University of Wuppertal, to appear 2006.
[2] Eldon R. Hansen: Generalized interval arithmetic, in K. L. Nickel (ed), Interval Mathematics, Lecture Notes in Computer Science, Vol. 29, Springer-Verlag, Berlin, 1975.
[3] W. Hofschuster, W. Krämer: C-XSC – a C++ class library for extended scientific computing. In Numerical Software with Result Verification, R. Alt et al. (eds), Springer Lecture Notes in Computer Science, LNCS 2991, 2004.

Session 3
Thursday, March 30, 13:30 - 15:30

Room: MA 005

Symbolics and Numerics

Chair:

Werner M. Seiler

13:30	Sauer	MA 005

H-bases – Computer Algebra For Numerical Computations

Tomas Sauer, Lehrstuhl fuer Numerische Mathematik, Justus-Liebig-Universität Giessen

While Gröbner bases are a well-established important tool in constructive, "numerical" ideal theory and an essential ingredient of all Computer Algebra software, the much older concept of H-bases (dating back to Macaulay) remains still widely unused and even unknown. The algorithmic "simplicity" of Gröbner bases relies on the fact that they are based on term orders which are single monomials for which divisibility is easily decided. There is, however, a price to be payed for this simplicity: due to the nature of term orders, Gröbner bases always prefer certain variables to others. As a consequence, these preferences destroy symmetry and Gröbner bases and the methods based on them show a discontinuous behavior, even for continuously changing situations and problems. In the context of numerical computations or perturbed coefficients, this can lead to erratic and almost disastrous results.

Here H-bases offer an alternative by considering homogeneous leading forms as one object and thus providing bases that can change gradually and continously with the problem and the requirements. The talk is specifically considering H-bases as tools in multivariate polynomial interpolation, in solving polynomial systems of equations and even for determining refinable function with a certain order of polynomial reproduction and minimal support.

14:10	Kartashova	MA 005

Bk-factorization As A Link Between Symbolics And Numerics

Elena Kartashova, RISC, Johann Kepler Universität

BK-factorization is a new constructive pure algebraic factorization method for bivariate linear partial differential operators of arbitrary order. As a by-product of

BK-factorization, general invariants are constructed (generalization of Laplace invariants) leading to construction of factorization for the whole family of equivalent operators. In cases when exact factorization does not exists, BK-factorization allows to construct approximate factorization of a given differential operator leading to drastic simplification of numerical simulations with the linear partial differential operators of higher order.

14:30	Weber	MA 005

Symbolic-numeric Methods For Investigating Kirchhoff Rods

Andreas Weber, Gerrit Sobottka, Liu Shu, Universität Bonn

Although it is a classical result that the static Kirchhoff equations for a flexible rod can be fully integrated, little use has been made of this fact for solving associated boundary value problems. We are investigating numeric solution methods for various boundary value problems of Kirchhoff rods, which are built on the symbolic solution schemes.

14:50	Rosenkranz	MA 005

A Novel Treatment Of Linear Two-point Boundary Value Problems

Markus Rosenkranz, Johann Radon Institute for Computational and Applied Mathematics

We present a new solution algorithm for linear two-point boundary value problems that works directly with the involved operators (differential operators, integral operators, boundary operators, multiplication operators), expressing the resolving Green's operator as a noncommutative polynomial in the basic operators. A suitable quotient of a noncommutative polynomial ring is used for modeling the operators, and computation is made possible by an underlying Groebner basis structure. The method is demonstrated on a few examples.

15:10	Regensburger	MA 005

Max-plus Linear Algebra And Nonlinear Ordinary Bvps

Georg Regensburger, Johann Radon Institute for Computational and Applied Mathematics

If we consider the real numbers extended by minus infinity with the operations $a \oplus b = \max\{a, b\}$ and $a \odot b = a + b$, we obtain the max-algebra or the max-plus semiring ("a ring without minus"). The analogue of linear algebra for these operations extended to matrices and vectors has been widely studied, for example, systems of linear equations, eigenvalue problems, rank and dimension.

In this talk, we discuss how max-plus linear algebra can be used to find symbolic solutions of nonlinear ordinary boundary value problems (BVPs). We consider first-order ordinary differential equations of the form $f(x, y'(x)) = 0$ and assume that we have a (symbolic) representation of the solutions of the initial value problem.

We can add arbitrary constants to a solution of such a differential equation, and the maximum (or minimum) of two solution is again a generalized solution, possibly nondifferentiable at some points. Thus max-plus (or min-plus) linear combinations of solutions are again (generalized) solutions. Using this observation, we show that the existence and uniqueness of a max-plus linear combination solving a given boundary value problem can be translated to the analogous questions for a corresponding max-plus linear system. We present a Maple implementation, illustrate several examples and finally discuss possible extensions of our approach.

16 Optimization

Organizers:

Alexander Martin, TU Darmstadt
Michael Hintermüller, Universität Graz

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: MA 142

Topics in Discrete Optimization

Chair:

Alexander Martin

13:30	Fügenschuh	MA 142

TOPOLOGY OPTIMIZATION OF BRANCHED SHEET METAL PRODUCTS WITH MIP

Armin Fügenschuh, Alexander Martin, TU Darmstadt

"Linear flow splitting" is a new technique to form branched profiles in an integral style out of sheet metal. It was invented at the Technical University of Darmstadt and is studied in the Collaborative Research Center (CRC) 666.

Each additional branch leads to a higher degree of freedom for the product design. Handling the large amount of possible product variants thus requires a methodical procedure. We split the design process of a branched sheet metal product in two steps: 1) Decision for an optimal topology by using methods from Discrete Optimization, and 2) Shape optimization based on this topology by using methods from Nonlinear Optimization.

In this talk we consider step 1) of the design process, where the functional constraints, such as stiffness or heat-transfer, are modeled as a mixed-integer programming problem. The solution of this model with branch-and-cut techniques yields the topology and coarse geometry of the profile, which is input for the refinement in step 2). Numerical results for test instances are presented.

13:50	Greif	MA 142

Geometry Optimization Of Branched Sheet Metal Products By All-at-o

Günter Greif, TU Darmstadt

In connection with the new technique “Linear flow splitting”, nonlinear optimization methods are used to find optimal geometries of product components. We split the optimal design process of a branched sheet metal product in two steps: 1) Decision for an optimal topology by using methods from Discrete Optimization. 2) Shape optimization based on this topology by using methods from Nonlinear Optimization.

In this talk we consider step 2) of the design process. We use an automated approach for the generation of topology-preserving parametrizations of the product component. Our aim is to optimize the geometry of the sheet metal product such that its stiffness is optimized under functional constraints, e.g., constraints on the cross section of closed chambers and on the thickness of the sheet metal. The full 3-D elasticity equations are used to model the stiffness of the component. We propose an Interior-Point All-at-Once method for the solution of the resulting nonlinear shape optimization problem, which interleaves the optimization with the solution of the 3-D elasticity equations in an efficient way. Moreover we present numerical results.

14:10	Günther	MA 142

Modelling Manufacturing Constraints For Branched Sheet Metal Produ

Ute Günther, TU Darmstadt

When complex sheet metal components are produced using linear flow splitting,the number of unrollings, i.e., the number of possible ways to produce that component, becomes too large to handle it without appropriate tools. It is possible to construct a certain graph so that every unrolling corresponds to a minimal spanning tree. However, when producing branched profiles in an integral style out of sheet metal, a number of manufacturing restrictions have to be observed, e.g., the length of the sheet metal and the maximum number of producible branches. Thus there are spanning trees which do not resemble valid unrollings. In order to deal with these restrictions, we will introduce additional constraints to the tree model. These constraints correspond to several graph-theoretical problems which make the overall problem NP-hard.

Whereas each of these problems has been studied separately, there are no algorithms known to handle them all at once. To combine these restrictions, we are analyzing the problem from two perspectives: Firstly, we consider the corresponding Mixed Integer Program and secondly, we are using a graph theoretical approach. In the talk, both approaches will be presented and it will be indicated how they can be solved.

14:30	**Koch**	**MA 142**

Finding The Strategic Corridor

Thorsten Koch, Gary Froyland, Nicole Megow, Konrad-Zuse-Zentrum

Patrick Coperation introduces an intermediate storage area into there Botany Bay container terminal to increase the efficiency of the rail/road interface of the terminal. We examined in a pilot project ideas how to manage the ISA. This includes control of the rail mounted gantry cranes, storage positions for the containers, and assignment of truck slots.

In the end a two phase approach was employed. Phase one features the soulution of an large integer program to fix timing decsions on a strategic level. Phase two consists of a relatively simple online algorithm. Results on real world data will be presented.

14:50	**Simeliene**	**MA 142**

Optimization Of Investment Policy

Nijole Simeliene, Forschungsverein Litauen

Modelling the demand for various consumer goods, the use of consumer goods and the purchase of consumer goods is of great significance. Therefore, the underlying objective functions have to be analyzed from both a theoretical and an application-oriented point of view. Investigation of a more stringent distribution policy is the first theme we focus on in this paper.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: MA 142

NLP-Techniques in Optimal Control, Stochastic and Multicriteria Optimization

Chair:

Michael Hintermüller

16:00	Grossmann	MA 142

General Path-following Penalty Methods Applied To Elliptic Control

Christian Grossmann, Institut für Numerische Mathematik, TU Dresden

Considered are elliptic control problems of the following type

$$J(y,u) := \tfrac{1}{2}\|y(\cdot,u)-z\|^2 + \tfrac{\alpha}{2}\|u\|^2 \to \ \text{min!}$$
$$\text{s.t.} \ -\Delta y = u \ \text{ in } \Omega, \ y=0 \ \text{ on } \partial\Omega, \quad u \in U_{ad}$$

with a bounded domain $\Omega \subset R^n$, given functions $\alpha > 0$, $z, a, b \in L_2(\Omega)$ and

$$U_{ad} = \{u \in L_2(\Omega) : \ a \le u \le b \ \text{ a.e. in } \Omega\}.$$

Finite element discretizations of the state as well as of the controls applied to the problem lead to finite dimensional optimization.

General primal-dual penalty-barrier path-following Newton methods, as considered in [1] for finite dimensional nonlinear programming, are applied to handle the control constrains. Its convergence behavior in dependence of the discretization is analyzed. Further the application of the proposed path-following method in case of additional state constraints of obstacle type is discussed.

[1] C. Grossmann; M. Zadlo, General primal-dual penalty/barrier path-following Newton methods for nonlinear programming, *Optimization*, 54 (2005), 641-663.
[2] U. Prüfert; F. Tröltzsch; M. Weiser, The convergence of an interior point method for an elliptic control problem with mixed control-state constraints, *ZIB-Report* 04-47, November 2004.
[3] S. J. Wright, *Primal-Dual Interior Point Methods*, SIAM Publ., Philadelphia, 1997.

16:20	Krejic	MA 142

On A Quasi-newton Method For Stochastic Optimization

Natasa Krejic, Department of Mathematics and Informatics, University of Novi Sad, Serbia and Montenegro

We consider a modification of the quasi-Newton method used in deterministic optimization and apply it to a stochastic objective function. Using estimated subgradients and matrix update from SR1 method quasi-Newton direction is generated. The step size is determined with line search rule. In order to avoid misjudgement of stationary due to stochastic nature, a statistical test is used instead of function values comparison. Convergence properties of the resulting iterative sequence are investigated. Some numerical results are presented.

16:40	Luzanin	MA 142

A Newton-like Method For Stochastic Problems

Zorana Luzanin, University of Novi Sad, Department of Mathematics and Informatics, Serbia and Montenegro

We present application of a Newton-like method to the problem of solving stochastic nonlinear system and, specially, to stochastic optimization problems. Directly determining the required Jacobian matrix (or gradient and Hessian matrix for optimization problem) has often been difficult or impossible in practice. The main idea is to use sample method for estimation of Jacobian and Hessian. Finally we present some preliminary numerical test results.

17:00	Rapajic	MA 142

Globally Convergent Jacobian Smoothing In Methods For Ncp

Sanja Rapajic, Department of Mathematics and Informatics, University of Novi Sad, Serbia and Montenegro

A new smoothing algorithm for the solution of nonlinear complementarity problems (NCP) is considered. It is based on semismooth equation reformulation of NCP by Fisher function and its related smooth approximation.

Globalization of methods for solving NCP is usually obtained by minimizing a merit function. If the search direction is a descent direction, monotone technique is recommended. The inexact direction may be a nondescent direction in general, so the sufficient reduction of the merit function is not always possible using monotone strategy. This is the reason why nonmonotone technique introduced by Li

and Fukushima is used for proving global convergence of the Jacobian smoothing inexact-Newton (IN) method.

17:20	Kasprzak	MA 142

Bi-objective Optimization Of In-plane Loaded Composite Plates

Jakub Kasprzak, Institute of Applied Mechanics, Poznan University of Technology, Poland

Composites are widely used in the form of multilayered plates which are loaded with in-plane forces. Since these plates are mostly thin-walled members they are prone to buckle. There are two ways of taking into account the critical load of such plates in designing process. Firstly, when the load of a plate is known, the critical load may be treated as an optimization constraint that leads to scalar optimization in which the weight of a structure is an objective. In the second approach, it may be considered together with the weight of a structure as an objective. This approach gives broader view on a designed structure and allow on finding relationship between the stiffness and weight of a laminate.

The second bi-objective approach is presented in this work. Symmetrical multilayered composite plates are considered, taking into consideration different ways of support and laminate types. Special attention is paid to reaction forces that may appear during loading non-balanced laminates. The multiobjective Differential Evolution algorithm is used in order to obtain non-dominated solutions of the problem. This makes it possible to obtain Pareto points, just at one run of the algorithm.

17:40	Stan	MA 142

Optimal Design Of 2 Dof Pkm

Sergiu-Dan Stan, Vistrian Maties, Radu Balan, Technical University of Cluj-Napoca, Romania

The aim of this paper is to show the usefulness of the multicriteria approach to optimize the Parallel Kinematic Machines (PKM). Variations of the kinematic performances index remain not constant throughout workspace. PKM potential is only then efficient exploited when their structure is optimal dimensioned from geometric point of view. So, their performances depend very strong on their geometry. Thus, optimization of the geometric parameters or optimal dimensioning has become an important issue for improving the PKM performances. Aiming to deal at the same time with multiple criteria in optimal design of PKM, we have developed a multiobjective genetic algorithm (MOGA) using concepts of Pareto optimality and niching techniques. Here, intended to show the advantages of using the MOGA, we applied it to a multicriteria optimization problem of 2 dof PKM. Genetic algorithms (GA) are so far generally the best and most robust kind of evolutionary algorithms. A GA has a number of advantages. It can quickly scan a vast solution set. Bad proposals do not affect the end solution negatively as they are simply discarded. The obtained results have shown that the use of MOGA in such kind of optimization problem enhances the quality of the optimization outcome, providing a better and more realistic support for the decision maker.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: MA 142

Applied Problems and Solution Techniques I

Chair:

Yuriy Kondratenko

13:30	Curtis	MA 142

Minimal Heat Loss For Given Volume Of Insulation

John Curtis, QinetiQ, England

The calculus of variations is applied to determine the shape of the insulation layer of given volume around a body which yields the minimum heat loss. Discussion of various boundary conditions including prescribed temperature and Newton's Law of Cooling is presented. It is shown that there can be substantial savings in heat loss when there is significant temperature variation on the surface of the body. Brief consideration is given to the extension to multiple layers and numerical solution of the general case.

13:50	Kutylowski	MA 142

Topology Optimization Procedure Based On Structure Stress History

Ryszard Kutylowski, Institute of Civil Engineering, Wrocław University of Technology, Poland

The main idea of this paper was taken from the human body bone optimization process, which is the real time process based on the strain-stress bone analysis. The minimum compliance approach is used. The stress analysis of the design points of the structure for succeeding optimization steps is the base of the topology optimization algorithm. Analyzing these stresses one can model the design points stress function for succeeding optimization steps. Knowing this function we can predict how to change the density for each design point for the next optimization steps. Proposed procedure let us to obtain the optimization process for the structure faster and final topology is "more optimal" than topology obtained using standard optimization procedures. This stress analyzing procedure, can be treated as a hardware of the sensors being the part of the "intelligent structure" for the real time structure reconstruction.

14:10	Dzjuba	MA 142

THEORETICAL AND EXPERIMENTAL RESEARCH OF OPTIMAL CYLINDRICAL SHELL

Anatoly Dzjuba, Pavel Bulakajev, Yury Selivanov, Dniepropetrovsk National University, Ukraine

The problem to determine optimal in-two-direction variable thickness of cylindrical shell is considered. The optimal process theory is used to determine the problem on the assumption of stress and strain restrictions. The problem to compute the stress-and-strain state is solved by combination of discontinuous (in radial direction) and continuous (in longitudinal direction) methods. The optimal thickness for minimum weight's shell is received by Pontryagin's maximum principle. The digital algorithm is elaborated and optimal shapes of local reinforcements are obtained for a few cases of shells. The experimental research is realized by holographic interferometry method for optimal and initial shells. The results of computer-based and experimental modeling are compared and certain conclusions are achieved.

14:30	Domek	MA 142

EXPERIMENTAL REVISION OF TIMING BELT'S LOADING MODEL IN FEM

Grzegorz Domek, Kazimierz Wielki University of Bydgoszcz, Poland
Ireneusz Malujda, Poznan University of Technology, Poland

In examination of timing belts with use of FEM, the accurate description of belt's material and selection of belt's loading model are equally essential. Materials used in belts production has non-linear elastic characteristics. Mathematical description of materials used in belts production appeared to come very close to the real characteristics. Some software allow for introduction of real characteristics and in such conditions it is easier to relate to the real conditions in gears with timing belts. Next problem treats about the correct way of forces distribution as well as fixing of the belt. Changes of the model result in obtaining of different tension maps. Experimental revision in durability research allows to point to the correct model of belt's loading.

14:50	Ranjbar	MA 142

Study Of Optimization Methods For Structural-acoustic Applications

Mostafa Ranjbar, Steffen Marburg, Hans-Jürgen Hardtke, TU Dresden

Finding the global minimum or even a substantial improvement of an objective function in structural-acoustic design is a real challenge. Reducing the computational costs such as the calculation time and the number of function evaluations while increasing the accuracy and the robustness of the results are the main criteria which should be considered. Actually, there is no individual optimization algorithm for structural-acoustic applications which is able to satisfy all of the mentioned criteria in once. An alternative is to think about a combination of the optimization and the approximation algorithms to enhance the performance of the entire minimization process. Therefore, we present experiences applying algorithms, e.g. local, global and mid-range approximation and optimization methods. Advantages and disadvantages of each method for finding the best minima will be investigated and reported. The results can help us for developing a hybrid robust optimization toolbox for structural-acoustic applications.

15:10	Nastase	MA 142

Multidisciplinary Aerodynamical Optimal Shape's Design

Adriana Nastase, Aerodynamisches Institut, RWTH Aachen

A weak interaction aerodynamic/structure, via additional or modified constraints needed for the structure stiffness, are introduced in the enlarged variational problem of the global aerodynamical optimal shape design.

This weak interaction, is the new element of this study and it leads to a modified aerodynamical global optimal shape design which satisfies also the requirements of the structure.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: MA 142

Applied Problems and Solution Techniques II

Chair:

Natasa Krejic

16:00	Kondratenko	MA 142

Multicriteria Optimisation Of Cargo Operations In Uncertainty

Yuriy Kondratenko, L. P. Klymenko, Petro Mohyla Mykolaiv State Humanities University, Ukraine
D. M. Pidopryhora, National University of Shipbuilding, Ukraine

Growth of a competition in the world charters market of ships makes ship-owners look for ways for decreasing the cost of sea transportation taking into account features of marine environment. The present paper is devoted to the problem of bunkering tankers' optimal cargo planing in uncertainty. The brief analysis of uncertain factors and existing approaches for solving the multiple-criterion optimisation problem is fulfilled with respect to specific features of the bunkering control processes: a) to distribute desired cargo on tanks; b) to keep a stability position for tanker; c) to minimize a free surface of liquid cargo. The complex three-component non-linear criteria taking into account restrictions of cargo tanks capacity and tanker's loading condition is developed. The gradient solution of the non-linear programming problem for the model of the tanker in the form of rectangular pontoon is presented and confirms efficiency of the suggested criterion as additive multimodal function. The necessity of dynamical character of restrictions applying is proved for the problem. The special emphasis is placed input data preparation (by a specially designed complex fuzzy algorithm) for the multiple-criterion optimisation task with respect to dynamical character of restrictions for the tanker's hull surface conditions (heel, trim and maximum draft).

16:40	Nedelkovski	MA 142

Expert System For Optimal Water Distribution At Irrigation System

Igor Nedelkovski, Zorica Kostadinovska, St. Kliment Ohridski University, Macedonia

An Expert System for optimal water distribution at an irrigation system will be presented. Expert system is of what-if analysis type and it is currently in the phase of testing at Hydro-System Strezevo in Bitola, Macedonia. Role of the system is to help the dispatchers at HS Strezevo to optimize level of water in the reservoir during irrigation period, taking in consideration satisfaction of needs of all water consumers (city, industry, and farmers) and in the same time ensuring maximal incomes from producing electricity from small hydro-power plant located at dam of the reservoir. In the paper structure of the expert system as well as the rules for optimal distribution of water will be explained in detail.

17:00	Paulianok	MA 142

Optimal Output On-line Control Via Dynamic Regulators

Nataliya Paulianok, Faculty of Applied Mathematics and Informatics, Belarusian State University, Belarus

A problem of optimal indirect control with the help of the dynamic regulator described by linear differential equations is under consideration. Control signals being given to the input of the regulator by some device and control functions roduced and sent to the input of the control object are bounded. The aim of the control is to transfer the object to the given terminal set providing maximal value for the performance index. Algorithms of the optimal feedbacks construction in real-time are justified. They are based on fast corrections of optimal open-loop solutions to optimal control problems arisen. The numerical examples are given.

17:20	Lupu	MA 142

Optimization Method For Airfoils In The Case Of Nonlinear Problems

Mircea Lupu, University Transilvania of Brasov, Romania

In the paper there are solved direct and inverse boundary problems and analytical solutions are obtained for optimization problems in the case of some nonlinear integral operators. It is modeled the plane potential flow of an inviscid, incompressible and limited or unlimited fluid jet, which encounters a symmetrical curvilinear obstacle - the deflector of maximal drag. There are derived integral, singular equations, for direct and inverse problems and the movement in the auxiliary canonical half-plane are obtained. Next, the optimization problem is solved in an analytical manner. The design of the optimal airfoil is performed and finally, numerical computations concerning the drag coefficient and other geometrical and aero dynamical parameters are carried - out. In fact we will present special problems for

scheme Valcovich-Birkhoff-Popp, when the jet is eliminated from channel and encountering the curvilinear airfoil. Particularly, we make the optimization for the case when the free jet encounter the airfoil, and then the special case when the obstacle in free flow (scheme Helmholtz) -impermeable parachute. The integral nonlinear operators of drag are optimized use the Jensen's inequality. Theoretical and practical, this analytical and numerical results are very important in relation with applications to the trust reversal devices, or the direction control of the reactive vehicles, wings airplanes, turbine blades are the bracket parachute.

17 Applied and numerical linear algebra

Organizers:

Miroslav Tuma, Academy of Sciences of the Czech Republic

Reinhard Nabben, TU Berlin

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: MA 043

H-matrices, model reduction, control theory

Chair:

Peter Benner

13:30	Ibragimow	MA 043

$\mathcal{H}$-MATRICES AND LOW RANK PLUS SPARSE MATRICES

Ilgis Ibragimow, Universität des Saarlandes

An approximation of fully populated matrices by $\mathcal{H}$-matrices play important role in the modern BEM computations since the $\mathcal{H}$-matrix approximation can be computed and stored in almost linear complexity, i.e. $\mathcal{O}(N \log^{\alpha} N)$ with moderate parameter α; the constants, however, in those complexity estimates are rather large, they easily lie in the 1000's!

The second open problem with the $\mathcal{H}$-matrices is a construction of a preconditioner. The rank of the small blocks in the preconditioner could be so large, that low rank presentation requires more amount of memory than a dense matrix.

In this work we suggest the new idea to consider the $\mathcal{H}$-matrix as low rank plus sparse matrix ($H = UV^T + S$). If the inverse or the preconditioner P for the sparse part of the matrix is computed ($S^{-1} \simeq P$), then the inverse for the complete matrix is differ to low rank matrix with the same rank of UV^T. It allows to prove that the convergence of the iterative method with the preconditioner based on the inverse of the sparse part of the matrix converges with the rank(UV^T) iterations.

To construct the sparse preconditioner we can use several approaches with fill-in optimization or/and multilevel methods.

The second advantage of $UV^T + S$ matrix representation stay in the smaller constants in the complexity estimates, hence the matrix requires smaller amount of memory and can be faster multiplied by the vector with comparison to the $\mathcal{H}$-matrix approach.

We present an implementation of this method and numerical results.

13:50	Börm	MA 043

$\mathcal{H}^2$-matrices With Variable Rank

Steffen Börm, *MPI für Mathematik in den Naturwissenschaften*

$\mathcal{H}^2$-matrices can be used to find data-sparse approximations of dense matrices. The basic idea is closely related to panel clustering and multipole methods: the matrix is subdivided into a hierarchy of blocks, and in each block an efficient low-rank approximation is applied.

For integral or partial differential operators related to elliptic problems, the typical storage complexity of an $\mathcal{H}^2$-matrix approximation of an $n \times n$ matrix is $\mathcal{O}(nk)$, where k is the rank used in the low-rank blocks.

In order to ensure a given accuracy ϵ, we have to choose $k \sim \log^\alpha(1/\epsilon)$, where α is a constant depending on the nature of the problem. In order to keep the matrix approximation error consistent with the discretization error, which will usually behave like $n^{-\beta}$, we have to use $k \sim \beta \log^\alpha n$ and get an effective complexity of $\mathcal{O}(n \log^\alpha n)$.

In some situations, it is possible to eliminate the additional logarithmic factors and reach a complexity of $\mathcal{O}(n)$ while keeping the discretization error and the matrix error consistent: a high rank is only required for a few large blocks, while a low rank proves to be sufficient for the majority of small blocks.

This talk presents an algorithm for constructing a variable-rank $\mathcal{H}^2$-matrix approximation of an arbitrary matrix. A careful analysis of the algorithm yields bounds for the approximation error, and numerical experiments demonstrate the practical applicability of the new method.

14:10	Baur	MA 043

H-matrix Based Balanced Truncation Method For Large-scale Systems

Ulrike Baur, *Institut für Mathematik, TU Berlin*
Peter Benner, *Fakultät für Mathematik, TU Chemnitz*

We consider linear time-invariant stable systems of the following form

$$\Sigma : \begin{cases} \dot{x}(t) &= Ax(t) + Bu(t), \qquad x(0) = x_0 \\ y(t) &= Cx(t), \qquad t \geq 0 \end{cases}$$

with $x(t) \in \mathbb{R}^n$, $u(t) \in \mathbb{R}^m$, $y(t) \in \mathbb{R}^p$ arising, e.g., from the discretization of parabolic PDEs. We will assume that the system Σ is large-scale, that means its order is $n = \mathcal{O}(10^5)$ and $n \gg m, p$. Model reduction aims at approximating the system by a system of much smaller order $r \ll n$. This is achieved by using the hierarchical matrix format and the corresponding formatted arithmetic resulting from the underlying PDE model in a balanced truncation implementation based on the matrix sign function method.

14:30	Blömeling	MA 043

Substructuring And Svd-based Model Reduction Methods

Frank Blömeling, TU Hamburg-Harburg

The direct applicability of SVD-based methods in model reduction of large linear systems is very limited. However, substructuring methods are a possibility to use these approaches.

A method called Automated Multilevel Substructuring (AMLS) is presented by J.K. Bennighof and R.B. Lehoucq in [*An Automated Multilevel Substructuring method for eigenspace computation in linear elastodynamics*, SISC 25(6), 2004] that has been successfully applied to eigenvalue computations of very large systems.

The variational interpretation given by Bennighof and Lehoucq for elliptic problems is adapted to parabolic problems to motivate the application to LTI-systems.

The SVD-based methods, i.e. balanced truncation, are solely applied to the resulting smaller subsystems.

Furthermore an extension of the reduction algorithm by the use of Krylov subspaces is given to improve the approximation quality of the reduced system.

14:50	Damm	MA 043

Linear Matrix Equations In Model Reduction For Bilinear Systems

Tobias Damm, Institut Computational Mathematics, TU Braunschweig
Peter Benner, Fakultät für Mathematik, TU Chemnitz

Model reduction is an important and well-established item in linear systems theory. Many of the methods make use of low-rank approximations of the controllability and the observability Gramians. In the recent literature, a similar approach has been discussed to reduce models of bilinear systems. In this case the computation of the Gramians requires the solution of generalized Lyapunov equations. In the talk we propose numerical methods to solve these generalized Lyapunov equations efficiently.

15:10	Stykel	MA 043

The Matrix Sign Function Method For Projected Lyapunov Equations

Tatjana Stykel, TU Berlin

We will discuss the numerical solution of projected generalized Lyapunov equations using the matrix sign function method. Such equations arise in the stability analysis and control problems including model reduction for descriptor systems. It is known that the matrix sign function method applied to a matrix pencil $\lambda E - A$ converges if and only if $\lambda E - A$ is of index at most two. In this case the convergence is quadratic if E is nonsingular, and it is linear, otherwise. We will propose a modification of the matrix sign function method that converges quadratically for pencils of arbitrary index. Numerical examples will be presented to demonstrate the properties of the modified method.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: MA 042

Iterative methods and preconditioner

Chair:

Reinhard Nabben

13:30	Mayer	MA 042

Some New Developments In Ilu Preconditioners

Jan Mayer, Institut für Angewandte Mathematik, Universität Karlrsuhe

Incomplete LU factorisations using Crout's version of Gaussian elimination have been fairly successful in preconditioning sparse linear systems. In this presentation, we will look at the possibility of combining this preconditioner with pivoting by columns and row interchanges to improve sparsity.

