APPLICATION OF MHD TECHNOLOGY IN NON-FERROUS METALLURGY IN SIBERIA

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Abstract: The present article reviews a number of the research works carried out by the staff of the specialized department "Electrotechnology and Electrotechnics" of the SFU in cooperation with a scientific and engineering company "NPC Magnetohydrodynamics" LLC, which aim is to solve the problems of MHD stirring of melts in furnaces and stirrers for melting-casting production of aluminum alloys.

1. Introduction.

Production of primary aluminum is a very energy-consuming process. Therefore electrolytic plants are usually built in the areas rich in energy resources. Eastern Siberia possesses good sources of power supply including the hydropower electric stations of Kans-Achinsk coal basin. Cheap energy in the region has contributed greatly to appearance of powerful production facilities both for primary aluminum and aluminum-based alloys. While preparing multi-component alloys it is essential to mix the melt in furnaces and stirrers in order to even its chemical composition and the temperature along the bath volume.

The present article describes the results of our team's research work connected with the problems of the location, form of the electric current and character of the inductor magnetic flux aimed to solve the problems of MGD stirring of a melt in furnaces and stirrers.

2. Stirring of a melt in furnaces and stirrers.

Magnetohydrodynamic (MHD) stirring technologies have lately become quite widespread. Stirring is considered to be effective if it leads to elimination of all the inhomogeneities in a melt and creates a homogenous structure along the bath volume. Inhomogeneities are divided into macroscopic and microscopic. In order to eliminate those inhomogeneities, MHD-stirrers should induce excitement of large-scale laminar and coherent vortex movements combined with small-scale pulsations in order to form associative formations in the melt [1].

The peculiarity of metal heating in gas or electric furnaces and stirrers is that the energy is normally transferred to the melt by radiating. Therefore, the temperature drop between the upper and lower melt layers reaches 100° C when heated for a long time. The upper layer high temperature helps increase the oxidation speed and saturation of the melt with hydrogen. When MHD-stirrers are turned on, the temperature between the layers is evened [2].

Let us consider two ways of installation of an MHD stirrer regarding the melt bath. The first way is as follows: the source of the running magnetic field is installed from the bath side wall. The second way: the inductor is placed under the bath bottom. Fig. 1 shows a sketch of the furnace with an MHD-stirrer inductor placed from the furnace side wall. Such an installation is more preferable in case when the installation of the inductor under the bottom will cause additional works to change the furnace foundation. However, recently metallurgical and aluminum factories have started using tilting furnaces.

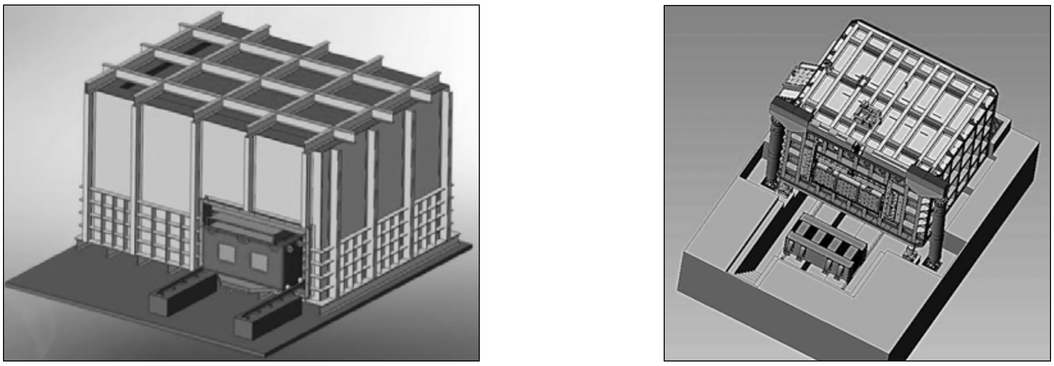


Figure 1: Sketches of static and tilting furnaces with MHD stirrers.

Fig. 1 shows the static and tilting furnaces with an inductor installed at the side wall of the furnace and under the bottom correspondingly.

To solve a problem of electromagnetic stirring of the melt in the furnace, a numerical model has been developed which has enabled to carry out the correct computation of the electromagnetic and thermal and hydrodynamic fields in a three-dimension setting taking into account the main peculiarities of the furnace and MHD-stirrer inductor [3, 4]. A mathematical model consists of two main parts: a mathematical model to analyze the electromagnetic field based on a Maxwell equation, which enables to define the distribution of the bulk force in the aluminum melt; and a mathematical model based on the Navier-Stokes equations, which enables to define the velocity field in the melt and the distribution of temperatures in the melt, the refractory lining and on the furnace surface both with and without the application of an MHD stirrer.

