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Statistical analysing of unsteady flows

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Abstract: *Leading topic of this article is description of the flow in the container with cuboid shape and statistical evaluation by energetic spectra. Energetic spectra are performed for different Taylor number (1.10^6, 5.10^6* and 1.10^8*) and the shape of these energetic spectra was compared with trend line -5/3. Inside of the container is an electrically conductive melt. This melt is driven by rotating magnetic field. This study obtains input data from the computing program NS-FEM3D, which uses DDS method of computing. The grid of the container has over 2 000 000 elements.*

1. Introduction

This study works with input data from the computing program NS-FEM3D[1]. Although data were stored into binary code, databases contain hundreds of GB and computational time reached up to 6 months. Computing is provided for different Taylor number with the same container. Several databases for different Taylor number (1.10^6, 5.10^6 and 1.10^8) are completely computed and currently it is necessary to find out if grid fineness and time step is sufficient to catch effects related with small and long live time. Taylor number increased by amplification of magnetic induction B.

The grid of the container has over 2 000 000 elements. Time steps are different for different Taylor number. The biggest time step ($50.3, 1.10^{-5}$ s) is in result database of Taylor number 1.10^6. The smaller time step ($50.3, 6.10^{-6}$ s) is for Taylor number 1.10^8.

Computations of the spectral analyze required FFT (Fast Fourier Transform) which was performed by software MathCad together with the final graphs. 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.

2. Problem formulations

A theory of flow behaviour under magnetic field effect is called magnetohydrodynamics (MHD). First mentions about MHD appeared in relation to astrophysics and geophysics. In the fifties the interest in MHD focused especially to plasma physics and thermonuclear fusion control. The interest in MHD was extended to industry later. Now the magnetic field is used in technical practice e.g. in metallurgy for controlled solidification of the melt, for suppressing of the natural convection thereby increasing homogeneity of the melt.

In recent years the interest in using magnetic field is focused to rotating magnetic field. In several scientific journals was performed a comparison between static and rotating magnetic field. Rotating magnetic field is more useful (generally rotating magnetic field needs B < 10mT and static magnetic field B > 100 mT). An advantage of rotating magnetic field is possibility of using with low electric conductivity of the melt. For elimination of unadvisable Taylor vortexes is necessary suitably set field intensity [2].

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 metallographical structure of casts. For more details about electromagnetic stirring see [3], [4], [5].

One of the possible interpretations of this problem is a cuboid container with the square bottom. The subject of this work is a description of unsteady melt inside this container. The flow of the melt is driven by rotating magnetic field which increases homogeneity of the melt and suppresses the natural convection.

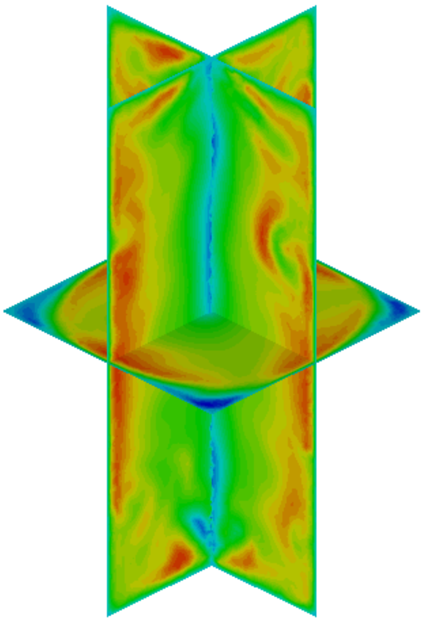

Figure 1: Instantaneous azimuthal velocities

Instantaneous azimuthal velocities are displayed in figure 1. Azimuthal velocities have dominant roles in this flow. This velocity gets the higher value of maximum, bigger amplitude and slower oscillation. [6]. Maxima of instantaneous azimuthal velocity of the mesh are appeared approximately in two-thirds of the imaginary incylinder radius. Minima are in the corners of the cross section and in the imaginary direct axis of the cuboid container.