13:50	Duintjer Tebbens	MA 042

Preconditioner Updates For Nonsymmetric Linear System Sequences

Jurjen Duintjer Tebbens, Miroslav Tuma, Institute of Computer Science, Academy of Sciences of the Czech Republic

When the computation of efficient preconditioners for individual linear systems of a sequence is expensive, significant reduction of costs can be achieved by updating previous preconditioners. For large and sparse systems, this has been done, among others, by recycling subspaces when using a Krylov subspace method, by means of small rank updates when applying Quasi-Newton methods or with diagonal updates for SPD systems arising from parabolic PDEs.

In this contribution we generalize the last approach to sequences of any type of nonsymmetric system. We show that we can define efficient updates by considering specific approximations of the difference between the system matrices. The talk envisages to address both these approximations as well as permutation techniques that can make the approximations even more accurate.

[1] M. Benzi and D. Bertaccini. Approximate inverse preconditioning for shifted linear systems. BIT Numer. Math., 43:231-244, 2003.
[2] L. Bergamaschi, R. Bru, A. Martinez, and M. Putti. Quasi-Newton preconditioners for the inexact Newton method. In Abstract book of the 2005 International Conference On Preconditioning Techniques, Atlanta, May 19-21, 2005.

[3] M.L. Parks, E. de Sturler, G. Mackey, D.D. Johnson, and S. Maiti. Recycling Krylov subspaces for sequences of linear systems. Technical Report UIUCDCS-R-2004-2421, University of Illinois, 2004.
[4] J. Duintjer Tebbens, M. Tuma. Preconditioner Updates for Solving Sequences of Large and Sparse Nonsymmetric Linear Systems, submitted to SIAM J. Sci. Comput.

14:10	Kallischko	MA 042

Fspai For Symmetric Positive Semidefinite Systems

Alexander Kallischko, Fakultät für Informatik, TU München

For systems $Ax = b$ of linear equations with symmetric positive definite A, preconditioning can be done with the FSPAI (Factorized SPAI) algorithm, which yields the sparse approximate Cholesky factor L_M of a symmetric positive definite preconditioner $M = L_M L_M^T \approx A^{-1}$. The sparsity pattern of L_M can be captured automatically. Now this approach is extended to the case of symmetric positive semidefinite A with several zero eigenvalues.

In order to reduce the computation time for FSPAI, the effects of some important matrix reordering algorithms are investigated. There will also be a focus on block-based approaches. Additionally, such methods benefit from FSPAI's high intrinsic parallelity.

Examples for symmetric positive semidefinite matrices arise from the simulation of 3D fluid flows when solving the Navier-Stokes equations. In order to satisfy the physical laws that describe the phenomena in incompressible flows, a descretization is employed that preserves both energy and impulse, also in the case of cartesian grids. After a Chorin projection, the Poisson matrix is symmetric positive semidefinite and the corresponding system of linear equations is solved by a parallel solver based on the preconditioned conjugate gradient algorithm, where FSPAI is employed as parallel preconditioner.

14:30	Ludwig	MA 042

Some New Variants Of Schwarz Iterations In Domain Decomposition

Elisabeth Ludwig, Reinhard Nabben, TU Berlin

Domain decomposition methods are widely used for solving partial differential equations. Strongly connected with domain decomposition methods are the multiplicative and additive Schwarz-type methods for solving the related linear systems. Here we establish some new variants of Schwarz methods. We give some convergence results for these methods and we consider the effect on convergence of algorithmic parameters such as the number of subdomains, the amount of overlap, and the result of inexact local solves.

14:50	Mense	MA 042

Algebraic Multilevel Methods For Nonsymmetric Matrices

Christian Mense, Reinhard Nabben, Institut für Mathematik, TU Berlin

The "Algebraic Multilevel Iteration" (AMLI) developed by Axelsson and Vassilevski is an algebraic multigrid method, which uses an approximation of the Schur complement as a coarse grid operator.

In its basic form the AMLI method can be rewritten as an additive Schwarz method. By taking a look at the corresponding multiplicative Schwarz method we get a new iteration scheme. Beside the symmetric positive definit case we will show convergence of the additive and multiplicative form for nonsymmetric M-matrices.

Under easy to satisfy conditions, the new multiplicative method will converge asymptotic faster than the corresponding additive method, the basic "Algebraic Multilevel Iteration" respectively.

We will also consider different kinds of approximations to speed up the convergence rate of these methods.

15:10	Bollhöfer	MA 042

Algebraic Multigrid For Indefinite Systems

Matthias Bollhöfer, Marcus Grote, Olaf Schenk, Institut für Mathematik, TU Berlin

We will discuss an algebraic multigrid method that is devoted for the solution of large sparse symmetric indefinite systems. In particular we address the situation when the system is highly indefinite. These cases arise e.g. from a discretization of a Helmholtz equation for high wave numbers or the Anderson model of localization. The method is essentially based on two major ingredients, namely the use of symmetric maximum weight matchings to increase the block diagonal dominance and the use of inverse-based coarsening which keeps the grid transfer bounded. We will illustrate the effectiveness of this approach for several numerical examples.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: MA 043

Eigenvalue Problems

Chair:

Matthias Bollhöfer

16:00	Betcke	MA 043

A Domain Decomposition Gsvd Method For Planar Eigenvalue Problems

Timo Betcke, *TU Braunschweig*

In 1983 Descloux and Tolley proposed a domain decomposition method for computing eigenvalues and eigenfunctions of the Laplace eigenvalue problem on planar domains. Their idea was to approximate an eigenfunction by linear combinations of Fourier-Bessel functions in each subdomain and to formulate the compatibility conditions between the subdomains as the minimization of the smallest eigenvalue of a parameter-dependent eigenvalue problem.

The drawback of their method is that it is limited to an accuracy of the square-root of machine precision. One solution to this problem was presented by Driscoll in 1997. Instead of minimizing a parameter-dependent eigenvalue he computed the zero of the derivative of the eigenvalue directly.

We present another solution to this problem. Instead of using eigenvalue problems we formulate the method as a generalized singular value problem. This formulation is highly accurate and robust towards ill-conditioning in the basis functions. Furthermore, it avoids the computation of integrals over the subdomains. The idea is to work directly with the basis functions evaluated on a set of discretization points rather than with inner products of the functions.

Several examples are shown involving accurate eigenvalue computations on some multiply connected domains with corner singularities.

16:20	Wrobel	MA 043

On Simultaneous Rootfinding Methods For Computing Singular Values

Iwona Wrobel, *Warsaw University of Technology, Poland*

We consider the applications of certain rootfinding methods for the bidiagonal singular value problem. The problem of computing singular values of a bidiagonal n-by-n matrix is equivalent to computing eigenvalues of a symmetric tridiagonal $2n$-by-$2n$ matrix. Thus methods for finding eigenvalues can be used here.

The algorithms we analyze are modifications of the classical Weierstrass method for computing all roots of a polynomial. They make use of the properties of a matrix, both in the algorithm itself and in the proper choice of the initial approximation and the stopping criterion.

Numerical tests performed in Matlab on a wide class of bidiagonal matrices of known singular values show that this algorithm has good numerical properties, if the zeros are well separated and the initial guess is sufficiently close to the exact solution. Therefore it can be recommended as a method of choice. Another advantage of the Weierstrass-type algorithms is a possibility of parallel implementation, values of a characteristic polynomial can be computed independently.

16:40	**Drygalla**	**MA 043**

Exact Innerproducts And The Accurate Computation Of Eigenvalues

Volker Drygalla, Institut für Numerische Mathematik, Martin-Luther-Universität Halle-Wittenberg

A simple method for the accurate computation of all eigenvalues of a dense nonsymmetric matrix is discussed.

It requires only a standard eigenvalue routine plus the extraprecise evaluation of innerproducts and possibly the solution of a system of linear equations with iterative refinement.

Error bounds for the computed eigenvalues are derived.

17:00	**Karow**	**MA 043**

Eigenvalue Perturbation Analysis For The Classical Lie And Jordan

Michael Karow, TU Berlin

The subject of the talk are eigenvalue perturbations of the form $\lambda(A) \rightsquigarrow \lambda(A+\Delta)$, where $A \in \mathbb{C}^{n\times n}$ is a fixed matrix and the matrix Δ is an element of a given perturbation class $\boldsymbol{\Delta}$. The latter is of the form $\boldsymbol{\Delta} = \{\Delta \in \mathbb{C}^{n\times n};\ \Delta^\star U = \epsilon\, U\, \Delta\,\}$, where U is unitary, $\epsilon = \pm 1$, and $\Delta^\star$ is either the transpose or the conjugate transpose of Δ. Note the the classical Lie and Jordan algebras including the sets of (skew) symmetric, (skew) hermitian persymmetric and (skew) hamiltonian matrices are of this type. We give formulas and algorithms for the associated μ-functions, eigenvalue condition numbers, pseudospectra and stability radii.

17:20	Schröder	MA 043

STRUCTURED KRONECKER FORMS FOR THE PALINDROMIC EIGENVALUE PROBLEM

Christian Schröder, TU Berlin

We consider structured generalized eigenvalue problems of the form

$$Ax = \lambda A^T x,$$

called palindromic eigenvalue problem. We will explain this name and give some applications. To characterize the spectral properties of this problem we introduce structured versions of the Kronecker canonical form. These forms also induce canonical forms of a square matrix under congruence. As an application we present a characterization of the set of matrices A that admit a factorization of the form $A = X^{-T}X$.

17:40	Saak	MA 043

ON ADI PARAMETERS FOR SOLVING PDE CONTROL-RELATED MATRIX EQUATIONS

Jens Saak, Peter Benner, Fakultät für Mathematik, TU Chemnitz
Hermann Mena, Escuela Politécnica Nacional del Ecuador

We study the selection of shift parameters for the alternating directions implicit (ADI) algorithm for the solution of Lyapunov and Riccati equations arising in linear quadratic regulator (LQR) problems for parabolic partial differential equations (PDEs). This leads to a rational minimax problem which has been considered by many authors. Since one needs to know the complete complex spectrum its optimal solution is not computable for the large scale systems arising from finite element discretization of PDEs. Therefore several alternatives for computing suboptimal parameters are discussed and compared for numerical examples.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: MA 042

Iterative methods for linear systems and miscellaneous

Chair:

Zdenek Strakos

16:00	Nabben	MA 042

Domain Decomposition Methods And Deflated Krylov Iterations

Reinhard Nabben, Institut für Mathematik, TU Berlin
Kees Vuik, TU Delft, The Netherlands

The balancing Neumann-Neumann (BNN) and the BPS preconditioner are fast and successful preconditioners within domain decomposition methods for solving partial differential equations. For certain elliptic problems these preconditioners lead to condition numbers which are independent of the mesh sizes and are independent of jumps in the coefficients (BNN). Here we give an algebraic formulation of these preconditioner. This formulation allows a comparison with another solution or preconditioning technic - the deflation technic.

By giving a detailed introduction into the deflation technic we establish analogies between the the BNN-, the BPS-method and the deflation technic.

In the BNN- and the BPS-method special restriction and prolongation operators are used to solve coarse grid problems. Within the deflation operator these restrictions are build by so called deflation vectors to generate a subspace.

Using this analogies we can theoretically compare the BNN-, the BPS-method and the deflation method. We prove that the effective condition number of the deflated preconditioned system is always, i.e. for all deflation vectors and all restrictions and prolongations, below the condition number of the system preconditioned by the balancing Neumann-Neumann preconditioner and the coarse grid correction preconditoner (BPS). Moreover, we establish a comparison of the A-norms of the iteration vectors generated by the preconditined CG-methods. We prove that deflation technic generates iteration vectors whose A-norms are less than the A-norms of the iteration vectors generated by the BNN-preconditioner.

16:20	Rozloznik	MA 042

Numerical Behavior Of Iterative Methods For Saddle-point Problems

Miroslav Rozloznik, Institute of Computer Science, Czech Academy of Sciences
Pavel Jiranek, TU Liberec, Czech Republic

In this contribution we study numerical behavior of several iterative Krylov subspace solvers applied to the solution of large-scale saddle point problems. Two main representatives of the segregated solution approach are analyzed: the Schur complement reduction method, based on an (iterative) elimination of primary variables and the null-space projection method which relies on a basis for the null-space for the constraints. Theoretical properties of the most frequently used stationary iterative methods and conjugate gradient-type methods when implemented to the Schur comlement or the projected system are studied and the numerical behavior of resulting schemes is discussed. We will show that rounding errors may considerably influence the numerical behavior of the resulting scheme. It is shown that depending on the considered scheme the maximum attainable accuracy of the approximate solution computed in a finite precision arithmetic can be related for most of them to the convergence of unknowns corresponding either to primary or dual variables. The necessity of pre-scaling or applying a safeguarding technique can ensure not only the convergence of the method, but it may lead to a higher maximum attainable accuracy of (all) unknowns computed in finite precision arithmetic.

This is a joint work with P. Jiranek and and it was supported by the project 1ET400300415 within the National Program of Research Information Society.

16:40	Norbert	MA 042

Parallel Algorithm For Linear Equations In Different Architectural

Varjasi Norbert, Széchenyi István University, Hungary

This paper presents an iterative parallel algorithm for general linear equations. The theoretical basis of this algorithm is a new approach to the minimal residual algorithms that permits different, highly parallel realizations on different farms of processors connected with network having different topology.

We present some parallel algorithms for different network topologies. We demonstrate the problems and realization of these algorithms on various computer networks with different topology. The results about the effectiveness of these realizations will be shown. Finally we summarize and examine the advantages and disadvantages of the recommended and tested algorithms and we show that the proposed family of algorithms are suitable for grid technology.

17:00	Gyozo	MA 042

A Scalable Parallel Algorithm For Solving General Linear System Of

Molnárka Gyozo, Széchenyi István University, Hungary

For solving linear system of equations is known several algorithms. Iteration algorithms are recommended for the large linear systems with sparse matrix. But for the case of general matrices the classic iterative algorithms are not applicable with a few exceptions. For example in some cases the Lanczos type algorithms are adequate. The algorithm presented here based on the minimization of residuum of solution and it has some genetic character. Therefore this algorithm seems to be applicable for construction of parallel algorithm for grid technology. Here we describe a sequential version of proposed algorithm and give its theoretical analysis. Moreover we give a possible parallel version of the proposed algorithm. Finally some numerical test results will be presented.

17:20	Boudinov	MA 042

Conjugate Direction Method For Large Nonsymmetrical Linear Systems

Edouard Boudinov, GSLA, FORTIS Bank, Netherlands
Arkadiy I. Manevich, Dniepropetrovsk National University, Ukraine

A new generalized conjugate direction method for large nonsymmetrical linear systems of equations is proposed. The method unifies advantages of such powerful algorithms as the generalized minimal residuals (GMRES) method and conjugate gradient (CG) method. Similarly to GMRES and some other Krylov-subspace methods for nonsymmetrical matrices, the proposed algorithm uses an entire sequence of orthogonal basis vectors, obtained in the Arnoldi process, which ensures high precision and stability of the method. But the algorithm differs from these methods in two important issues: 1) the obtained orthogonal vectors coincide with the residuals, and 2) the method employs explicitly computed A-conjugate (in a generalized sense) directions to determine iterates. These features, together with some recurrent formulas, allow avoiding solution of an auxiliary linear problem with the Hessenberg matrix in each iteration, unlike GMRES. The advantages of the proposed method are illustrated by the results of extensive numerical experiments with large-scale ill-conditioned linear systems. The results are compared to that of the known efficient algorithms for unsymmetrical linear problems, and the proposed method is found to be superior in terms of the running time.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: MA 043

Eigenvalue Problems

Chair:

Valeria Simoncini

13:30	Moro	MA 043

Perturbation Of Multiple Eigenvalues

Julio Moro, Departamento de Matemáticas, Universidad Carlos III de Madrid, Spain

Taking Lidskii's asymptotic expansions as a starting point, we discuss different aspects of the perturbation of multiple, eventually defective eigenvalues of matrices or, more generally, of matrix polynomials. Among them are the variation of spectral structure under perturbations of low rank, the analysis of Hölder condition numbers, either structured or unstructured, and the application of directional derivatives of eigenvalues to a frequency isolation problem.

The material in this talk corresponds to joint work with Froilán M. Dopico, Juan Egaña, María J. Peláez and Fernando de Terán.

14:10	Voss	MA 043

An A Priori Bound For Automated Multi-level Substructuring

Heinrich Voss, Kolja Elssel, TU Hamburg-Harburg

The Automated Multi-Level Substructuring (AMLS) method has been developed to reduce the computational demands of frequency response analysis and has recently been proposed as an alternative to iterative projection methods like Lanczos or Jacobi-Davidson for computing a large number of eigenvalues for matrices of very large dimension. Based on Schur complements and modal approximations of submatrices on several levels AMLS constructs a projected eigenproblem which yields good approximations of eigenvalues at the lower end of the spectrum. Rewriting the original problem as a rational eigenproblem of the same dimension as the projected problem, and taking advantage of a minmax characterization for the rational eigenproblem we derive an a priori bound for the AMLS approximation of eigenvalues.

14:30	Schwetlick	MA 043

Block Rqi For Symmetric Matrices Converges Cubically

Hubert Schwetlick, Institut für Numerische Mathematik, TU Dresden
Uwe Schnabel, ITI Ges. für ing. Inf.-Verarbeitung, Dresden

In 1998, Lösche/Schwetlick/Timmermann proposed a Block Rayleigh Quotient Iteration (RQI) for approximating a q-dimensional simple invariant subspace of a symmetric matrix and proved its quadratic convergence. Now we show that this methods converges even cubically as the the classic RQI in case $q = 1$ does. Moreover, we reformulate the method in a Jacobi-Davidson-like style such that, instead of bordered matrices, projected matrices are used for computing the required corrections.

14:50	Mehl	MA 043

Resurrecting Eberlein's Jacobi-like Method

Christian Mehl, TU Berlin

In 1987, Patrica Eberlein proposed a Jacobi-like algorithm for the solution of the standard eigenvalue problem with a general (non-Hermitian) complex matrix. This algorithm was shown to be convergent in experiments, but neither a proof of global, nor of local convergence of the method has been given so far.

Although the original method is not competitive with the QR algorithm, there has been renewed interest in Eberlein's Jacobi algorithm in recent years, because it can be generalized to structured (but non-Hermitian) eigenvalue problems like Hamiltonian eigenvalue problems, generalized Hermitian eigenvalue problems, and palindromic eigenvalue problems.

In the talk, we show that Eberlein's Jacobi method is locally and asymptotically quadratically convergent and investigate the practical performence of the algorithm with the help of numerical experiments.

15:10	Mehrmann	MA 043

Generalization Of Symplectic Matrices To Matrix Polynomials

Volker Mehrmann, D. Steven Mackey, Niloufer Mackey, Christian Mehl, Institut für Mathematik, TU Berlin

We discuss the generalizations of Hamiltonian and symplectic matrices to matrix polynomials. These generalization (even and palindromic) have the correct spectral symmetry and allow to treat large classes of optimal control problems, including singular continuous and discrete descriptor systems. We also discuss proper structure preserving linearizations for these matrix polynomials.

Session 6
Wednesday, March 29, 16:00 - 18:00

Room: MA 043

Iterative methods

Chair:

Joerg Liesen

16:00	Frommer	MA 043

Shifted Linear Systems: Algorithms, Applications, Theory

Andreas Frommer, Universität Wuppertal

Families of shifted linear systems are of the form $(A+\sigma_i I)x = b$ with the σ_i being a collection of shift parameters. The key observation is that the Krylov subspaces of the matrices $(A+\sigma_i I)$ with respect to the r.h.s b do not depend on σ. In this talk we will review a number of algorithms for solving such families of systems which exploit the shifted structure and will address their convergence properties, including shifted restarted GMRES and shifted BiCGstab(ℓ). We will then show how such families of systems arise in various applications, for example trust region methods in nonlinear optimization, Tichonov-Philips regularization of ill-posed problems or lattice QCD. But shifted linear systems play also a fundamental role whenn approximating the action of a matrix function on a vector like in $\exp(A)\cdot b$ or $\mathrm{sign}(A)\cdot b$, and we will highlight their role in both, practial computation as well as theoretical results on convergence properties

16:40	Strakos	MA 043

Stopping Criteria In Iterative Methods - A Miscellaneous Issue?

Zdenek Strakos, Institute of Computer Science, Academy of Sciences, Czech Republic

In solving linear algebraic systems, direct and iterative methods are often combined in order to benefit from advantages and eliminate disadvantages of both approaches. Incomplete and modified variants (for keeping the computational cost low) of various decompositions are used in order to speed-up iterative algorithms and to increase robustness of resulting solvers.

Relationship between direct and iterative methods, and also between direct and iterative parts of modern solvers is, however, not always clearly explained in the numerical linear algebra literature. As a result, for some practitioners the main advantage of iterative methods over direct methods still primarily lies in the folklore that "their memory (mostly) and computational requirements are moderate". The possibility of stopping iterative methods early, by relating an appropriate measure of accuracy of the computational stage to the accuracy of other stages of the solution process, such as discretization, is rarely considered an advantage. On the contrary, a need of stopping criteria is often presented as a disadvantage of iterative methods. Discussion of stopping criteria is even in major books on iterative methods moved to miscellaneous issues.

With iterative methods, the cost of computation is given by the sum of the costs of individual iterations needed for obtaining a sufficiently accurate approximate solution. The memory and computational requirements of iterative methods are not automatically low in comparison with direct methods. They are low providing that we can stop before the computational (and sometimes also memory) requirements become excessive. And they can indeed become excessive, e.g. with the GMRES method, unless we can stop early.

In our contribution we will very shortly review the approach to stopping criteria in iterative methods in the major numerical linear algebra and iterative methods textbooks. We then recall some major recent contributions of several authors towards development of efficient stopping criteria based on estimates of error norms and on modified normwise relative backward error. We will finish with some practical recommendations.

This contribution is supported by the National Program of Research Information Society under Project 1ET400300415.

17:00	Hnetynkova	MA 043

Lanczos Tridiagonalization And The Core Problem

Iveta Hnetynkova, Zdenek Strakos, Academy of Sciences of the Czech Republic

The Lanczos tridiagonalization is a well known algorithm that transforms a real symmetric matrix **A** to a symmetric tridiagonal form. The Golub-Kahan bidiagonalization, also referenced as the Lanczos bidiagonalization, reduces a general rectangular matrix to upper or lower bidiagonal form. There are several ways describing the relationship between these two algorithms, see, e.g., C.C. Paige: Bidiagonalization of matrices and solution of linear equations in SIAM J. Numer. Anal. 11 (1974).

In the paper Core problems in linear algebraic systems (to appear in SIAM J. Matrix Anal. Appl.), C.C. Paige and Z. Strakoš analyze a linear approximation problem $Ax \approx b$. They describe the following fundamental property of the bidiagonalization algorithm: when it is applied to an extended matrix $[b, A]$, it determines the so called core problem, which extracts all necessary and sufficient information needed to solve the problem with the original data. In this contribution we explain the relationship between the core problem theory and the known results about the Lanczos tridiagonalization.

17:20	Simoncini	MA 043

PROJECTION METHODS FOR APPROXIMATING THE MATRIX EXPONENTIAL ...

Valeria Simoncini, Universita di Bologna, Italy

In this talk we review Krylov subspace methods for approximating the action of the matrix exponential, namely y = exp(A) v, with A of large dimension and possibly structured. Moreover, we discuss the use of the exponential matrix in the numerical treatment of certain dynamical systems.

17:40	Popolizio	MA 043

ON ACCELERATION METHODS FOR APPROXIMATING THE MATRIX EXPONENTIAL

Marina Popolizio, Dipartimento di Matematica, Università di Bari, Italy
Valeria Simoncini, Università di Bologna, Italy

Hochbruck and van den Eshof have recently proposed an acceleration technique for the numerical approximation of the matrix exponential [1]. In this talk we will present new theoretical results associated with this approach, that allow us to derive an effective strategy for the selection of the acceleration parameter.

Computational aspects will also be addressed.

[1] J. van den Eshof, M. Hochbruck, *Preconditioning Lanczos approximations to the matrix exponential*, to appear in SIAM J. Sci. Comp.

Session 7
Thursday, March 30, 13:30 - 15:30

Room: MA 043

Iterative methods

Chair:

Andreas Frommer

13:30	Ernst	MA 043

Krylov Subspace Methods And Matrix Functions

Oliver Ernst, Michael Eiermann, TU Bergakademie Freiberg

We present an overview of applications, mainly from the field of partial differential equations, which require the evaluation of $f(A)b$ where A is a linear operator or matrix and b is a vector. We then discuss various approximation schemes for this quantity with special emphasis on Krylov subspace approximations and present some recent convergence results.

14:10	Gutknecht	MA 043

The Block Grade Of A Block Krylov Space

Martin H. Gutknecht, Seminar for Applied Mathematics, ETH Zürich
Thomas Schmelzer, Computing Laboratory, Oxford University, UK

The so-called grade of a vector b with respect to a nonsingular matrix A is the dimension of the (largest) Krylov (sub)space generated by A from b. It determines in particular, how many iterations a Krylov space method with linearly independent residuals requires for finding in exact arithmetic the solution of $Ax = b$ (if the initial approximation x_0 is the zero vector).

We generalize the grade notion to block Krylov spaces and show that this fundamental property carries over to block Krylov space methods for solving linear systems with multiple right-hand sides.

14:30	Liesen	MA 043

Effects Of Nonnormality On The Convergence Of Gmres

Jörg Liesen, Institut für Mathematik, TU Berlin

The GMRES method is the de facto standard Krylov subspace method for solving large and sparse nonsymmetric linear systems $Ax = b$. Its modified Gram-Schmidt implementation recently has been shown to be backward stable for any numerically nonsingular matrix A. Unfortunately, work and storage requirements of GMRES applied to a general nonsymmetric matrix grow linearly with the iteration number, so that effective preconditioning is a must in most real-world applications.

Devising effective preconditioners is a difficult problem particularly when A is nonnormal, since in such cases the convergence properties of GMRES are not fully understood. In this talk we will discuss the open question what properties of the given data influence the convergence of GMRES in the nonnormal case. Using results of recent joint work with Zdeněk Strakoš (Czech Academy of Sciences) we will particularly demonstrate the principal difficulties of any GMRES convergence analysis which is based on eigenvector expansion of the initial residual when the eigenvector matrix is ill-conditioned.

14:50	**Tichý**	**MA 043**

Gmres And The Polynomial Numerical Hull For A Jordan Block

Petr Tichý, Jörg Liesen, TU Berlin

The convergence analysis of the GMRES method for solving linear algebraic systems $Ax = b$ is still an active area of research. If A is normal, then GMRES solves a certain approximation problem on the spectrum of A. For nonnormal matrices, the situation is much less clear. A possible approach for investigating the GMRES convergence behavior in the nonnormal case is to concentrate on the *ideal* GMRES approximation

$$\Phi_k^A \equiv \min_{p \in \pi_k} \|p(A)\| ,$$

that represents a bound on the *worst-case* GMRES residual norm. Two open research problems arise. First, for which classes of nonnormal matrices can the value Φ_k^A be identified with the worst-case GMRES residual norm? Second, how can the value of Φ_k^A be evaluated or estimated?

In this talk we address both these two questions for a very simple nonnormal matrix, namely an n by n Jordan block J. Under some assumptions, we show that ideal and worst-case GMRES are identical at steps k and $n-k$ such that k divides n, and we derive explicit expressions for the $(n-k)$th ideal GMRES approximation. Furthermore, we extend previous results in the literature by showing new results about the radii of the polynomial numerical hulls of Jordan blocks. Using these, we discuss the tightness of the lower bound on the ideal GMRES approximation that is derived from the radius of the polynomial numerical hull of J.

15:10	Zemke	MA 043

Abstract Perturbed Krylov Methods

Jens-Peter M. Zemke, *TU Hamburg-Harburg*

We present the framework of “abstract perturbed Krylov methods”, a new, unified point of view on different types of Krylov subspace methods. We give a brief informal sketch of the behavior to be expected from approximations to solutions of linear systems and eigenpairs. The results are applicable to exact arithmetic, finite precision computations including semiduality approaches, and inexact methods.

Session 8
Thursday, March 30, 16:00 - 18:00

Room: MA 043

Mixed Problems

Chair:

Miroslav Tuma

16:00	Potts	MA 043

Fast Summation At Nonequispaced Knots By Nffts

Daniel Potts, Stefan Kunis, Gabriele Steidl, TU Chemnitz

We use the recently developed fast Fourier transform at nonequispaced knots (NFFT) in a variety of applications. The NFFT realized the fast computation of the sums

$$f(w_j) = \sum_{k=-n/2}^{n/2-1} f_k \, \mathrm{e}^{-2\pi \mathrm{i} k w_j} \qquad (j = -M/2, \dots, M/2-1)$$

where $w_j \in [-1/2, 1/2)$.

Fast summation. The fast computation of special structured discrete sums

$$f(y_j) := \sum_{k=1}^{N} \alpha_k K(\|y_j - x_k\|) \quad (j = 1, \dots, M)$$

or from the linear algebra point of view of products of vectors with special structured dense matrices is a frequently appearing task. We develop a new algorithm for the fast computation of discrete sums based on NFFTs. Our algorithm, in particular our regularisation procedure, is simply structured and can easily be adapted to different kernels K, e.g.

$$\frac{1}{x}, \, \frac{1}{x^2}, \, x^2 \log x, \, \log x, \, (x^2 + c^2)^{\pm 1/2}.$$

We prove error estimates to obtain clues about the choice of the involved parameters. Furthermore we generalise this method to the sphere S^2.

Fast Gauss transform.

We apply the fast summation method in order to compute discrete Gauss transforms with complex parameters, i.e., for given complex coefficients $\alpha_k \in \mathbb{C}$ and source knots $x_k \in [-\frac{1}{4}, \frac{1}{4}]$, our goal consists in the fast evaluation of the sum

$$f(y) = \sum_{k=1}^{N} \alpha_k \mathrm{e}^{-\sigma|y-x_k|^2}$$

at the target knots $y_j \in [-\frac{1}{4}, \frac{1}{4}]$, $j = 1, \ldots, M$, where $\sigma = a + \mathrm{i}b$, $a > 0, b \in \mathbb{R}$ denotes a complex parameter.

