ELECTROVORTEX PUMPS

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Introduction. The necessary condition for initiation of the pumping effect is the requirement that the lines of the electric current must cross the streamlines of the transient flow in the channel [1, 2]. This is usually achieved in two ways: either by supplying the electric current to the channel through the walls via special electrodes or by placing inside the channel current conducting partitions [1, 2]. The channel thickness is normally much less than its planar dimension. A turbulent flow in such a channel can be described by two-dimensional equations obtained by averaging the Navier–Stokes equations based on the shallow water approximation. Here we assume that the turbulent friction in the liquid is defined by friction of viscous sub-layers at the lower and upper boundary walls [3, 4]

$$\partial_t \mathbf{V} + (\mathbf{V}\nabla)\mathbf{V} = -\nabla P + \Delta\mathbf{V} + (\kappa_1 + \kappa_2\,|\mathbf{V}|)\mathbf{V} + S\gamma\mathbf{f}^{\mathrm{em}}, \qquad \nabla\cdot\mathbf{V} = D(x,y).$$

1. Kabakoff's pump. At the beginning of 60-ies Stock Company "AVIS- MA" use windingless MHD-pumps (Fig. 1) for casting magnesium ingots. The pump consists of three plane branch pipes butt-welded at the angle of 120°. The current of 4-5 kA takes the path through the two branch pipes.

The Π-shaped core fitted over the pipes enhances the magnetic field of the current and conducts it to the channel. In the channel the electric current interacts with the magnetic field and generates the electromagnetic forces, which pull the metal out of the third branch pump. In such a way the whole system acts as a metal transfer pump. The tests on the gallium setup and the results of numerical experiments show that the maximum pressure developed by this type of the pump is not large (Fig. 2). This pump is easy to manufacture and operate but suffers from a number of drawbacks: The Π-shaped core fitted over the pipes enhances the magnetic field of the current and conducts it to the channel. In the channel the electric current interacts with the magnetic field and generates the electromagnetic forces, which pull the metal out of the third branch pump. In such a way the whole system acts as a metal transfer pump. The tests on the gallium setup and the results of numerical experiments show that the maximum pressure developed by this type of the pump is not large (Fig. 2). This pump is easy to manufacture and operate but suffers from a number of drawbacks:

- Prior to actuation the channel of the pump must be filled with liquid metal.
- The electric current is delivered to the channel via special (copper) buses welded to the pump body. Since the channel walls are heated to a high temperature, the welds at the buss joints rapidly fail.
- The pump generates a rather low pressure

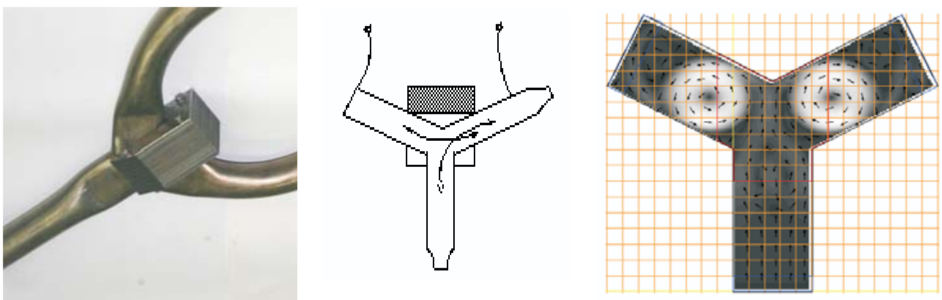

Fig. 1.

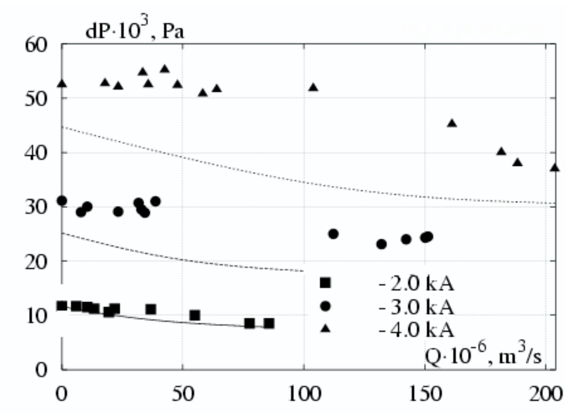

Fig. 2.

2. Push-pull pump. One way to increase pressure generated by the pump is to locate two Kabakoff's pumps in tandem. The cores of one of these pumps are arranged in such a way that the electromagnetic forces push the metal through the third channel rather than pull it in.

The results of numerical experiments and gallium circuit tests showed that such an alternate can produce a higher pressure (Fig. 3) and has the advantage of being free from brass bus leads.

