A study of the influence of rotating magnetic field of permanent magnets on the cylindrical melt bath

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Abstract. Nowadays magnetohydrodynamic (MHD) equipment and technologies controlling the flows of conducting liquids are widespread in various technical fields. Among other things, they are used in metallurgical industry for transportation, refinement, dosing, and other operations with melted metals. The demand for special aluminium alloys in the key branches of Russian economy makes growing requirements for their quality and performance characteristics, which in turn generate demand for development of new MHD-equipment and improvement of the existing equipment and technologies. Therefore a study of the processes taking place in the layers of conducting liquid under the influence of electromagnetic powers is highly important for both scientific and practical purposes. This article presents the results of numerical modelling of the influence of rotating magnetic field of permanent magnets on the speed of the movement of molten aluminum carried out via ANSYS software.

1. Introduction
Magnetohydrodynamic technologies are used quite extensively in smelting and foundry industry. They are implemented for the mixing of the smelt to intensify the salt refinement process in dispensing ladles, to achieve the necessary evenness of the temperature field and chemical composition in induction mixer baths and resistance mixers, to stir the smelt in the channels of channel induction furnaces in order to intensify the heat exchange within it, and to intensify the heat exchange between the smelt coming out of induction unit and the smelt in the furnace bath, as well as to transport the smelt from smelting furnace to the mixer via MHD pumps.

Today the methods most widely used for these purposes are the electromagnetic methods of influence of travelling (or rotating) electromagnetic field on liquid metal, realized with the help of electromagnetic coil systems, generating sinusoidal or rectangular periodical electromagnetic field. Electromagnetic, thermal, hydrodynamic processes taking place under this influence are studied well enough and a thorough overview of this problem is presented in the monograph [1]. But these methods have a number of shortcomings (for instance, electric efficiency <50% and power factor not higher than 15-20%), which encourages the search for new methods of MHD stirring of melts, more economical and easier to implement. From this point of view an interesting notion is to use a system of movable permanent magnets, which have higher overall efficiency, reaching 75-80%, and power factor over 80%, simple design, easier maintenance.

Quite a lot of studies are dedicated to researching the electromagnetic processes in cylindrical metallic raw elements during their heating with permanent magnets [2-5], but the questions of the interaction between the magnetic field of movable magnets and the molten metal are not studied enough.
The most well-researched and often implemented today pumps are MHD pumps with permanent magnets used for the transportation of lightweight alloys [1, 6-8], but the problem of the stirring of melts via movement of the magnetic field of permanent magnets is covered by few studies [9-10].

The present article examines the influence of rotating magnetic field of permanent magnets on the speed of the movement of molten aluminium

2. Problem statement
In order to examine the electromagnetic and hydrodynamic processes taking place in the molten metal bath, a numerical model was created via ANSYS software, enabling to calculate the electromagnetic parameters of the system, such as active power produced in the melt and the rotation resistance moment, as well as velocity field in the liquid metal bath.

This magnetohydrodynamic problem was divided into a stationary electromagnetic problem and a stationary hydrodynamic problem in a one-sided connection. As the electromagnetic problem was solved, a distribution of Lorentz forces was received, and those were used as volume forces in the solving of the hydrodynamic problem [6-7].

Figure 1 shows the design used as a basis for the model created for the calculation of the combined electromagnetic and hydrodynamic problems. The cylindrical melt bath was 80 mm in diameter and 1000 mm long. Technical gap $z$ between the surface of the bath and the magnets varied from 5 mm to 30 mm during the modelling process. Height of the magnets was $h = 50$ mm, residual induction $1$ T, coercivity $1050$ kA/m. The speed of permanent magnets moving around the raw metal element varied from 2 to 25 r/s [1-3]

3. Results of numerical modelling
3.1. Calculation results for the electromagnetic problem
Numerical calculations were carried out with the following variables: rotation speed of the magnetic system $- \omega$; the number of pole pairs in the magnetic system $- n$; technical gap between the permanent magnets and the raw element $- z$.

Figure 2 presents the relations of active power produced in the melt to the rotation speed of the magnetic system with technical gap $z = 10$ mm and the ratio between angular size of the gap and the angular size of the magnet $Ag/Am = 1$ for varying numbers of pole pairs. As the rotation speed grows, and the number of pairs of magnetic poles increases, a substantial rise of total active power produced in the raw metal element takes place.

It is apparent from Figure 2 that active power grows approximately tenfold in the speed range from 5 to 22 r/s regardless of the number of pole pairs.
3.2. Calculation results for the magnetohydrodynamic problem

This article presents the calculation results for the stationary hydrodynamic problem with rotation speed of the magnetic system of 5, 10, 15 r/s.

Figure 4 presents the distribution of Lorentz forces with rotation speed of the magnetic system 5 r/s, used as the volume force for the solution of the hydrodynamic problem.

Figure 5 shows the picture of melt rotation speed distribution as stream lines, with rotation speed of the magnetic system 5 r/s.

Figure 6 presents the speed distribution over the melt bath radius with various rotation speeds of the magnetic system. Melt speed $V$, growing from the axis to the outer surface of the melt bath, reaches its highest point and then drops to zero at the outer surface of the bath. Meanwhile, when the angle speed of magnet rotation is increased, the maximum speed of melt movement reaches higher values and shifts nearer to the outer surface of the melt bath.

It is apparent from Figure 6 that the highest speed of melt movement is achieved at some distance from the top and bottom of the cylindrical bath to its centre, which is a result of the melt interacting with the bath wall. The model study has shown that apart from the azimuth movement of the melt, movement according to the axis of the system also takes place.
Figure 4. Distribution of Lorentz forces in the melt bath with a rotation speed of 5 r/s.

Figure 5. Distribution of melt movement speed as stream lines with a rotation speed of the magnetic system of 5 r/s.

Figure 6. Graph of the speed variation across the melt bath radius with various values of the rotation speed of the magnetic system (1 – 15 r/s, 2 – 10 r/s, 3 – 5 r/s).

Figure 7. Graph of the relation of maximum melt speed to the rotation speed of the magnetic system.

Figure 7 presents the graph demonstrating the relation of maximum speed of the melt to the rotation speed of the magnetic system. With increasing rotation speed of the permanent magnet system the speed of the melt also grows, gradually approaching the established value.

4. Conclusion
A model of interconnected electromagnetic and magnetodynamic processes taking place during the stirring of molten metal in vertical cylindrical bath via rotating magnetic field of permanent magnets has been developed.

Relations of active power and the moment of resistance of the cylindrical volume of the melt against the rotating magnetic field of permanent magnets to the speed of the movement of the magnetic systems are found.

The distribution of speed of the melt movement in the cylindrical vertical bath and the dependence of the maximum value of the melt movement on the angle rotation speed of the permanent magnet system are found.
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