16:40	Smoktunowicz	MA 043

Iterative Improvement Of Singular Triplets Of Matrices

Alicja Smoktunowicz, Joanna Gil, Warsaw University of Technology, Poland

We consider some ways in which iterative refinement may be used to improve the computed singular triplets of matrices using only fixed precision arithmetic. A comparison of various techniques of iterative refinement with respect to efficiency, numerical stability and accuracy is given.

17:00	Popa	MA 043

Hybrid Algorithms In Image Reconstruction

Constantin Popa, Elena Băutu, Ovidius University, Constanţa
Andrei Băutu, Mircea cel Bătrîn Naval Academy, Constanţa, România

In this paper we present a class of hybrid algorithms for image reconstruction in computerized tomography. Each algorithm combine in an alternate manner a Kaczmarz-like iteration with a genetic-like algorithm. The later one maintains a set of possible solutions, which it tries to improve by evolving them into more performant ones. From this view point, the genetic algorithm plays the role of a *regularizer* which, combined with the *smoother* behaviour of the Kaczmarz-like step can eventually give an efficient and robust method. Experiments are also presented for some image reconstruction problems in computerized tomography.

Acknowledgments: The paper is partially suported by the C.N.M.P. INFOSOC Grant 131/2004.

17:20	Dirr	MA 043

A New Type Of C-numerical Range Arising In Quantum Computing

Gunther Dirr, U. Helmke, M. Kleinsteuber, Mathematisches Institut, Universität Würzburg
Th. Schulte-Herbrüggen, Fakultät für Chemie, TU München

In this talk we consider a new type of numerical range that is motivated by recent applications in quantum computing. The object of interest is the so-called local C-numerical range $W_{\mathrm{loc}}(C, A)$ of A. It is defined by restricting the unitary transformations involved in the definition of the ordinary C-numerical range to the Lie subgroup $SU(2) \otimes \cdots \otimes SU(2)$, i.e. to the n-fold tensor product of unitary (2×2)-matrices.

First, the local C-numerical range is shown to have rather unusual geometric properties, e.g. it is in general not simply connected. Then a conjugate gradient algorithm on the Lie group $SU(2) \otimes \cdots \otimes SU(2)$ is presented to estimate the size of $W_{\mathrm{loc}}(C, A)$ by determining the tightest rectangular box in the complex plane containing $W_{\mathrm{loc}}(C, A)$. Moreover, we explain in some detail why the community of quantum computing is interest in such optimization tasks.

17:40	**Shorten**	**MA 043**

AIMD FOR GENERAL DECENTRALISED RESOURCE ALLOCATION

Robert Shorten, Chris King, Hamilton Institute, National University of Ireland Maynooth, Ireland

Traffic generated by the *Transmission Control Protocol* (TCP) accounts for 85% to 95% of all traffic in today's internet. TCP, in congestion avoidance mode, is based primarily on the Chiu and Jain's *Additive-Increase Multiplicative-Decrease* (AIMD) paradigm for decentralized allocation of a shared resource (e.g., bandwidth) among competing users. A fundamental assumption in proving the efficacy of AIMD is that the limits on the shared resource is defined by a function that is linear in the utilisation of each of the network users and that the normal to this constraint surface is positive. In this paper we allow for non-linear constraints. Necessary and sufficient conditions for the network to have a globally stable equilibria are given (both in deterministic and stochastic case), and the rates of convergence to this equilibria are also determined.

18 Numerical methods for differential equations

Organizers:

Bernd Simeon, TU München
Christian Wieners, Universität Karlsruhe

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: MA 004

DAEs

Chair:

B. Simeon

13:30	Lamour	MA 004

PRACTICAL TESTS OF INDEX DETERMINATION OF DAES

René Lamour, Institut für Mathematik, Humboldt-Universität Berlin

The index of a differential-algebraic equation (DAE) describes the difficulties you have to expect solving this DAE. Practical tests of the numerical determination of the (tractability) index of nonlinear DAEs are reported.

13:50	Bächle	MA 004

A STRUCTURE PRESERVING INDEX REDUCTION METHOD FOR MNA

Simone Bächle, Institut für Mathematik, TU Berlin

Transient analysis in industrial chip design leads to very large systems of differential-algebraic equations (DAEs). The numerical solution of these DAEs strongly depends on the so called index of the DAE. In general, the higher the index of the

DAE is, the more sensitive the numerical solution will be to errors in the computation. So, it is advisable to use mathematical models with small index or to reduce the index.

This talk presents an index reduction method that uses information based on the topology of the circuit. In addition, we show that the presented method retains structural properties of the DAE.

14:10	Dokchan	MA 004

Numerical Integration Of Daes With Critical Points

Rakporn Dokchan, Institut für Mathematik, Humboldt-Universität zu Berlin

We study linear, time-varying differential-algebraic equations (DAEs) with somehow critical points. Assuming density of the regular points and the existence of continuous extensions of certain projectors, those singular DAEs can be decoupled into algebraic equations and a scalarly implicit inherent ordinary differential equation (ODE). Under the same assumptions, one can introduce harmless critical points that allow to reveal a non-singular inherent ODE. Here, we prove stability and convergence of stiffly-accurate Runge-Kutta methods for index-2 DAEs with harmless critical points.

14:30	Ebert	MA 004

Element-based Index Reduction In Electrical Circuit Simulation

Falk Ebert, Simone Bächle, Institut für Mathematik, TU Berlin

The equations arising in circuit simulation are usually very large differential-algebraic equations (DAEs). In practical applications, these equations almost always have a differentiation index larger than one.

It is a well known fact that in general DAEs of index higher than 1 show bad numerical behaviour with respect to stability and accuracy. It is therefor recommendable to reduce the index of such equations.

Many known methods rely on the algebraic transformation of the DAE. In industrial simulation however, this is rarely possible as alterations to the used solvers are nearly impossible. We will present alternative methods that change the circuit topology instead of the resulting equations to generate analytically equivalent systems of index one. We will give examples of the procedure using the free circuit simulator SPICE as reference simulator. We will show that even without changes to the simulator, just by the topologial preprocessing step, we will be able to improve accuracy and computation time of small test examples.

14:50	Wunderlich	MA 004

Numerical Treatment Of Second Order Differential-algebraic Systems

Lena Wunderlich, Institut für Mathematik, TU Berlin

We consider the numerical treatment of systems of second order differential-algebraic equations. The classical approach of transforming a second order system to first order by introducing new variables can lead to difficulties such as an increase in the index or the loss of structure. We show how we can compute a strangeness-free system using the derivative array approach. Further, we present BDF methods, Runge-Kutta methods and General Linear Methods for the direct numerical solution of second order differential-algebraic systems and demonstrate their behavior with numerical examples.

15:10	Surla	MA 004

On A Spline Collocation Method For A Singularly Perturbed Problem

Katarina Surla, Department of Mathematics and Informatics, University of Novi Sad, Serbia and Montenegro
Zorica Uzelac, Ljiljana Teofanov, Department for Fundamental Disciplines, University of Novi Sad, Serbia and Montenegro

We consider a singularly perturbed boundary value problem with two small parameters. The problem is numerically solved using a quadratic spline collocation method. The suitable choice of collocation points provides the inverse monotonicity enabling utilization of barrier function method in the error analysis. Numerical results give justification of the proposed method.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: MA 005

Flow Problems

Chair:

C. Wieners

13:30	Bause	MA 005

Higher Order Mixed Approximation Of Weakly Regular Solutions

Markus Bause, Institut für Angewandte Mathematik, Universität Erlangen-Nürnberg

In this contribution a higher order finite element approach to a coupled variably saturated groundwater flow and bioreactive contaminant transport model is considered. Higher order techniques have proved advantageous in the reliable numerical simulation of biochemically reacting transport processes, due to their less inherent numerical diffusion. For the calculation of the groundwater flow field mixed finite element methods are prefered due to their inherent conservation properties and since they provide a flux approximation as part of the formulation itself. Typically, lowest order mixed Raviart-Thomas elements are used for solving the parabolic-elliptic degenerate Richards equation describing the motion of groundwater, since this model admits solutions of low regularity only. Here, our numerical results obtained by a higher order mixed finite element approach of Brezzi-Douglas-Marini type to elliptic, parabolic and degenerate partial differential equations with solutions of low regularity are presented and carefully compared to corresponding results based on lowest order Raviart-Thomas mixed finite element calculations.

13:50	Eberhard	MA 005

Simulation Of A Free Boundary Problem Modeling Lesion Growth

Jens Eberhard, Jay Walton, Universität Heideberg

We consider a mathematical model of the formation of an atherosclerotic lesion based on a simplification of Russell Ross paradigm of atherosclerosis as a chronic inflammatory response. Atherosclerosis is a disease characterized by the accumulation of lipid-laden cells in the arterial wall. This disease results in lesions within the artery that may grow into the lumen restricting blood flow and, in critical cases, can rupture causing complete, sudden occlusion of the artery resulting in heart attack, stroke and possibly death. It is now understood that when chemically modified low-density lipoproteins (LDL cholesterol) enter into the wall of the human artery, they can trigger an immune response mediated by biochemical signals sent and received by immune and other cells indigenous to the vasculature. The presence of modified LDL can also corrupt the normal immune function triggering further immune response and ultimately chronic inflammation. The investigated model focuses on the inflammatory component of the pathogenesis of cardiovascular disease with the interplay between chemical and cellular species in the human artery. The atherosclerotic lesion consists of a build up of lipids, lipid laden immune cells, and debris in the subendothelial intima of a large muscular artery. This lipid, and potentially nectrotic core, is typically covered by a cap composed of smooth muscle cells and poorly formed connective tissue. The model with the chemotaxis results in a coupled system of reaction diffusion equations describing the state of the various species involved in the disease process.

During the earliest stages of lesion formation, the artery wall may dilate (a process called remodeling) so that blood flow is not restricted. Eventually, the lesion bulges into the lumen causing some degree of occlusion of the artery. The model of lesion formation therefore includes intrusion into the lumen. The problem is stated in terms of a non-linear, coupled system of mostly parabolic PDEs on a domain with a moving boundary. The free boundary consists of an inner boundary which is permitted to evolve as the lesion grows due to an evolution equation. We perform numerical simulations with a fully implicit finite volume discretization method involving the non-linear boundary conditions also on the moving boundary. For solving the moving boundary problem we solve the evolution equation within the framework of a Level set function. The simulations demonstrate that the model captures certain observed features such as the localization of immune cells, the build-up of lipids and debris and the isolation of a lesion by smooth muscle cells.

14:10	**Chamakuri**	**MA 005**

Numerical Computation Of Heat And Mass Transfer In Fluidized Beds

Nagaiah Chamakuri, Gerald Warnecke, Institut für Analysis und Numerik, Otto-von-Guericke Universität
Stefan Heinrich, Institut für Apparate- und Umwelttechnik, Otto-von-Guericke Universität
Mirko Peglow, Institut für Verfahrenstechnik, Otto-von-Guericke Universität

The aim of the talk is the simulation of concentration and temperature distributions inside fluidized beds with a uniform liquid distribution. Further, a physically based 2D model is developed for the heat and mass transfer processes in fluidized beds with a spray nozzle. The model is a coupled and semi-linear system of convection-reaction-diffusion equations. We considered the numerical solution of these semi-linear partial differential equations with discrete boundary conditions using linear finite elements on an adaptive triangular grid in space and implicit methods in time. We present calculations using, semi implicit and implicit methods in time, and different solvers for solving the linear systems. The complex correlations of mass and liquid flow rates, mass transfer, heat transfer, drying, and transient two dimensional air humidity, air temperature, degree of wetness, liquid film temperature and particle temperature were simulated.

14:30	Faustino	MA 005

Interpolating Wavelets Applied To The Navier-stokes Equations

Nelson Faustino, Universidade de Aveiro, Portugal

In the last decade, wavelet and multi-scale methods have been successfully applied to linear elliptic operator equations, such as the Stokes equations. In particular, the changing of the formulation into a saddle point problem is very helpful in this setting. A well establish theory was proposed by A.Cohen, S. Dahlke, W. Dahmen, A.Kunoth, K.Urban *et al* in the 90's.

One of the main existing problems is to extend these techniques to nonlinear operator equations, such as the Navier-Stokes equations.

Some of the main problems involved are the evaluation of the nonlinear terms, stability and wavelet preconditioning for non-linear operators.

In this talk we will present a Wavelet-Galerkin scheme for the stationary Navier-Stokes equations based on the application of interpolating wavelets.

To overcome the problems of nonlinearity, we apply the machinery of interpolating wavelets approach proposed by S. Dahlke, K. Groechenig and P. Maass (1999), in order to obtain problem-adapted quadrature rules. One of the advantages of our approach will be that no construction of divergence-free interpolating wavelets is needed.

Finally, we apply Newton's method to approximate the solution in the given ansatz space, using as *inner* solver, the Uzawa scheme or one of its non-stationary variants based on Krylov subspace methods. To obtain approximations of a higher accuracy, we apply our scheme in a multi-scale context. Special emphasize will be given for the convergence of the scheme, stability and wavelet preconditioning.

14:50	Düster	MA 005

Cfd Based On A Dg Method Solving The Discrete Boltzmann Equation

Alexander Düster, Ernst Rank, Lehrstuhl für Bauinformatik, TU München

A discontinuous Galerkin method for solving the discrete Boltzmann equation is presented, allowing to compute approximate solutions for fluid flow problems. Based on a two-dimensional high order finite element and an explicit Runge-Kutta time stepping scheme, the D2Q9 model is discretized and the results are compared to the exact solution of the Navier-Stokes equations. Several numerical examples are considered, including stationary and transient problems with curved boundaries. It is demonstrated that the proposed method allows to obtain the desired, highly efficient exponential convergence rate.

[1] B. Szabó, A. Düster, E. Rank. The p-version of the finite element method. In: E. Stein, R. de Borst, T.J.R. Hughes, editors. Encyclopedia of Computational Mechanics, John Wiley & Sons, 2004.
[2] A. Düster, L. Demkowicz, E. Rank. High-order finite elements applied to the discrete Boltzmann equation. International Journal for Numerical Methods in Engineering, in press.

15:10	**Seibold**	**MA 005**

Multigrid And M-matrices In The Finite Pointset Method

Benjamin Seibold, TU Kaiserslautern

The Finite Pointset Method (FPM) is a Lagrangian particle method for flow problems, employing meshfree finite difference approximations. We focus on incompressible, viscous flow equations, which are solved using the Chorin projection method.

In the classical FPM derivatives are approximated by a quadratic least squares approximation using all particles inside a “smooting length”. In general this approach yields stencils with both positive and negative weights aside from the central point.

We present how and under which conditions on the particle geometry, optimization methods can force the stencils to have only negative weights aside from the central point. This approach yields smaller stencils and an M-matrix structure, which is of interest for various linear solvers, for instance multigrid solvers. We apply algebraic multigrid to solve the linear systems which arise in the projection step.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: MA 004

H-Matrices and Related Topics

Chair:

C. Wieners

16:00	Bebendorf	MA 004

The Hierarchical Lu Decomp. For Singularly Perturbed Problems

Mario Bebendorf, Fakultät für Mathematik und Informatik, Universität Leipzig

Although the asymptotic complexity of direct methods for the solution of large sparse finite-element systems arising from second-order elliptic partial differential operators is far from being optimal, these methods are often preferred over modern iterative methods. This is mainly due to their robustness. In this talk it is shown that an (approximate) LU decomposition can be computed in the algebra of hierarchical matrices with almost linear complexity and with the same robustness as the classical LU decomposition.

As an application we consider convection dominated problems. It will be seen from both, analysis and numerical experiments, that this approximate LU decomposition guarantees a bounded number of iterations independently of the perturbation parameter if it is used as a preconditioner.

16:20	Djokic	MA 004

Efficient Update Of Hierarchical Matrices Assembled By Aca & Hca

Jelena Djokic, Max-Planck-Institut für Mathematik in den Naturwissenschaften

$\mathcal{H}$-matrices have been used for solving various kinds of problems which require large matrices. The discretisation of an integral equation leads to a full matrix that can be approximated by an $\mathcal{H}$-matrix. The natural question that arises in the context of adaptive grid refinement is: if the discretisation becomes *locally* finer, is it possible to update an existing $\mathcal{H}$-matrix instead of constructing a new one?

The first update algorithms have been developed in the case when the interpolation scheme is used for assembling the low-rank blocks. The results we obtained have proven the efficiency of the method, and therefore we have tried to update the $\mathcal{H}$-matrices in the case when the low-rank blocks are assembled by adaptive cross approximation (ACA) or hybrid cross approximation (HCA). We shall also consider the case when the refinement of the grid is not done locally. The numerical results will demonstrate the efficiency of the update algorithm.

16:40	**Le Borne**	**MA 004**

Hierarchical Matrix Preconditioners For Saddle Point Problems

Sabine Le Borne, Tennessee Technological University, USA

For saddle point problems in fluid dynamics, several popular preconditioners exploit the block structure of the problem to construct block diagonal or block triangular preconditioners. The performance of such preconditioners depends on whether fast, approximate solvers for the linear systems on the block diagonal as well as for the Schur complement are available.
In this talk, we will construct these efficient preconditioners using hierarchical matrix techniques in which fully populated matrices are approximated by blockwise low rank approximations. Numerical results will illustrate the new preconditioners.

17:00	**Constantiniu**	**MA 004**

New Nodal/element Basis Interpolation Scheme For Galerkin Methods

Alexandru Constantiniu, Paul Steinmann, TU Kaiserslautern

A multitude of new Galerkin methods have emerged in the last years, based on novel scattered data interpolation schemes. Many questions have been raised in the numerical methods field. Among them the element dependence or element-free choice remains an open one.

In this contribution we propose a new interpolation method based on the concepts of proximal neighborhood and generalized barycentric coordinates. The scheme needs no predefined connectivity between the nodes and uses an adapted and optimal polyhedral tessellation.

We start by representing the domain by a set of arbitrary distributed points. Using their proximities we create a unique tessellation, optimally adapted to the nodes distribution. Over the obtained elements we use shape functions based on generalized barycentric coordinates, with striking properties valid in any dimension.

If the elements are simplices or the nodal distribution is regular, the proposed method can be reduced to the classical finite element interpolation. If the distribution becomes irregular, a mesh is built in an automatic and computationally convenient way and rational barycentric coordinates of minimal degree are used.

Without any predefined connectivity between the nodes, the method can be considered as a mesh-independent one. With shape functions depending exclusively on the elements geometry, the method can be seen as an extension of the finite element interpolation scheme.

17:20	Geiser	MA 004

Domain-decomposition Methods For Parabolic Problems

Juergen Geiser, Institut für Mathematik, Humboldt-Universität zu Berlin

In this paper we consider complex parabolic equations with multi-physical processes for applications in porous media and phases transitions. The solver methods are based on an overlapping Schwarz wave form relaxation method for overlapped subdomains, see [1]. We derive the theory for a system of convection-diffusion-reaction equations and present the accuracy and the efficiency of the domain-decomposition-methods. On overview to a multi-dimensional theory is given and error-estimates are derived. The exactness and the efficiency of the methods are investigated through solutions of different model problems of scalar and weakly coupling systems of convection-reaction-diffusion equation.

[1] D.Daoud, J.Geiser, “Fractional-Splitting and Domain-Decomposition Methods for Parabolic Problems and Applications”, *Preprint No. 1096 of the Weierstrass Institute for Applied Analysis and Stochastics, Berlin, Germany*, January 2006.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: MA 005

Fluid Dynamics and Related Topics

Chair:

B. Simeon

16:00	**Louda**	**MA 005**

Numerical Solution Of Turbulent Flow In A Turbine Cascade

Petr Louda, Karel Kozel, Jaromír Příhoda, FME CTU Prague

We consider a mathematical model of 2D turbulent flow through the SE 1050 turbine cascade in subsonic and transonic regime. The model of turbulent flow is based on Favre averaged Navier-Stokes equations with SST two-equation turbulence model.

The system of Favre averaged Navier-Stokes and turbulence model equations is discretized in space by means of cell centered finite volume method on a grid of quadrilaterals. The inviscid flux is formulated by AUSM velocity splitting or AUSMPW+ scheme. Higher order accuracy is achieved by 1D linear reconstruction with van Leer limiter. The discretization of diffusive flux is central using dual finite volumes. The time discretization uses backward Euler scheme (implicit) with solution of turbulence model equations decoupled from the NS equations. The linear system is solved iteratively by a relaxation method with direct block tri-diagonal system inversion on selected family of grid lines.

The results achieved on H-type grid and agree well with measurements (Institute of Thermomechanics, Prague) in terms of flow-field structure and surface pressure. The AUSMPW+ scheme gives almost same results as AUSM, however without pressure oscilations in shear layers and with greater robustness. In SST model, we studied influence of source term formulation in the flow with shock wave. Whereas rigorous formulation leads to high turbulent kinetic energy increase in shock wave, “rotational” formulation gives opposite effect. The computed kinetic energy loss coefficients are systematically lower than those reported from measurements.

16:20	**Müller**	**MA 005**

Using Csp For Modeling Burgers-turbulence

Burkhard Müller, D. A. Goussis, B. Rogg, Ruhr-Universität Bochum

Usually LES is applied by solving the Burgers-equation with sufficient accuracy. Unlike LES the *Computational Singular Perturbation*-method (CSP, created for reducing stiff ODE-systems describing Chemical Kinetics), works *without* filtering. In addition CSP detects the radicals in the reactions by the *Radical pointer*. CSP transforms the ODE's by a new set of basis-vectors $\mathbf{a}_i$ to $d\boldsymbol{\eta}/dt = \sum_{i=1}^{N} \mathbf{a}_i f^i$($\boldsymbol{\eta} = [\eta_1, ..., \eta_N]$ is the chemical species-vector, $\mathbf{a}_i f^i$ are modes representing timescales).

Our aim was to simplyfy the ODE's of the discretized Burgers-equation by CSP. For that we translated the *Radical pointer* for the fastest mode ($i = 1$) ($RP(1)$) in the turbulent system. $RP(1)$, a projection of all velocity-nodes into the fastest mode, is given by the diagonal of $\mathbf{a}_1\mathbf{b}^1$ ($\mathbf{b}^1 \odot \mathbf{a}_1 = 1$). It forms a maximum in the shock, we observe an arising peak, which tapers off until $t \approx 0.3$. Then ($t \to \infty$) the peak retains its shape, what indicates, that after $t \approx 0.3$ the nodes with *non-negligible* $\partial v_i/\partial t$ are concentrated *only* in the shock. If we set $\partial v_i/\partial t = 0$ outside the peak, the ODE's are simplified without lost of accuracy.

Apart from simplifying the shape of $RP(1)$ gives informations about the spatial distribution of the smallest turbulence structures.

16:40	Sladek	MA 005

Mathematical Modelling Of Atmospheric Flow Over Complex Topography

Ivo Sladek, Ludek Benes, Karel Kozel, Czech Technical University
Tomas Bodnar, Institute of Thermomechanics, Czech Academy of Sciences

The paper deals with a mathematical modelling and numerical investigation of a 3D-flow in the atmospheric boundary layer over a complex topography, given by a surface coal field, including pollution dispersion. A part of topography around the coal field is covered by a forest blocks which significantly influence the flow-field and the pollution dispersion. Some results from this real-case problem will be presented. A special non-linear forest model has been implemented as well. The flow itself is supposed to be stationary, viscous, incompressible, turbulent and neutrally stratified.

The mathematical approach is based on the system of full RANS equations written in the conservative form and additional transport equation for passive pollutant (coal dust). The problem is closed by a simple algebraic turbulence model and proper boundary conditions. A wall is modelled by a no-slip condition.

The artificial compressibility method is used for the numerical analysis with conjunction of the finite volume method and the explicit Runge-Kutta multistage time integration scheme. The method is theoretically second order accurate on an orthogonal grids.

17:00	Audusse	MA 005

Well-balanced And Conservative Discretizations For Coriolis Forces

Emmanuel Audusse, Rupert Klein, Anthony Owinoh, Université Paris, France

We are interested in the problem of numerical simulations for a shallow water flow on a rotational domain (for climate, meteorological or industrial applications). The existence of non-standard steady states and complex stability properties make this hyperbolic system of PDEs a great numerical challenge.

We introduce two new finite volume discretizations that are adpated to this problem. The first one is directly designed to be *well-balanced* for the problem of the preservation of the geostrophic equilibrium. The heart of the second one is to ensure the conservativity of the discrete inertial (linear or angular) momentum. In particular we are able to exhibit a new discrete Coriolis term which is no more centered on the cell but defined at the cell interfaces. Then a *well-balanced* extension using the solution on an additional Poisson problem is presented.

Some numerical tests are devoted to the comparison of these new methods with a classical one. In particular it appears that both new methods allow us to obtain a noticeable improvement for computations on non-isotropic meshes.

17:20	Vater	MA 005

A Semi-implicit Projection Method For The Zero Froude Number Swe

Stefan Vater, Rupert Klein, Institut für Mathematik, FU Berlin

A new semi-implicit projection method for the zero Froude number shallow water equations is presented. This method enforces the underlying divergence constraint on the velocity field, in two steps. First, the numerical fluxes of an auxiliary hyperbolic system are computed with a standard second order method. Then, these fluxes are corrected by solving two Poisson-type equations, which are discretized using a *Petrov-Galerkin* finite element formulation with piecewise bilinear ansatz functions for the unknown variable. The scheme is written in conservation form. It is formulated as an *exact* projection method, in which the divergence constraint is exactly satisfied up to machine accuracy. The piecewise linear components of the momentum are employed for the computation of the numerical fluxes at the new time level.

In order to show the stability of the projection step, a *primal-dual mixed* finite element formulation is derived, which is equivalent to the Poisson-type equations of the new scheme. Using the abstract theory of Nicolaïdes (1982) for generalized saddle point problems, existence, uniqueness and stability of the discrete method are proven. Numerical results show significant accuracy improvements over a former version of the method.

17:40	Konglok	MA 005

A K Model For Simulating The Dispersion Of Sulfur Dioxide In Urban

Sureerat A. Konglok, *Suwon Tangmanee, King Mongkut's University of Technology, Thailand*
Lawrence Crane, John H. Miller, Institute for Numerical Computation and Analysis, Ireland

Polluted air causes harmful effects on human health and effects the global climate. A finite difference model of the pollution equation in a tropical turbulence environment is developed; and is applied to determine the concentration of pollution in Bangkok.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: MA 004

BEM and Related Topics

Chair:

C. Wieners

13:30	Wendland	MA 004

Fast Boundary Element Method For Eddy Current Heat Production

Wolfgang L. Wendland, Institut für Angewandte Analysis und Numerische Simulation, Universität Stuttgart
Zoran Andjelic, ABB Schweiz AG
Jens Breuer, CoCreate Software GmbH & Co. KG
Olaf Steinbach, TU Graz

One of the most challenging problems in high energy electrical devices is the simulation of the so-called hot spots and their cooling by fluid or air flow. In this lecture we present the treatment of Maxwell equations in metallic Lipschitz domains and the surrounding air by the use of an appropriate boundary integral equation formulation and a corresponding boundary element saddle-point problem in combination with domain decomposition. For the computation of the eddy current we use a Hodge decomposition on the polyhedral boundary surface involving also an inhomogeneous Laplace-Beltrami equation on the boundary surface. Once the eddy currents are computed, one has to solve a coupled nonlinear transmission problem for the temperature distribution and finally needs to couple the temperature field with a flow simulation. Under particular circumstances, the flow simulation can be replaced via Prandtl's boundary layer model which leads to a nonlinear Robin boundary condition for the temperature. Numerical results for some electrical devices such as an high energy transformer will be presented.

13:50	Sauter	MA 004

Efficient Solution Of Time Domain Boundary Integral Equation

Stefan Sauter, Institut für Mathematik, Universität Zürich
Wolfgang Hackbusch, Wendy Kress, MPI Leipzig

In our talk, we will consider the numerical solution of wave equation. The formulation as a time domain boundary integral equations involves retarded potentials.

For the numerical solution, we employ the convolution quadrature method for the discretization in time and the Galerkin boundary element method for the space discretization.

We will introduce a simple a-priori cutoff strategy where small entries of the system matrix are replaced by zero. The threshold for the cutoff is determined by an a-priori analysis.

This method reduces the computational complexity for solving time domain integral equations from $O(M^2 NLog(N))$ to $O(M^{1+s} NlogN)$ for some s in (0,1), where N denotes the number of time steps and M is the dimension of the boundary element space.

14:10	Banjai	MA 004

A Refined Bem Convergence Theory For Helmholtz Problems

Lehel Banjai, Stefan Sauter, Institut für Mathematik, Universität Zürich

Recently, a refined finite element convergence theory for Helmholtz problems with high wave number k was introduced. We apply this framework for the boundary element method, in particular for the Galerkin discretization of the Brakhage-Werner integral equation for the Helmholtz problem. The condition for stability and a quasi-optimal error estimate is expressed in terms of approximate invariance of the boundary element space under a certain solution operator. That is, if $\mathcal{T}_k$ is the solution operator and S the boundary element space we require that $\mathcal{T}_k S \approx S$, the precise meaning of which will be given in the talk.

As an application of the theory we consider the case of scattering by a sphere. We derive that $hk \lesssim 1$ is a sufficient condition for stability and quasi-optimality when using piecewise-constant boundary elements, where h is the global mesh width. This is in contrast to the finite element method applied to the PDE, where the stability condition is $hk^2 \lesssim 1$ unless special finite elements are used. We also show that the constant in the quasi-optimality estimate is independent of k. Up to our knowledge, this is an improvement over the previously available estimates.

14:30	Kähler	MA 004

$\mathcal{H}^2$ Based 3d-wavelet Galerkin Bem

Ulf Kähler, Fakultät für Mathematik, TU Chemnitz
Helmut Harbrecht, Reinhold Schneider, Institut für Informatik und Praktische Mathematik, Christian Albrechts Universität zu Kiel

This talk is devoted to the fast solution of boundary integral equations on unstructured meshes by the Galerkin scheme. To avoid the quadratic costs of traditional discretizations with their densely populated system matrices it is necessary to use fast techniques such as hierarchical matrices, the multipole method or wavelet matrix compression, which will be the topic of the talk.

