

Description of Lorentz forces in the cuboid container

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Abstract Leading topic of this article is description of Lorentz forces in the container with cuboid shape. Inside of the container is an electrically conductive melt. This melt is driven by rotating magnetic field. Numerical simulations of these unsteady flows were performed in commercial software Ansys Fluent (version 13). Input data (Lorentz forces in the container with cuboid shape) were also obtained from the computing program NS-FEM3D, which uses DDES method of computing as a turbulent approach. Related velocity field of the melt inside the container was displayed and described as well.

1 Introduction

A theory of flow behaviour under magnetic field effect is called magnetohydrodynamics (MHD). First mentions about MHD appeared in relation to astrophysics and geophysics. Nowadays the magnetic field is used in technical practice. Rotating magnetic field generates eddy flow in electric conductive melt. This effect is used to e.g. for non-contact electromagnetic stirring of the melt in metallurgy and for crystal growing, when rotating magnetic field homogenize of varied metal alloy and fine metal. The melt flow positively affects metallographic structure of casts. For more details about electromagnetic stirring see [1], [2].

This process is possible to simulate by commercial software Ansys Fluent (version 13) using MHD module for computing MHD processes. Contours of Lorentz forces are also possible to obtain by computing code NS-FEM3D, which uses DDES method of computing as a turbulent approach. This code was validated by several studies [3] especially for cylindrical container. Several articles for unsymmetrical container were published over the last years [4]. Contours of Lorentz forces obtained by these two methods are described in this article.

2 Problem formulation

This work could be interpreted as a flowing melt inside the container. The melt inside the container is an electrically conductive and melt flowing is driven by rotating magnetic field (**Fig. 1**). Shape of the container could be various. In my previous works analytical formula of Lorentz forces in cylindrical container was inferred [5]. Comparing of Lorentz forces in cylindrical container (used analytical formula) and cuboid container (simulated by computing program NS-FEM3D) was published in [6]. Comparing Lorentz forces (and caused unsteady flows) obtained by analytical formula and simulated by software Ansys Fluent was performed in [7]. In this article will be described unsteady flows caused by rotating magnetic field in cuboid container. In Navier-Stokes equations for flow calculations the external forces are occurred. In the flow of melt driven by a rotating magnetic field these forces are the Lorentz forces. Contours of these forces could be simulated by commercial software Ansys Fluent (version 13) or in computing code NS-FEM3S.

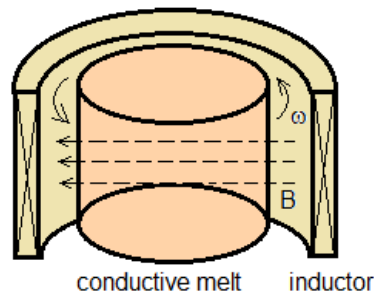


Fig. 1 Description of the electromagnetic stirring

3 Solutions in software Ansys Fluent

The Magnetohydrodynamics (MHD) module is provided as an additional module with the standard ANSYS FLUENT licensed software. The ANSYS FLUENT MHD model allows analysing the behaviour of electrically conducting fluid flow under the influence of constant (DC) or oscillating (AC) electromagnetic fields [8]. Equations of MHD are solved through user-defined scalar (UDS) transport equations. Other model-related variables such as the external magnetic field data, current density, Lorentz force and Joule heat are stored as user-defined memory (UDM) variables [8]. Computing of MHD in Fluent is possible by two different methods – solving magnetic induction equation or scalar potential equation. Both methods are solved by scalar transport equations. Solution by magnetic induction uses two or three transport equations (2D or 3D solution). Solution by electric potential uses only one transport equation. MHD module is relatively new and some computing limits and other parts (solidification, simulation of free surface etc.) will be added to upgraded version. Some computing limits are: computing program is set for the melt with sufficient conductivity, it can be set up only magnetic induction value (no current density), it is assumed that frequency is low etc.

