TRAVELING MAGNETIC FIELD PUMP

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Abstract
In this paper, we consider an MHD-pump generating a traveling magnetic field. It consists of six C-shaped inductors located one after another. A flat channel for pumping liquid metal is placed in the gap between the inductors. The cores are fed by the alternating current from the three-phase source and are connected in such a way as to provide generation of a traveling wave. Due to the pump construction, the electrical windings in such a pump are located at a safe distance from the heated channel with liquid metal. The channel can be quickly removed and placed back into the pump. The paper presents the results of experimental and numerical investigations of the temperature regimes and numerical simulation of the magnetic fields in the ferromagnetic cores of the pump inductor. Numerical computation has been done to evaluate the electromagnetic volume forces, acting on the transporting channel. The pressure drop- flow rate characteristics of the pump has been obtained for a gallium circuit. The workability of the pump has been tested in liquid magnesium.

Introduction
Application of the traveling field pumps in nonferrous metal casting industry has some restrictions, which are mainly due to design peculiarities of these pumps. Indeed, in the case of traditional design, the electric windings of such pumps are found to be in the immediate vicinity of the strongly heated channel, which leads to their overheating and eventually to rapid failure. Thus, for example, in a traveling field pump used for casting large-size magnesium ingots, the electric windings are the most frequently replaced pieces of the pump because due to extremely high temperature regime they fail very quickly. On the other hand, a traveling field pump has an elementary configuration of a straight channel, which can be easily and quickly made of a metal tube (as is usually done for liquid magnesium and similar metals), which is certainly an obvious advantage of these pumps over the other types.
The main feature that distinguishes the design of the traveling field pump from the standard linear pumps is the use of C-shaped inductors for generation of the traveling electromagnetic wave, which allows one to locate vulnerable coils at some distance form the hot channel with liquid metal. This, however, does not ensure a sufficient protection of the coils against their over heating by the hot channel walls and foreign currents (from magnetic dissipation fields) produced in the inductor cores. Therefore to reduce deleterious effects it is necessary to investigate the temperature hydrodynamic and electromagnetic fields in the constructional elements of the MHD pump [1].

Numerical calculation of electromagnetic fields
To simulate numerically the inductor of the traveling field pump it is necessary to calculate the distribution of the magnetic field. Such numerical calculations are essential for revealing the zone, in which the value of the magnetic field induction will be too high. With this approach, a magnetic field of the prescribed value can be generated in the gap of the inductor of rather small dimensions. The calculations of the electromagnetic fields have been carried out using the advantages of the ANSYS software product. The following computational scheme has been proposed: a model consisting of three inductors has been constructed in a three-dimensional space. The central inductor incorporates three biasing coils, while the neighboring inductors are considered passive. The advantage of this approach is that it allows us to take into account the dissipation of the magnetic field by closing the magnetic field through the neighboring passive inductors.
To fit the geometrical parameters of the model and to simplify the calculations we used two symmetry planes. The magnetic fields inside the inductor were calculated based on the non-linear characteristics of magnetization B-H.
The nonlinear characteristics of magnetization B-H used for calculations allowed us to reveal “weak” zones of the inductor, which are most liable to magnetic saturation (red zones with the value of the magnetic field of about 1.8T). Note that the value of the magnetic field in the gap of the inductor is the parameter that is also essential for the primary estimation of the characteristics of the traveling field pump. To gain a deeper insight into the interaction between the electromagnetic fields in the inductors of the traveling field pump, the magnetic field simulations were made for a variety of geometrical parameters. In particular, in the process of calculation we varied the size of the nonmagnetic gap of the inductor (30mm and 35 mm) and the thickness of the inductor (from 70mm to 110 mm).The results showed that the magnetic field in the gap increases with the inductor thickness. This can be explained by an increase in the inductor volume, which leads to a decrease in the saturation threshold, i.e. the magnetic field dissipation reduces essentially. A decrease in the width of the nonmagnetic gap has the same positive effect.

Hydrodynamic calculation
We consider a plane fluid layer (liquid metal) bounded by the solid walls. The planar dimension of such a channel is much greater than its thickness. A liquid metal in the channel is under the action of the volume electromagnetic forces. The flow occurring in the channel can be of a transit pattern [2].

The fluid flow in a plane channel under the action of electromagnetic forces is described by the Navier-Stokes equations. Here, the inductionless approximation is fulfilled on the basis that the velocity of the metal flow is low. Therefore the inverse effect of the flow on the magnetic field is neglected.
Thus, the velocity field of the turbulent flow in a plane channel has been defined using the above mentioned approximate equations. The numerical simulations have been carried out using the correlated scheme for velocity and pressure. The equations in partial derivatives are approximated by applying the conservative schemes of the finite–difference method. In the numerical realization of the boundary conditions for vorticity the internal iterations have been used.
We have calculated the patterns of the flow in the pump channel. The obtained results suggest that the interaction of the electromagnetic forces initiates in the channel an irregular vortex flow responsible for the appearance of the pulsations of pressure generated by the pump. The calculated average amplitude of pulsation was of order of 5% of the total pressure developed by the pump.

Thermal calculation

During pump operation, heat generation occurs in different elements of the pump. Liquid magnesium flows through a flat MHD-channel placed between the poles of cores. Although the channel is heated to 670 ^{0}C and heat-insulated, it transfers heat to pump cores, which leads to heating the pump elements. When an electric current passes through the pump coils, heat is generated. The temperature of some elements may be high and may exceed the threshold for heat resistance of the pump material. Therefore, we have performed a series of physical experiments on a physical model of the pump and appropriate thermal calculations for a pilot model of the pump. The purpose of these investigations is to design the pump structure, in which the temperature of its elements during pump operation would not exceed the threshold for heat resistance of the pump material.
Calculation of the temperature field in the elements of the MHD pump has been carried out by solving the relevant equations for heat radiation from the appropriate sources. Heat transfer boundary conditions are imposed on the external surfaces of the pump element. These are described by the corresponding approximate heat conduction equation (the Newton equation).

Physical experiment on a gallium circuit

The pump was tested on a gallium circuit. In experiments, the gallium alloy (Ga 87,5%; Sn 10,5%; Zn 2%) was transferred by the pump. The pressure drop-flow rate characteristics of the pump were determined for different values of the phase current in the pump.
To control the three-phase electric current, we used a special power source with partial compensation of the reactive energy of the pump. Pressure generated by the pump was measured with the measuring system METRAN, and the flow rate of the gallium alloy was measured using a conductance flow meter designed by the authors.
We applied these measurement results to obtain the pressure drop-flow rate characteristics of the pump for phase currents and the dependence of the maximal head pressure developed by the pump (in the absence of the flow rate) on the value of the phase current.

Physical experiment with liquid magnesium

The MHD-pump was tested in experiments with liquid magnesium. To this end, the pump was mounted on a special rack near the crucible furnace for liquid magnesium. Experiments showed that the pump successfully pumped magnesium from the crucible into the receiver tank. At phase current of 50 A, the height of the column of magnesium lifted by the pump was 1.2 m at the beginning of discharge and 1.4 m at the end of discharge. The average flow rate of the pump was 1.32 kg/sec. Because of the complexity of the experiment and the long-term preparation, no repeated experiments with magnesium were carried out, and therefore the spread of average flow rate values was not determined.

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