On the given, possibly unstructured, mesh we construct a wavelet basis providing vanishing moments with respect to the traces of polynomials in the space. With this basis at hand, the system matrix in wavelet coordinates can be compressed to $\mathcal{O}(N \log N)$ relevant matrix coefficients, where N denotes the number of unknowns.

For the computation of the compressed system matrix with suboptimal complexity we will present a new method based on the strong similarities of substructures of the $\mathcal{H}^2$ matrices and the used wavelet basis.

In the end numerical 3D-results will be presented, which will substantiate the theoretical results.

14:50	**Heubeck**	**MA 004**

Finite Elements For Long Semiconductor Laser Resonators

Britta Heubeck, Christoph Pflaum, Universität Erlangen-Nürnberg

The time-dependent Helmholtz equation describes the behaviour of the electromagnetic wave in a laser. Our aim is to solve this partial differential equation for semiconductor lasers. As DFB-lasers consist of a very long resonator in comparison to the wavelength of the laserlight, standard finite element methods cannot be applied. Therefore, a widespread method for this kind of problems is the transfer matrix method. A restriction of this method is, that it can only be applied to the time-periodic Helmholtz equation in 1D. We propose a new approach by multiplying the linear nodal basis functions of the finite element method by appropriate sinus and cosinus functions. In comparison to established methods, this new approach requires less grid points and leads to a more accurate solution. Numerical results are presented.

15:10	**Oevermann**	**MA 004**

A Finite Volume Method For Poisson's Equation With Discontinuities

Michael Oevermann, Institut für Energietechnik, TU Berlin
Rupert Klein, Fachbereich Mathematik und Informatik, FU Berlin

Elliptic equations with variable coefficients and discontinuities across embedded interfaces often arise as a component in modelling physical problems. Examples include incompressible two-phase flow with surface tension featuring jumps in pressure and pressure gradient across the interface or heat conduction between materials of different heat capacity and conductivity.

Cartesian grid methods are attractive for reasons of easy grid generation and simple and accurate difference operators. However, the allowance of complex external or embedded boundaries is usually very difficult. In this work we present a finite volume method on cartesian grids for the solution of the two-dimensional Poisson equation $\nabla \cdot (\beta(\boldsymbol{x})\nabla u(\boldsymbol{x})) = f(\boldsymbol{x})$ with embedded interfaces and variable, discontinuous coefficients and solution discontinuities across those interfaces. The embedded interface is represented via a level-set approach. The method uses bilinear ansatz functions on cartesian grids for the solution $u(x)$ resulting in a compact nine-point stencil. The resulting linear problem has been solved with a standard multigrid solver. Singularities associated with vanishing partial volumes of intersected grid cells or the dual bilinear ansatz itself are removed by a two-step asymptotic approach. The method achieves second order of accuracy in the L^∞ and L^2 norm.

Session 6
Wednesday, March 29, 13:30 - 15:30

Room: MA 005

Diverse Topics

Chair:

B. Simeon

13:30	Schmelzer	MA 005

Talbot Quadratures And Rational Approximations

Thomas Schmelzer, Lloyd N. Trefethen, J. A. C. Weideman, Oxford University, United Kingdom

Many computational problems can be solved with the aid of contour integrals containing e^z in the the integrand: examples include inverse Laplace transforms, special functions, functions of matrices and operators, parabolic PDEs, and reaction-diffusion equations. One approach to the numerical quadrature of such integrals is to apply the trapezoid rule on a Hankel contour defined by a suitable change of variables. Optimal parameters for three classes of such contours have recently been derived: (a) parabolas, (b) hyperbolas, and (c) cotangent contours, following Talbot in 1979. On the other hand, convergence at a rate apparently about twice as fast can be achieved by using a different approach: best supremum-norm rational approximants to e^z for $z \in (-\infty, 0]$, following Cody, Meinardus and Varga in 1969. It is shown that the quadrature formulas can be interpreted as rational approximations and the rational approximations as quadrature formulas. Possible applications are briefly discussed.

13:50	Chapko	MA 005

A Comprasion Of Landweber And Hybrid Methods For Inverse Problems

Roman Chapko, Nadiya Vintonyak, Ivan Franko National University of Lviv, Ukraine

We consider the reconstruction of interior inclusion in semi-infinite canonical domains for the Laplace equation with Dirichlet condition on the boundary of the domain. The numerical solution of this nonlinear and ill-posed problem is realized by Landweber method and hybrid method.

The regularized Landweber method gives the opportunity to reduce the inverse problem to the solving of some direct and adjoint boundary value problems on each step of the iteration. For the solution of these problems we use the indirect variant of boundary integral equation with Green function technique. Then the corresponding boundary value problem is reduced to integral equation with an unknown density on the inclusion. The full discretization is realized by the discrete collocation method with using of sinc- and trigonometric quadrature rules for integrals with various singularities.

The hybrid method combines decomposition and Newton methods. In contrast to the Landweber method it does not need to solve direct problems on each iteration. Firstly, the linear integral equation of the first kind with continuous kernel is solved by Tikhonov regularization method. In the second step the unknown boundary curve is found by determining a curve on which the homogeneous Dirichlet condition is satisfied in some least squares sense.

We investigate - mostly numerically - regularization properties of both methods with respect to a sequence of perturbed data. Numerical examples are presented for such semi-infinite regions: half-plane, half-strip, strip and quadrant.

14:10	Schäfer	MA 005

Partial Space Moment Approximation For Radiative Transfer

Matthias Schäfer, Martin Frank, Rene Pinnau, TU Kaiserslautern

Usual moment approaches for radiative heat transfer (like the PN approximation) have problems to handle anisotropic situations. For improving this behavior the so called partial space moment approximations were developed. The idea of this approach and the analysis of the resulting models will be presented here. Finally the new approach will be compared with several well-known models by some test cases.

14:30	Herceg	MA 005

On A Nonequdistant Difference Scheme Of Chawla Type

Djordje Herceg, Dragoslav Herceg, Department of Mathematics and Informatics, University of Novi Sad, Serbia and Montenegro

We present a fourth-order finite difference method for general second-order nonlinear boundary value problem $-u'' + f(x, u, u') = 0$ subject to two-point boundary conditions. We use nonequidistant discretization mesh and each discretization of the differential equation at an interior mesh point is based on just three evaluations of f. The present paper extends the results given in Chawla (1978) to the case of nonequidistant mesh. Numerical examples are considered to demonstrate computationally the fourth order of the method.

14:50	Yunusi	MA 005

Numerical Solutions Of Des In Partial Derivations

Mahmadyusuf Yunusi, Mahvash Yunusi, Firdavs Yunusi, Makhrifat Gulova, Tajik State National University, Tajikistan

The work is devoted to mathematical modelling of non-linear process of heat-mass transfer having place at product transporting with magistral pipe. The numerical method is based and numerical solutions are given and discussed.Development of magistral pipes system and creating of automated system of product transporting advances series of practically important problem such as determination of optimal size of pipe isolation. At pipe transporting products,which have temperature less or greater than ground temperature, transporting process may be accompanied with change of phase status (melting or freezing). Change of phase status commonly bring to deformation of pipe, which may be eliminated or reduced by corresponding isolation (for given reserve of pipe). Problem of temperatures interaction includes two groups of equations, first describes product flow on pipe-hydrodynamical equations, second describes process of heat conductivity at border and grand-non linear heat transfer problem with discontinuous coefficients and moving boundaries (Stefan type problem). Hydrodynamical equation we transform to first order equation for product temperature(oil, gas, hot water). With regard to said above mathematical modelling of described above process reduces to solution typical next boundary value problem with conditions:

$$\left\{\begin{array}{c} bv_t = (kv_x)_x + \frac{1}{r}(rkv_r)_r, 0 < x < L, r_0 < r < r_1, 0 < t \leq t_k, \\ v|_{t=0} = v_0(x,r), (x,r) \in G, kv_x|_{x=0} = 0, kv_x|_{x=L} = 0, r_0 > 0, \\ kv_r|_{r=r_1} = 0, kv_r|_{r=r_0} = \alpha(x)[v|_{r=r_0} - T(x,t)], v(x,R(x,t),t) = v^*, \\ \kappa\phi_t = (k \;\; grad\; v|_{R+0} - k \;\; grad\; v|_{R-0}, grad\phi), \\ \frac{\beta_0}{\omega}T_t + T_x = \beta(x)T + \beta_1\alpha(x)v(x,r_0,t) + \beta_2, \\ T|_{t=0} = T_0(x), T|_{x=0} = T_1(t), \end{array}\right.$$

where $V = V(x,r,t), T = T(x,t)$ are correspondingly temperatures of ground and product,conversion at point x in time t, R is a moving boundary, $F_i(.)$ are given functions, $v^*, \omega, \beta_i, v_0, T_0, T_1$, $\beta(x) = -\beta_1, \alpha(x), \beta_2, \bar{\beta}, \phi$, and

$$b = \left\{ \begin{array}{ll} c_1(v)\rho_1(v), & v < v^* \\ c_2(v)\rho_2(v), & v > v^* \end{array} \right\},$$

$$k = \left\{ \begin{array}{ll} k_1(v), & v < v^* \\ k_2(v), & v > v^* \end{array} \right\},$$

are physical parameters of ground and product and are given,$\alpha = \alpha(\delta(x))$ is permissible isolation function from set A,
$A = \left\{\alpha : 0 < \alpha_{min} \leq \alpha(x) \leq \alpha_{max}, \int_0^L \alpha(x)dx = \hat{\alpha}\right\}$. It is noted that process of heat transfer of isolation will be accounted if we shall define coefficients of b, k

in isolation area.At theoretical purposes for numerical solution of considerable non-linear problem is replaced by so named smooth problem.

The Difference Approximation. Now we formulate difference approximating problem. Let functions $v^h(x,r,t), R^h(x,t)$ satisfy next conditions:

$$\begin{cases} bv^h_{\hat{t}} = \Lambda_1 v^h, & t = t+\tau/2, \\ bv^h_t = \Lambda_2 v^h, & t = t+\tau, \quad (x,r,t) \in Q^h \\ v^h|_{t=0} = v_0, & Q^h = G^h + \Theta, \end{cases}$$

$$\begin{cases} a_0 v^h_x = \frac{h_1}{2} bv^h_{\hat{t}}, & x = 0, t = t+\tau/2, \\ a_1 v^h_{\hat{x}} = -\frac{h_1}{2} bv^h_{\hat{t}}, & x = L, t = t+\tau/2, \end{cases}$$

$$\begin{cases} a_2 v^h_r = \frac{h_2}{2} bv^h_t + \alpha^h (v^h|_{r_0} - T^h), & r = r_0, t = t+\tau, \\ a_3 v^h_{\hat{r}} = -\frac{h_2}{2} bv^h_t, & r = r_1, t = t+\tau, \end{cases}$$

$$v(x, R^h(x,t), t) = v^*,$$

where G^h and Θ^h are corresponding to G and $[0, t_k]$ difference domains, $b = b(v^h)$, a_i are corresponding boundary values of k, $\Lambda_1 = (kv_{\hat{x}})_x$,$\Lambda_2 = (\hat{kvr})_r$, $v^h_{\hat{x}}, v^h_x$, $v^h_{\hat{r}}, v^h_r$, $v^h_{\hat{t}}, v^h_t$ are difference derivatives, $h = (h_1, h_2, \tau) > 0$ is a step of the net domain.

The main results. 1). There is one only one generalized solution (bounded function from W^1_2) the initial problem and it depends continuously in L_2 from initial data. Corresponding the smooth problem has also one classical solution. under usually conditions . 2). The solution of difference approximation problem stable converges to solution of smooth boundary problem with rate $O(\tau + h_1^2 + h_2^2)$ at internal points of discrete domain Q^h and with rate $O(\tau(h_1+h_2) + h_1^2 + h_2^2)$ at boundary points. For any permissible isolation function $\alpha = \alpha(\delta(x))$ from set A, the solution of difference problem converge to generalized solution of the initial boundary problem with rate $O(\sqrt{\tau + h_1 + h_2})$.

15:10	Beda	MA 005

Anticipatory Computation And The Models Of Dynamical Systems

Peter B. Beda, Budapest University of Technology and Economics, Hungary

In analytical dynamics the model of a mechanical system is called the equation of motion. We have a lot of possibilities for such modeling, there are the direct applications of the axioms of Newton, or the various forms of the Lagrange equations. The classical way of thinking assumes an (obvious?) equivalence of the results of various derivations of the equation of motion. However, the order of the system or the number of the independent variables are not the same and when numerical methods are applied to solve them, they may lead to different results. For example we may consider cases when the mathematical model of a controlled mechanical system is studied, the equations describing control are often treated as constraints.

Our aim in conventional mechanics is somehow to "eliminate" them by a proper selection of the generalized coordinates to reduce the number of equations to solve. However, control engineers do the opposite: they concentrate mainly on control variables and the essential part of the equations describing the system are the set of control equations. If we compare the two approaches we may find a build-in anticipatory nature cased by the elimination of the control variable.

Session 7
Wednesday, March 29, 16:00 - 18:00

Room: MA 004

Solid Mechanics

Chair:

C. Wieners

16:00	Attia	MA 004

The Use Of The Mtw-element In A Mgm For Linear Elasticity

Frank S. Attia, *Gerhard Starke, Institut für Angewandte Mathematik, Universität Hannover*

For solving the equations of isotropic linear elasticity using finite elements, there are different approaches to get a method which does not suffer a loss of performance when it is used for nearly incompressible materials. This is a property of the elements used. In order to keep the number of variables small, it's desirable to choose a pure displacement formulation and a finite element with only "a few" degrees of freedom, but on the other hand the discrete version of Korn's Inequality has to be fullfilled to gain existence and uniqueness of a discrete solution.

Such an triangular element has been introduced by Mardal, Tai and Winther (see [*A Robust Finite Element Method for Darcy-Stokes Flow*, SIAM J. Numer. Anal., Vol. 40, No. 5, pp. 1605-1631]) for "a macroscopic model for flow in an 'almost porous media' ".

The bilinear form of the corresponding variational formulation indicates that this element can be used for elasticity, too.

For the multigrid method the smoother as well as the prolongation operator have to incorporate the structure of the finite element spaces (in particular the divergence free subspaces).

The use of this element for solving the equations of linear elasticity with a multilevel method is discussed in this talk.

16:20	Starke	MA 004

Adaptive Least-squares Finite Element Methods In Elastoplasticity

Gerhard Starke, *Institut für Angewandte Mathematik, Universität Hannover*

A least-squares mixed finite element method for the incremental formulation of elasto-plasticity with isotropic hardening is presented. The nonlinear least-squares functional is shown to constitute an a posteriori error estimator on which an adaptive refinement strategy may be based. For the finite element implementation under plane strain conditions, quadratic (i.e., next-to-lowest order) Raviart-Thomas elements are used for the stress approximation while the displacement is represented by standard quadratic conforming elements. Computational results for a benchmark test problem of Prandtl-Reuss plasticity under plane strain conditions are presented.

16:40	**Rempler**	**MA 004**

An Extended Fe Formulation For Elasto-plastic Materials

Hans-Uwe Rempler, Wolfgang Ehlers, Institut für Mechanik (Bauwesen), Universität Stuttgart
Christian Wieners, Institut für Praktische Mathematik, Universität Karlsruhe

For a numerical discretization of plastic material behaviour with the standard Finite Element Method (FEM), the plastic evolution equations are in general evaluated at each integration point. Therefore, it is necessary to provide internal variables, or so-called history variables, for all of those points, which contain the plastic stress behaviour of the last time step. Since this method concludes an enormous amount of numerical memory, in particular for numerous integration points, it may prohibit the calculation of large problems.

In this contribution, the general possibility of transfering the evaluation of the plastic evolution equations from inside the element to the element nodes is examined. Therefore, the internal variables containing the plastic strains are converted in additional degrees of freedom. Due to this formulation, the memory requirement needed is cut down if the amount of integration points is larger than the number of element nodes. By reducing the discrete points, where the plastic evolution equations are evaluated, one can conclude the bluring of the plastic strains. Hence, to prevent incorrect statements for the distribution of plastic deformations, the benefits of h-adaptivity are investigated.

A couple of different numerical examples is discussed and compared regarding their accuracy, memory requirement, and calculation time using the FE tool PANDAS.

17:00	**Lovadina**	**MA 004**

A Posteriori Error Estimates For Plates

Carlo Lovadina, Università di Pavia and IMATI-CNR, Italy
Rolf Stenberg, Institute of Mathematics, Helsinki University of Technology, Finland

We present an *a posteriori* error analysis for some mixed finite element methods to approximate the solution of the Reissner-Mindlin plate problem. We focus our attention on a low-order triangular mixed element based the so-called "Linked Interpolation Technique". For such a scheme we introduce a suitable residual-based error estimator, and we discuss its *reliability* and *efficiency*. In particular, we show that the error estimator is robust with respect to the choice of the thickness parameter. Even though we will consider only the clamped plate case, our analysis can be easily adapted to cover other boundary conditions of mechanical interest.

We notice that despite its importance, only few results on the *a posteriori* error analysis for plate finite element methods have been previously developed.

17:20	Wobker	MA 004

HPC TECHNIQUES FOR THE FEM SIMULATION IN STRUCTURAL MECHANICS

Hilmar Wobker, Stefan Turek, Bob Svendsen, Institut für Angewandte Mathematik, Universität Dortmund

For the solution of large scale simulations in structural mechanics iterative solving methods are mandatory. The efficiency of such methods can crucially depend on different factors: choice of material parameters, quality of the underlying computational mesh and number of processors in a parallel computing system. We distinguish between three aspects of 'efficiency': *processor efficiency* (degree to which the solving algorithm is able to exploit the processor's computational power), *parallel efficiency* (ratio between computation and communication times) and *numerical efficiency* (convergence behaviour).

With our software package FEAST we pursue the aim to develop a solver mechanism which at the same time gains high efficiencies in *all* three aspects, while trying to minimise the dependencies mentioned above. FEAST is mainly based on a collection of generalised tensor-product meshes and specially adapted Linear Algebra routines for FEM discretisations. Closely connected to our meshing concept, which allows for adaptive mesh refinement and 'locally hiding' mesh irregularities, is a highly efficient hierachical solving strategy, which uses a generalised multigrid-/domain decomposition approach. We show how FEAST can be applied to solve problems from the field of structural mechanics, where the main focus will be on (nearly) incompressible elastic material.

17:40	Kukielka	MA 004

MODELING AND NUMERICAL ANALYSIS OF THE THREAD ROLLING PROCESS

Krzysztof Kukielka, Leon Kukielka, Technical University of Koszalin, Poland

The paper presents the physical and mathematical models of deformations (displacements and strains) and stress in the cold process of thread rolling. The process is considered as a geometrical and physical non-linear, initial as well as boundary value problem. The phenomena on a typical incremental step were described using a step-by-step incremental procedure, with an updated Lagrangian formulation. The state of strains was described by Green-Lagrange's tensor, while the state of stress by the second symmetrical Pioli-Kirchhoff's tensor. The object was treated as an elastic (in the reversible zone) and visco-plastic body (in non-reversible zone) with mixed hardening. The variational equation of motion in three dimensions for this case was proposed. Then, the finite elements methods (FEM) and dynamic explicit method (DEM) were used to obtain the solution. For numerical analysis were used two method: 1rst requires introducing the boundary conditions for displacements in the contact zone determined by model investigation and 2nd one requires the adequate determination of the contact zone without introduction of boundary conditions. Examples of calculations of influence of a friction coefficient on the state's deformation and stress on the thread rolling were presented. The results of numerical analysis are compared and verified in experimental investigation.

Session 8
Wednesday, March 29, 16:00 - 18:00

Room: MA 005

Reaction-Diffusion Equations and Related Topics

Chair:

B. Simeon

16:00	Reinhardt	MA 005

Multidimensional Inverse Heat Conduction Calculations

Hans-Jürgen Reinhardt, Jörg Frohne, Franz-Theo Suttmeier, FB Mathematik, Universität Siegen
Dinh Nho Hào, Hanoi Institute of Mathematics

Inverse Heat Conduction Problems (IHCPs) have been extensively studied over the last 50 years. They have numerous applications in many branches of science and technology. The problem consists in determining the temperature and heat flux at inaccessible parts of the boundary of a 2- or 3-dimensional body from corresponding data – called "Cauchy data" – from accessible parts of the boundary. It is well-known that IHCPs are illposed which means that small perturbations in the data may cause large errors in the solution.

In this contribution we first present the problem and the associated adjoint problem in a variational formulation. The adjoint problem and the corresponding adjoint operator are extremely important for the iterative regularization of IHCPs by, e.g., the Conjugate Gradient Method.

We show examples of calculations for 2-dimensional IHCPs where the direct problems are solved with the Finite Element package DEAL.

Dinh Nho Hào, H.-J. Reinhardt, Y. Jarny. A variational method for multidimensional linear inverse heat conduction problems. *Matimyas Matematika* (Special Issue) (1998), 48-56.
F.T. Suttmeier, On concepts of PDE-Software: The cellwise oriented approach in DEAL. *Numerical Algorithms*, 2005.

16:20	Linß	MA 005

Layer-adapted Meshes For Time-dependent Reaction-diffusion

Torsten Linß, Niall Madden, TU Dresden

We consider singularly perturbed reaction-diffusion problems of the type

$$u_t - \varepsilon^2 u'' + ru = f \quad \text{in} \quad (0,1) \times [0,T]$$

subject to appropriate boundary and initial conditions. The nature of the differential equation changes when $\varepsilon \to 0$ giving rise to boundary layers that require special attention in the design of numerical methods, in particular local refinement of the meshes used.

We give a parameter-robust convergence result for arbitrary meshes that allows easy classification of various layer-adapted meshes proposed in the literature.

16:40	**Ehrhardt**	**MA 005**

NONLOCAL BOUNDARY CONDITIONS FOR HIGHER-ORDER PARABOLIC EQUATIONS

Matthias Ehrhardt, Andrea Zisowsky, Institut für Mathematik, TU Berlin

This talk deals with the efficient numerical solution of the two-dimensional one-way Helmholtz equation posed on an unbounded domain. In this case one has to introduce artificial boundary conditions to confine the computational domain.

The main topic of this work is the construction of so-called discrete transparent boundary conditions for state-of-the-art parabolic equations methods, namely a split-step discretization of the high-order parabolic approximation and the split-step Padé algorithm of Collins.

Finally, several numerical examples arising in optics and underwater acoustics illustrate the efficiency and accuracy of our approach.

17:00	**Pochai**	**MA 005**

A ONE-DIMENSIONAL MATHEMATICAL MODEL OF WATER POLLUTION CONTROL

Nopparat Pochai, Suwon Tangmanee, Department of Mathematics, King Mongkut's University of Technology, Thailand

Water pollution assessment problems arise frequently in environmental science. In this research, the finite element method for solving the one-dimensional of steady convection-diffusion equation with constant coefficients is presented; this is used to optimize water treatment costs.

17:20	**Jovanovic**	**MA 005**

Difference Schemes For A General Parabolic Problem With Interface

Bosko Jovanovic, University of Belgrade, Serbia and Montenegro
Lubin Vulkov, State University of Rousse, Bulgaria

Interface problems occur in many applications in science and engineering. Mathematically, interface problems lead to partial differential equations whose input data and solutions have discontinuities across one or several hypersurfaces, which have lower dimension than that of the domain where the problem is defined. Various forms of conjugation conditions satisfied by the solution and its derivatives on the interface are known. The numerical methods designed for smooth solutions do not work efficiently for interface problems.

In the present work, we investigate a general parabolic interface problem in rectangular domain, crossed by curvilinear interface. By suitable change of variables problem is transformed into analogous one with rectilinear interface. Generalized solution of the problem belongs to a special space of Sobolev type and the corresponding a priori estimate is obtained. For the numerical solution of the problem, some finite difference schemes with averaged right-hand sides are proposed. Implicit scheme is unconditionally stable but inefficient while the factorized scheme is unconditionally ρ-stable and efficient. Convergence rate estimates in discrete Sobolev-like norm, compatible with the smoothness of data, are obtained.

17:40	Müller	MA 005

Numerical Simulation Of Dendritic Crystal Growth

Rüdiger Müller, Humboldt-Universität zu Berlin

Dendritic crystal growth occurs during solidification of metallic melts and several other materials. The mathematical model leads to a free boundary problem of partial differential equations, the modified Stefan-Problem. In the case of vanishing kinetic undercooling, the evolution of the solid-liquid interface is not given by a mean curvature flow any more. Instead the interface velocity has to be computed explicitly from the temperature gradients at the interface.

For the discretization of the temperature field finite elements and adaptive multigrids are used. Because moving interfaces cannot properly be incorporated into edges of each grid of a multigrid hierarchy, we use an implicit level-set representation of the solid-liquid interface that, in contrast to the phase field method, preserves the interface as a sharp surface. Now elements may be intersected by the interface and Dirichlet conditions have to be taken into account on surfaces in the interior of the elements. Standard iterative methods and grid transfer operators can be reused although there is no information about the moving interface in the multigrid itself.

In numerical simulations dendritic patterns evolve that show good agreement with different features of physical experiments.

Session 9
Thursday, March 30, 13:30 - 15:30

Room: MA 004

Finite Elements and Related Topics

Chair:

C. Wieners

13:30	Heinrich	MA 004

NITSCHE MORTARING COMBINED WITH THE FOURIER-FINITE-ELEMENT METHOD

Bernd Heinrich, Beate Jung, Fakultät für Mathematik, TU Chemnitz

The paper deals with the combination of the Nitsche mortaring with the Fourier-finite-element method in the framework of domain decomposition. The mortar approach is applied to the Dirichlet problem of the Poisson equation in three-dimensional axisymmetric domains Ω with non-axisymmetric data. The approximating Fourier method yields a splitting of the 3D-problem into a finite set of 2D-problems. For solving the 2D-problems on the meridian plane Ω_a of Ω, the Nitsche-finite-element method with non-matching meshes and piecewise linear elements in 2D is applied. Some important properties of the approximation scheme are derived. The rate of convergence in some H^1-like norm is proved to be of the type $\mathcal{O}(h + N^{-1})$ (h: mesh size on Ω_a, N: length of the Fourier sum), in the L_2-norm $\mathcal{O}(h^2 + N^{-2})$ in case of a regular solution. Using graded local mesh refinement around the corners of Ω_a generating re-entrant edges, the results can be preserved also for non-regular solutions with edge singularities. Finally, some numerical results are presented.

13:50	Franz	MA 004

SUPERCONVERGENCE OF SDFEM FOR ELL. PROBLEMS WITH PARABOLIC LAYERS

Sebastian Franz, Torsten Linß, Institut für Numerische Mathematik, TU Dresden

We analyze the superconvergence properties of the Galerkin FEM and of the streamline-diffusion finite element method (SDFEM) using bilinear functions in the case of elliptic problems with characteristic layers. To resolve the layers we use appropriate Shishkin meshes.

For the SDFEM we give an optimal choice for the streamline-diffusion parameter δ for maximal stability in the induced streamline-diffusion norm. In the parabolic boundary layer we are able to show that δ can be chosen of order $\delta = C\varepsilon^{-\frac{1}{4}}N^{-2}$ which is confirmed by numerical results.

14:10	**Stiemer**	**MA 004**

Adaptive Fe-discretizations Of Mixed Elliptic-parabolic Pdes

Marcus Stiemer, Fachbereich Mathematik, Universität Dortmund

Boundary value problems of mixed type arise in many practical problems. Consider, e.g., electromagnetic metal forming, where the evolution of the deformation field of a mechanical structure consisting of well conducting material is coupled with an electromagnetic field, triggering a Lorentz force, which drives the deformation process. Inside the region covered by material, diffusion of the electromagnetic field takes place, while outside, the equilibrium state is instantaneously assumed. The corresponding model equation is parabolic inside material regions and elliptic outside. The purpose of this work is to develop a rigorous a posteriori error control for the finite element discretization to such mixed problems. It is examined in how far adaptive mesh refinement enables to compensate for the reduced regularity due to transition zones between elliptic and parabolic areas. Based on error estimators to be derived, mesh adaption strategies are presented, particularly in cases with time dependent diffusivity distribution.

14:30	**Zarin**	**MA 004**

A Finite Element Method For Two-parameter Perturbed Problems In 2d

Helena Zarin, Dept. of Mathematics and Informatics, University of Novi Sad, Serbia and Montenegro
Ljiljana Teofanov, Faculty of Technical Sciences, University of Novi Sad, Serbia and Montenegro
Hans-Görg Roos, Institut für Numerische Mathematik, TU Dresden

We consider a singularly perturbed elliptic problem with two small parameters posed on the unit square. Based on a decomposition of the solution, we prove uniform convergence of the finite element method in an energy norm. The method uses piecewise bilinears on a layer-adapted Shishkin mesh. Numerical results confirm our theoretical analysis.

14:50	**Schneider**	**MA 004**

Automatic Anisotropic Mesh Adaption

René Schneider, *Peter Jimack, Fakultät für Mathematik, TU Chemnitz*

The solutions to many PDEs have highly anisotropic features, like boundary layers for example, whose efficient approximation can be very challenging. Anisotropic meshes, for example of Shishkin type, have proven an important ingredient in efficient solution methods for such problems. Traditionally the generation of these meshes was based on *a priori* analysis of the problem. In many situations *a priori* analysis may not be available. In those cases automatic mesh adaption based on *a posteriori* error estimates is essential to obtain efficient numerical methods.

Historically, the majority of work on automatic mesh adaption has focused on locally uniform h-refinement, which is clearly inappropriate for producing anisotropic meshes. We present a new approach to automatic anisotropic mesh adaption based upon using not only *a posteriori* error estimates, but also their sensitivity with respect to the node positions in the mesh. This sensitivity information may be obtained at moderate expense using the discrete adjoint technique, but provides useful information to guide anisotropic refinement by means of techniques from mathematical programming.

Numerical results will be presented which demonstrate the feasibility of this approach for a number of model problems.

