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PUMPING EFFECT IN Y- AND Ψ-SHAPED CHANNELS WITH Π-SHAPED CORES

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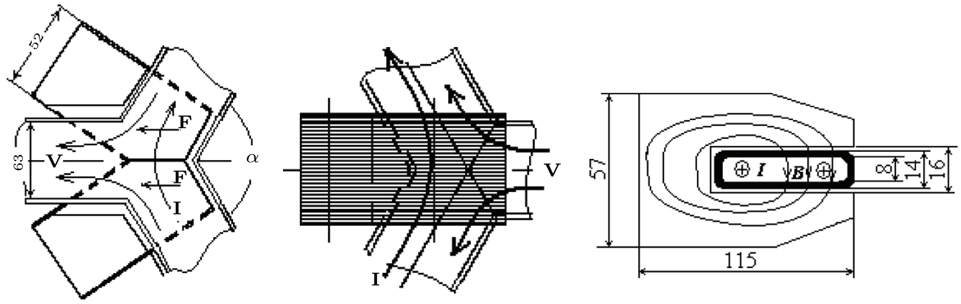
The hydrodynamic characteristics of Y- and Ψ-shaped channel of the MHD pump are studied both experimentally and numerically. Calculation of magnetic and hydrodynamic fields in MHD channels is performed. The pressure drop – flowrate characteristics of these fields are determined. The obtained data are compared with the results of physical experiments carried out using a gallium circuit.

1. Introduction. Under certain conditions, the interaction between the electric current passing through the liquid metal in the MHD channel and its own magnetic field seems to be the main cause of the pumping effect in this channel. The MHD pumps operating in this way are sometimes called "winding free" to emphasize the fact that they do not use electric windings for magnetic field generation. The pumps of this type usually have special ferromagnetic cores, which enhance the magnetic field of an electric current passing through the channel and create a certain kind of magnetic field distribution. The magnetic field and the electric current interact, thus producing an electromagnetic force, which drives the liquid metal into motion. The winding free MHD pumps operating in the above-mentioned way have found applications in foundry. For instance, these pumps are in service at Berezniki JSC AVISMA Ltd. Company and Solikamsk Magnesium Plant (Russia), where they are used to supply liquid magnesium to the foundry conveyer. These pumps have a very simple design, which makes it possible to manufacture the channels at the plant where the pumps are employed, and offer no problems when replacing the one channel with a new one. Moreover, the pumps can be easily operated and maintained.

2. Presentation of the problem. The channel of the pump under consideration consists of three flat branch pipes welded in the form of letter Y. The welded joint is embraced by one or two Π-shaped ferromagnetic cores (Fig. 1). An electric current, which passes successively through two of the three branch pipes generates a magnetic field, which is enhanced by the Π-shaped ferromagnetic cores. This magnetic field interacts with the electrical current, producing a volumetric force, which creates the pumping effect in the channel.

Depending on the position and orientation of the cores embracing the Y-shaped channel, the liquid metal flows in the channel in one direction or in the opposite one (Fig. 1). This specific feature of the channel is utilized in the design of the MHD-pump, where the channels are arranged in series along a single pipeline [1], and so the pump of this type develops a higher pressure than the pump with one Y-shaped channel [2].



(*a*) (*b*) (*c*)

Fig. 1. The Y-shaped channel with two (*a*) and one (*b*) Π-shaped cores. (*c*) Schematic illustration of the lines of the magnetic field generated by the electrical current in the channel with a Π-shaped core.

In the channel of such a pump, in the zone near the ferromagnetic core edges, where the magnetic field is strongly non-uniform, a vortex flow occurs, which essentially contributes to the appearance of the pumping effect [3]. In the Y-shaped channel, at the welded joint of the branch pipes, the pumped metal flow rotates at some angle that has an impact on the hydrodynamic characteristics of the channel. Therefore, it is reasonable to determine the dependence of the hydrodynamic characteristics of the Y-channel on its geometrical parameters, e.g., on the angle α between the branch pipes, through which the electrical current passes (Fig. 1).