Topic of this article is description of this unsteady flow in the container and statistical evaluation by energetic spectra. Energetic spectra are performed for different Taylor number and the shape of these energetic spectra was compared with trend line -5/3.

3. Energetic spectra in dependence on wave number

The mesh of the container is unstructured with more than 2 000 000 elements.
Some lines points were chosen from this unstructured mesh. Because of the unstructured grid, points of line have not constant distance from each other and they cannot be accurately in the line. Virtual points of the lines were set consequently. Distance between each point of the line was constant. It was applied weighting function to find kinetic energy in virtual points from real points [7], [8]. Number of points on one line is 256.

Lines are in the area of two-thirds of the imaginary in-cylinder radius (location 2/3 L) and in area of seven-eighth of the imaginary in-cylinder radius (location 7/8 L). Locations of lines are displayed in figure 2.

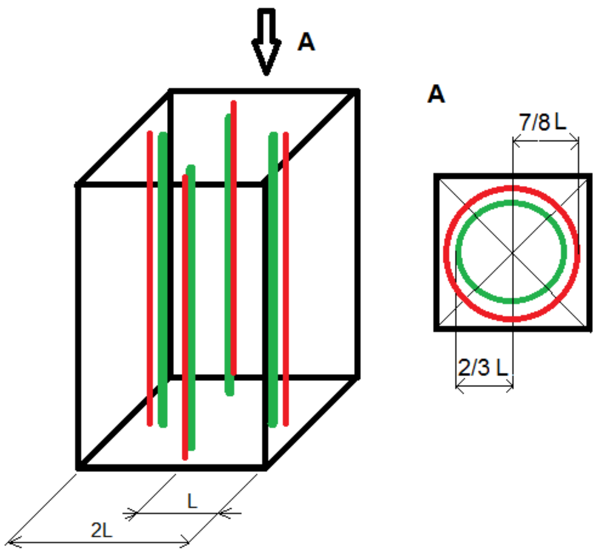

Figure 2: Location of lines in the container

Fluctuation of kinetic energy of virtual points were transformed by FFT (Fast Fourier transform) and averaged. FFT was executed in the software MathCad. Fluctuations of kinetic energy values of virtual line points were stored separately for each of time step. A file of one time step contained fluctuation of kinetic energy values of whole line points in that time following FFT and averaging of each time step.

Spectra graphs could be displayed in dependence on location of point in z-axis (or more precisely on wave number). Because this container is symmetrical, this symmetry was taken as advantage. Results of that line were performed four-times and after that these records were together averaged.

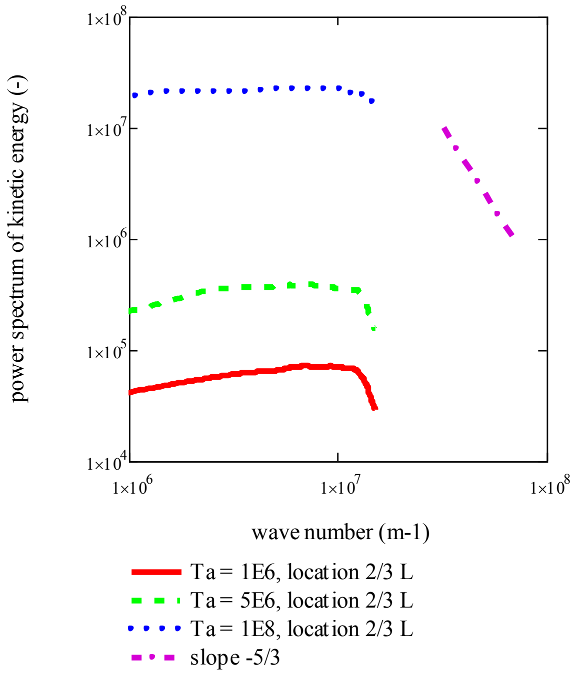

Figure 3: Dependence power spectrum of kinetic energy on wave number

(Ta = 1.10^6, Ta = 5.10^6, Ta = 1.10^8, location 2/3 L)