As a result of the numerical analysis of the hydrodynamic field on the melt, the pictures of the velocity field and motion trajectory have been received, an estimation of the turbulent movement has been made and the integral parameters of the system “inductor-melt” have been defined.

The distribution of the velocity field with the established melt movement (t = 180 s) with the inductor installed under the bath bottom is shown in Fig. 2a.

A significant factor influencing the kinetics of the alloy solution is the presence of the developed turbulent movement in the area of the distribution of the alloying elements. The area with the significant turbulent movement and the dynamics of its change can be presented with a change of the iso-volume with the kinetic energy of the turbulent pulsations k > 0.001 m^2/s^2 at the moments of time 20 s and 90 s in Fig. 5. From the figure, it is clear that the increase of the turbulent movement happens rather slowly and the main area with the

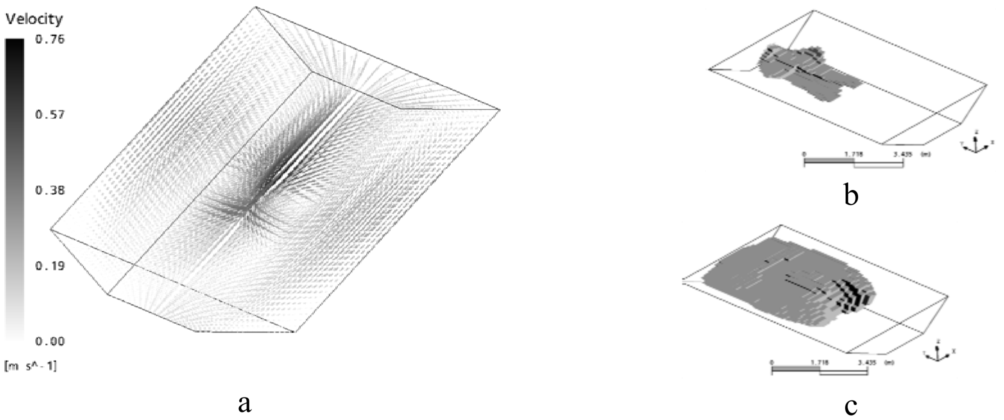


Figure 2: Velocity field in the melt (a) and the energies of turbulent pulsations (k > 0.001 m^2/c^2) at the time moments 20 s (b) and 90 s (c).

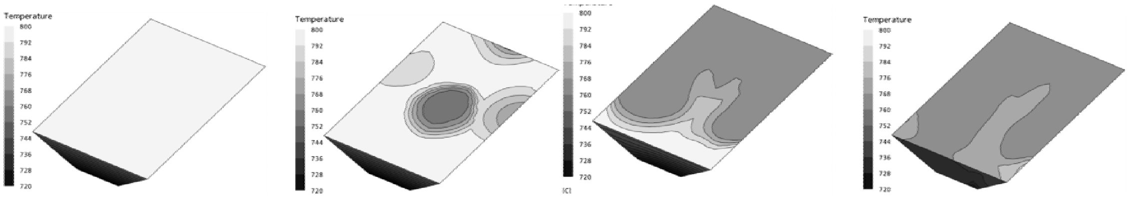


Figure 3: The dynamics of the temperature distribution of the melt surface.

developed turbulence is only observed at the outlet of the inductor (Fig. 2b). The developed turbulent movement at the moment of time 90 s nearly coincides with the area of the main motion trajectories (Fig. 2c) and takes 2/3 of the melt bath volume.

Apart from accelerated solution of the alloys, MHD-stirring leads to evening the temperature in the melt. The temperature distribution on the melt surface at different moments of time is shown in Fig. 3.

The temperature analysis shows that in the central part of the bath there is a significant heat-and-mass transfer thanks to the ascending currents leading to quick evening of the temperature above the inductor. Besides, it follows from the temperature distributions that in the area in front of the inductor (inlet of the inductor) there is a zone of the melt stagnation which is stirred badly. The presence of the area with the melt stagnation speaks for the necessity to reverse the running magnetic field.

MHD stirrers used at the present time are normally fed with sinusoidal currents, have low efficiency and the power coefficients. An MHD-stirrer, fed with non-sinusoidal periodical currents, having certain inductor parameters and power source operation modes, has a distinct advantage over MHD-stirrers with sinusoidal feeding, while presence of pulsing electromagnetic forces leads to elimination of micro-inhomogeneities in multi-component melts [5]. Let us suppose, that for each phase of the inductor winding there is a periodic strain of a rectangular shape *u(t)* (Fig. 4). As each phase has an active resistance *R* and inductivity *L*, there is a transition process whenever the voltage polarity changes. The length of the transition processes t_n depends on the parameters of the inductor *R* and *L*, and is defined with the time constant $\tau_в$. Taking into account the law of commutation and the character of the transition processes the electric current form i*(t)* will also have the form shown in Fig. 4. Upon the completion of the transition process there is a stage in the winding with the length t_y, during which the current does not change. The electromagnetic field will repeat the form of the currents.