The flow of liquid metal in a flat Y-shaped channel is described by the approximate two-dimensional equations:

$$\begin{cases} \dfrac{\partial V_x}{\partial t} + \dfrac{\partial V_x^2}{\partial x} + \dfrac{\partial V_y V_x}{\partial y} = -\dfrac{\partial p}{\partial x} + \Delta V_x + \kappa_1 V_x + \kappa_2 \mid \mathbf{V} \mid V_x + \tilde{S} f_x \\ \dfrac{\partial V_y}{\partial t} + \dfrac{\partial V_x V_y}{\partial x} + \dfrac{\partial V_y^2}{\partial y} = -\dfrac{\partial p}{\partial y} + \Delta V_y + \kappa_1 V_y + \kappa_2 \mid \mathbf{V} \mid V_y + \tilde{S} f_y \\ \qquad \dfrac{\partial V_x}{\partial x} + \dfrac{\partial V_y}{\partial y} = 0 \end{cases}$$

Here, for length, velocity and volume forces, the following quantities are taken: h is the layer thickness), ν/h (ν is the kinematic viscosity of the liquid), f_0 is the characteristic value of the volume forces in the layer. $\tilde{S} = (f_0 h^3)/(\rho \nu^2)$ is a dimensionless complex. The condition, at which the velocity of liquid metal tends to zero, is imposed on the lateral walls of the channel.

Based on the known velocity field and volumetric electromagnetic forces and using the Poisson equation, we have found the pressure field to determine the head pressure developed by the pump for different values of the metal discharge through the channel

$$\Delta p = 2\left(\frac{\partial V_x}{\partial x}\frac{\partial V_y}{\partial y} - \frac{\partial V_y}{\partial x}\frac{\partial V_x}{\partial y}\right) + \kappa_2\left(V_x \frac{\partial \mid \mathbf{V} \mid}{\partial x} + V_y \frac{\partial \mid \mathbf{V} \mid}{\partial y}\right) + \tilde{S}\left(\frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y}\right).$$

The results of numerical experiments show that the pressure generated in the Y-shaped channel with two cores (Fig. 1*a*) is dependent not only on the strength of the electric current passing through the channel, but also on the angle α between the channel branch pipes. It has been found that at some angle the pumping effect can be maximal (Fig. 2). The edges of the Π-shaped cores generate an

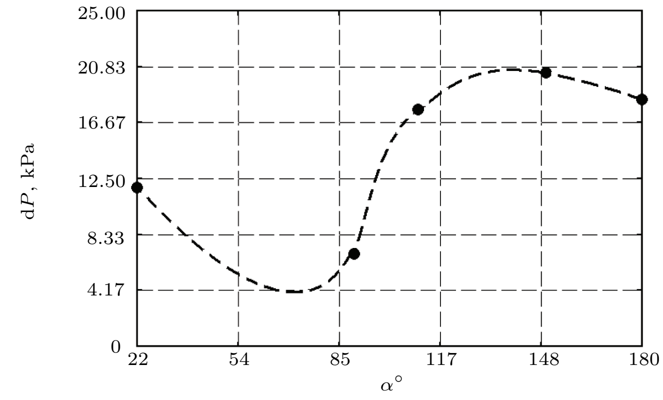


Fig. 2. Calculated relationship between the pressure generated in the Y-shaped channel and the angle α at 3000 A (core arrangement is similar to that shown in Fig. 1). It can be readily seen that the highest pressure is developed by the channel when the angle of divergence of branch pipes lies in the interval 110° to 180°.

