Metamodel-Based Uniform Cooking by Microwave Phase Shift

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The challenge for the fast food market is to provide quality food in a hurry and to this end high speed cooking equipment with microwave (MW) heating is essential. MW heating is non-uniform mainly because of the inherently uneven distribution of the electromagnetic field inside the oven cavity [1]. Moreover, the energy absorption process is strongly affected by shape, size, dielectric properties of materials, temperature distribution, position of the workload, as well as by the cavity geometry and dimensions. Several methods of making the temperature more uniform, such as hardware-based methods (e.g. mode stirrer) and modeling-based optimization ones [2] have been developed. In this paper a model-based method, which does not involve moving parts, is presented. It applies when two MW sources are provided, which can be fed by phase-coherent currents in order to produce MW destructive and constructive interference zones, thus reducing the temperature of the hot spots and increasing the temperature of cold spots. The effectiveness of the phase shift method is studied with a 3D coupled FEM analysis on a realistic test case model. The optimal phase shift for uniform cooking is estimated by a metamodel based optimization (MBO) approach in order to limit computing costs.

In the numerical model two physical phenomena, i.e. electromagnetic wave propagation and heat transport, are coupled together by the thermal effects of MW energy deposition and the temperature-dependent material parameters. The coupled problem is solved by means of a FEA commercial software (COMSOL). The optimization algorithm has been implemented in the MATLAB environment.

The optimal phase shift for uniform cooking is obtained by MBO in order to limit the number of FEM analyses which are computationally demanding. Generally speaking, MBOs consist in running the simulations at a set of points (experimental design) and fitting the response surface (RS) [3] to the resulting input-output data, so that a *metamodel* (MM) is obtained [4]. The MM provides an approximation of an objective function (OF) and can be used for optimization.

Computer simulations show that the phase shift of MW power sources significantly affects heating patterns and hot spot temperatures. The particular choice of OF allows for properly assessing the heating rate and the spatial temperature distribution. The optimization algorithm uses the RS methodology with successive enhancement by selecting the next sampling point in the region of interest. The goal of this technique is the infill criterion, which is biased towards both local exploitation of promising basins of attraction and global exploration of the search space. Finally, the MBO method guarantees a good approximation of the FEM model and a limited computing cost since a small number of samples in the design domain is required. The next step will involve an experimental validation of the proposed method.

References

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