Provisionally the process of the interaction of such fields shape with the bath liquid metal can be divided into two stages. The first one – when the field does not change (time t_y), and has a maximally deep penetration into the metal thickness, and the second one when the

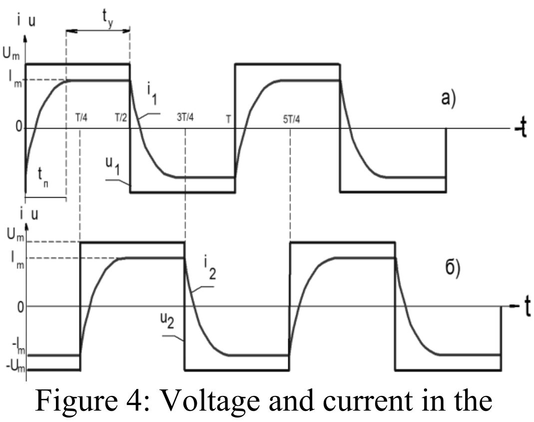


Figure 4: Voltage and current in the inductor phases.

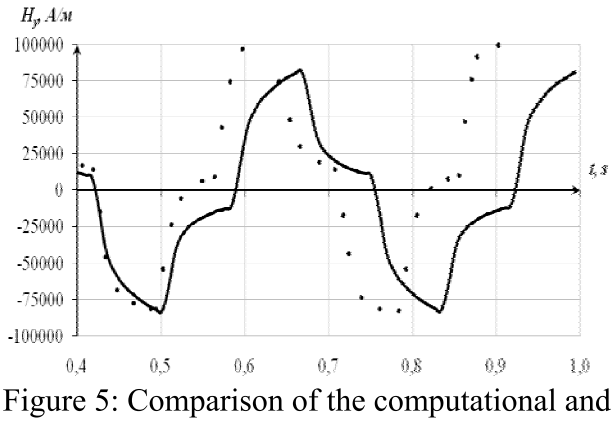


Figure 5: Comparison of the computational and experimental data (on the right).

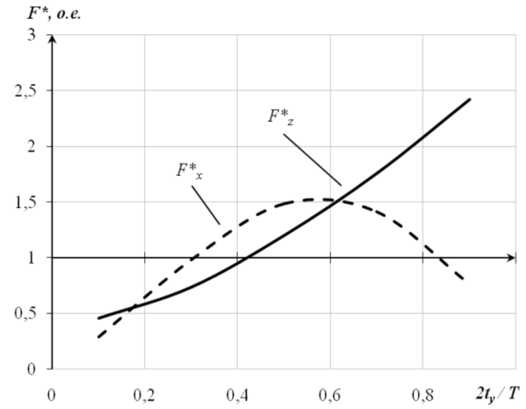


Figure 6: Components of the electromagnetic force with different parameters of the impulse relative the sinusoidal feeding.

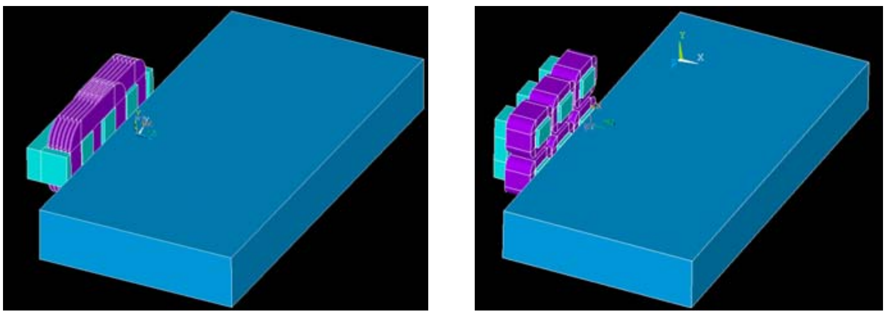
field changes with the course of time with a high speed (time t_n), and there are ring (vortex) currents appearing in the metal thickness. The currents interact with the field and create a force that brings metal into motion. For effective stirring of liquid metal in the bath, it is reasonable to influence the melt with the running electromagnetic field. For this there are two and more windings installed in the inductor that are fed with the source with the voltage equal in form and frequency but with the voltages shifted in phase. For example, for a two-phase inductor the phase shift between the voltages can be *T/4* (Fig. 4).

