Influence of length of partitions on the generation of transit flow in MHD-channel

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Abstract. The process of the transit flow generation in the magnetohydrodynamic channel of the pump is investigated. Its design provides for the variation of the flow-rate of the liquid metal without changing the current in the channel. The pressure in the pump channel creates by an electromagnetic force through the interaction of a longitudinal electric current with its own magnetic field. C-shaped ferromagnetic cores are put on the channel. The current generates its own magnetic field which magnetizes the cores. The total magnetic induction vector of the current’s magnetic field and the field of the cores is orthogonal to the channel plane. The arising electromagnetic force generates a transit flow through the channel which is caused by the presence of flow partitions in it. The pump is tested on the gallium circuit. The pressure drop at the locked mode and variable flow rate mode for different values of channel overlapping by C-cores and their different numbers has been measured in the experiment. The pressure drop — flow-rate characteristics of the channel are determined at different values of overlap the channel.

1. Introduction

The use of various magnetohydrodynamic (MHD) devices in the liquid metals transport systems has been carried out for a long time. A significant development in this area was observed in the 60s and associated with progress in the field of nuclear energy due to the cooling of a nuclear reactor in which liquid sodium has been used as a coolant. At about the same time, the intensive application of MHD technology in metallurgy has began. The transportation of liquid metal using a ladle to the site of casting is most often used in production. This process is difficult to mechanization and automatation and so involves a considerable amount of hard and dangerous operations. It is should be noticed that when the metal is poured the ingots of relatively poor quality are obtained due to the content of non-metallic inclusions. It is also very difficult task to regulate the consumption of the melt. Besides the liquid metal can ignite in contact with atmosphere air. The typical example are liquid sodium and magnesium.

Currently, the safer and better way is to transport liquid metal using various electromagnetic pumps [1–6]. The development of industry needs the emergence of new type of pumps or the improvement of existing ones. Such a pump should be cheap to production and simple in its design. Thus, the study of MHD processes related to various operations in the foundry and the metallurgy is very important.

One of the promising areas is the use of the MHD channel with a ferromagnetic core as the main structural element. Consider the scheme of a conduction MHD channel using a C-shaped ferromagnetic core (Fig.1a) witch was taken from [7]. When the electric current $j$ passes
through the channel the ferromagnetic core is magnetized by the currents own magnetic field. The induction of \( B \) is creating in the gap. The interaction of the initial current and magnetic field generates an electromagnetic force \( \mathbf{F}_{\text{em}} = \mathbf{j} \times \mathbf{B} \), which causes the flow of a liquid metal.

\[ \text{Figure 1.} \] The sketch of the MHD channel with a ferromagnetic core (left) and the sketch of the experiment to determine the characteristics of the core and the generated electromagnetic force (right).

In this paper, the process of generating a transit flow in the magnetohydrodynamic channel of the pump is studied. The design of the pump provides the varying the flow-rate \( Q \) of liquid metal without changing the current \( j \) in the channel. A simple and reliable solution in this case is the mechanical movement of the cores which regulates the degree of channel overlap by ferromagnetic C-cores. Another advantage of this type of pump is the absence of windings. It allows to operate at high temperatures. The pressure drop \( P \) in the pump channel creates by electromagnetic force. The total magnetic field induction vector is orthogonal to the channel plane. It consists of current’s magnetic field in the nonmagnetic gap of the cores and the field of the C-cores. The arising electromagnetic force generates the transit flow through the channel which is caused by the presence of partitions in it.

The features and advantages of these channels are as follows. The current is supplied to the channel from an external source. Therefore, there are no copper windings in the channel. So, the pump can be used at high temperatures. The ferromagnetic C-cores are magnetized by their own electromagnetic field. This significantly increases the electromagnetic force and allows to govern its direction.

In [3,6–8] the approach of MHD channel to control the flow of liquid metal has been developed. For example, there were the transportation of metal between areas of metallurgical production. The works have been made in the laboratory of ICMM UB of RAS (Perm, Russia). In the above studies, the performance of the MHD channel was regulated by the magnitude of the current. Therefore, every characteristics are defined under the fixed position of the cores. The influence of the C-core position on the characteristics of the channels has not been studied.

There are tasks where it is necessary to fix the value of the current strength and at the same time change the flow-rate of the pump. An example is the electromagnetic purification of liquid metal in the MHD channel with transit flow [9,10]. One of the solution is to change the flow-rate by mechanically moving ferromagnetic cores. The purpose of this work is to study the influence of the ferromagnetic cores position and the geometry of the channel on the characteristics of the MHD pump.
2. Methods

At the first stage the experimentally determination of the characteristics of the C-core and the electromagnetic force (fig. 1b) has been performed. In this experiment, it was necessary to obtain characteristics of the C-core, without using it in a real channel with a liquid metal. The channel modelled by the plate 1 to which the C-core 3 was placed. The electrodes were connected to the tails of the plate. When the current form the current source 2 Heiden was turned the C-core was drawn into the plate (or vice versa). In this case, the mass change before and after the current was switched on was measured by the electronic scales 4. Thus, the dependence of the electromagnetic force on the supply current was measured at different positions of the C-core relative to the plate. The Hall sensor 5 of the Lakeshore 421 Gaussmeter was measured the components of the magnetic field in two directions depending on the current.