Session 11
Thursday, March 30, 16:00 - 18:00

Room: MA 004

Diverse Topics

Chair:

B. Simeon

16:00	Hart	MA 004

Numerische Aspekte Für Das Projektions-iterationsverfahren

Etery Hart, Nationale Universität Dnepropetrovsk, Ukraine

Es wurde numerische Effektivität für das Projektions-Iterationsverfahren von finite Elemente erforscht. Als Beispiel wird die Auflösung der Aufgabe zur Bestimmung des Plattspannungszustandes von isotrophischen Platten mit einem Loch im Zentrum analysiert. Laut der Hauptidee dieser Methode werden die gegebene Differentialgleichungen (eine Operatorgleichung im Hilbertraum) durch eine Folge der angenäherten Operatorgleichungen ersetzt, die nach finiten Elementenverfahren erhalten wurden. Zur Lösung dieser Folge von Mehrgitteraufgaben, angefangen mit einer gewissen Nummer $n = N$, wird das Iterationsverfahren von obere Relaxation angewendet. Dabei werden für jede angenäherte Operatorgleichung nur einige Iterationen konstruiert. Die letzte Näherung zur n-ten Gleichung dient als Anfangsnäherung zur nächsten $(n + 1)$-ten Gleichung. Es wurde Fehlerabschätzung zu diesem Verfahren erhalten und numerische Vergleichanalyse mit üblichen finiten Elementenverfahren und finiten Differenzeverfahren unternommen. Einige Schlussfolgerungen und Empfehlungen zur Anwendung dieser Methode wurden formuliert.

16:20	Krylova	MA 004

Non-linear Eigenvalues Of Boundary Problem For Differential ...

Tetyana Krylova, State Technical University, Ukraine

The two-stage spline-collocation method with optimization of points of spline is used for finding of eigenvalues of this boundary problem with non-linear parameter for differential equation of six order. The problem about vibrations of closed circular envelopes by uniform exterior stress is related to the boundary value problem on eigenvalues with non-linear parameter for differential equation of six order.

The problem can be solved in two stages.1 stage. The approximated solution of problem is presented as some spline on even splitting for example as polynomial spline. The method of a spline-collocation is used. For finding all unknown coefficients we use boundary conditions and perform collocation in spline node. As a result we shall obtain a linear algebraic homogeneous system of all unknowns. The linear algebraic homogeneous system has the solution, if its continuant is equal to null. Equating null as a continuant of this system, we shall obtain an equation for the definition of eigenvalues. We calculate approximated eigenvalues. 2 stage. For each retrieved eigenvalue we take asymptotically suboptimal splitting. The approximated solution of problem is presented either as a trigonometric spline, or by the way of an interpolative strained spline. We find upgraded approximated eigenvalues equating to null the continuant of the obtained linear algebraic homogeneous system of equations as related to all unknowns . Retrying once again we achieve more split-hair accuracy of approximating of a method.

16:40	Kudratillo	MA 004

BOUNDARY VALUE PROBLEM FOR HIGHER ORDER ABSTRACT PARTIAL DIFFERENT

Fayazov Kudratillo, Xojiev Ikrom, National University of Uzbekistan

We will consider ill-posed boundary value problem for higher order abstract partial differential equation in Hilbert space. The theorem of uniqueness and conditionally stability will be proved. The proof of these theorems are followed from a prori inequalities that will be find from the intial equations. The methods driving these inequalities are logarithmic convexiry and Carleman's estimate method. Exampls corresponding to initial problems from mathematical physics promlems will be given. Approximate solutions some applications problems will be construct by A.Tichonov's regularization method. Formula for calculation regularization paremets will be given too.

17:00	Kurpa	MA 004

R-FUNCTIONS METHOD FOR SOLVING NONLINEAR PROBLEMS OF SHELL THEORY

Lidija Kurpa, National Technical University "KhPI", Ukraine

There are proposed algorithms to solve nonlinear boundary value problems of shell shallow theory and plates with complex form and different boundary conditions. R-functions theory and variational methods are assumed as the basis of worked out algorithmic. In particular the following problems are considered: the geometric nonlinear problems of bending isotropic shallow shells; large amplitude free and

forced vibration of the orthotropic plates; large amplitude free vibration of the isotropic shells . The worked out method allows finding the upper and below critical load for shallow shells of an arbitrary planform under action of lateral loading. Constructive resources of the R-functions theory are used for building the complete sequences of the coordinate functions in an analytical form, satisfying the different boundary condition in the case of the complex boundary. It should be noted that application of the R- functions theory allowed to obtain the formulas structures taking into account the cut domain and crack. The effectiveness of the worked out algorithms have been illustrated on numerous nonlinear problems deal with bending and large amplitude vibration. The obtained numerical results and its comparing with known ones confirm the reliability of the proposed method and created software.

Session 12
Thursday, March 30, 16:00 - 18:00

Room: MA 005

Diverse Topics

Chair:

C. Wieners

16:00	Takaci	MA 005

The Difference Schemes For Operator Difference Equations

Djurdjica Takaci, Department of Mathematics and Informatics, Faculty of Science, Serbia and Montenegro

We construct an approximate solution of a differential equation in the field of Mikusiński operators, by using difference schemes similar to classical ones. In particular, the matrices with elements of the form $a_{ij} = a^1_{ij} I + a^2_{ij}\ell$, where I is an identity operator, ℓ is an integral operator and a^1_{ij}, a^2_{ij} are numerical constants, for $1 \le i, j \le n$ are considered. The error of approximation is estimated in the case of diagonally dominant matrices.

16:20	Tarasova	MA 005

Boundary Element Method In Domain With Disturbed Boundary

Tetyana Tarasova, Dniepropetrovsk National University, Ukraine

Disturbed boundary-value problems are wide spread in different fields of modern mathematical physics. If the disturbance is enough small, such problems require an application of some asymptotic expansion for their solution. As a rule, analytical methods are used together with asymptotic methods, but there are a lot of examples of successfully applications of numerical methods for this aim. However most of the mentioned examples belong to cases of disturbed boundary condition and disturbed inhomogeneous term. The case of disturbed boundary was calculated analytically for very restricted number of domains or numerically by direct application of a numerical method. However last approach requires a very accurate numerical algorithm with high sensitivity, what is not always possible. Application of asymptotic expansion for differential formulation is impossible, because boundary shape is not functionally represented there. There is completely another situation in boundary integral formulation, where the boundary shape function is a part of both integrands and therefore asymptotic expansion can be easy constructed. Thus combined boundary element and small parameter method is proposed for numerical solution of boundary-value problems with disturbed boundaries. A sensitivity of the proposed algorithm is sufficiently more than sensitivity of direct application of any numerical method including boundary element method, what was shown as theoretically as by numerical experiments. Taking into account a well-known high accuracy of boundary element method, if can be concluded that the proposed algorithm is sufficiently better for the considered kind of problems than other approaches. The proposed approach is illustrated by several examples of numerical solutions of boundary-value problems with disturbed boundary.

16:40	Yevdokymov	MA 005

Potential Theory Application To Onsager's Equation System

Dmytro Yevdokymov, Dniepropetrovsk National University, Ukraine

A lot of heat and mass transfer phenomena in porous media and microgravity are described by Onsager's equation system. The effects of coupled diffusion, thermodiffusion and so on are taken into account there. Since the mentioned effects are relatively small the correspondent coefficients in Onsager's matrix are small too. Conventional Onsager's equation system can be transformed into a system of heat conduction equations with thermal diffusivities equal to eigenvalues of Onsager's matrix. The object of the present work is generalized Onsager's equation system, where constant velocity convective transfer and specific source terms (which are proportional to desirable variables) are taken into account. Similar transformation is built for generalized Onsager's equation system. In order to apply potential theory it is necessary to construct a fundamental solution matrix. Fundamental solution matrix for generalized Onsager's equation system is constructed from known fundamental solutions of parabolic type partial differential equations, using the specialy proposed transformation. Then boundary integral analog of generalized Onsager's equation system is obtained. And boundary element method can be applied for its numerical solution. In dependence on prescribed boundary conditions, the problem can be considered in new variables (if the boundary conditions are such, that the initial system is decomposed into separate heat conduction equations) or initial variables (in any other case). The developed approach is illustrated by several examples of numerical calculations.

17:00	Tumashova	MA 005

Deformation State Of Flexible Cylindrical Shells

Olga Tumashova, Dept. of Numerical Mathematics and Programming, National University "Lvivska Politechnika", Ukaine

The problems of equilibrium of thin elastic shells in of deforming are given with the nonlinear systems of connectied differential equations. The problems of deforming thin elastic cylindrical shells with variable thickness and curvature in one direction, based on the solving two-dimentional nonlinear problem. This nonlinear problem are solved using difference approximations, linearization , a stable method of discrete orthogonalization. Consider the elastic shallow cylindrical panel with variable thichness and curvature, which is under the normal surface load. As the base we take the equations, discribing nonlinear task about the strain of shallow shells under the strangth influenses in supposition, that curvature or thickness-variables.

The two-dimentional nonlinear problem are solved using the methods: difference approximations, linearization and discrete orthogonalization. Consider the deformation of the elastic shallow cylindrical panel with variable thickness and curvature is under the influence of normal surface load.

19 Optimization of differential equations

Organizers:

Vincent Heuveline, Universität Karlsruhe
Michael Hinze, TU Dresden

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: MA 415

Chair:

Vincent Heuveline

13:30	**Griesse**	**MA 415**

Optimal Control In Magnetohydrodynamics

Roland Griesse, RICAM, Linz, Österreich

Magnetohydrodynamics, or MHD, deals with the mutual interaction of electrically conducting fluids and magnetic fields. In particular, the magnetic fields interact with the electric currents in the fluid and exert a Lorentz force. This feature renders it so phenomenally attractive for exploitation especially in processes involving liquid metals, and in crystal growth. Therefore MHD technology is used routinely today by engineers, for instance to stir molten metals during solidification, to dampen their undesired convection-driven flow during casting, to filter out impurities, and to melt and even levitate metals.

The tayloring of currents and magnetic fields offers the possibility to drive the fluid in a desired way. In this presentation, we apply an optimal control approach to incompressible MHD problems. Necessary optimality conditions along with numerical methods for their solution are discussed.

14:10	**Goetz**	**MA 415**

Control Of Crystallization Processes

Thomas Goetz, Rene Pinnau, FB Mathematik, TU Kaiserslautern

Crystallization processes appear in a wide range of industrial processes, from chip production to fiber spinning. We present the differential equations which model the crystallization and describe some optimization problems arising in an industrial context. Tools from optimal control are applied to solve these problems.

14:30	Meyer	MA 415

Optimal Control Of Sublimation Growth Of Semiconductor Crystals

Christian Meyer, TU Berlin

An optimal control problem arising from the optimization of crystal growth via the physical vapor transport (PVT) method is considered. After analyzing the state equation and its linearization, first- and second-order optimality conditions are stated. Moreover, a sequential quadratic programming (SQP) method is presented that uses an active set method to solve the linear quadratic subproblems arising in each step. Finally, the talks ends with the descibtion of the discretization and some numerical examples.

14:50	Görner	MA 415

Mpc For The Burgers Equation Based On An Lqg Design

Sabine Görner, Peter Benner, Fakultät für Mathematik, TU Chemnitz

The talk deals with optimal control problems for semilinear parabolic PDEs where process and measurement noise can occur. We discuss the solution of such problems by using a Model Predictive Control (MPC) strategy. For the resulting sub-problems we will use a Linear Quadratic Gaussian (LQG) design. Thus we will discuss the efficient implementation of the LQG approach since it is the major computational part in the MPC scheme for this class of optimal control problems. We will present some numerical results for the Burgers equation.

Session 2
Tuesday, March 28, 16:00 - 18:00

Room: MA 415

Chair:

Michael Hinze

16:00	Pinnau	MA 415

Mathematical Tasks In Optimal Control Of Radiative Heat Transfer

René Pinnau, *TU Kaiserslautern*

During the last years optimization and identification problems for radiative heat transfer in many areas of application, like glass cooling or combustion chamber design, gained considerable attention in the engineering and mathematics community. Due to the high numerical complexity of the underlying model equations this poses several challenging questions concerning model reduction techniques and the construction of fast optimization algorithms. In this talk we will give an overview on the mathematical tools which were recently developed for the solution of these problems.

16:40	Herty	MA 415

Analysis For An Optimality System In Radiative Transfer

Michael Herty, *TU Kaiserslautern*

Optimal control problems for the radiative (heat) transfer equation are introduced and formulated. Those problems arise in many applications as for example cooling of glass, gas turbine combustion chambers or combustion in car engines. The problems are challenging from a mathematical and numerical point of view due to the high dimensionality of the underlying phase space. The starting point of the discussion are the necessary and sufficient optimality conditions for a tracking-type optimization problem using the full radiative transfer equations in two and three space dimensions. We present analytical results on the first-order optimality system and propose a numerical method for solving the arising system. Finally, we present examples on source inversion and edging problems.

17:00	Lahmer	MA 415

Optimal Data Selection For Piezoelectric Material Characterization

Tom Lahmer, Barbara Kaltenbacher, FAU Erlangen
Volker Schulz, Universität Trier

In the simulation and design of piezoelectric transducers the exact knowledge of the entries in the material tensors – the elastic, dielectric and piezoelectric coupling coefficients – is an important prerequisite. Our task is the identification of these coefficients from indirect measurements, namely electric impedance data at different frequencies. This leads to a parameter identification problem for a system of coupled PDEs, which we solve by regularized Newton iterations. A crucial issue is the selection of frequencies at which measurements are taken. In this talk we discuss the problem of choosing these frequencies in an optimal way to preserve efficiency of our identification scheme while improving reliability of the reconstruction results. For this purpose, we formulate this task as an optimization problem with PDE constraints and propose two approaches for its solution. The first one is based on a fixed number of frequencies, whose positions are optimized. The second one uses a weighting function, whose optimal choice induces the selection of a variable number of frequencies. A presentation of numerical results for both methods as well as an appropriate combination of them concludes the talk.

17:20	Dmitruk	MA 415

Optimal Online Control Of Large Scale Dynamical Systems

Natalia Dmitruk, Institute of Mathematics, National Academy of Sciences of Belarus
Anton Naumovich, Belarussian State University, Minsk, Belarus

In the paper we present one approach to optimal online control of a large-scale dynamical system describing a group of q linear interconnected objects, where connections between the members of the group are assumed to be presented by a small number of variables or equations. First we discuss the method for fast construction of optimal open-loop controls and their online correction for realization of the optimal feedbacks. Then in order to reduce computations during online solution of optimal control problems the method is equipped with a special procedure for approximations of the information used in the course of iterations. We show that a proper use of the structure of interconnections in the system allows to integrate no more than q small systems of ODE's, corresponding to the members of the group, instead of solving the initial large system.

Session 3
Wednesday, March 29, 13:30 - 15:30

Room: MA 415

Chair:

Ekaterina Kostina

13:30	Carraro	MA 415

Parameter Estimation And Optimal Experimental Design For Pde

Thomas Carraro, Vincent Heuveline, Rechenzentrum, Universität Karlsruhe (TH)

The solution of a parameter estimation problem aims at determining parameters occurring in the physical model by means of measurements which are usually subject to random errors. The variances of parameter estimates and prediction depend upon the experimental design. A poorly designed experiment may result in unnecessarily large variances and imprecise predictions leading to a waste of resources. Our goal is to propose a numerical method leading sequentially to an optimal design of experiments assuming partial differential equations for the state equations involved in the parameter identification problem. We consider different formulations of this problem which take into account the statistical properties of the random error of the measurement and analyse their impact on the solution process. A numerical method which allows to consider stationary and time dependent problem is presented with numerical experiments.

14:10	Menshikov	MA 415

Inverse Problem For The Differential Equation Under Uncertainties

Yuri Menshikov, Dnepropetrovsk National University, Ukraine

The inverse problem of definition of the right part of the ordinary differential equation with constant coefficients under the given approximately particular solution is considered. The uncertainties of the differential equation is formed by the inexactitude in the given coefficients of the equation. The problem is reduced to the solution of the Vollterra integral equation of the first kind with an inexact kernel and inexact right hand part. The various variants of statement of an inverse problem are considered. The most plausible solution is defined as the solution of an extreme problem of a finding of the greatest lower bound of functional $F(p, z)$ on z, where p is the vector of parameters of the initial differential equation, z is the possible solution of a inverse problem. Functional $F(p, z)$ characterizes the maximal deviation of the given approximate particular solution of the initial differential equation from the particular solution of the differential equation with the possible solution of an inverse problem z at various changes of a vector of parameters p. The conditions are obtained under which most plausible solution of a inverse problem exists, unique and is steady to small changes of the initial data. As a test example the inverse problem for the Duffing?s differential equation is solved.

14:30	Göttlich	MA 415

Modelling And Optimization Of Supply Chains On General Networks

Simone Göttlich, Michael Herty, Axel Klar, TU Kaiserslautern

A mathematical model describing supply chains on general networks is introduced. In this context, a general supply chain network is given by arcs $j \in \mathcal{J}$ and vertices $i \in \mathcal{V}$. Each arc j corresponds to a supplier and an associated queue located in front. Suppliers are connected to each other at vertices $i \in \mathcal{V}$. The model consists of partial differential equations governing the dynamics on each supplier and ordinary differential equations for the evolution of queues. In addition to this continuous model, a linear-discrete model is presented. Optimization problems comparing the different approaches are numerically investigated and difficulties are pointed out.

14:50	Winkler	MA 415

A Priori Discretization Error Estimates Of Ocp In Nonconvex Domain

Gunter Winkler, Thomas Apel, Arnd Rösch, UNIBW München

An optimal control problem for an elliptic equation is investigated with pointwise control constraints. The domain is assumed to be polygonal but non-convex. The corner singularities are treated by a priori mesh grading. Approximations of the optimal solution of the continuous optimal control problem will be constructed by a projection of the discrete adjoint state. It is proved that these approximations have convergence order h^2.

Session 4
Wednesday, March 29, 16:00 - 18:00

Room: MA 415

Chair:

Roland Griesse

16:00	Vexler	MA 415

Adaptive Finite Elements For Parabolic Optimization Problems

Boris Vexler, Dominik Meidner, Johann Radon Institute for Computational and Applied Mathematics

In this talk we present an adaptive algorithm for efficient solution of optimization problems governed by parabolic partial differential equations. The discretization of the state equation is based on the space-time finite element method. We derive a posteriori error estimates which assess the error between the solution of the continuous and the discrete optimization problem with respect to a given quantity of interest. In order to set up an efficient adaptive algorithm we separate the influence of the time discretization, the space discretization and the discretization of the control variable. This allows to balance these types of error and successively to improve the accuracy by construction of locally refined meshes for time, space and the control discretizations. We discuss numerial examples illustrating the behaviour of our method.

16:40	Theißen	MA 415

Controlling Evolution Equations Into Stationary Solutions

Karsten Theißen, Westfälische-Wilhelms-Universität Münster

Directing evolution equations into one (maybe unstable) stationary solution is an important task for many practical applications. If you formulate this problem as an optimal control process, it is not useful to regularise the control in the cost functional. In this case the control appears linear in the system, which leads to bang-bang and singular optimal control functions. For many applications it is difficult to compute this optimal control, because of the occurrence of complex nonlinearities in the system, but it is adequate to find any function, which will control the equation to the stationary solution, even it is not optimal. Here we describe a local optimization method, similar to instantaneous control ideas, which will construct such a control. Numerical examples will be presented for an activator-inhibitor reaction-diffusion model, which plays an important role in the simulation of dissipative solitons in a gas discharge system.

17:00	Arens	MA 415

Levelset Methods In A Benchmark For Thermoacoustic Instabilities

Kai Arens, Hans Joachim Klingshirn, Peter Rentrop, TU München

Gas turbines can suffer from combustion instabilities and combustion driven oscillations. As a prestep 3D benchmark problem for the complicated interactions between acoustics and thermal heat release, a tube geometry is investigated. For the representation of the flamesurface a Level Set approach was chosen. The resulting model includes the impact of curvature on the laminar burning velocity as well as the potential flow field and underlying velocity fields due to vorticity and volume expansion across the flamefront. The acoustic equations and the thermal heat release are coupled by the acoustic velocity which is also included in the flame model. A numerical simulation of this benchmark problem is presented as a first step towards optimizing or controlling the stability behavior of the system.

Session 5
Thursday, March 30, 13:30 - 15:30

Room: MA 415

Chair:

Rene Pinneau

13:30	Strauss	MA 415

Existence And Approximation Results In Design Optimization

Frank Strauss, Vincent Heuveline, Ben Schweizer, Rechenzentrum der Universität Karlsruhe

Typical design optimization problems in rotordynamics include the minimization of a given objective function, such as the mass of the rotor, by changing the shape of the rotor. In addition constraints requiring the shift of certain natural frequencies are important. We show that there exists a solution for this kind of optimization problem for a class of rotors based on a physical model including effects of rotary inertia and gyroscopic moments. For the numerical treatment of the problem a finite element discretization based on a variational formulation is considered. We prove that the solution of the discretized optimization problem converges towards the solution of the continuous problem if the discretization parameter tends to zero. Finally, a priori estimates for the finite element approximation are presented.

14:10	Vossen	MA 415

Sufficient Conditions For Bang-bang And Singular Controls

Georg Vossen, Westfälische Wilhelms-Universität Münster

We consider optimal control problems with control appearing linearly and study optimal controls which can contain bang-bang as well as singular arcs. We will discuss several approaches for verifying different types of optimality for a given trajectory. Dmitruk has developed sufficient conditions for totally singular arcs including a special coercivity condition, which is closely related to the well-known transformation of Goh. We will present a verification technique for this coercivity condition based on differential equations of Riccati-type with certain boundary conditions. If the control is a combination of bang-bang and singular arcs, we will develop sufficient conditions for optimality with respect to variations of the switching points and along the singular arc. Therefore, the control will be transformed to a totally singular one by using the multiprocess technique, for which the method based on the Riccati-equation can be applied. Another technique for verifying the optimality of the switching points is the formulation of the so-called induced optimization problem, which transforms the control problem to a finite-dimensional optimization problem. Optimality in this problem can be shown by solving certain initial value problems. We will present numerical examples to illustrate the verification methods.

14:30	Balashevich	MA 415

Optimization Of Linear System Under Convex End-point Constraints

Natalia Balashevich, *Institute of Mathematics, Minsk, Belarus*

A linear control system transferred to a convex end-point set is considered. A method of on-line constructing a realization of optimal feedback maximizing a linear end-point objective function is suggested. At first, an algorithm of constructing an open-loop solution is worked out. It is based on the previously elaborated algorithm of solving linear optimal control problems. A method of successive approximation of convex end-point set by linear surfaces and correction of the solution to approximative linear problems is suggested. The solution of the linear problem serves as initial approximation for new refining procedure which accounts nonlinearity in constraints.

Then, the method of constructing open-loop solutions is modified in order to generate a realization of optimal closed-loop control in any particular control process. A procedure of correcting open-loop solution for a current position in time less than the quantization period to obtain the optimal open-loop control for a next realized position is elaborated. Realization of the optimal feedback presents a sequence of the first signals of optimal open-loop controls for every realized position.

14:50	Kubitz	MA 415

Smoothing Solver For Nonsmooth Least-squares Methods

Jörg Kubitz, *Institut für Angewandte Mathematik, Hannover*

Mixed least-squares FEM for Elastoplasticity leads to a nonsmooth nonlinear least-squares optimization problem. Since pure Gauss-Newton iteration does not work in this case another method is needed. After a brief overview about general methods for nonsmooth optimization a problem-adapted optimization method based on ϵ-smoothing is presented. The idea behind is derived from a equivalent reformulation as nonlinear complementarity problem. The algorithm is both simple and fast.

Session 6
Thursday, March 30, 16:00 - 18:00

Room: MA 415

Chair:

Thomas Carraro

16:00	Kostina	MA 415

Robustness Issues In Model Validation For Complex Dynamic Systems

Ekaterina Kostina, *IWR Universität Heidelberg*

Methods for parameter estimation and design of optimal experiments are the key methods for validation of models.

Estimating model parameters from experimental data is crucial to reliably simulate dynamic processes. In practical applications, however, it often appears that the data contains outliers. Thus, a reliable parameter estimation procedure is necessary that deliver parameter estimates less sensitive (robust) to errors in measurements.

Another difficulty that occurs in practical applications is that the experiments performed to obtain necessary measurements are expensive, but nevertheless do not guarantee sufficient identifiability. The optimization of one or more dynamic experiments in order to maximize the accuracy of the results of a parameter estimation subject to cost and other technical inequality constraints leads to very complex non-standard optimal control problems. One of the desired property of optimal experiments is their insensitivity against uncertainties in parameter values which are only known to lie in a - possibly large - confidence region. Hence, robust optimal experiments are required that solve worst-case (min-max) optimization problems.

The paper presents new effective algorithms for robust parameter estimation and design of robust optimal experiments in dynamic systems. Numerical results for real-life applications from chemistry and chemical engineering will be presented.

16:40	Hintermüller	MA 415

Path-following In Constrained Minimization

Michael Hintermüller, *Karl Kunisch, Institut für Mathematik, Universität Graz*

Primal-dual path-following methods for constrained minimization problems in function space with low multiplier regularity are introduced and analyzed. Regularity properties of the path are proved. The path structure allows to defined approximating models which are used for controlling the path parameter in an iterative process for computing a solution of the original problem. The Moreau-Yosida regularized subproblems of the new path-following technique are solved efficiently by semismooth Newton methods. The overall algorithmic concept is provided and numerical tests (including a comparison with primal-dual path-following interior point methods) for state constrained optimal control problems show the efficiency of the new concept.

17:00	Schiela	MA 415

The Control Reduced Interior Point Method

Anton Schiela, Martin Weiser, Zuse Institut Berlin

The control reduced interior point method is a primal interior point method for the solution of PDE constrained optimal control problems. The idea is to eliminate the control from a regularization of the optimality system. Pathfollowing with respect to the regularization parameter yields a superlinearly convergent method in function space and thus provides a good basis for a function space oriented algorithm: adaptive pathfollowing is performed in on the continuous level by an affine covariant inexact Newton corrector. Discretization is performed only in the innermost loop when solving linear equations. This can be done efficiently and adaptively with linear or quadratic finite elements, since the control reduced formulation permits optimal error estimates. Numerical examples illustrate the performance of the algorithm.

17:20	Wachsmuth	MA 415

Numerical Verification Of Optimality Conditions

Daniel Wachsmuth, Arnd Rösch, Institut für Mathematik, TU Berlin

A class of optimal control problem for a semilinear elliptic partial differential equation with control constraints is considered. It is well known that sufficient second-order conditions ensure the stability of optimal solutions, the convergence of numerical methods. Otherwise, such conditions are very difficult to verify (analytically or numerically). We will propose a new approach: Starting with a numerical solution for a fixed mesh we will show the existence of a local minimizer of the continuous problem. Moreover we will prove that this minimizer satisfies the sufficient second-order conditions.

20 Dynamics and control

Organizers:

Birgit Jacob, Technische Universitaet Berlin
Kurt Schlacher, Universität Linz

Session 1
Tuesday, March 28, 13:30 - 15:30

Room: MA 001

Controllability and controller design

Chair:

Bernhard Lampe

13:30	Meurer	MA 001

FEEDFORWARD CONTROL OF THE TEMPERATURE DISTRIBUTION IN A CUBOID

Thomas Meurer, Andreas Kugi, Lehrstuhl für Systemtheorie und Regelungstechnik, Universität des Saarlandes

The design of feedforward tracking control is considered for the temperature distribution in a cuboid, where the temperature on a single lateral surface can be arbitrarily prescribed by a control input. It is shown that there exists a so-called flat or parameterizing output, namely the temperature gradient on the lateral surface opposing the input surface, which allows to explicitly derive the inverse infinite-dimensional system representation. Thereby, differential operators of infinite order are obtained relating the temperature distribution and the boundary input with the flat output and its time-derivatives. Convergence of these operators is verified by assigning suitable trajectories of a certain Gevrey class for the flat output. This e.g. allows us to realize finite-time transitions between stationary temperature profiles along prescribed trajectories, which is illustrated in several simulation scenarios. Furthermore, it can be shown that the considered approach provides a systematic, closed-form solution to the so-called controllability moment problem initially posed by Fattorini in 1975 (SIAM J. Contr. Optim, 13 (1)) for the boundary control of the temperature distribution in a parallelepipedon. In summary, the results of the paper provide a promising initial extension of the flatness-based tracking control design approach to spatially multi-dimensional distributed-parameter systems.

13:50	Kugi	MA 001

Nonlinear Control Of A Variable Displacement Axial Piston Pump

Andreas Kugi, Franz Fuchshumer, Lehrstuhl für Systemtheorie und Regelungstechnik, Universität des Saarlandes

In this contribution a mathematical model of a variable displacement axial piston pump controlled by a solenoid valve is derived. For the purpose of a controller design the mathematical model is simplified using singular perturbation arguments. The goal of the controller design is to track prescribed trajectories in either the pump volume flow or the load pressure for arbitrary unknown load conditions. The control concept as being proposed comprises a flatness-based feedforward controller and a nonlinear dynamic controller for the error system utilizing the benefits of the so-called adaptive backstepping approach. It will be shown that in case of a self-supplied pump the control task becomes much more difficult since the load pressure itself has a strong influence on the dynamics of the swash plate actuator and the solenoid valve changes the volume flow of the pump to the load. The stability of the closed-loop system can be proven by means of Lyapunov's theory. The controller is implemented in the rapid prototyping system dSPACE and was excessively tested in an experimental setup. The measurement results show an excellent performance of the closed-loop system in the whole operating range and thus also confirm the theoretical results.

14:10	Sepahvand	MA 001

Robust Control Of Mechatronic Systems With Sensor Uncertainties

Kheirollah Sepahvand, Steffen Marburg, Hans-Jürgen Hardtke, Institut für Festkörpermechanik, TU Dresden

Parametric variation and variation of the mathematical model of sensors for multivariable control of mechatronic systems are modeled as a mixed parametric and dynamic uncertainty. A family of models is described by means of a nominal model and multiplicative weighted dynamic uncertainty. Using Linear Fractional Transformations (LFT), we obtain all transfer functions between each input and output. For designing a controller to achieve a prescribed level of robust performance, a robust H_∞ control design method is employed. The robust H_∞ controller is designed based on the complex mode and the H_∞ control theory. A method to design for robust performance is to synthesize a controller that minimizes the robust stability conditions while scaling the certain requirements until the robust performance is satisfied. The numerical simulation shows robustness of the designed controller.

