ZÁPADOČESKÁ UNIVERZITA V PLZNI

FAKULTA STROJNÍ

KATEDRA ENERGETICKÝCH STROJŮ A ZAŘÍZENÍ

ZÁPADOČESKÁ UNIVERZITA V PLZNI

POWER SYSTEM ENGINEERING, THERMODYNAMICS & FLUID FLOW

2012

JEDNOTLIVÝ PŘÍSPĚVEK ZE SBORNÍKU

evropský sociální fond v ČR

EVROPSKÁ UNIE

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

OP Vzdělávání pro konkurenceschopnost

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

THE DELAYED DETACHED EDDY SIMULATION USED FOR MAGNETICALLY DRIVEN FLOW IN SQUARE CONTAINER

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This paper focuses to the properties of flow in the square container which is driven to Lorentz force field which comes into being pursuant rotating of magnetic field. The fluid in the container represented melt of alloy. The results are obtained by numerical simulations. The model of simulation contain one of modern turbulence model – Delayed Detached Eddy Simulation among others. Further is described basic model of the numerical simulations, method of verification of code and results are defined in dimensionless form.

Key words: Magnetohydrodynamic, DDES

Introduction

The numerical simulations in sphere dynamic of fluid are more frequently used for solutions of complicated problems. Sometimes it happens than a solutions cannot be solve by measurement way, because till this time don't exists the appropriate equipment. One of cases can be producing of special casts, which came into being by method solidification during taking effect of force field which comes into being pursuant rotating of magnetic field. Relevant measurement of properties of the flow in this case is impossible presently. It is caused by the strong magnetic field, high temperature solubility of melt. In this cases a numerical simulations of the process is suitable way for taking of results. Numerical simulations of flows of fluid in turbulent mode are still one of the most difficult problems of thermomechanics.

This paper focuses just to problem of magnetically driven flow of melt in square container. The casts which come into being by this method have usually better mechanical properties than casts which come to being by common methods. Batter mechanical properties are by reason of finer metal crystals structure. In this paper it is shown some results of the simulations. Modern method of computation of turbulence problem is used – Delayed Detachet Eddy Simulation (DDES) turbulence model.

The first chapter contains basic mathematical model and some information of used computational code. The second chapter contains method of code verification. The third chapter shows basic philosophy of problem solution. Results of simulations of flow in container are shown in chapter four. Results, approach of solution and future approach to problem are summary in the conclusion.

1. Basic mathematical model

The simulations are solved as incompressible flow with constant molecular viscosity ν. The mathematics model includes Navier-Stokes equation in form (1) and continuity equation in form (2). Where u means velocity vector, p pressure, ρ density, t time, ν_t turbulence viscosity which is determined by the turbulence model and f_L is term of force field, which is used only in case of benchmark magnetically driven flow. In case of DDES model ν_t is solved by means of

Spalart-Allmaras turbulence model [1], which is determined by only one transport equation (3) with additional conditions (4, 5).

$$\frac{\partial u}{\partial t} + \nabla \cdot uu = -\frac{\nabla p}{\rho} + \nabla \cdot \left[(\nu_t + \nu)(\nabla u) \right] + f_L \tag{1}$$

$$\nabla \cdot u = 0 \tag{2}$$

$$\frac{D\tilde{\nu}}{Dt} = c_{b1}\tilde{S}\tilde{\nu} + \frac{1}{\sigma}\left\{ \left[(\nu + \tilde{\nu})\nabla\tilde{\nu} \right] + c_{b2}(\nabla\tilde{\nu})^2 - (c_{w1} f_w)\left(\frac{\tilde{\nu}}{d}\right)^2 \right\} \tag{3}$$

$$\tilde{S} = S + \frac{\tilde{\nu}}{\kappa^2 d^2} f_{\upsilon 2} \tag{4}$$

$$\nu_t = \tilde{\nu} \cdot f_{v1} \tag{5}$$

$$\tilde{d} = d - f_d \max\{0; d - C_{DES}\Delta\} \tag{6}$$

Where $\tilde{\nu}$ means so called modified turbulence viscosity, S means size of vorticity and d distance of wall boundary condition. In case DDES turbulence model [2] the d parameter is changed for $\tilde{d}$ which is formulated in (6). Function f_d is determined in (7). The force field term is determined as time averaged generated by the magnetic field. Basic equation is noted in (8). Magnetic induction has constant rotating angular velocity.