Further studies were carried out to the MHD channel (Fig. 2,3). In this paper the conduction type MHD channel is studied. An electromagnetic force is created in the pump channel by means of a conduction mechanism: electric current is supplied to the channel inlet and outlet from an external source. The flat channel of the pump having width $b$ is made of stainless steel. The fluid partitions with length $s$ are placed inside the channel (Fig. 2a). They are staggered and partially overlap the channel. There are small holes for exit the air during the channel filled with the liquid metal. The channel may be completely empty after the drain of liquid metal. The C-shaped ferromagnetic cores are placed on the channel. The overlap length is $h$ (Fig. 2a). The current generates its own magnetic field which pass into the cores. They are magnetized and the magnetic induction closes in the gap. Its vector is orthogonal to the current density vector. The arising electromagnetic force generates the flow through the channel (Fig. 2b), which is caused by the presence of partitions. The main advantage of the presented MHD pump is the ability to control the flow of liquid metal without changing the current in the channel. Sometimes it
is necessary to fix a certain value of the electric current in the channel but to change the metal flow-rate. The best and reliable solution in this case is the mechanical movement of the C-cores to adjust the degree of channel overlap $h$.

![Figure 4. Sketch of the gallium circuit.](image)

The working regimes of the pump was studied with the use of the gallium circuit of the ICMM UB RAS (Perm, Russia). The tubes having the internal diameter of 20 mm filled with a gallium alloy (Ga87.5%+Sn10.5%+Zn2%). The circuit equipment allows to change the hydraulic resistance of the circuit and to measure the pressure drop $P$ developed by the pump, the flow-rate $Q$ of gallium alloy and the current $I$ flowing through the pump channel. In the experiment the $PQ$-characteristics for different values of channel overlapping by C-cores $s$ and their different numbers $N$ were measured. The circuit includes storage tank 1 for the alloy (Fig. 4), expansion tank 2, vacuum system 3, system with inert gas 4 and filter 5. The flow is regulated by a valve 6 and the flow-rate $Q$ is measured by electromagnetic flow meter 7. The pressure drop $P$ is determined by the pressure gauges 8. The circuit is equipped with a water cooling system 9 and thermocouples 10. The pump 11 is connected to the pipeline 13 circuit with flanges. All measured data was transmitted to the computer using the NI DAQ and processed in the LabView system. The measurement error does not exceed 5%.

3. Results

The electromagnetic force generated by the MHD channel quadratically depends on the current (fig. 5a) passing through the channel. This indicates the absence of saturation of the ferromagnetic C-core. The magnetic field quickly disperses from the edges of the C-core (fig. 6). The greatest magnitude of the force is concentrated in the tail of the C-core in gap.

In the main part of the study the $PQ$-characteristics were obtained for various configurations of the MHD channel. Each of the $PQ$-characteristic is the dependence of the pressure drop between the channel entrance and its output on the flow-rate of the liquid metal flowing through the channel. The loss of pressure due to hydraulic resistance is significantly lower than the developed pressure.

In the every studied configuration there is a specific value of the overlap $s$ by the ferromagnetic C-core. If $s$ is less than critical the pump gives insignificant productivity. The productivity is the smallest for $s = 60$ mm (7a). The using only one C-core makes it impossible to precise control the characteristics of the pump output.
Figure 5. The dependencies of the electromagnetic force on the supply current (a) and the z-component of the magnetic field induction on the x-coordinate.

Figure 6. The dependencies of the magnetic field components on the y-coordinate: (a) x-component, (b) y-component, (c) z-component.

When the two cores are used in the same section, the result changes significantly (7b). For three upper positions of the C-cores the PQ-characteristics of the pump are close to each other and for two lower positions the PQ-characteristics are also close but in a different region. This feature of the systems behaviour does not allow to recommend this configuration for smoothing flow-rate control. The analysis showed that the least drastic change in the MHD pump output is for channel overlap $s = 70$ mm.

Figure 8 represents the PQ-characteristics of the pump for different current strengths at fixed position of one C-core having maximum overlap of the channel. At small values of the electric current the pump flow-rate is very weak. For the two lower current values the characteristics are close. The increase in current leads to increase in output which however stops after reaching the penultimate current value. This indicates the asymptotic evolution of the system to a certain state. After that the increase in current leads to insignificant increase in output. Thus there is no need to use the greatest values of the current strength to achieve the greatest output.

The PQ-characteristics of most of the channel configurations are close to linear. It indicates a small value of hydraulic resistance. At the same time the nonlinear segment is observed (fig. 8b) for the case of using all C-cores at a high flow-rates. The large flow-rate leads to increase the influence of gallium circuit hydraulic resistance on the output. However there is a clear quantitative difference between PQ-characteristics for different currents in the case of using all the C-cores in the pump.
Figure 7. PQ-characteristics for the various positions of the ferromagnetic cores: (a) one core in the first section, (b) two cores in the first section.

Figure 8. PQ-characteristics for the various positions of the ferromagnetic cores: (a) one core in the first section, (b) all six cores in all sections.

4. Conclusions

In the present study, several channels with C-shaped cores have been investigated. The electromagnetic force quadratically depends on the current passing through the channel. It indicates the absence of saturation of the ferromagnetic C-core. The magnetic field quickly disperses from the edges of the C-core. The maximum of the magnetic field is in the gap between the poles at a distance of 10 mm from its tail. The output of the pump is insignificant when the value of C-core overlap length $h$ is smaller than some value for all configurations of the channel. This value is the smallest for partitions size $s = 60$ mm. The most smooth change in the output of the pump occurs for partitions size $s = 70$ mm.

The PQ-characteristics is flat and close to the linear for the most channel geometries. It indicates a small value of hydraulic resistance of the channel. The results of th study will be used to verify the mathematical models of these devices which has been developed in [3,6,8,11]. The MHD pumps of the output capability mentioned above can be used in metallurgy for pumping and pouring of molten metals.
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