14:30	**Sattel**	**MA 001**

A Note On Vehicle Guidance Control Using A Mechanical Analogy

Thomas Sattel, Thorsten Brandt, Heinz Nixdorf Insitut, Universität Paderborn

Driver assistance and safety systems become more and more evident in modern vehicles. However, for future driver assistance systems, such as collision avoidance systems, fundamental research is still necessary. This contribution focuses on stability issues of the controller design for vehicle guidance along emergency trajectories. A nonlinear vehicle yaw-plane model is presented. The equations of motion are approximately separated into non-controllable and controllable terms. The controllable terms can be substituted by an appropriate generalized force term which can be interpreted as a combination of springs and dampers acting between a vehicle fixed reference point and a reference point traveling along the desired trajectory in some distance ahead of the vehicle. This mechanical analogy addresses a broad class of possible controller implementations. The choice of the spring and damper models as well as the positions of the reference points on the vehicle and on the trajectory have significant influence on the stability of the guidance system. The direct method of Lyapunov is used to obtain statements on the choice of the controller parameters for stable driving along emergency trajectories.

14:50	**Mandaloju**	**MA 001**

Analogue Implementation Of The Funnel Controller

Nagendra Mandaloju, University of Southampton, United Kingdom
Stephan Trenn, Institut für Mathematik, TU Ilmenau

In many tracking control problems, pre-specified bounds for the evolution of the tracking error should be met. The “funnel controller” addresses this requirement and guarantees transient performance for a fairly large class of systems. In addition, only structural assumptions on the underlying system are made; the exact knowledge of the system parameters is not required. This is in contrast to most classical controllers where only asymptotic behaviour can be guaranteed and the system parameters must be known or estimated. Until now, the funnel controller was only studied theoretically. We will present the results of an analogue implementation of the funnel controller. The results show that the funnel controller works well in reality, i.e. it guarantees the pre-specified error bounds. The implementation is an analogue circuit composed of standard devices and is therefore suitable for a broad range of applications.

15:10	Brzakala	MA 001

Dynamical Stability Of A Viscoelastic Bar

Aneta Brzakala, Zbigniew Wojcicki, Institute of Civil Engineering, Wroclaw University of Technology, Poland

The paper analyses the stability of a simple-supported viscoelastic bar (of the Zener material model) which is subjected to parametric excitation of a periodic nature. The physical model of the system is of the continuous type, but the proposed approach yields a transformation of the mathematical model from the partial differential equation to an ordinary one. Such a transformation is made possible by the use of an approximation function for the bending line of the beam. This way, the system is governed by a homogeneous, ordinary differential equation of the third order with periodic coefficients. For stability studies the Floquet theory is applied, i.e. absolute values of eigenvalues of the monodromy matrix determine the stability of the solution. The results of the stability analysis are presented as a number of curves separating stability regions from regions of instability. Furthermore, the sensitivity analysis of a parametric periodic system is discussed. The main focus is the influence that the values of stiffness and damping coefficients of the Zener model have on the stability of the differential equation, which describes the vibration of the viscoelastic bar. The results based on the Zener model are compared to the ones for the Voigt-Kelvin type.

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: MA 041

Mechanical systems

Chair:

Michael Hanke

13:30	Rudolf	MA 041

Messung Langsam Veränderlicher Lasten Mit Piezosensoren

Christian Rudolf, Jörg Wauer, Institut für Technische Mechanik, Universität Karlsruhe (TH)

Piezoelektrische Sensoren eignen sich aufgrund ihrer hohen Dynamik sehr gut zur Messung hochfrequenter Signale. Bei tiefen Frequenzen ($\ll 1$ Hz) wird jedoch das Messsignal aufgrund der Ableitwiderstände in der Keramik drastisch reduziert, und die Messung langsamer Signale ist daher problematisch. Diese Schwierigkeiten können jedoch unter Ausnutzung des Funktionsprinzips einer Schwingsaitenwaage überwunden werden. Über einen Hebel werden Schwingungen einer zu Transversalschwingungen resonant angeregten Saite auf das Piezoelement übertragen. Das nun gemessene Signal setzt sich aus dem gesuchten Lastanteil des langsam veränderlichen Vorgangs und dem dynamischen Lastanteil aus der Saitenschwingung zusammen und ist daher leicht erfassbar. Eine Änderung der aufgebrachten Last führt über den Hebel zu einer Veränderung der Vorspannung der Saite, woraus eine Veränderung der Eigenfrequenz resultiert. Durch eine Untersuchung der Frequenz mit Hilfe von Frequenzzählern oder Phasenregelkreisen (PLL) kann auf die Vorspannung der Saite und damit auf die anliegende Last zurückgeschlossen werden.

14:10	Neuber	MA 041

Aufbau Und Regelung Einer Magnetführung Für Werkzeugmaschinen

Cord-Christian Neuber, Lars Panning, Institut für Dynamik und Schwingungen, Universität Hannover
Berend Denkena, Franz Kallage, Institut für Fertigungstechnik und Werzeugmaschinen, Universität Hannover

Der größte Anteil der am Markt erhältlichen Werkzeugmaschinen ist mit Wälzführungen ausgestattet. Diese Führungen begrenzen aufgrund von Reibung, Verschleiß und schlechten Dämpfungseigenschaften die Maschinendynamik. Gerade

im Bereich der Hochgeschwindigkeitsbearbeitung (high speed cutting, HSC) begrenzen sie die dadurch die erreichbare Produktivität. In diesem Beitrag wird ein für Werkzeugmaschinen vollkommen neuartiges Führungskonzept vorgestellt, das in einem neu entwickelten Hochgeschwindigkeits-Bearbeitungszentrum, der *schnellen Maschine*, umgesetzt wurde. Die Spindelachse dieser Maschine wird mit Hilfe einer aktiven Magnetführung kontaktfrei geführt. Schwerpunkt des Beitrags sind die sich ergebenden neuen Möglichkeiten der Einflussnahme auf das Maschinenverhalten durch eine intelligente Regelung der Magnetführung. Die aktive Regelung ermöglicht die Einstellung der Steifigkeit und des Dämpfungsverhaltens der Führung, periodische Störungen lassen sich identifizieren und aktiv dämpfen. Durch den prinzipbedingt vorhandenen Luftspalt ist es möglich, die Führung als hochdynamischen Aktor zum Ausregeln von Abweichungen der weiteren Achsen der Maschine einzusetzen.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: MA 001

Differential Algebraic Equations

Chair:

Achim Ilchmann

16:00	März	MA 001

Feedback Solutions Of Optimal Control Problems With Dae Constraint

Roswitha März, Institut für Mathematik, Humboldt-Universität zu Berlin

An optimal feedback control will be proposed for linear-quadratic optimal control problems with constraints described by differential-algebraic equations. For that purpose, a new implicit Riccati equation (Riccati differential algebraic system) will be provided, and its solvability will be investigated. It will be shown that one can do without those strong consistency conditions as used previously.

Also the solvability of the resulting closed loop system and the relations between Riccati equations and Hamiltonian systems will be considered.

This is a joint work with Galina A. Kurina

16:20	Virnik	MA 001

On Controllability Of Positive Descriptor Systems

Elena Virnik, TU Berlin

We consider linear time-invariant control systems of the form

$$\begin{aligned} E\dot{x} &= Ax + Bu, \ x(t_0) = x_0 \\ y &= Cx, \end{aligned}$$

where $x \in \mathrm{C}(\mathbb{R}_+, \mathbb{R}^n)$ is the state vector function, $u \in \mathrm{C}(\mathbb{R}_+, \mathbb{R}^m)$ the input vector function, $y \in \mathrm{C}(\mathbb{R}_+, \mathbb{R}^p)$ the output vector function and $E, A \in \mathbb{R}^{q\times n}$, $B \in \mathbb{R}^{q\times m}$, $C \in \mathbb{R}^{p\times n}$ are constant coefficient matrices. When economical, biological or chemical systems are modelled by descriptor systems, in which the state x describes concentrations, populations of species, or numbers of cells, then the solution is a nonnegative vector function. Hence, the numerical methods for the control or simulation should respect this special structure. This leads to a number of problems. In particular, the application of the classical control is not necessarily possible. We will give an introduction to positive systems, present generalisations of results for positive systems in the ODE case to the case of descriptor systems and finally talk about the applicability of classical control theory in the positive setting.

16:40	Lindert	MA 001

Steuerung Und Regelung Von Lti-systemen In Dae-darstellung

Sven-Olaf Lindert, Kurt Reinschke, Institut für Regelungs- und Steuerungstheorie, TU Dresden

In diesem Beitrag werden Regelstrecken, die sich durch ein lineares zeitinvariantes Algebrodifferentialgleichungssystem modellieren lassen und mehrere Steuereingänge besitzen, betrachtet. Dabei kann beispielsweise an die Euler-Lagrangeschen Bewegungsgleichungen mechanischer Systeme mit n Freiheitsgraden und $m \geq 1$ Aktuatoren gedacht werden.

Es wird bewiesen, dass es genau m *Basissignale* gibt, die durch ein System von m linearen Algebrodifferentialgleichungen definiert werden. Dieses Gleichungssystem wird aus der gegebenen Streckenbeschreibung hergeleitet.

Die zeitlichen Verläufe der m Basissignale können bei Einhaltung bestimmter Glattheitsbedingungen beliebig vorgegeben werden. Aus einer solchen Vorgabe folgen die zugehörenden Verläufe der m Steuersignale und aller übrigen Systemsignale auf eindeutige Weise. Diese mathematische Gesetzmäßigkeit lässt sich regelungstechnisch zur Trajektoriensteuerung nutzen.

Im Falle instabiler Übertragungsfunktionen von den Steuergrößen zu den Basisgrößen müssen die gewählten Trajektoriensteuerungen durch Folgeregelungen ergänzt werden.

Es wird ein allgemeines Wirkungsplan-Schema der Trajektoriensteuerung mit Folgeregelung vorgestellt. Ferner wird diskutiert, in wie weit die Folgeregelung als Abtastregler realisiert werden kann.

17:00	Lampe	MA 001

Causal Polynomial Stabilisation Of Forward Models Of Discrete Pmd

Bernhard Lampe, Efim Rosenwasser, Institut für Automatisierungstechnik, Universität Rostock

Stabilisation is one of the most fundamental control tasks, which includes the construction of the set of stabilising controllers for a given class of processes. For finite dimensional linear time invariant processes and controllers, several authors gave formulae to describe all stabilising controllers by parametrised sets. A well-known variant is the Youla-Kucera parametrisation. The authors extended this approach to the class of processes in polynomial matrix descriptions (PMD), which include descriptor systems. However, the application to forward models is connected with honest difficulties, because the parametrised set contains causal as well as non-causal controllers. But the non-causal controllers are not realisable and have to be removed for further considerations. The suggested contribution presents a method to construct the set of all causal stabilising controllers for strictly proper causal forward models of discrete PMD processes.

17:20	**Reis**	**MA 001**

DECOUPLING OF ABSTRACT DAES

Timo Reis, TU Berlin

The Kronecker normal form is a powerful theoretical tool in the study of linear and time-invariant differential-algebraic control systems, especially for the separation of algebraic and differential parts. We consider here the generalization to the operator case, i.e. we investigate infinite dimensional descriptor systems. Applications are given by the perturbation analysis and consistent initialization of coupled systems of PDEs and ODEs.

Session 4
Tuesday, March 28, 16:00 - 18:00

Room: MA 041

Controllability and optimality

Chair:

Birgit Jacob

16:00	Istratie	MA 041

Optimal Interception With Terminal Constraints.

Vasile Istratie, Department of Flight Dynamics, Elie Carafoli National Institute for Aerospace Research, Romania

This work studies the interception laws for maneuvering targets with known trajectories in the of the three-dimensional case while in [1], where this problem is solved in the planar case. Optimal interception problems are defined, which include constraints on the initial and final flight-path angles of the interceptor. For cases where the initial flight-path angle can be frailly assigned, it is include in the optimization problem. The interceptor is moving at a constant velocity and can change its flight direction by applying bounded normal acceleration. The variational problem is of Lagrange type and the optimum control to be determined being the acceleration due to thrust. The target is moving along an a priori known trajectory with known velocity. The coordinates describe the location of the interceptor and the target, respectively, relative to the origin of an arbitrary reference coordinate system. The problem is to find the acceleration - the optimal control input time history, so that the equations of the interceptor are satisfied and the performance index (the minimum of fuel) is minimized while intercepting a target with a known trajectory. By means of the Legendre-Clebsch condition it is demonstrated that the formulated optimization problem is a maximum problem. The optimization problem is solved applying the Pontriaghin Rs maximum principle, as well as in the problem from Ref. 2. So, the above defined problem of optimal control is transformed in a two point boundary problem. The nonlinear differential equations of the extremes where any kind of approximation was eliminated are precisely integrated by a numerical method, shooting, [3], [4]. Numerical example that demonstrate the optimal trajectories are presented showing also the effect of the interceptor initial flight-path angle on the interception characteristics.

[1] Idan, M., Golan, M. O., and Guelman, M., Optimal Planar Interception with Terminal Constraints, Journal Of Guidance, Control, and Dinamics,Vol. 18, No. 6, 1995, pp. 1273-1279.

[2] Istratie, V., Minimum Time Otimal Rendezvous on Orbits. GAMM 2004, March 21-27, University of Regensburg, Germany.
[3] Callies, R., and Bulirsch, R., AIAA Guidance Navigation and Control Conference, July 29-31, 1996, San Diego, CA, USA.
[4] Istratie, V. Shooting Type Methods for Solving the two Point Boundary Value Problem in the Optimization of Flight Vehicles Evolutions, GAMM 97, March 24-27, 1997, University of Regensburg, Germany.

16:20	**Ursu**	**MA 041**

New Developments In Robust Synthesis With Antiwindup Compensation

Felicia Ursu, Ioan Ursu, Elie Carafoli National Institute for Aerospace Research, Romania
Lucian Iorga, Mechanical and Aerospace Engineering, Rutgers University, U.S.A.

An integrated methodology of robust control synthesis, with antiwindup feedback compensation, is developed in the framework of the classical general robust servomechanism problem. The servocompensator structure is proved to be close to the one designed for step signals. The stabilizing compensator synthesis is achieved through a linear quadratic optimal procedure. An antiwindup compensation is added to deal with the adverse effects caused by control saturation. The work extends, both in continuous and discrete time, some recent results of the authors [1-2]. Numerical simulations are presented to validate the proposed procedure.

[1] Ursu, I., F. Ursu, M. Vladimirescu, T. Sireteanu (1998), From robust control to antiwindup compensation of electrohydraulic servo actuators, Aircraft Engineering and Aerospace Technology, Vol. 70, No. 4, pp. 259-264, © MCB University Press.
[2] Ursu, F., I. Ursu, M. Vladimirescu (2001), Robust synthesis with antiwindup compensation for electrohydraulic servo actuating primary flight controls, Proceedings of the 15th IFAC Symposium on Automatic Control in Aerospace, Bologna/ Forli, Italy, September, 2-7, pp. 197-202, © IFAC.

16:40	**Popescu**	**MA 041**

Analysis Of Optimality In Singular Control

Mihai Popescu, Institute of Statistics and Applied Mathematics, Romania

Maximum Priciple gives as necessary condition for the optimality of the admissible trajectories. Among the trajectories satisfying the Maximum Principls, there

are ones for which the associated control is not determined by this principle these are the singular extremals. The singular casee is proper to differential sysytems, linear in the control variable, and correspond to the vanishing of the Hessian this fact renders improper the use of the well-known Ricatti matrix equation, whose solution of which allows the optimality analysis for the non-singular case. The practical problem involving singular control appear in tyhe spatial dynamics. Thus the trajectories for rocket, having limited thrust, exhibit a singularity with respect to the fuel consumption. Lawden showed that the singular arc of intermediate thrust satisfies the Pontriaghin's Principle and hence may minimize the fuel consumption in the orbital transfer with final time not precised. By using the generalized Legendre-Clebsch conditions, Kelley proved non-optimality of the intermediate thrust arc (Lawden's spiral).

The proposed method in this paper for the optimality analysis of the singular arc of rocket transfer trajectories uses the second variation sign as well as the final state variation. The obtained criterion determine the sufficient optimality and non-optimality conditions. Then the non-optimality of teh singul;ar arc in the transfer with a minimum fuel consumption is proved.

17:00	Kostin	MA 041

Method Of Intergo-differential Relations For Optimal Beam Control

Georgii Kostin, Vasily Saurin, Institute for Problems in Mechanics RAS, Russia

The approaches to modelling and optimization of controlled dynamical systems with distributed elastic and inertial parameters are considered. The general integro-differential method for solving wide class of boundary value problems is developed and criteria of solution quality are proposed. The numerical algorithm for discrete approximation of controlled motions is worked out and applied to design the optimal control low steering an elastic system to the terminal position and minimizing the given objective function. The polynomial control of plane motions of a homogeneous cantilever beam is investigated. Such type of system disturbances can induce essential elastic deflections and lead to sufficient computational difficulties when the conventional approaches are used. The optimal control problem of beam transportation from the initial rest position to given terminal state, in which the full mechanical energy of the system reaches its minimal value, is considered. The obtained numerical results are analyzed and compared with the conventional Fourier's solution.

17:20	Yugay	MA 041

Avoiding Problem Under The Absence Of Superiority (nonlinear Case)

Lew Yugay, Uzbekistan

The problem of trajectories' avoiding from given terminal set in conflict controlled processes described by nonlinear systems of ordinary differential equations is considered.

Many authors investigated this problem under condition of strong superiority for one of controlled side named evader. The case when evader (making avoiding of trajectories) has not any superiority against his opponent (pursuer) was considered by M. S. Nikolskiy (Russia), N. Satimov(Uzbekistan) and J. Yong (China). Those authors assumed for pursuer some geometrical superiority on size of control parameter sets and his opponent named evader has not geometrical superiority but has some advantage in choosing of control functions.

The avoiding process for the case when the evader has not any geometrical superiority against pursuer and both sides choose its controls from the same set of piecewise constant functions is considered. The correspondence conflict controlled systems described by nonlinear differential equations. It is obtained sufficient conditions providing a possibility of trajectories' avoiding from arbitrary admissible initial position.

Session 5
Wednesday, March 29, 13:30 - 15:30

Room: MA 001

System theory

Chair:

Kurt Schlacher

13:30	Ilchmann	MA 001

Time-varying Linear Systems: Relative Degree And Normal Form

Achim Ilchmann, Markus Müller, Institut für Mathematik, TU Ilmenau

We define the relative degree of time-varying linear systems, show that it coincides with Isidori's and with Liberzon-Morse-Sontag's definition if the system is understood as a time-invariant nonlinear system, characterize it in terms of the system data and their derivatives, derive a Byrnes-Isidori normal form with respect to a time-varying linear coordinate transformation, and finally characterize stability of the zero dynamics.

13:50	Zwart	MA 001

Well-posedness And Regularity Of The Undamped Wave Equation

Hans Zwart, Department of Applied Mathematics, University of Twente, The Netherlands

We study the undamped wave equation on a one dimensional (bounded) spatial domain with control and observation at the boundary. First we show that for a special choice of the control and the observation this defines a well-posed system. This means that for any initial condition and any locally square integrable input function, the state trajectory is continuous and the output is locally square integrable. Furthermore, we show that the corresponding transfer function is regular, i.e., has a limit for s going to infinity.

Next we change the control and observation. Using the idea of feedback we show that this system is again well-posed and regular for almost all choices of control and observation.

The property of well-posedness is needed, if one wants to design a LQ-optimal controller for the system.

Finally, we show that the ideas in this presentation can be extended to a much larger class of systems, i.e., vibrating plate, Maxwell equation, etc.

14:10	Röbenack	MA 001

High Gain Observers Using An Approximate Observer Normal Form

Klaus Röbenack, Institut für Regelungs- und Steuerungstheorie, TU Dresden

If one can transform a nonlinear system into observer normal form, it is possible to design an observer with exactly linear error dynamics. Unfortunately, many systems of practical relevance violate the existence conditions of the normal form. This drawback can be circumvented by means of an approximate observer canonical form.

Even for an approximate observer normal form, the actual computation of the associated transformation is usually very difficult. Quite often, it is not possible to find a symbolic expression for the required change of coordinates. We suggest a nonlinear observer design procedure that avoids this difficulty.

14:30	Kielau	MA 001

Generalized Helmholtz Conditions For The Existence Of A Lagrangian

Gerald Kielau, Peter Maißer, Institut für Mechatronik e.V., Chemnitz

Modern methods of the non-linear control theory are based on so-called Lagrange models $\{\Lambda,\ D\}$ consisting of two energetic state functions: Λ-Lagrangian, D-dissipation function, which on certain conditions can be assigned to the motion equations of mechanical, electrical and electromechanical systems with a finite degree of freedom. A physical system whose motion equations can be derived according to the well-known Lagrange approach using a Lagrange model $\{\Lambda,\ D\}$ is called an Euler-Lagrange system.

The existence of such a $\{\Lambda,\ D\}$-model is necessary applying methods of the so-called passivity-based control of Euler-Lagrange systems.

The special case $D \equiv 0$ has been considered by H. v. Helmholtz 1887. He focus to the problem of the existence of a so-called kinetic potential of the first-order $\Lambda = \Lambda(\dot{q}, q, t)$ with respect to a given set of 2^{nd}order ODE system, which can be regarded as motion equations of any dynamical system. Helmholtz found 4 necessary and sufficient conditions and, in case of fulfilling he also gave a method to calculate Λ.

This paper presents a generalization of Helmholtz' problem. For the simultaneous existence of two state functions $\Lambda(\dot{q}, q, t)$ and $D(\dot{q}, q, t)$ necessary and sufficient conditions are given.

A starting point for this approach are the classical Helmholtz-conditions slightly modified. The basic idea is at first to separate dissipative terms from the given ODE system and to design a dissipation function D if the corresponding integrability conditions are satisfied. The Lagrangian Λ follows like in Helmholtz' paper.

14:50	Gaull	MA 001

Zellabbildung Für Dynamische Systeme Mit Störungen

Andreas Gaull, Edwin Kreuzer, Mechanik und Meerestechnik, TU Hamburg-Harburg

Die Methode der Zellabbildung ermöglicht eine Analyse des globalen Langzeitverhaltens nichtlinearer Systeme. Für ungestörte Systeme, welche durch nichtsinguläre Abbildungen beschrieben werden, ist die Zellabbildung durch eine Diskretisierung des zugehörigen Frobenius-Perron-Operators charakterisiert. Analog dazu bietet sich eine Beschreibung der Dynamik durch geeignete Markov-Operatoren an, wenn dem an sich deterministischen Systemverhalten zufällige Störungen überlagert sind. In diesem Artikel werden die Grundzusammenhänge der Zellabbildung für dynamische Systeme mit Störungen erläutert und die Ableitung der beteiligten Operatoren motiviert. Die Berücksichtigung der Störterme erfolgt dabei in Form stochastischer Prozesse, die additiv oder multiplikativ mit der deterministischen Systemabbildung verknüpft sind. Die Ausführungen werden durch numerische Untersuchungen ergänzt.

15:10	Schöberl	MA 001

Geometric Analysis Of Hamiltonian Mechanics Using Connections

Markus Schöberl, Kurt Schlacher, Johannes Kepler Universität Linz

From a geometric point of view connections appear naturally in an intrinsic description of mechanics, such that the equations remain their structure, even when time dependent transformations are applied. This is obvious for time variant systems, but nevertheless also interesting in the time invariant case, from a control point of view, if stabilization of trajectories is the demand. The choice of connections is of course not unique and physical considerations are essential for the proper selection. When considering the equations of motion with respect to an observer, the correct interpretation of the velocity and the linear momentum requires a space-time connection, which takes into account the velocity of the observer. To derive the change of the momentum in an intrinsic way the introduction of a so called dynamic connection is important. The Hamiltonian approach also makes essential use of the space-time connection and furthermore there exists the Hamiltonian connection which gives us the possibility to split the Hamiltonian vector field into a vertical and a horizontal part, respectively. We will show how this splitting of the Hamiltonian vector field can be used to give a geometric interpretation of the power flows with respect to the Hamiltonian description.

Session 6
Wednesday, March 29, 13:30 - 15:30

Room: MA 041

Fuzzy control and identification

Chair:

Birgit Jacob

13:30	Kondratenko	MA 041

Fuzzy Arithmetic Analytic Models For Triangular Uncertain Numbers

Volodymyr Kondratenko, Dept. of Cybernetics, Taras Shevchenko Kyiv National University, Ukraine

This paper deals with the investigations of fuzzy numbers with triangular membership functions. Special attention is paid to analytic models of the membership functions for fuzzy arithmetic operations' results.

Such kind of fuzzy arithmetic operations as addition, subtraction, multiplication and division are under consideration. It is possible to calculate the membership function of result fuzzy sets forming after implementation of fuzzy arithmetic operations using max-min convolution algorithms. But a lot of computer memory and calculate time should be provided during realisation of max-min convolution.

According to study a fuzzy arithmetic for triangular uncertain numbers it is well known the resulting fuzzy sets for addition and subtraction operations have linear membership functions. But for multiplication and division of triangular fuzzy numbers the resulting membership functions have non-linear character.

General linear and non-linear analytic models of resulting membership functions for the above- mentioned fuzzy arithmetic operations are given. The parameters of triangular fuzzy numbers are input data for the developed models. The models are based on the analysis of roots of algebraic equations describing linear and non-linear resulting membership functions.

Modelling results confirm the efficiency of developed mathematical models, which can be used for realisation of decision-making and control algorithms in uncertainty.

13:50	Ursu	MA 041

Fuzzy Supervised Neurocontrol Of Electrohydraulic Servos

Ioan Ursu, Felicia Ursu, George Tecuceanu, Radu Cristea, Elie Carafoli National Institute for Aerospace Research, Romania

The work presents recent theoretical and experimental investigations concerning the neuro-fuzzy control synthesis as applied to electrohydraulic servos actuating primary flight controls. The control algorithm is built around a neurocontrol designed to optimize a performance index. Whenever the neurocontrol saturates or a certain performance parameter of the system decreases, the scheme of control switches to a feasible and reliable fuzzy logic control. In accordance with simulation studies developed in previous works of the authors [1-3], the neuro-fuzzy controlled system is proved to be sometimes better than the corresponding classical PI or LQG systems. Therefore, the presented results are very encouraging from viewpoint of intelligent control strategies development. It is worth noting that the entire control synthesis is thought as a model free approach, thus ensuring reduced design complexity and focusing on increased system robustness.

[1] Ursu, I., F. Ursu, L. Iorga (2001), Neuro-fuzzy synthesis of flight control electrohydraulic servo, Aircraft Engineering and Aerospace Technology, United Kingdom, 73, 5, © MCB University Press.
[2] Ursu, I., F. Ursu (2002), Active and semiactive control, Romanian Academy Publishing House, 356 pp.
[3] Ursu, I., F. Ursu (2004), New results in control synthesis for electrohydraulic servos, International Journal of Fluid Power, 5, 3, pp. 25-38, © Fluid Power Net International FPNI and Tu Tech, TUHH Technologie Gmbh.

14:10	**Pervukhina**	**MA 041**

Analysis Of Adaptive Filtering Algorithm For Random Consequences

Elena Pervukhina, Tatyana Stepanchenko, Alexey Pervukhin, Sevastopol National Technical University, Ukraine

There are many filtering methods which react on real changing of empirical data. Nevertheless, in spite of theoretical background of design of algorithms, that are optimal from classical point of view, received estimations often differ from real values of elements of estimated consequences, particularly under the condition of deficient information.

In [1-2] the algorithm of adaptive filtering for random consequences at a priori unknown noise covariance functions has been proposed. The Kullback-Leibler divergence measuring the difference between two distributions of random variables is considered as filtering criterion.

This paper presents the analysis of characteristics of proposed adaptive filter for random consequences, determined by difference equations. Special attention is given to frequency investigation for stationary random consequences. The results are compared with classic Kalman approach.

1. Pervukhina E. Identification of technical system on trials for adaptation to specific functioning model // Zeitschrift für Angewandte Mathematik und Mechanik 76, suppl.3, 1996, 533.
2. Pervukhina, E., Emmenegger J.-F. Adaptive time series filters obtained by minimization of the Kullback-Leibler divergence criterion // International Journal of Applied Mathematics, vol. 17, No. 1, 2005, 69-89.

Session 7
Wednesday, March 29, 16:00 - 18:00

Room: MA 001

Numerical Methods

Chair:

Andreas Kugi

16:00	**Mohr**	**MA 001**

Galerkin-based Time Integrators For Finite Plastodynamics

Rouven Mohr, Paul Steinmann, TU Kaiserslautern

Computational modelling often demands the incorporation of dynamic effects. The consideration of computational continuum dynamics requires in particular advanced numerical techniques to satisfy the classical balance laws like balance of linear and angular momentum or the laws of thermodynamics.

Energy and momentum conserving time integrators are well-established in computational dynamics for the elastic case [1]. Algorithmic conservation of energy and angular momentum have been shown to be closely related to quadrature formulas that were required for the calculation of time integrals. Conserving schemes were constructed for general hyperelastic material models which are based on the introduction of a special algorithmic stress, see [2, 3].

In this contribution we deal with the enhancement of these concepts for geometrically nonlinear plasticity. First, we apply concepts of geometrically nonlinear continuum mechanics and finite elements in space to receive a semidiscrete system of equations of motion based on a Hamiltonian-type formalism. The formulation of finite plasticity adopts a multiplicative decomposition of the deformation gradient in an elastic and a plastic part, see [4, 5]. For the temporal approximation of the semidiscrete system also finite elements are used.

The resulting time-stepping scheme for geometrically nonlinear plastodynamics is analysed regarding its conservation properties.

[1] Betsch, P. and Steinmann, P. (2001): “Conservation Properties of a Time FE Method. Part II: Time-Stepping Schemes for Nonlinear Elastodynamics”, *Int. J. Numer. Meth. Engrg.*, Vol. 50, pp. 1931-1955.
[2] Gonzalez, O. (2000): “Exact Energy and Momentum Conserving Algorithms for General Models in Nonlinear Elasticity”, *Comput. Methods Appl. Mech. Engrg.*, Vol. 190, pp. 1763-1783.
[3] Gross, M. (2004): “Conserving Time Integrators for Nonlinear Elastodynamics”, *UKL/LTM T 04-01*, University of Kaiserslautern.