3.1 Ansys Fluent set-up

Mesh of the cuboid container was created in Ansys meshing. Boundary conditions are set as wall. Number of mesh elements is c. 500 000 (including refinement in the area of boundary layers). This mesh was exported to Ansys Fluent. Because of AC electromagnetic field unsteady computing was chosen. Computing code NS-FEM3D uses DDES method of computing as a turbulent approach. Because of comparable results, that model (with RANS model Spalart – Allmaras) was chosen in Fluent as well. Taylor magnetic number of this flow is $1 \cdot 10^6$, turbulent approach is necessary. MDH module was unloaded and magnetic induction computing method was chosen. Solving MHD equations was extended for Lorentz forces computing. Physical values of density, electric conductivity and viscosity were set the same as in NS-FEM3D (density $\rho = 6361 \text{ kg}\cdot\text{m}^{-3}$, kinetic viscosity $\nu = 3,4 \cdot 10^{-7} \text{ m}^2\cdot\text{s}^{-1}$, electric conductivity $3,3 \cdot 10^6 \text{ S}$). The cover of the container was chosen as insulated walls. The values of external magnetic field was chosen – AC field with angular velocity of the field $\omega = 439 \text{ s}^{-1}$ and amplitude of magnetic induction in x and y direction $B_0 = 4.478 \cdot 10^{-3} \text{ T}$. Magnetic induction has only components B_x a B_y because is assumed that vertical size of bipolar inductor is bigger than the height of the melt in the container. Time step is very small - 10^{-6} s in the begging of computing, $5 \cdot 10^{-5} \text{ s}$ passing the initial problems. Value of time step is that small because of bad convergence and angular velocity of the field $\omega = 439 \text{ s}^{-1}$. Total time is c. 2 s.

3.2 Postprocessing

Lorentz forces in Fluent are possible to display only in Cartesian coordinate system and only as instantaneous values but Lorentz forces are changed because of AC field (**Fig. 2**).

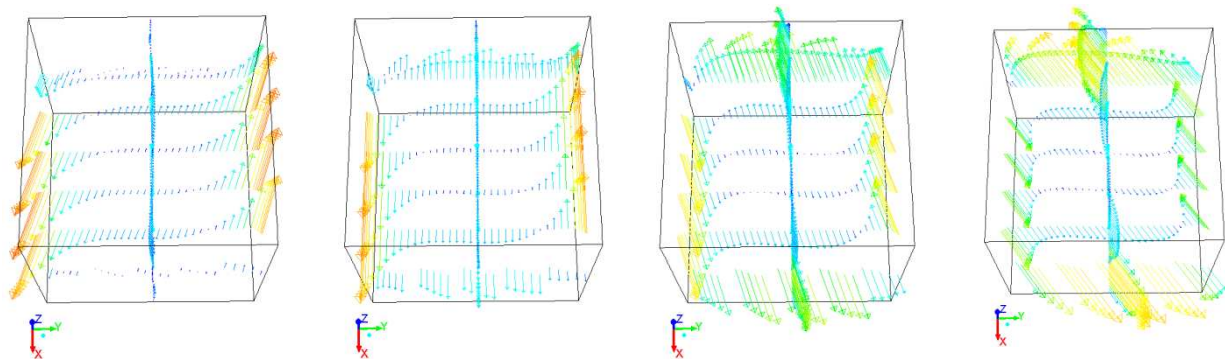


Fig. 2 Vectors of Lorentz forces in different computing time

Contours of Lorentz forces are displayed in **Fig. 3a**. These contours in Fluent include forces in x, y and z directions. In NS-FEM3D (and analytical formula for Lorentz forces in cylindrical container) part of Lorentz forces in z direction is zero. It is caused by some simplifications in boundary conditions (scalar potential $\Phi_2 = 0$ – see [5]) and $B_z = 0$. Maxima of Lorentz forces are displayed by red colour, minima by blue colour. Maxima of these forces are occurred on the outer walls of container in the half of container high. On the contrary minima of magnetic forces are in the axis of container and on upper and lower base (based on boundary conditions).