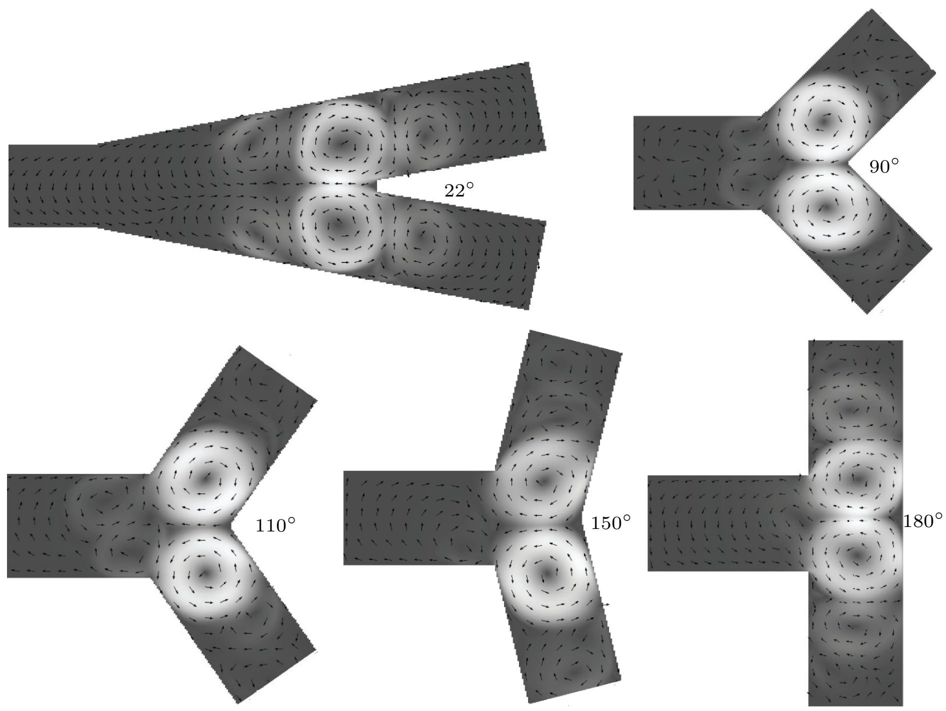


Fig. 3. Velocity fields in Y-channels for various angles α between the inlet branch pipes. Two *Pi*-shaped cores embrace the channel in a way similar to that shown in Fig. 1.

electrovortical flow in the channel. When the angles α are small or equal to 180°, the vortex pattern becomes unstable with time. The calculations indicate that at these angles the alternate strengthening and weakening of the left and right vortices in the channel takes place (Fig. 3). At intermediate angles ($\alpha = 150°$), the pattern of the vortex seems to be the most stable structure, and the pressure generated by the Y-channel is maximum (Fig. 2).

As already mentioned above, during the operation of the channel, the pumped metal flow undergoes rotation at some angle at the welded joint of the branch pipes in the Y-shaped channel, which impairs the hydrodynamic characteristics of the

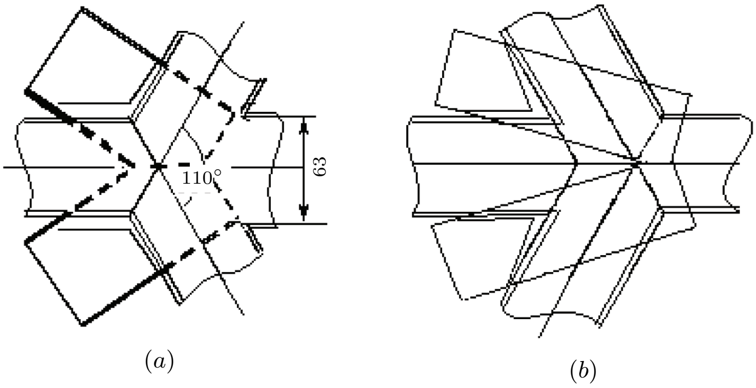


Fig. 4. The Y-shaped channel embraced by ferromagnetic cores in two different ways.

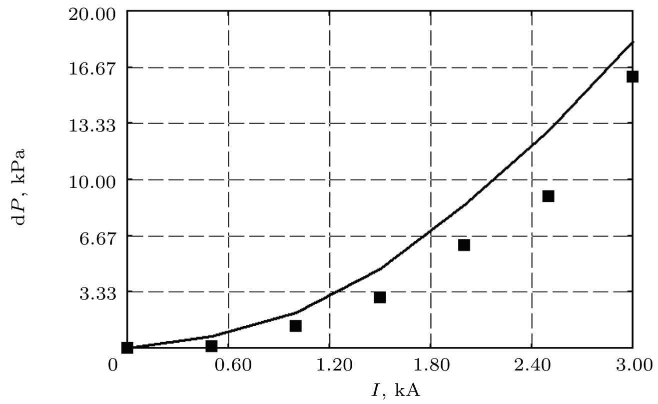


Fig. 5. Pressure drop developed by the Ψ-channel in the gallium circuit at stop regime versus the electrical current value (core arrangement is similar to that shown in Fig. 4*a*). Dots show the experimental data, and the solid line indicates the results of calculation.

channel. To improve these characteristics, the channel can be supplemented with an additional branch pipe, and, as a result, the main metal flow goes through the channel without bends, i.e., it does not lose energy. Such channel is the Ψ-shaped channel, where the liquid metal runs through the channel middle part and the electric current through the lateral branch pipes. If the channel is embraced by two Π-shaped cores in the same way, as in the case of the Y-channel (Fig. 4*a*), the interaction of the electric current in the channel with the magnetic field enhanced by the cores will give rise to volumetric electromagnetic forces, which will produce the pumping effect in the channel.

With reference to the results of calculations and experiments, we can conclude that the pressure developed in the Ψ-shaped channel only slightly differs from that developed by the Y-shaped channel (Fig. 5). An analogous situation was observed under the flow rate regimes of these channels (Fig. 6). It is convenient to combine the Ψ- and Y-shaped channels with similar series-connected channels. The pressure developed by such a tandem might be higher than that developed by a single channel (Fig. 7).