$$f_d = 1 - \tanh[(8r_d)^3] \text{ and } r_d = \frac{\nu + \nu_t}{\sqrt{\partial x_j u_i \partial x_i u_j}\,\kappa^2 d^2} = \frac{\tilde{\nu}}{S\kappa^2 d^2} \tag{7}$$

$$f_L = 2 \cdot Ta \cdot \left(\vec{j} \times \vec{B}\right) \tag{8}$$

$$Ta = \frac{\sigma \cdot \omega \cdot B_0^2 \cdot L^4}{2 \cdot \rho \cdot \nu^2} \tag{9}$$

Where $\vec{B}$ means dimensionless magnetic induction and $\vec{j}$ means dimensionless electric potential. *Ta* is so called dimensionless magnetic Taylor number. Exact determination of a force field generated by the rotating magnetic field is better reported in [3].

The computing software is successfully validated by means of solutions laminar flow and flow generated by magnetic field [3, 4]. The computational code is based on finite element approach with explicit scheme providing further second order accuracy in time and space. Specifically code use only grids with tetragonal elements.

2. Code verification

The computational code with implementation of turbulence model was verification by benchmark past a cylinder. The calculations are realized at two modes of Reynolds number – 3900 and 140000. Unsurprisingly results of simulations of benchmark with Re number 3900 are better than in case Re = 140000. It is due to choice of the turbulence model. The results of both type simulations indicate than used code and this option is relatively usable other case problems.

The following figure 1shows results of time averaged x-component of velocity in three profiles past cylinder. Figure shows results of most relevant simulation which was realize using grids which contain 2524325 elements and 3 dimensional effects can prove. The results are compared with experimental result Re = 3900 [5, 6] and Re = 140000 [7]. Other property of flow was compared with experimental results (drag and lift coefficient, Strouhal number, Reynolds stress) and good agreement was found.

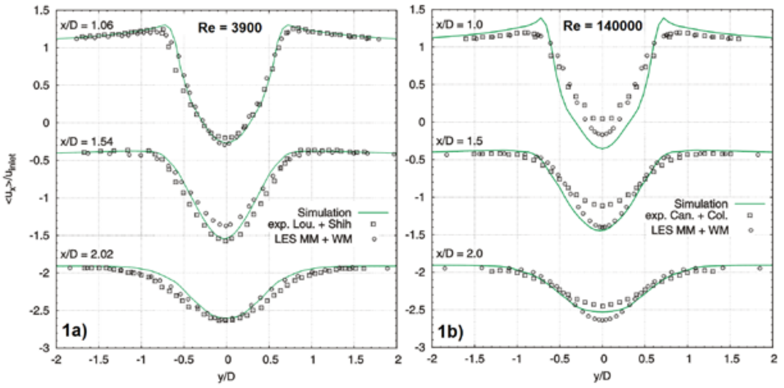

Figure 1: Time averaged x-component of velocity vector, 1a) Re=3900, (Lorenco and Shih [5], LES MM + WM [6]), 1b) Re=140000, (LES MM + WM [6], Cantwell and Coles [7]

3. Philosophy of solution of flow in square container

Full simulation of problem magnetically driven flow is benchmark flow in square container which is generated by steady forced field. Basic geometry of the benchmark domain is shown in figure 2a). Every boundary conditions are defined like static wall.

For this solution s important one precondition – angular velocity of fluid must be slower than angular velocity of magnetic induction. Mode of flow is determined by magnetically Taylor number (9). A process in metallurgy is under way cooling of melt. That means the viscosity of melt increase with decline of temperature. Accordingly a Taylor number (*Ta*) decline as well. There is precondition of low cooling to precondition of approximately constant temperature in full volume. Process is solved like isothermal problem and results of different Taylor number mode symbolize different temperatures. Five modes of *Ta* was study – 10^6, 5.10^6, 10^7, 5.10^7 and 10^8. One simplification is used – model of Newtonian fluid for melt. Figure 2b shows comparison simulations results (maximal angular velocity) with analytical Davidson theory [8].