The electric current is delivered to the channels through the metal conveying pipe-line where it is induced by special transformer. However, before starting, it is necessary to fill the channels of this pump with liquid metal – to perform preliminary vacuumizing operation.

3. Tandem pump. To increase the head (discharge) pressure, the main metal pipe-line is equipped with a cascade system of pumping cells (Fig. 4). Each cell represents a plane channel with the internal conducting partition, which provides crossing of the electric current lines with the hydrodynamic streamlines of the transient flow.

The Π-shaped ferromagnetic yoke embraces the cell and enhances the magnetic field generated by the current flow through the cell. The current is led into the cell through its inlet and outlet, so that the cells can be distributed in series over the metal pipe-line, which in this case serves as an electric conductor. In the tandem pumps the bus leads are replaced by metal conveying pipe-lines, which allows us to transform the pump into a submersible model. It is merely placed into a protective housing, after which it can be readily submerged into a melt. In this case, the pump channel will always be filled with liquid metal which renders the vacuumizing procedure unnecessary. The results of numerical experiments and gallium circuit tests led us to conclude that the pressure

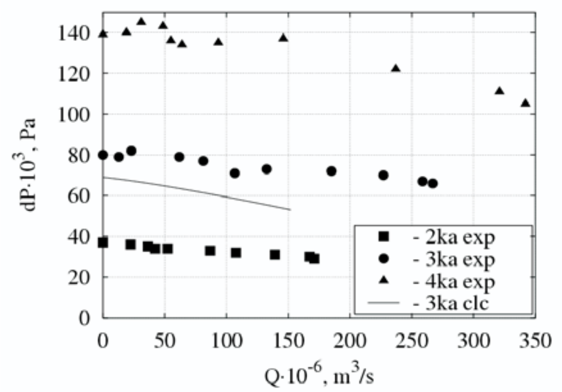

Fig. 3.

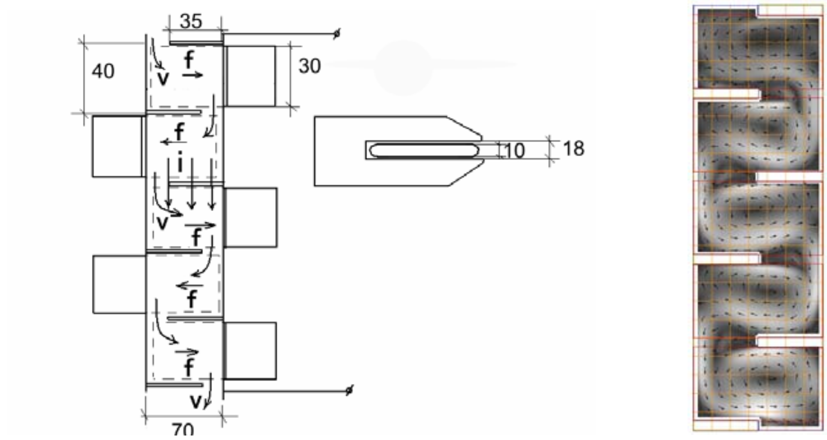

Fig. 4.

developed in the 5-cell pump at the current of 2000 A is higher than that in the Kabakoff's pump (Fig. 5).

A submersible pump composed of 11 pumping cells was manufactured at our laboratory and was tested for liquid magnesium pumping at the Solikamskiy magnesium works. The testes showed that during operation the pump cleans the metal from non-metallic inclusions, which, in the long run, choke the channel of the pump causing it to collapse. Since the number of the partitions in the channel is rather great its cleaning poses serious problems.

4. Pumps with L- and Z-channels. Intersection of the electric current lines and streamlines of the transient flow can be achieved without usage of conducting partitions. By initiating a vortex motion in the channel it is possible to disturb the streamlines of the transient flow in such a way that they begin to cross the lines of the electric current giving rise to pumping effect. As an example let us consider a plane L-channel with a liquid metal, through which an electric current is passed. The Π-shaped yoke is placed round the channel as shown in Fig. 6. The edges of the yoke generate a vortex flow, which disturbs the streamlines of the transient flow making them cross the current lines. The pumping effect arising in this case is not large. The pump tested in gallium experiments generated the discharge pressure of about 2000 Pa at the current value of 1600 A.

To increase the head pressure L-channels are connected successively in the Z-channel. According to the results of numerical and physical experiment the head pressure generated in this device is much higher than in the L-channel, Fig. 7.