[4] Lee, E.H. (1969): "Elastic-Plastic Deformation at Finite Strains", *Journal of Applied Mechanics*, Vol. 36, pp. 1-6.
[5] Simo, J.C. (1992): "Algorithms for static and dynamic multiplicative plasticity that preserve the classical return mapping schemes of the infinitesimal theory", *Comput. Methods Appl. Mech. Engrg.*, Vol. 99, pp. 61-112.

16:20	Wirth	MA 001

State Dependent AIMD Algorithms And Consensus Problems

Fabian Wirth, Mehmet Akar, Robert Shorten, Hamilton Institute, National University of Ireland Maynooth, Ireland

Congestion control algorithms frequently employ an AIMD method (additive increase multiplicative decrease). The problem can be described as several users competing in a fair manner for the same resource and backing off, when the requests exceed availability. In the classical linear case, the dynamics of each individual source can be described by

$$x_i(k+1) = \beta_i x_i(k) + \frac{\alpha_i}{\sum \alpha_j} \sum_{j=1}^{n} (1-\beta_j) x_j(k)\,,$$

where $k = 0, 1, 2, \ldots$ enumerates the congestion events. In the linear case the dynamics of this problem is well understood even in a probabilistic setting and fairness and convergence results are known.

In the talk we discuss stability results for nonlinear extensions of AIMD algorithms as they are used in congestion control on high speed links. In these algorithms we consider update rules of the form

$$x_i(k+1) = \beta_i x(k) + T(x(k)) f_i(x_i(k))\,,$$

where $T(x(k)) > 0$ is implicitly defined through the constraint equation

$$\sum_{i=1}^{n} \beta_i x_i(k) + T(x(k)) f_i(x_i(k)) = 1\,.$$

Using generalized convexity arguments it can be shown for large classes of nonlinear algorithms, that a globally asymptotically stable fixed point exists. In the talk we will show, that the problem can be related to generalized consensus algorithms and discuss some fairness properties.

16:40	Solmaz	MA 001

General Inertia And Circle Criterion

Selim Solmaz, Oliver Mason, Robert Shorten, Hamilton Institute, National Univ. of Ireland-Maynooth, Ireland

In this paper we extend the well known Kalman-Yacubovic-Popov (KYP) lemma to the case of matrices with general regular inertia. We show that the version of the lemma that was derived for the case of pairs of stable matrices whose rank difference is one, extends to the more general case of matrices with regular inertia and in companion form. We then use this result to derive an easily verifiable spectral condition for a pair of matrices with same regular inertia to have a common Lyapunov solution (CLS), extending a recent result on CLS existence for pairs of Hurwitz matrices that can be considered as a time-domain interpretation of the famous circle criterion. We give numerical examples to show the efficacy of our results.

17:00	Balan	MA 001

A Mpc Algorithm Applied To Nonlinear Processes

Radu Balan, Vistrian Maties, Olimpiu Hancu, Sergiu-Dan Stan, Technical University of Cluj-Napoca, Romania

Model predictive control (MPC) is an optimization-based approach that has been successfully applied to a wide variety of control problems. When MPC is employed on nonlinear processes, the accuracy of the model has significant effect on the performance of the closed loop system. Hence, the capabilities of MPC will degrade as the operating level moves away from its original design level of operation. A solution to avoid these problems is multiple model adaptive control approach (MMAC) which uses a bank of models to capture the possible input-output behavior of processes. Other solutions include the use of a nonlinear analytical model, combinations of linear empirical models or some combination of both. This paper presents an MPC algorithm which uses on-line simulation and rule-based control. The basic idea is the on-line simulation of the future behaviour of control system, by using a few candidate control sequences and based on nonlinear equations of the analytical model. Finally, for every sample interval, the simulations are used to obtain the optimal control signal. These issues will be discussed and nonlinear modeling and control of two processes will be presented: a single-pass concentric-tube counter flow heat exchanger and the inverted pendulum on a cart.

17:20	Örtel	MA 001

Integrated Motional Measurement System For A Flexible Beam

Thorsten Örtel, Jörg Wagner, Universität Stuttgart

Integrated navigation systems based on gyros and accelerometers are well established devices for vehicle guidance. The system design is traditionally based on the assumption that the vehicle is a rigid body. However, generalizing such integrated systems to flexible structures is possible. The example of the motion of a simple beam being considered here is meant to be a first approach to obtain sophisticated motional measurements of a wing of a large airplane during flight.

The principle of integrated navigation systems consists of combining different measuring methods by using their specific advantages. Gyros and accelerometers are used to obtain reliable signals within a short period of time. On the other hand, aiding sensors like radar units and strain gauges are used because of their long-term accuracy. The kernel of the integrated system consists, however, of an extended Kalman filter that estimates the motion state of the structure. Besides the sensor signals, the basis for the filter is an additional kinematical model of the structure. By means of a model reduction, a kinematical model of the beam was developed.

Based on simulation the paper presents this approach, the appropriate sensor set, and first estimated motion results.

17:40	Siegmund	MA 001

Vortex Merger Is A Bifurcation In Time

Stefan Siegmund, Goethe-Universität Frankfurt

Nowadays huge amounts of observational and numerical data are available to reconstruct and predict the behavior of an underlying dynamical system, e.g. velocity fields in oceanography. However, the dynamics is typically non-stationary, i.e. time-varying and the available data is discrete in time and space and available only over a finite time interval. As a consequence the classical asymptotic methods of dynamical systems theory do not apply.

In this talk we present such an example namely the merging of two vortices modelled by the Poisson and Vorticity equation. Since the vortices merge after some time, the velocity field of the particles is not stationary, is not known analytically and is given only numerically as the solution of the PDE. The solution of the PDE gives rise to a time-dependent (nonautonomous) ODE which is discretized in time and space and is known only on a finite-time interval. This nonautonomous ODE undergoes a bifurcation as two vortices come close together and merge to one big vortex. However, classical methods do not apply, since the bifurcation does not depend on a parameter but on time. The description of this merging process as a bifurcation in time leads to a new aspect of time-dependent bifurcation theory, an actual topic of research.

Session 9
Thursday, March 30, 13:30 - 15:30

Room: MA 001

Vibration problems

Chair:

Kurt Schlacher

13:30	Wójcicki	MA 001

Parametric Vibration In Footbridges

Zbigniew Wójcicki, Jacek Grosel, Institute of Civil Engineering, Wrocław University of Technology, Poland

The possibility of exciting horizontal parametric resonance vibration in a cable stayed footbridge as a result of a premeditated action of a group of people, or of crowd movement, is analysed. Large horizontal transverse vibration are caused by the vertical periodic synchronised movement of people, which is analogical to the movements of a person on a swing. The question is how large a group of people is able to excite dangerous parametric transversal vibration in the system. To answer such a question, three simple theoretical models of bridge with people are put under consideration: the pendulum whose length is changing periodically, the opposite pendulum whose length is changing periodically and the elastic pendulum. It is assumed that the modal mass may swing in a plane like a pendulum and oscillate vertically at the same time. Finally, the length of the pendulum changes periodically. The swinging pendulum corresponds to the horizontal modal movement of the bridge's deck. The vertical oscillate of the pendulum corresponds to forced vertical vibration of the bridge's deck near the eigenfrequency for which eigenform is vertical. Solutions of these simple models, together with an energetic approach, give a good estimation of parametric resonant zones.

The authors want to distinguish if the situation is worse when the vertical eigenfrequency is equal to the horizontal eigenfrequency (flutter case) or when the vertical eigenfrequency is two times greater then the horizontal one (subharmonic parametric instability).

13:50	Stavroulakis	MA 001

Vibration Suppression Of Smart Beams Under Stochastic Loading

Georgios Stavroulakis, Department of Production Engineering and Management, Technical University of Crete, Greece

M. Betti, Department of Civil Engineering, University of Florence, Italy
C. C. Baniotopoulos, Department of Civil Engineering, Aristotle University, Greece

Due to the increasing requirements of high structures in modern building, active vibrations control is an actual scientific concern. As a matter of fact it is well know that strong wind could induce severe vibration on tall buildings and then discomfort to the occupants (and maybe also damage of sensitive equipments on the buildings). By piezoelectric material itis s possible to develop a self-adaptive structure, which could react to the environmental noise and minimize the effect of the applied disturbances. Typically a smart structure consists of a host structure incorporated with sensor and actuators that are coordinated by a controller.

Under the assumption that piezoelectric sensors and actuators are perfectly bonded to the host structures, we develop a Finite Element Model for a typical beam. Wind-type loads are taken into account. Herein the integration of control actions into the commercial finite element code ANSYS is realized. The results are compared with a model developed within MATLAB. The final aim of this paper is to provide a simplified but accurate description of the dynamic response of smart beams incorporating active piezoelectric elements.

14:10	**Sniady**	**MA 001**

Vibrations Of An Elastically Connected Double-string System

Pawel Sniady, Jaroslaw Rusin, Wrocław University of Technology, Poland

We consider vibrations of an elastically connected double-spring complex system subjected to moving concentrated forces. This system is treated as two strings connected by an elastic layer. The motion of the system is described by two partial differential equations. It is shown that some solutions of the system response can be obtained not only in the series but also in the closed forms.

1. Z. Oniszczuk, Transverse vibrations of elastically connected double-string complex system. Part II: forces vibrations, Journal of Sound Vibration, 2000, 232 (2), 367-386.
2. P. Sniady, Vibrations of girders under moving load, 1976, Pr. Nauk. Inst. Inz. Lad., Politechniki Wroclawskiej, (in polish).

14:30	**Majcher**	**MA 001**

Sensitivity Analysis Of Multi-storey Building Due To Blast Loading

Krzysztof Majcher, Wladyslaw Mironowicz, Zbigniew Wójcicki, Institute of Civil Engineering, Wroclaw University of Technology, Poland

In this paper the vibration problems of multi-storey column-slab buildings are considered. Vibrations are caused by the explosion in the building and destruction of some construction elements. The influence of sudden loss of these elements as well as the explosion pressure are taken into account. In particular, the influence of destruction location on the building vibrations is examined. Sensitivity analysis is carried out by means of the set of the solutions method.

14:50	**Takacs**	**MA 001**

Theoretical And Experimental Investigation Of Tyre Dynamics

Denes Takacs, Gabor Stepan, Budapest University of Technology and Economics, Hungary

The lateral vibration of towed wheels, called shimmy, is a well-known phenomenon in vehicle system dynamics. This lateral vibration may be related to the elasticity of the suspension system or to the elasticity of the wheel. The second case is important since the majority of the vehicles have pneumatic tyres. The contact between the wheel and the ground can be characterised by means of a contact line, and the deformation of the tyre can be modelled by the lateral displacement of this contact region. We use a 1 degree-of-freedom model and consider rolling without sliding. Consequently, the kinematical constraint of rolling is given in the form of a partial differential equation (PDE), which can be transformed into a delay differential equation (DDE) with distributed time delay. The stability chart of the linear system is calculated. The shapes of the contact line are determined at different parameter points of the stability chart. To verify these results, an experimental device was built that is able to demonstrate shimmy. One of the stability boundaries is identified on the experimental rig, and quasi-periodic vibrations are observed close to a double Hopf bifurcation point of the chart.

Session 10
Thursday, March 30, 16:00 - 18:00

Room: MA 001

Modeling

Chair:

Birgit Jacob

16:00	Hancu	MA 001

Modeling, Simulation And Control Of A Hydraulic Servo System

Olimpiu Hancu, Vistrian Maties, Radu Balan, Technical University of Cluj-Napoca, Romania

Hydraulic actuators are widely used in industrial applications due to several advantages like large force and torque, high power to weight ratio, rapid and accurate response. In this paper a nonlinear model of a hydraulic servo system is developed by means of the associated differential equations and then simulated using Matlab techniques. The model describes the behavior of a servo system FESTO TP511 with MOOG-DDV633 servovalve and includes the nonlinearities of friction forces, valve dynamics, oil compressibility and load influence. The nonlinear model is used to design an optimal controller based on estimated state parameters through simulation. A digital control platform based on Atmel ATmega8535 microcontroller is used to compare the behavior of hydraulic system under PD and optimal control. The control platform was designed like an interface between PC and process: the control algorithm runs on PC and the digital platform assures amplifying, filtering and data communication functions. Both simulation and experimental results are provided to show the effectiveness of the proposed model and control method.

16:20	Dhanu Singh	MA 001

Modeling Of Pneumatic Hybrid Actuator Using Exponential Approaches

Mahendra Dhanu Singh, K. Liem, Andres Kecskeméthy, Universität Duisburg-Essen
R. Neumann, Festo AG & Co. KG.

The present paper describes a mathematical model for the control of a hybrid actuator consisting of a fluidic muscle and a linear pressure spring which is inflated

by a proportional directional control valve in 3/3-way function. The device is applied for physical simulation of arbitrary force/displacement relationships.

The mathematical model of the system fluidic muscle/valve consists of the approximation of the pressure time-history by an exponential function. The coefficients of the exponential function are identified from corresponding measurement and Least Squares minimization. The advantages of this approximation are that the differential equation for the pressure becomes linear and the computations more efficient. This makes the approach suitable for model-based control. The paper shows that with the proposed model sufficient accuracy can be achieved such as to have a good mathematical model for feedback linearization. For later use the device can be employed in fields of biomechanics as well as in general environments such as motion simulations.

16:40	Ionescu	MA 001

A Geometric Modelling Of Nonlinear Rlc Networks

Delia Ionescu, Institute of Mathematics "Simion Stoilow" of the Romanian Academy, Romania

The aim of this paper is to give a formulation of the dynamics of nonlinear RLC circuits as a geometric Birkhoffian system and to discuss in this context the concepts of regularity, conservativeness, dissipativeness. An RLC circuit, with no assumptions placed on its topology, will be described by a family of Birkhoffian systems, parameterized by a finite number of real constants which correspond to initial values of certain state variables of the circuit. The configuration space and a special Pfaffian form, called Birkhoffian, are obtained from the constitutive relations of the involved resistors, inductors and capacitors and from Kirchhoff's laws. Under some assumptions which will be made on the voltage-current characteristic for resistors, it is shown that, a Birkhoffian system associated to an RLC circuit is dissipative. For RLC networks which contain a number of pure capacitor loops or pure resistors loops the associated is never regular. A procedure by means of which the original configuration space can be reduced to a lower dimensional one, thereby regularizing the Birkhoffian, it is also presented. In order to illustrate all these, specific examples are discussed in detail.

17:00	Poppe	MA 001

The Immune Response As An Optimal Control Problem With Time-delays

Lisa Poppe, TU Berlin

The treatment of a pathogenic disease process can be modeled as an optimal control problem with time-delays in several state variables. The resulting system describes the innate immune response and consists of both ordinary differential equations and delay differential equations, where the delay is constant but disease specific. In this talk the numerical treatment and optimal solutions are discussed.

17:20	Strömgren	MA 001

Semidiscretization Of A Pdae System Modelling A Heat Exchanger

Magnus Strömgren, Michael Hanke, Royal Institute of Technology, Sweden

We consider the model of a heat exchanger as a component in a heat pump system. From the Euler equations of compressible fluid flow our model is derived by eliminating the fast time scales associated with the sound speed. The resulting degenerate hyperbolic system turns out to be a PDAE. Taken together with the state equations for the refridgerant in consideration (CO2) this model presents a mathematical and numerical challenge.

Previously, we have analysed the well-posedness of a linearised version of the PDAE system. The perturbation index of the system turned out to be 2 w.r.t space and 1 and 2, respectively, w.r.t time depending on whether friction was included in the model or not.

In this talk we present new results concerning the stability- and index properties of the DAE that results from a semidiscretization of the PDAE system. Several different discretisations are considered. In each case we present convergence analysis for the linearised equations and make numerical experiments with the full nonlinear system to verify the relevance of this analysis.

17:40	Antritter	MA 001

Trajectory Design Using Differential Parameterizations

Felix Antritter, Joachim Deutscher, Lehrstuhl für Regelungstechnik, Universität Erlangen-Nürnberg

Considered is an underactuated ship model which is not static input-output decouplable with respect to the control output. By dynamic extension a well defined relative degree can be achieved when the feedforward velocity is non-zero. However, for zero forward velocity the state transformation into input-output normal form becomes non-invertible and also the decoupling matrix becomes singular. Thus, inversion based methods as well as other methods for the feedforward controller design that rely on the existence of an input-output normal form cannot be used to design trajectories that include such points.

In this contribution a differential parameterization of the ship with the non-flat control output is derived, which establishes a Lie-Baecklund equivalence to a system in input-output normal form. Also the differential parameterization of the ship exhibits a singularity when the forward velocity is zero. However, a reparameterization of one of the two components of the output in terms of the other allows to evade the singularity and thus the design of trajectories that steer the ship away from a rest position becomes possible. The solution to this trajectory tracking problem is strongly motivated by the transfer of methods that are used for differential parameterizations of flat systems to the differential parameterization of non-flat systems.

21 Mathematical image processing

Organizers:

Joachim Weickert, Universität des Saarlandes
Martin Hanke-Bourgeois, Johannes Gutenberg-Universität

Session 1
Wednesday, March 29, 13:30 - 15:30

Room: MA 042

Differential Equations and Variational Models I

Chair:

Joachim Weickert

13:30	Steidl	MA 042

Higher Order Total Variation Regularization

Gabriele Steidl, Universität Mannheim
S. Didas, Universität des Saarlandes

We study higher order TV regularization in one and two dimensions. In the one-dimensional discrete setting, we show a relation between higher order TV regularization and support vector regression with spline kernels. In 2D, we generalize the dual approach of Chambolle et al. to higher order derivatives which prevents staircasing effects. Finally, we apply higher order TV functionals in the context of simultaneous estimation and decomposition of optical flows.

14:10	Acker	MA 042

Pde Based Visualization Of Nonstationary Flows

Jens Friedrich Acker, Universität Dortmund

An advanced method for visualizing nonstationary flows will be presented, which is based on directed diffusion and transport of noise textures.

The direction is given by a precalculated nonstationary flow field which is interpolated in time and used inside of a PDE formulation of an anisotropic diffusion-transport problem, which is solved by FEM/multigrid methods. The solutions of this problem form a feature scale space towards coarser features in time. By the use of a blending strategy, solutions at different feature scales are used to stabilize the final output around a fixed feature scale.

14:30	Frick	MA 042

Inverse Scale Space Methods For Surface Denoising

Klaus Frick, Otmar Scherzer, Universität Innsbruck

Iterative regularization procedures using Bregman distances have turned out to provide a useful approach for tasks in imaging, such as denoising or deblurring. In combination with total variation regularization this method inverts the fundamental axiom of fidelity, i.e. the iterated solutions converge to the original (noisy) image as times goes to infinity. We present a similar technique for surface denoising within the framework of level set methods, where we replace the L^2 fit-to-data term by a novel distance measure, that incorporates the deviation of level sets.

14:50	Nemitz	MA 042

Structure Enhancing Smoothing Of 3d Mr Angiography Data

Oliver Nemitz, Martin Rumpf, Tolga Tasdizen, Ross Whitaker, Institut für Numerische Simulation, Universität Bonn

We propose a novel concept of shape prior for the segmentation and fairing of tubular structures based on the notion of anisotropic area energy and the corresponding geometric gradient flow, where energetically elongated ellipsoidal shapes aligned to the tubular structures are preferred. The problem is formulated in a level set framework, and a stable and robust method for the identification of the local prior is presented. The resulting algorithm is able to smooth the vessels, ensure a round cross section and in particular bridge gaps in the underlying raw data. A narrow band strategy ensures efficiency of the method.

15:10	Burgeth	MA 042

Nonlinear And Singular Pdes For The Processing Of Tensor Fields

Bernhard Burgeth, Joachim Weickert, Mathematik und Informatik, Universität des Saarlandes
Michael Breuß, Mathematik und Informatik, TU Braunschweig

Matrix-valued data sets or functions, referred to as tensor fields, are used, for instance, in civil engineering to describe anisotropic behavior of physical quantities. Stress and diffusion tensors are prominent examples. The output of diffusion tensor magnetic resonance imaging (DT-MRI) are 3×3-tensor fields as well. In medical sciences this image acquisition technique has become an indispensable diagnostic tool.

Evidently there is an increasing demand to develop image processing tools for the filtering and analysis of these matrix-valued functions.

In the standard case of scalar-valued images u the nonlinear parabolic partial differential equations

$$u_t = \pm \|\nabla u\|^p$$

and

$$u_t = \operatorname{div}\left(\frac{\nabla u}{\|\nabla u\|^q}\right)$$

are used to perform filtering and denoising processes. By means of the first equation one accomplishes the fundamental morphological operations of dilation (+) or erosion (-) with flat ($p = 1$) or quadratic ($p = 2$) structuring functions. The second, singular equation describes total variation ($q = 1$) or balanced-forward-backward ($q = 2$) diffusion as an image filtering process.

In this talk we will propose the matrix-valued counterparts of the equations above and demonstrate their usefulness in processing tensor fields. We will present numerical schemes that can be used to solve these equations successfully in the matrix-valued setting. Numerical experiments on both synthetic and real world data substantiate the effectiveness of our matrix-valued, nonlinear diffusion filters.

Session 2
Wednesday, March 29, 16:00 - 18:00

Room: MA 042

Inverse Problems

Chair:

Martin Hanke-Bourgeois

16:00	Kirsch	MA 042

Inverse Scattering Problems For Maxwell's Equations

Andreas Kirsch, Universität Karlsruhe

In this talk we study time-harmonic electromagnetic scattering problems. After a short repetition of known results for the direct and inverse problems we present the factorization method to determine the support of the contrast of the permittivity or permeability from the far field operator.

16:40	Bredies	MA 042

An Optimal Control Problem In Image Processing

Kristian Bredies, Dirk A. Lorenz, Peter Maass, Universität Bremen

As a starting point of this talk we present a control problem in mammographic image processing which leads to non-standard penalty terms and involves a degenerate parabolic PDE which has to be controlled in the coefficients.

We then discuss the equivalence of methods for solving minimization problems, namely the classical conditional gradient method from constrained optimization and the surrogate method from linear inverse problems. The surrogate method was recently proposed by Daubechies, Defrise and De Mol for solving linear inverse problems where the solution is known to have a sparse representation in a certain basis. Particularly, it is suitable for non-quadratic penalty terms.

We propose a generalization of the conditional gradient method for non-convex functionals which covers the conditional gradient method as well as the surrogate method. We prove that this new algorithm converges in norm. This also gives a deeper understanding of the method of surrogate functionals.

Further we show an application to the above mentioned control problem in image processing.

17:00	Gebauer	MA 042

Detecting Objects By Low-frequency Electromagnetic Imaging

Bastian Gebauer, Joh. Gutenberg-Universität Mainz

We consider the problem of detecting magnetic objects by electromagnetic imaging, i. e. by applying time-harmonic surface currents on an electric device and measuring the backscattered electromagnetic field. At low frequencies the propagation of the electromagnetic waves becomes diffusive. We will show that in this case the measurements can be considered as a good approximation to measuring magnetostatic fields induced by steady currents.

Mathematically this means that the time-harmonic Maxwell's equations can be replaced by the elliptic curl-curl equation. Using a version of the Factorization Method that holds for general elliptic problems we show that the location of the magnetic objects is uniquely determined by the measurements. The method also yields a non-iterative reconstruction algorithm that does not rely on numerically solving the underlying partial differential equations. We also show some numerical results for this algorithm.

17:20	Griesmaier	MA 042

Identification Of Small Inhomogeneities: Asymptotic Factorization

Roland Griesmaier, Habib Ammari, Martin Hanke, Institut für Mathematik, Johannes Gutenberg-Universität Mainz

We consider the boundary value problem of calculating the electrostatic potential for a homogeneous conductor containing finitely many small insulating inclusions. We give a new proof of the asymptotic expansion of the electrostatic potential in terms of the background potential, the location of the inhomogeneities and their geometry, as the size of the inhomogeneities tends to zero. Such asymptotic expansions have already been used to design direct (i.e. non-iterative) reconstruction algorithms for the determination of the location of the small inclusions from electrostatic measurements on the boundary, e.g. MUSIC-type methods. Our derivation of the asymptotic formulas is based on integral equation methods. It demonstrates the strong relation between factorization methods and MUSIC-type methods for the solution of this inverse problem.

17:40	Schuster	MA 042

Can Projection Methods Be Useful For Detecting Optical Flow?

Thomas Schuster, Joachim Weickert, Universität des Saarlandes

Detecting the optical flow field means to determine the displacement field from an image sequence. Assuming that the brightness of the image is constant leads to the optical constraint equation which is the starting point to formulate the problem as a minimization problem for a functional, which consists of a data and smoothness term. The latter one is to guarantee solvability of the problem and filling-in phenomena. In the talk we present the idea to solve this optimization problem applying projection methods. That means we omit the smoothness term and minimize an appropriate functional in a finite-dimensional subspace. The application of piecewise linear splines is presented in this context. The talk is to be understood as an issue of discussion whether such methods might be suited for optical flow problems or not.

Session 3
Thursday, March 30, 13:30 - 15:30

Room: MA 042

Correspondence Problems

Chair:

Bernd Kawohl

13:30	**Modersitzki**	**MA 042**

Mathematical Methods For Image Registration

Jan Modersitzki, Universität Lübeck
Eldad Haber, Emory University, USA

The importance of mathematical image processing in state-of-the-art life sciences is rapidly increasing. An excellent example is medical imaging with techniques like computer tomography (CT), magnetic resonance imaging, positron emission tomography (PET), to name a few. A central problem in image processing is the so-called registration, also called fusion, matching, or warping. Registration means to align given images taken from different objects, times, devices, and/or perspectives in order to provide a point to point correspondence of displayed items. We show some examples explaining the relevance and versatility of the problem.

In contrast to the huge variety of different applications and specialized techniques used to address the problem, we present a flexible but unified approach to registration. We show that our problem is ill-posed and explain some typical regularization strategies. Moreover, we comment on approaches to add a priori knowledge and to reduce the uncertainty in regularization.

Our model leads to large scaled constrained optimization problem, where the number of unknowns and the number of constraints might be of order 10^7. Since standard optimization schemes can not be used, we also comment on our numerical approach.

14:10	**Berkels**	**MA 042**

Symmetric Ambrosio-tortorelli Based Registration

Benjamin Berkels, Martin Rumpf, Institut für Numerische Simulation, Universität Bonn
Jingfeng Han, Joachim Hornegger, Institut für Mustererkennung, Universität Erlangen-Nürnberg

We propose a new symmetrical framework that allows to solve image denoising, edge detection and non-rigid image registration simultaneously. It is based on the Ambrosio–Tortorelli approximation of the Mumford–Shah model. This approximation is extended to solve the registration symmetrically, i.e. permutation of the input images does not change the results. The minimization of an energy leads to a decomposition of the image into a piecewise–smooth representative, which is the denoised intensity function, and the phase field that approximates the edge-set. The minimization also provides an edge based registration of two images by aligning the phase field of one image to the gradient image of the other image. The non–rigid transformations are estimated simultaneously in two directions, while one consistency energy term constrains the transformations to be inverse to each other. The optimization is done with Finite Elements and a regularized gradient flow in an EM type manner. A multi-scale implementation scheme is applied to improve the results. We have performed preliminary medical evaluation in 2D and 3D on T1 and T2 MRI data, where the experiments show encouraging results.

14:30	**Olischlaeger**	**MA 042**

An Image Processing Approach To Surface Matching

Nadine Olischlaeger, Marc Droske, Nathan Litke, Martin Rumpf, Institut für Numerische Simulation, Universität Bonn

Establishing a correspondence between two surfaces is a basic ingredient in many geometry processing applications. Existing approaches, which attempt to match two embedded meshes directly, can be cumbersome to implement and it is often hard to produce accurate results in reasonable time. In this paper, we present a new variational method for matching surfaces that addresses these issues. Instead of matching two surfaces via a non-rigid deformation directly in $\mathbb{R}^3$, we apply well established matching methods from *image processing* in the parameter domains of the surfaces. A matching energy is introduced which may depend on curvature, feature demarcations or surface textures, and a regularization energy controls length and area changes in the induced deformation between the two surfaces. The metric on both surfaces is properly incorporated into the formulation of the energy. This approach reduces all computations to the 2D setting while accounting for the original geometries. Consequently a fast multiresolution numerical algorithm for regular image grids can be applied to solve the global optimization problem. The final algorithm is robust, generically much simpler than direct matching methods, and computationally very fast for highly resolved triangle meshes.

14:50	**Ruhnau**	**MA 042**

Optical Stokes Flow

Paul Ruhnau, Christoph Schnörr, Mannheim Universität

We present an approach to particle image velocimetry based on optical flow estimation subject to physical constraints. Admissible flow fields are restricted to vector fields satifying the Stokes equation. The latter equation includes control variables that allow to control the optical flow so as to fit to the apparent velocities of particles in a given image sequence. We show that when the real unknown flow observed through image measurements conforms to the physical assumption underlying the Stokes equation, the control variables allow for a physical interpretation in terms of pressure distribution and forces acting on the fluid. Although this physical interpretation is lost if the assumptions do not hold, our approach still allows for reliably estimating more general and highly non-rigid flows from image sequences.

15:10	Köstler	MA 042

Including Landmark Based Information In Optical Flow Problems

Harald Köstler, Ulrich Rüde, Universität Erlangen-Nürnberg

Optical flow and the related non-rigid image registration both lead to a variational minimization problem that requires robust and efficient numerical solvers due to the often non-smooth input data and the large number of unknowns in real applications.

We have implemented a flexible framework that can handle the usual data terms and various regularizers, e.g. isotropic and anisotropic diffusion based or elastic regularizers. In addition to that it is possible to specify the solution at certain points using e.g. information from manually set landmarks or automatically detected features. In the presence of such singular points, called small islands in the literature, the multigrid convergence rate can deteriorate dramatically.

In our talk we focus on methods to restore the usual efficiency of a standard multigrid solver. We enhance our solver by using Galerkin coarsening, block- or linewise smoothers and iterant recombination. When applying these techniques one can observe the usual good convergence rates even in the case of non-smooth input data.