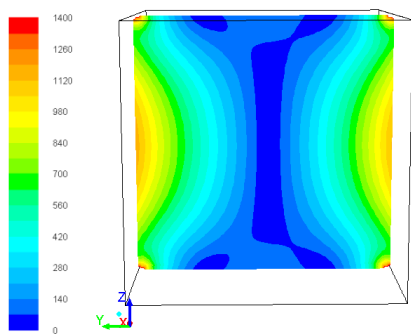


Fig. 3a Contours of Lorentz forces in Fluent

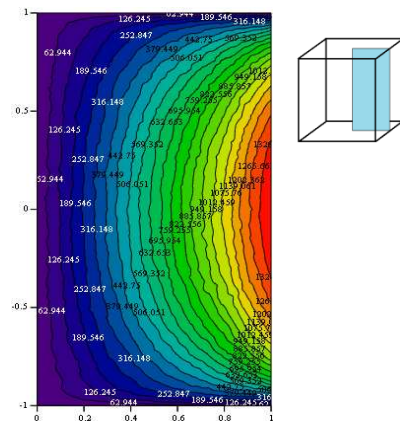


Fig. 3b Contours of Lorentz forces in NS-FEM3D

4 Solutions in computing code NS-FEM3D

Input data for comparing Lorentz forces in the container with cuboid shape were obtained from the computing program NS-FEM3D which uses DDS method of computing. The Delayed Detached Eddy Simulation model has been applied as a turbulent approach. This approach was implemented for higher Taylor number. Without any turbulent approach study of unsteady flows driven by magnetic field was limited only for lower Taylor number. Complete summary of applied mathematical model and validations see in [3], [4]. The grid of container was unstructured. Whole grid has over 2 200 000 elements. Database from this computing code were created by data matrix – coordinates of grid node points, values of Lorentz forces component in the

Cartesian coordinate system. And this database was processed in software MathCad (version 15). Contours of Lorentz forces (time averaged) are displayed in **Fig. 3b**. These contours include forces only in x and y direction. Time averaged velocity fields in vertical and horizontal plane are displayed in **Fig. 4 a, b**.

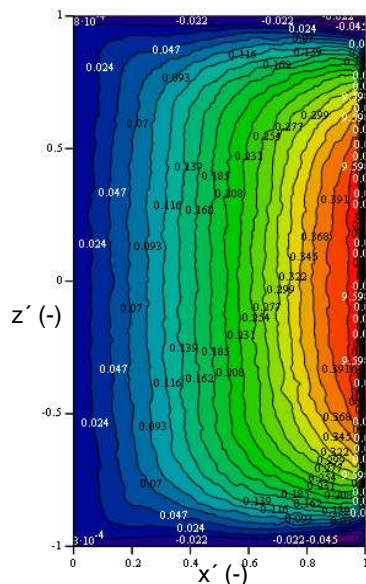


Fig. 4a Contours of mean velocities in vertical plane

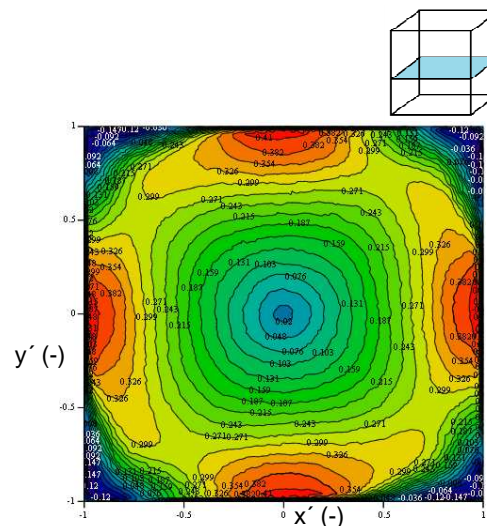


Fig. 4b Contours of mean velocities in horizontal plane

5 Conclusions

Contours of Lorentz forces were displayed in Fluent and in MathCad (from NS-FEM3D data). They are placed at the same area and values are similar (exact values are not comparable because of only instantaneous forces in Fluent). Maxima of Lorentz forces are in area of bigger distance from axial axes (because of large melt mass). Velocity contours answers to contours of Lorentz forces. Differences are in area near corners. Moving melt (dominantly in azimuthal direction) accelerates and decelerates. As a result relatively significant turbulent coherent structures are appeared. Near upper and lower base the melt is affected edges and friction.

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