4. Results of simulations of flow in square container

Most important results are in form of pictures, which shows behavior of full flow field.

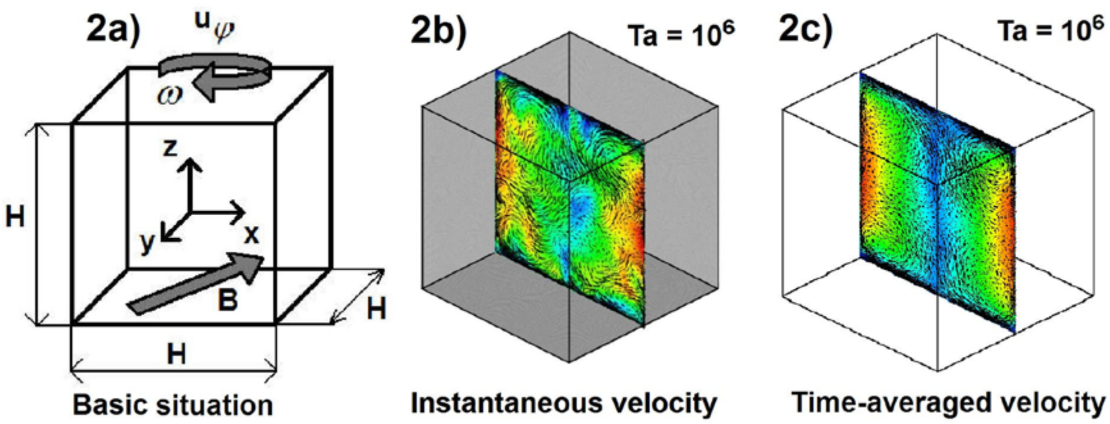

Figure 2: Flow in container 2a) Basic situation, 2b) Instantaneous velocity, 2c) Time-averaged velocity

Figure 2 shows basic situation – 2a) rotating magnetic field, 2b) is shoot of instantaneous velocity in color scale with vectors for case Ta = 10^6, 2c) shows time-averaged velocity in color scale with vectors for case Ta = 10^6.

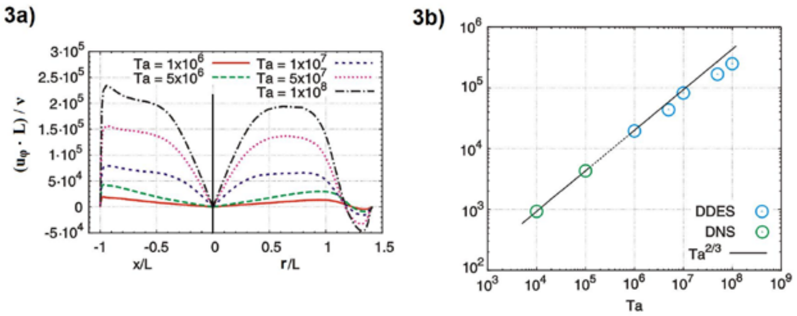

Figure 3: Flow in container 3a) Dimensionless velocity profiles for middle horizontal plane – central line and diagonal line, 2b) comparison of simulation and Davits 2/3 analytical dependence

Figure 3a) shows dimensionless velocity profiles for middle horizontal plane – central line and diagonal line. Figure 3b) shows relatively good agreement in comparison of simulations result – maximum of angular velocity with Davits 2/3analytical dependence.

Conclusion

The philosophy of proceeding of simulations of flowing melt square container which is driven by magnetic field was shown. Proceeding of verification of correctness of results was sketched as well. Another work will be focused to analyze of achieved data and using of new IDDES turbulence model.

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Acknowledgment

The authors thank to the grant SGS 2823 at Technical University of Liberec.

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