Our results consist of the optical flow for 2D image sequences and the image registration of 3D medical data sets.

Session 4
Thursday, March 30, 16:00 - 18:00

Room: MA 042

Differential Equations and Variational Models II

Chair:

Jan Modersitzki

16:00	Kawohl	MA 042

Mumford-shah Vs Perona-malik: An Analytic View At Image Processing

Bernd Kawohl, Mathematisches Institut, Universität zu Köln

In my lecture I shall try to demonstrate that variational approaches to image processing and PDE-approaches via backward-forward diffusion have many things in common. In fact, once these approaches are discretized they virtually coincide.

16:40	Boiger	MA 042

An Efficient Local Morphological Scheme For The Amss

Wolfgang Boiger, Folkmar Bornemann, TU München

The affine morphological scale space (AMSS) is the unique nonlinear scale space satisfying invariance properties including affine invariance (Alvarez et al., 1993). As shown by Guichard, Morel and others, it can successfully be used to denoise images with salt & pepper noise. We present an efficient local morphological scheme for the AMSS, which is based on an idea of Lionel Moisan for binary images. The proof of convergence is outlined and numerical experiments are shown.

17:00	Breuß	MA 042

Discretisation Of Stabilised Inverse Diffusion Equations

Michael Breuß, Institut Computational Mathematics, TU Braunschweig

We consider consistent and conservative approximations of stabilised inverse diffusion processes. It is shown that a minmod-type stabilisation is a necessary feature of such schemes. It is also shown, that the so-called staircasing, or terracing, artefacts are usual incidents in numerical approximations. Moreover, it can be shown that this property is independent of the choice of grid parameters. Numerical tests complement the stated theoretical results.

17:20	**Welk**	**MA 042**

Dynamical Systems In The Modelling Of Space-discrete Image Filters

Martin Welk, Joachim Weickert, Irena Galić, Universität des Saarlandes
Gabriele Steidl, Universität Mannheim

Image filters based on partial differential equations (PDEs) are a versatile tool in digital image processing. Some particularly interesting filters, however, rely on PDEs with singularities which pose obstacles to their analysis and numerical implementation.

Spatial discretisations of these filters can be modelled as dynamical systems of ordinary differential equations. In this setting, singularities are easier to control, allowing the derivation of important well-posedness results. In some cases, even analytical solutions of the dynamical systems can be stated which give rise to novel numerical methods for the underlying PDE-based image filters.

In this talk, results on singular diffusion processes and shock filters will be reported.

22 Theoretical studies and engineering applications of vortical flows

Organizers:

Egon Krause, RWTH Aachen

Session 1
Tuesday, March 28, 09:30 - 12:00

Room: H 2032

Vortices in atmospheric and geophysical flows

Chair:

Egon Krause
Lu Ting

09:30	Klein	H 2032

Three-layer Structure Of Gradient Wind Vortices In The Atmosphere

Rupert Klein, Eileen Mikusky, Potsdam Institut für Klimafolgenforschung
Anthony Owinoh, Mathematik & Informatik, FU Berlin

Hurricanes and strong mid-latitude storms, such as "Lothar", are representatives of the so-called gradient wind regime. In this regime, the inertial, Coriolis, and pressure gradient forces dominate the horizontal momentum balance. A systematic multiple scales/matched asymptotic analysis for such vortices reveals a three-layer structure:

The outermost layer covers the entire depth of the troposphere. Here, the leading order flow is axisymmetric and purely circumferential. Matching of the vortex core structure to the geostrophic wind in the vicinity of the vortex yields both the overall vortex motion and the (order one) vertical tilt of the vortex axis.

The second layer near the surface features leading order radial flows. High-speed horizontal motion towards the vortex center occurs and provides the massflux needed to maintain the strong upward flow observed in the vortex core throughout the tropospheric layer.

The diabatic heat deposition througout the tropospheric layer is an external input for the abovementioned two-layer structure. Current work suggests that hot, unstable plumes from an even thinner surface layer provide for diabatic heating via latent heat release.

10:00	Buhler	H 2032

Interactions Between Waves And Vortices

Oliver Buhler, Courant Institute of Mathematical Sciences, New York University, U.S.A.

Recent theoretical, numerical, and experimental topics will be presented concerning the interactions between waves (such as surface waves or internal gravity waves) and vortices in two and three dimensions.

These nonlinear wave-mean interactions are known to be important in fields such as, for instance, atmosphere ocean dynamics and in offshore or coastal engineering. Furthermore, the waves in question are typically too small to be resolved in numerical models, and hence the faithful modelling of the nonlinear wave-mean interactions is an important sub-grid scale problem.

Examples discussed in this talk include the nonlinear interactions between vortices and waves caused by refraction and wave breaking, and the generation of waves and vortices by fluid-structure interactions in the field of bio-locomotion.

11:00	Tanabe	H 2032

Laboratory Experiments On Vortices Colliding With Multiple Islands

Aya Tanabe, Department of Mathematics, Imperial College London, United Kingdom
Claudia Cenedese, Department of Physical Oceanography, Woods Hole Oceanographic Institution, U.S.A.

The present study investigates in the laboratory the behaviour of a self-propagating cyclonic vortex colliding with aligned circular cylinders representing an island chain. For non-dimensional geometrical parameters corresponding to the "real" ocean, the flow within the vortex was "funnelled" between two cylinders at one of the passages and a dipole formed, much like water ejected from a circular nozzle generates a dipole ring. After the dipole formed, the cyclonic part of the dipole became dominant. Depending on the configurations of the obstacles and the initial vortex position, a relatively large offspring was produced either directly from the cyclonic part of the dipole, or from the "remnant" of the original vortex at the gap positioned just "South" of the gap where the dipole formed. The vortex centre, radius and circulation (before and after the interaction) were computed from the velocity field. It was found that intense vortices experienced greater amplitude loss than weak vortices, and the number of offspring was one in general, independently of the length of the obstacles. These experimental results may explain recent oceanic observations of North Brazil Current (NBC) rings interacting with the Lesser Antilles in the Eastern Caribbean Sea.

11:30	**Shokina**	**H 2032**

Numerical Simulation Of Stationary Flows In Rivers With Islands

Nina Shokina, Höchstleistungsrechenzentrum Stuttgart (HLRS)

The present work continues the investigations [1]-[2] in the field of numerical modelling of stationary fluid flows with surface gravitational waves in multiply-connected domains in the framework of the plane shallow water model.

The difference equations are obtained by the integro-interpolational method. The system of 9-point second order difference equations for the stream function is solved by the successive over-relaxation method. The approximation for the vorticity function leads to the upwind first order scheme with a variable stencil.

In [1] and [2] the economic direct method has been used for calculating the vorticity function under the conditions: 1) no rest points; 2) no closed stream lines. Now the alternating triangular iterative method is developed under the first condition only. The difference problem is solved by the relaxation method using the implicit scheme. The stabilizing operator is approximately factorized, and the difference scheme is realized by the method of fractional steps.

The numerical results for the flow around the island are presented.

[1] Khakimzyanov G.S., Shokina N.Yu. (1997) Rus J Numer Anal Math Model 12(4):335-348
[2] Khakimzyanov G.S., Shokina N.Yu. (2003) Comput Technol 8(2):102-111
[3] Khakimzyanov G.S., Shokina N.Yu. (1999) Rus J Numer Anal Math Model 14(4):339-358

Session 2
Tuesday, March 28, 13:30 - 15:30

Room: MA 313

Vortices in complex flows

Chair:

Lu Ting
Egon Krause

13:30	Shashikanth	MA 313

Dynamics And Control Of A Moving Cylinder And Point Vortices

Banavara Shashikanth, Department of Mechanical Engineering, New Mexico State University, U.S.A.

A Hamiltonian system of a 2-D rigid circular cylinder dynamically interacting with N point vortices external to it is considered. This dynamic model is an idealized example of coupled fluid-solid systems interacting in the presence of vorticity and has applications to problems in engineering, such as locomotion of autonomous underwater vehicles, and in nature,such as swimming of fish. The Hamiltonian structure, symmetries and the dynamics for the cases N=1 and N=2 will be briefly discussed. In addition, the application of time-optimal control theory, in particular Pontryagin's maximum principle, will also be discussed.

14:00	Ishii	MA 313

Numerical Analysis Of 3d Vortical Cavity Flow

Katsuya Ishii, Shizuko Adachi, Information Technology Center, Nagoya University, Japan

The stability properties of the vortical flow of an incompressible fluid in a rectangular three-dimensional container with a large spanwise aspect ratio driven by a moving solid lid are studied using a combined compact finite difference (CCD) scheme with high accuracy and high resolution. In particular, the change of the flow structures in the cavity with Reynolds numbers is focused before a time-periodic flow. The results of the flow in the cavity with a spanwise aspect ratio 6.5 show that the basic flow of a lid-driven cavity with a primary eddy and secondary eddies are observed near the side wall at Re<850. However, while a closed stable streamline is found near the side wall at Re<400, two stable closed streamlines localized near the symmetric plane are found at Re=700. The change of the

flow pattern present in this system affects the diffusion properties in the flow but seems to have no qualitative effect on the global flow properties which includes energy dissipation in the cavity.

14:30	Crespo Del Arco	MA 313

Pattern Dynamics In Rotating Rbc With Realistic Boundary Condition

Emilia Crespo Del Arco, José Joaquín Sánchez-Álvarez, Departamento de Física Fundamental, Facultad de Ciencias UNED, Spain
Eric Serre, Universites d'Aix-Marseille I, II & III, France
Friedrich Busse, Institut für Physik, Universität Bayreuth

The Küppers-Lortz instability occurs in rotating Rayleigh-Bénard convection and is a paradigmatic example of spatiotemporal chaos. Since the steady state of convection rolls is unstable to disturbance rolls oriented with an angle of about 60 degrees with respect to the given rolls in the prograde direction [G. Küppers and D. Lortz, J. Fluid Mech. 35, 609 (1969)], a spatio-temporally chaotic pattern is realized with patches of rolls continuously replaced by other patches in which the roll axis is switched by about 60 degrees. Surprisingly and contrary to this established scenario, [K. M. S. Bajaj, J. Liu, B. Naberhuis, and G. Ahlers, Phys. Rev. Lett. 81 (1998)] observed experimentally square patterns in a cylindrical layer in the range of parameters where Küppers-Lortz instability was expected. In this work we present square patterns which we have obtained in a numerical study by taking into account realistic boundary conditions. The Navier-Stokes and heat transport equations have been solved in the Oberbeck-Boussinesq approximation. The numerical method is pseudo-spectral and second order accurate in time. In the results of the numerical computations the rotation velocity of the square pattern increases linearly with the control parameter $\varepsilon = (Ra - Ra_c)/Ra_c$, as in the experiment of Bajaj et al. Furthermore, it was observed that this velocity decreases when the aspect ratio of the cylinder increases. These results indicate that the square pattern appears when the flow is laterally confined. The range of ε for which this pattern is stable tends to vanish for more extended layers.

15:00	Recktenwald	MA 313

Turbulent Channel Flow Rotating About The Streamwise Axis

Ingo Recktenwald, Wolfgang Schröder, Aerodynamisches Institut, RWTH Aachen

Simulation of rotating turbulent flows is a major issue in computational fluid dynamics (CFD) today. Some research has been done concerning channel flows with a vertical rotation axis perpendicular to the main flow direction. However, only in the recent past investigations have been done on channel flows with a rotation about the streamwise axis. In analyses of this type of flow based on Lie-group theory and DNS it was found that a secondary flow perpendicular to the main flow direction is generated. Furthermore, the main profile experiences a pronounced distortion compared to a non-rotating flow.

To validate the numerical findings, a fully developed turbulent channel flow was investigated experimentally by the use of stereoscopic particle-image velocimetry (PIV). To examine the development of the velocity distribution a test rig was set up at the Institute of Aerodynamics and measurements were performed at several rotational speeds at Reynolds number $Re_{bulk} = 2550$, calculated with the channel half-width and the bulk velocity. The results of the experiments confirm the development of a secondary flow, which has been found to be correlated to the rotational speed, and also show the distortion of the main flow velocity profile and the influence on the RMS-values.

Session 3
Tuesday, March 28, 16:00 - 18:00

Room: MA 313

Point and line vortices

Chair:

Patric Bontoux
Denis Blackmore

16:00	Knio	MA 313

Recurrent Motions For Perturbed Three Point Vortex Dynamics

Omar Knio, Denis Blackmore, Lu Ting, Department of Mechanical Engineering, The Johns Hopkins University, U.S.A.

Much research, beginning with the definitive work of Synge 1949, in which he derived the motion invariants, has produced a thorough description of the dynamics of three point vortices (3PV) in an ideal fluid in the plane. The results can be concisely formulated in terms of the complete integrability of the Hamiltonian governing equations. Recently, the authors and their collaborators have treated three point vortices in a half-plane and axisymmetric motion of three coaxial vortex rings (3CVR) in 3-space as nonintegrable perturbations of planar 3PV flows. They have obtained sufficient conditions on the initial vortex configurations for the existence of quasiperiodic and periodic orbits, but their results have been almost exclusively qualitative. We present more detailed characterizations of such recurrence behavior for 3PV in the half-plane and 3CVR in 3-space. This is accomplished - for all vortex strengths - by finding properties that guarantee that the invariants of the unperturbed system remain within prescribed regions for solutions of the perturbed systems. For example, the perturbation term in the half-plane case is analyzed so as to locate closed orbits and estimate their periods under certain initial conditions. Numerical simulations are provided for further insights into the nature of the dynamics.

16:30	Lim	MA 313

Vortex Line Statistics - New Results By Path-integral Monte Carlo

Chjan Lim, Mathematical Sciences, Rensselaer Polytechnic Institute, U.S.A.

Ensembles of vortex lines have been found in rotating superfluid He 4, high temperature superconductors and more recently in Bose-Einstein condensates in magnetic traps, where they appear as quantized line defects.

It is well known in the new vortex matter community, that at lower temperatures, the vortex line ensemble form a crystalline solid and has an elastic modulus associated with its 2D cross-sectional lattice structure. At high temperatures $T >> 1$, this vortex lattice melts and Monte-Carlo simulations of Andersen and Lim show that it then behave like a vortex liquid of hard disks of radius $r(T)$ (non-interacting except for the non-overlap condition).

In this talk, I will derive a second modulus of elasticity E for the vortex line ensemble at high temperatures. Unlike the first elastic modulus of the vortex lattice which is energetic in nature (calculated on the basis of minimizing the internal energy), the second modulus of elasticity is entropic in nature. Numerical evidence of my theoretical prediction of a second (entropic) elastic modulus for vortex lines is found in the incompressibility of the vortex lines statistics.

17:00	Mamaev	MA 313

Dynamics Of Vortex Sources In An Ideal Fluid

Ivan Mamaev, Institute of Computer Science, Russia

The problem of motion of vortex sources on a plane is considered. Set by A. Fridman and P. Polubarinova-Kochina, this problem is of considerable interest in meteorology and oceanology. Cases of integrability are indicated and qualitative analysis of them is performed. Generalization of the motion of a vortex source on a two-dimensional sphere is performed. Also the issue of the presentation in Hamiltonian form of equations of motion is discussed.

Session 4
Wednesday, March 29, 13:30 - 15:30

Room: MA 313

Dynamics of vortex structures and filaments

Chair:

Denis Blackmore
Patrick Bontoux

13:30	**Borisov**	**MA 313**

Dynamics Of A Rigid Body And Vortex Structures In An Ideal Fluid

Alexey Borisov, Institute of Computer Science, Russia

We consider the issues of interaction of a rigid body and point vortices moving in an unbounded volume of an ideal incompressible fluid. The case of motion of a circular cylinder and a point vortex is analysed qualitatively and shown to be integrable. Nonintegrability of the system of interacting arbitrary rigid body (particularly, of elliptic form) and a point vortex is indicated. Also, the case of the plane-parallel motion is considered.

14:00	**Kevlahan**	**MA 313**

Stochastic Lagrangian Dns Of Vortex Reconnection

Nicholas Kevlahan, Department of Mathematics & Statistics, McMaster University, Canada

We describe a numerical method for calculating vortex merging in two dimensions and vortex reconnection in three dimensions based on a stochastic Lagrangian representation of the 3D Navier-Stokes equations proposed by Constantin & Iyer (2005). Our approach is a direct numerical simulation (DNS) of the exact stochastic representation of the Navier-Stokes equations, in contrast to conventional vortex methods which are Lagrangian models of the deterministic vorticity equation. We will compare the stability and accuracy of this method with the usual Eulerian DNS and with conventional vortex methods. We are particularly interested in the properties of this DNS in the limit of large Reynolds numbers.

14:30	**Prykarpatsky**	**MA 313**

Some Aspects Of Chern-simons Type Vorticity Solutions

Yarema Prykarpatsky, Anatoliy Prykarpatsky, Institute of Mathematics at NASU, Ukraine

The 2-D Josephson type media are supposed to be equivalently modelled by means of Chern-Simons-Higgs geometric Lagrangian functionals. It is shown that the corresponding Chern-Simons-Higgs model possesses of special structure singular geometric objects which can be interpreted as vortices of the Josephson medium. An N-vortex configuration studied in the frame of adiabatic approximation, revealed its particle-like Hamiltonian structure. The two-vortex configuration is investigated in detail, their motion is discussed making use of only analytical tools. Some special solutions are singled out as limiting cases.

15:00	Accary	MA 313

Simulation Of Transitional Convection In Near-critical Fluids

Gilbert Accary, Isabelle Raspo, Patrick Bontoux, IMT - Technopole de Chateau-Gombert, France

When approaching the gas-liquid critical point, several properties of a fluid exhibit strong anomalies. Particularly, the thermal diffusivity vanishes and the compressibility tends to infinity. This leads to the puzzling heat transfer mechanism of the piston effect responsible for the fast temperature equilibrium in supercritical fluids under zero gravity. We consider a supercritical fluid in the Rayleigh-Bénard configuration. This configuration is an interesting system to study hydrodynamic stability because of the existence of two convection-onset criteria which, for a normally compressible fluid, are separately relevant at very different space scales: the Rayleigh criterion in which the compressibility of a fluid is neglected (valid at small and intermediate space scales), and the Schwarzschild criterion which usually plays at large atmospheric scales where the effect of the hydrostatic pressure is prominent. Direct numerical simulations are carried out using a finite volume method. Violent instabilities are triggered by very weak heating due to the strange properties of these fluids and the flow becomes turbulent for very unusual heating intensity (mK) and cavity size (cm). Nevertheless as the heating decreases, convection is damped-out due to the competition between the two convection-onset criteria and a reverse transition to stability is obtained without any external intervention.

Session 5
Wednesday, March 29, 16:00 - 18:00

Room: MA 313

Aerodynamic applications

Chair:

Wolfgang Schröder
Rupert Klein

16:00	**Dietz**	**MA 313**

HELICOPTER TIP VORTEX CONSERVATION BY VORTEX-ADAPTED CHIMERA GRIDS

Markus Dietz, Siegfried Wagner, Ewald Krämer, Institut für Aerodynamik und Gasdynamik, Universität Stuttgart

The tip vortices of the rotor blades influence remarkably not only the aerodynamics of a helicopter rotor but have also a severe impact on the aeroelastic and aeroacoustic behavior of the rotor. To minimize truncation errors in numerical schemes, thus reducing the numerically caused dissipation of the tip vortices, higher order schemes and/or finer grids would be necessary. Both measures would enormously increase the computational effort.

To improve the tip vortex conservation of a helicopter rotor in a CFD simulation a new idea is presented that uses vortex-adapted Chimera grids to achieve a local refinement of the grid and thus to reduce the numerical dissipation of the vortex.

The CFD calculation by FLOWer (DLR) is trimmed for thrust and longitudinal and lateral mast moment using weak fluid-structure coupling by the flight mechanics code HOST (Eurocopter). Based on the CFD loads HOST applies a correction on its aerodynamic loads and re-trims the rotor. This cycle is repeated until convergence has been reached. In case of convergence the simplified HOST aerodynamic model has been completely replaced by CFD aerodynamics.

The capabilities of vortex-adapted grids are evaluated by comparison of both the qualitative flow field and the azimuthal and radial blade loading with respect to the standard grid setup and a grid setup featuring a refined background grid.

16:30	**Ling**	**MA 313**

NUMERICAL STUDIES ON VORTICITY MODIFICATION IN WAKE-TYPE FLOW

Guocan Ling, Jiayu Niu, Institute of Mechanics, Chinese Academy of Sciences, China

Hongliang Zhao, Scientific Research Department, University of Science and Technology, China

The influence of spanwise disturbances on the vorticity distribution in wake-type shear flow was studied with DNS, based on a hybrid compact finite difference-spectral method. The incoming uniform flow profile was changed with a local exponential decay disturbance, a stepped variation in momentum defect, and a sinusoidal wavy disturbance with different wariness. The spatial-temporal evolution of the flow was computed mainly for Re=200. The results show that the local and stepped disturbances lead to a chain-like twisted and a periodic spot-like vortex dislocation, respectively, the latter exhibiting spanwise vortex splitting and reconnection. The waviness and the characteristic length of the incoming flow profile determine the development of the flow instability and the vorticity distribution. For higher waviness a strongly curved wavy spanwise vortex is generated first, associated with obliquely distributed streamwise and vertical vortex branches. With increasing time spanwise vortex shedding is completely suppressed in the near wake region. The flow presents a steady state with stronger vertical vorticity downstream. The influence of the characteristic length of the incoming flow on the vortex development yields similar results. The spatial variation of the vorticity clearly shows how vorticity diverts in the wake caused by the different spanwise disturbances.

17:00	Serre	MA 313

Spectral Vanishing Viscosity For Les Of Rotor-stator Flow

Eric Serre, Patrick Bontoux, Michael Schaefer, La Jetee Technopole de Chateau-Gombert
Eric Severac, La Jetee Technopole de Chateau-Gombert, France

Turbulent regimes in confined flow between a rotating and a stationary disk are studied using high-order numerical simulations. A pseudo-spectral algorithm is stabilized using a Spectral Vanishing Viscosity method (SVV). The SVV method first developed to solve non-linear hyperbolic equations, typically the Bürgers equation, exhibits the property of preserving the spectral accuracy of the approximation developed in DNS. The paper will present preliminary results at high Reynolds numbers and will demonstrate the efficiency of the SVV method for high-order LES modelling of confined rotating flows.

Session 6
Thursday, March 30, 13:30 - 15:30

Room: MA 313

Vortices with axial flow

Chair:

Rupert Klein
Guocan Ling

13:30	Brøns	MA 313

Topology Of Vortex Breakdown Bubbles

Morten Brøns, Anders Bisgaard, Technical University of Denmark

A vortex breakdown of bubble type is a secondary, closed flow structure on a main vortex. It occurs in number of vortex flows of technological interest. A classical set-up for the study of vortex breakdown is a fluid-filled closed circular cylinder where one end-cover is rotating. Depending on the aspect ratio of the cylinder and the Reynolds number, one or more breakdown bubbles can occur. We study the effect of a slow rotation of the other cover numerically. Based on a dynamical systems approach, we propose a simple numerical scheme for an efficient generation of bifurction diagrams. We find that the flow topology is very sensitive to variation of the rotation rate of the two covers, and give a complete description of the possible topologies and bifurcations. In particular, we indentify a new type of vortex breakdown which is initiated off the main vortex axis.

14:00	Klaas	MA 313

Investigation Of Normal And Oblique Shock/vortex Interaction

Michael Klaas, Wolfgang Schröder, Aerodynamisches Institut, RWTH Aachen

Velocity measurements of a slender streamwise vortex and oblique shock/vortex interaction as well as flow visualizations of vortex breakdown caused by normal and oblique shock/vortex interaction are presented. The velocity profile of the supersonic wing tip vortex is measured using a two-component Laser Doppler Velocimetry (LDV) system. In order to obtain information about the velocity field in the interaction region of the vortex and the oblique shock, Particle-Image Velocimetry (PIV) is used to measure the velocity distribution in vertical measurement planes parallel to the main flow direction at Mach numbers ranging from

$Ma_\infty = 1.4$ to 2.3. The global structure of the flow field is visualized by means of schlieren technique in combination with a high-speed digital video camera. The LDV measurements yield that the vortex possesses a distinct wake-like profile in the axial Mach number distribution and a tangential Mach number profile with the shape of an asymmetric Burgers vortex. The experimental results also reveal that the swirl ratio of the vortex decreases as it travels downstream. A locally normal shock in the vicinity of the vortex core and the strong time-dependent behavior of the flow field are evidenced by the flow visualizations.

14:30	Takahashi	MA 313

The Influence Of Turbulence On A Columnar Vortex With Axial Flow

Naoya Takahashi, Takeshi Miyazaki, Department of Mechanical Engineering and Intelligent Systems, Univ. Electro-Communications, Japan

The interaction between a columnar vortex and external turbulence is investigated numerically. The q-vortex, a model for trailing vortices, is immersed in a field of isotropic homogeneous turbulence which itself is produced by a direct numerical simulation of decaying turbulence. The formation of turbulent eddies around the columnar vortex and the vortex-core deformations are studied in detail by visualizing the flow field. In the less-stable case with $q = -1.5$, small thin spiral structures are formed inside the vortex core. In the unstable case with $q = -0.45$, the linear unstable modes grow until the columnar vortex makes one turn. Its growth rate agrees with that of the linear analysis of Mayer and Powell (*J. Fluid Mech.*, **245** 91-114, 1992). After the vortex completes two turns, a secondary instability is excited which causes the collapse of the collumnar q-vortex, after which many fine scale vortices appear abruptly.

15:00	Fröhlich	MA 313

Large Eddy Simulation Of Swirl Flows In Annular And Co-annular Jet

Jochen Fröhlich, Institut für Technische Chemie und Polymerchemie, Universität Karlsruhe
Manuel Garcia-Villalba, Wolfgang Rodi, Institut für Hydromechanik, Universität Karlsruhe

Swirl flows have many important applications in technology. One of them is the stabilization of flames through swirl-generated recirculation zones in combustion devices. Already the constant-density flow exhibits substantial complexity of coherent structures in experiments.

The talk presents an overview over Large Eddy Simulations of such flows under realistic conditions in terms of Reynolds number and swirl number which have been performed by the authors. Different flow regimes and typical vortex structures are discussed. The influence of a pilot jet and its location on the flow is investigated. It turns out that a retraction of the pilot lance, frequently applied to reduce the heat load on the structure, can drastically increase the unsteadiness of the flow.

Session 7
Thursday, March 30, 16:00 - 18:00

Room: MA 313

Vortex interaction

Chair:

Guocan Ling
Denis Blackmore

16:00	Huppertz	MA 313

Vortex/engine-jet Interaction In The Near Wake Of A Swept Wing

Guido Huppertz, Wolfgang Althaus, Wolfgang Schröder, Aerodynamisches Institut, RWTH Aachen

The presence of an engine jet significantly influences the structure of aircraft wake flow. Unlike long-wave instabilities, which primarily depend on global parameters like span, vortex spacing, vortex core size, and their respective ratios, short-wave instabilities strongly depend on the structure of the vortex core, its tangential velocity profiles, the axial flow, the pressure gradient, the turbulence level, and the properties of the spiral wake. Stereo PIV measurements are conducted in the wind tunnel downstream of the trailing edge of a swept wing half model with an attached model engine. Investigations are performed at three spanwise positions of the engine with a freestream velocity of $u_\infty = 27\ m/s$ yielding a Reynolds number based on the mean chord of $Re_{cm} = 2.8\ x\ 10^5$. The results indicate that a spanwise change of the location of the engine jet modifies the stability properties of the wake flow. The engine position inboard of the flap-edge leads to higher wandering amplitudes of the wing-tip vortex. For the engine position outboard of the flap-edge the wake deficit inside the wing-tip vortex core is stronger and the distance between the wing-tip and flap-edge vortices is higher, which indicates a longer coexistence of the 2-vortex system.

16:30	Krause	MA 313

Influence Of Winglets On Near-field Of Tip Vortex

Egon Krause, Martin Nockemann, Ronald Abstiens, RWTH Aachen

The influence of three winglets on the near-field of a tip vortex, generated by a rectangular half-wing with a CLARK Y profile, mounted to a flat plate, was

studied with the triple hot-wire probe, developed at the Aerodynamisches Institut. The tip cap of the wing was equipped with a single winglet on the upper surface in the first experiment, an additional one of smaller span on the lower surface in the second, and two winglets of equal span in the third. The winglets were inclined to the direction of the main flow by 60 degrees. Measurements of the time-averaged axial and azimuthal velocity components, of the turbulence intensity, and of the Reynolds stresses obtained in the near-field of the tip vortex in planes normal to the main flow direction, exhibited, that additional tip vortices were generated on the winglets, affecting the roll-up process and changing the distribution of vorticity in the near-field. Contour plots in the main-flow direction show, that the winglets enlarge the radial extent of the tip vortex, but also reduce the magnitude of vorticity. The maximum reduction of the time-averaged azimuthal velocity component was approximately 50% compared the tip vortex of the plain cap.

17:00	**Hörnschemeyer**	**MA 313**

Tip Vortex Wake Destabilization With And Without Winglets

Ralf Hörnschemeyer, S. Kauertz, S. Haverkamp, G. Neuwerth, Institut für Luft- und Raumfahrt, RWTH Aachen

Wake vortices are an inevitable by-product of lift. Another airplane following too closely can be dangerously influenced by the induced rolling moments. Consistent adherence to the prescribed safety margins ensures safe flight, however it also obstructs the capacity of large airports. To remedy the expected future capacity problems, research is being carried out world wide.

A conceivable possibility is the utilization and directed excitation of instabilities in the vortex wake to accelerate the vortex decay. In the 1970's it was already shown by Crow that it is possible to create inherent instabilities in the vortex wake. Studies based on the work of Crouch, Fabre and Ortega to destabilize the vortex wake accomplished at the ILR. Particle Image Velocimetry meassurements in a water towing tank show a large potential for destabilization by adequately choosing the circulation and vortex ratios. The rolling moment factor on a following airplane in relation to the lift could be more than halved in the far field. Further investigations to excite these instabilities by oscillating rudders show a clearly faster decrease of the induced rolling moment. In new investigations winglets are equipped with rudders and shall accelerate the vortex decay in combination with ailerons.

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