It has been found experimentally that the Ψ-shaped channel tandem develops a pressure, which is somewhat higher than the pressure generated by the tandem of Y-shaped channels. Therefore, unlike the Ψ-shaped channel with cores arranged,

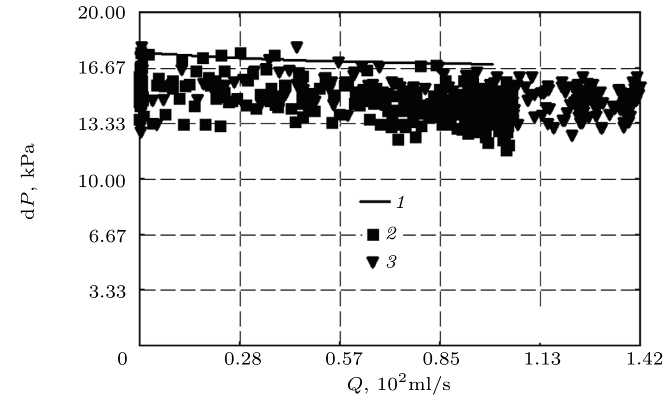


Fig. 6. Experimental pressure drop – flow rate characteristics of Ψ-shaped (2) and Y-shaped (3) channels (core arrangement is similar to that shown in Fig. 4*a*). The electric current is 3000 A. Solid line (*1*) indicates the results of calculation for the Y-shaped channel.

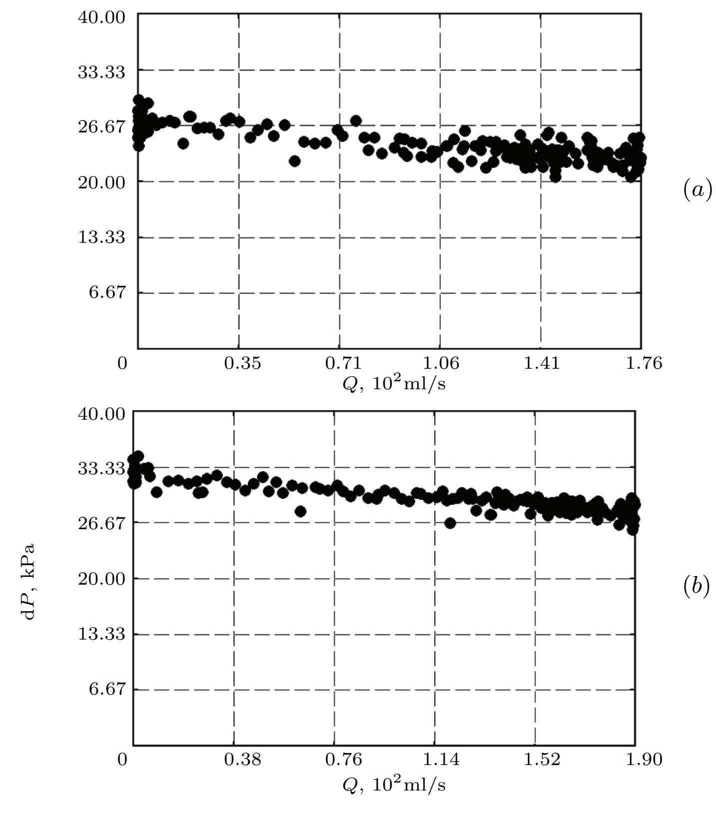


Fig. 7. Experimental pressure drop – flow rate characteristics of Ψ- and Y-shaped channels with similar series-connected channels: (*a*) for two connected Y-shaped channels; (*b*) for two connected Ψ-shaped channels. For the Y-shaped channels, the core arrangement is the same as in Figs. 1*a*,*b*, and for the Ψ-shaped channels it is the same as in Figs. 4*a*,*b*.

as shown in Fig. 4*a*, the Y-shaped channel with cores arranged, as shown in Fig. 4*b*, develops a pressure, which is still higher than the pressure generated by the Y-shaped channel.

3. Conclusion. The numerical and physical experiments have shown that the head pressure developed by the winding-free MHD pump with a flat Y-channel is dependent on the channel geometry. It is shown that there is an angle between the branch pipes of the channel, where the head pressure generated by this channel achieves its maximum. By combining two channels, one can significantly increase the head pressure developed by the MHD pump, and the incorporation of an additional central branch pipe into the channel (two channels are combined) causes a further increase in head pressure value.

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