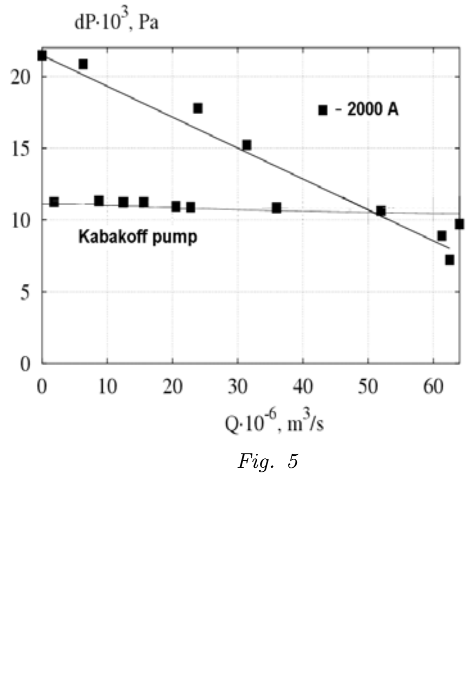

Fig. 5

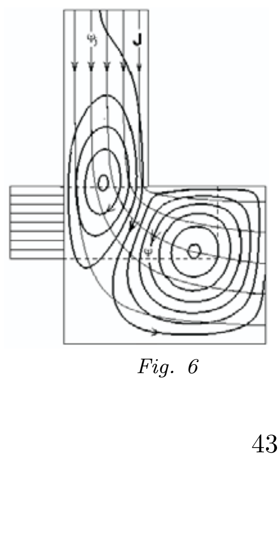

Fig. 6

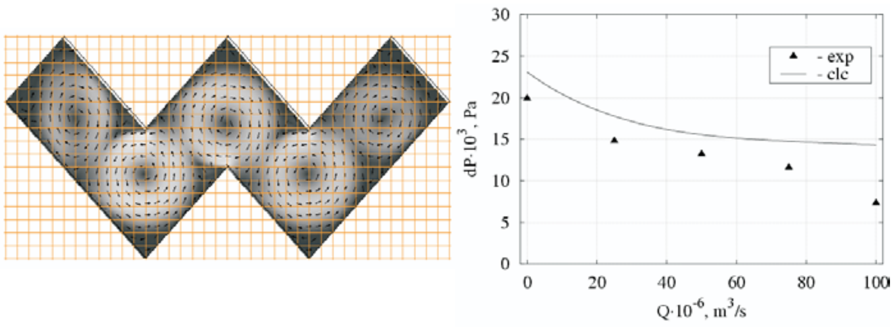

Fig. 7

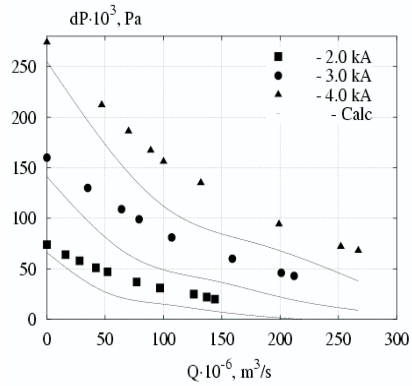

Fig. 8 *Fig. 9*

5. Electrovortex centrifugal pump. Among windingless MHD-pumps discussed in this paper the electrovortex centrifugal pump generates the largest head pressure and flow rate. In this model, the same pipe line is used for current supply and metal transfer. A number of ferromagnetic yokes placed round the channel increase the magnetic field of the electric current flowing through the channel. The interaction of the current with its own magnetic field generates in the channel a vortex flow of liquid metal and the arising centrifugal forces produce the pumping effect (Fig. 8). The numerical calculations, physical experiments on the gallium circuit and liquid magnesium tests show that this pump outperforms its counterparts in almost all characteristics (Fig. 9) This type is designed and constructed to provide a reliable and simple operation. As practice showed, even short instructions were sufficient to teach foundry workers to operate the pump.

The only disadvantage revealed during tests is the difficulty with its re-actuation after a long period of idle time.

The pump was used in the foundry shops of "AVISMA" Ltd company as a device for liquid magnesium transfer to casting conveyer and as an element of continuous casting plant for large-scale ingots. It was also used at the Solikamskiy magnesium works for continuous casting of large-scale and round ingots.

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REFERENCES

1. S.Yu. Khripchenko. Electrovortex flows in thin layers of conducting fluids. *Magnetohydrodynamics*, vol. 27 (1991) no. 1, pp. 115–119.
2. S. Denisov, V. Dolgikh, S. Khripchenko. Electrovortex MHD-pumps. In *Proc. 4^{th} Intern. PAMIR Conf. "Magneto Hydro Dynamic at Dawn of Third Millennium"* (Presqu'île de Gien, France, 2000), vol. 2, pp. 687–692.
3. M.E. Mann, S.Yu. Khripchenko. *Magnetohydrodynamics*, vol. 28 (1992) no. 1, pp. 77–84.
4. I. Kolesnichenko, S. Khripchenko. *Magnetohydrodynamics*, vol. 38 (2002) no. 4, pp. 391–398.