In order to determine the electromagnetic characteristics of MHD-stirring with non-sinusoidal periodical feeding with different values of a relative parameter $t_y^* = 2t_y/T$, a mathematical model of transition electromagnetic processes was developed. To check the developed mathematical model an experimental device consisting of a two-phase inductor with impulse power supply source was developed and constructed. The frequency of inductor supply is 3±0.3 *Hz*. The similar parameters were used to carry out the numerical modeling with the application of the developed mathematical model [6], as a result of which the dynamics of the electromagnetic field was obtained. The comparison chart for the data obtained is shown in Fig. 5. The mentioned charts show that the mathematical model correctly simulates the character of the magnetic field shape and can be used to analyze electromagnetic process in MHD-stirrers with non-sinusoidal periodical currents.

Fig. 6 shows computational dependencies of the electromagnetic force components on the relative parameter $2t_y/T$. The values of the electromagnetic forces are shown relatively to the force with non-sinusoidal feeding of the similar frequency.

As it follows from the charts shown, with $2t_y/T \geq 0.4$ the values of the both tangential and normal components of the electromagnetic force with non-sinusoidal feeding of the inductor winding exceed the similar values of the inductor windings fed with sinusoidal currents. In addition, the computations and measuring taken at the physical modeling have shown that in general the consumption of the reacting power decreases in comparison with an option when the inductor winding is fed with a sinusoidal current.

One of the problems of MHD-stirrers, installed from the bath side, is their low operational efficiency when the metal level in the bath is less than 0.3m. To solve this problem, it is proposed to use a stirrer with a transversal magnetic flux (Fig. 7b) [7].



a b

Figure 7: MHD stirrer with longitudinal and transversal magnetic fluxes.

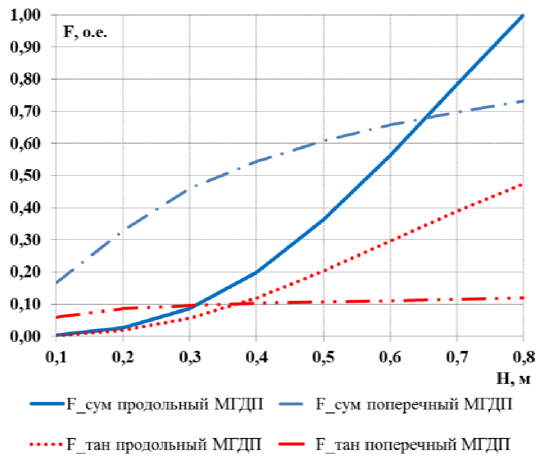


Figure 8: integral force values created by the electromagnetic field in the melt

To evaluate the operational efficiency of a MHD-stirrer with a transversal magnetic flux (Fig. 7b), numerical modeling of electromagnetic processes was made. For comparison, a MHD-stirrer with a longitudinal magnetic flux was chosen (Fig. 7a). Size, weight and power parameters of the stirrer with a transversal magnetic flux were similar to a MHD stirrer with a longitudinal magnetic flux.

Fig. 8 shows the obtained integral force values, created by the operation of the MHD-stirrer with longitudinal and transversal magnetic fluxes. There is a metal level in the bath along the axis of abscissas. There are force values in relative units along the axis of ordinates; the effort developed by the MHD stirrer with a longitudinal magnetic flux in the melt with the level of 0.8 m is taken as 100%.

As we see from the charts, when the furnace is fully filled with the melt, the stirrer with a longitudinal magnetic flux creates a great effort. However starting from the metal level of 0.6 meters the stirrer with a transversal flux is more efficient. When the metal level is less than 0.2 meters from the rated value, the stirrer with a transversal magnetic flux has a better operational efficiency. MHD-stirrers with a transversal magnetic flux installed on the furnace side wall are better to be used to provide efficient stirring in static melting furnaces with a low melt level (less than 0.3 m). In this case, the size, weight and power parameters will be similar to the existing devices.

3. Conclusion

1. In order to obtain the homogenizing melt in the whole volume of the furnace-stirrer bath it is necessary to carry out MHD stirring with reversing of the melt motion trajectory.
2. An MHD-stirrer with non-sinusoidal periodical currents carries out stirring of liquid metals in a more efficient way, at that the power coefficient increases and stirring time decreases.
3. For efficient stirring in static furnaces and stirrers with the melt level less than 0.3 meters it is reasonable to use MHD-stirrers with a transversal magnetic flux, installed from the side wall.

4. References

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