Figure 3 shows dependence power spectrum of kinetic energy on wave number. Location of averaged lines is 2/3 L. Graphs are different only in Taylor number. Graph for Ta = 1.10^6 has the smallest Taylor number from examination range, Graph for Ta = 1.10^8 has the bigger number. Graphs for Ta = 1.10^6 and Ta = 5.10^6 are enough data for FFT. Magenta dot-and-dashed line with trend of -5/3 is displayed in graphs for comparing. It is possible to say that spectra achieved similar trend.

Graph for bigger Taylor number reaches higher power spectrum of kinetic energy. The first part of spectra shows vortex section with the biggest energy. Energy is removed from main flow in deformation of vortex. This energy is transferred to big (most deformed) vortex. Afterwards is this energy moved to smaller vortex through the use of cascades. Energy transfer is allowable for only those vortexes which are in nearby the area with higher wave number value. After that the smaller vortex dissipates as effect of viscosity. Graph for Ta = 1.10^8 has not enough data for FFT. Container mesh for higher Taylor number is too rough with large grid spacing. DDS methods used for calculations do not catch up effects related with smaller life time. For calculation with that higher value of Taylor number finer mesh is necessary.

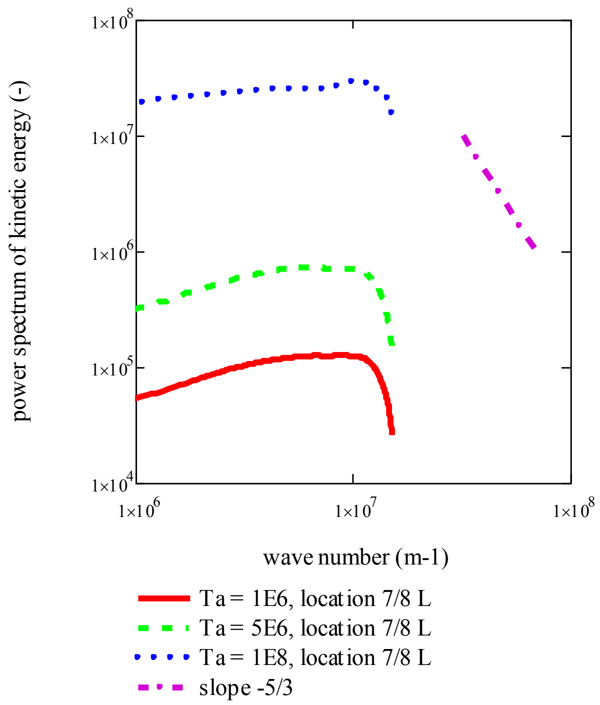

Figure 4: Dependence power spectrum of kinetic energy on wave number

(Ta = 1.10^6, Ta = 5.10^6, Ta = 1.10^8, location 7/8 L)

Dependence power spectrum of kinetic energy on wave number is in figure 4. These graphs are different only in Taylor number. Location of averaged lines for figure 3 is 7/8 L (so nearby container wall). Magenta dot-and-dashed line has slope -5/3. In the first part of graph falling spectra achieved similar trend with slope -5/3. After that the energy is faster lost (probably the effect of walls). Graph for bigger Taylor number reaches higher power spectrum of kinetic energy.

4. Conclusion

Computer programs which were generated are intended for statistical analysing of unsteady turbulent flow. The Fast Fourier Transform for obtaining energetic spectra was performed by software MathCad.

Near container corners small vortexes are appeared. These vortexes have smaller energy than main flow and they are absorbed by corner vortexes.

Energetic spectra in dependence on wave number were performed for different Taylor number. For higher Taylor number is using container mesh too rough with large grid spacing.

DDS method used for calculations does not catch up effects related with smaller life time. For calculation with that higher value of Taylor number finer mesh is necessary.

5. Acknowledgements

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