Symulacja numeryczna urządzeń termoakustycznych z falą stojącą

Praca doktorska

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Abstract

Numerical simulation of standing wave thermoacoustic devices

The dissertation concerns the modelling of the operation of thermoacoustic devices by means of models of different classes. The research was performed adopting different numerical approaches to the simulation of thermal and flow processes occurring in thermoacoustic devices. The results obtained by means of different numerical methods were compared with the results of the analytical solution of Rott's equations. The analysed models included one-, two- and three-dimensional cases solved using different numerical software packages.

A program which is commonly used for thermoacoustic calculations, based on the one-dimensional numerical solution of Rott's equations, is the DeltaEC platform. Since it is a non-commercial tool, it has a number of limitations and its conscious use requires in-depth studies. Therefore the dissertation presents the procedure adopted to construct the model, define the boundary conditions and select the program settings to ensure its stable operation. The conducted simulations, treated as reference cases, were validated using an own analytical solution.

Further research was carried out with the use of the Ansys CFX and Ansys Fluent commercial packages, which are based on the finite volume method and the finite element method, respectively. As one-dimensional models do not reflect local phenomena, modelling in higher dimensions is desirable and creates an opportunity to obtain results much closer to real conditions. Most often, due to the need to ensure an acceptable computation time, the modelling is carried out in a plane system.

Because the heat transfer in the DeltaEC program is arbitrary and cannot be modified, and due to the far-reaching simplifications in this area observed in the literature, it was decided to analyse the heat transfer more deeply by means of CFD methods. For this purpose, the phenomena occurring within the stack and heat exchangers during

the oscillating motion of gas were studied. The simulations demonstrated that for the stack channels, which are usually very small, the use of popular heat transfer correlations was inappropriate. It was also observed that the optimal heat transfer occurs at a thermal penetration depth which is approximately equal to the hydraulic radius of the channel. Due to the computation time, performing this type of simulations required adequate limitation of the computational domain and application of dynamic boundary conditions defined using the developed UDF script.

In the next stage, numerical simulations were performed of the thermoacoustic engine operation. The method of the numerical mesh preparation using the ICEM CFD program and the way in which the boundary conditions were defined for three different degrees of the 2D model simplification are presented. An approach to modelling standing wave motors that ensures self-excitation of thermoacoustic oscillations is also described. Due to the long computation time of a single variant, a way is presented that makes it possible to accelerate the achievement of the steady state by introducing a pre-distribution of pressure in the device. The results are compared with those produced by the DeltaEC program, and the observed reasons for the differences in the solutions are discussed.

Next, the concept of a dual motor, composed of two standing wave motors connected by a common piston, is presented. The two motors operate with a phase shift relative to each other providing a continuous supply of power to the piston. Within the works, a numerical model of such a device was built and simulations of its operation were carried out. Among others, the impact of the piston inertia on the device operating parameters was determined. The modelling required dynamic remeshing of the model due to the piston motion. The dynamics of the piston were mapped using an original own UDF script.

The final stage of the works was to model the operation of a Hofler refrigerator powered by an acoustic wave coming from a loudspeaker. The modelling was performed in a 3D system analysing the effect of the drive ratio (DR) on the heat transfer in the device. The results show that there is an optimum DR value that ensures the highest efficiency of the refrigerator.