EXPERIMENT AND NUMERICAL SIMULATION OF NEW TYPE MHD PUMP USING ROTATING TWISTED MAGNETIC FIELD

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Introduction. Recently, applications of electromagnetic force are developed in the steelmaking process handling molten steel of over 1500°C [1]. Until today, however, there is no electromagnetic pump applicable to hightemperature molten metals, such as molten steel. At present, the annular linear induction pump (ALIP) is one of the most familiar conventional induction pumps [2]. It has an iron core installed in the duct so that the magnetic field may traverse the flow. However the iron core loses the ferromagnetic property when temperature is higher than its Curie point. Therefore, the ALIP are not applicable to high-temperature molten metals.

The authors have proposed and studied a new type MHD pump using a rotating twisted magnetic field, applicable to high-temperature molten metals [3]–[5]. The stator of our proposed machine generates the rotating twisted magnetic field by a helical coil (see Fig. 1*b*). This pump does not need the iron core in the duct because the rotating twisted magnetic field can traverse the center of the duct, as shown in Fig. 1*c*. This field gives axial thrust to a secondary conductor as well as rotational torque. Hence, the proposed machine has both properties of the linear pump and the rotary stirrer.

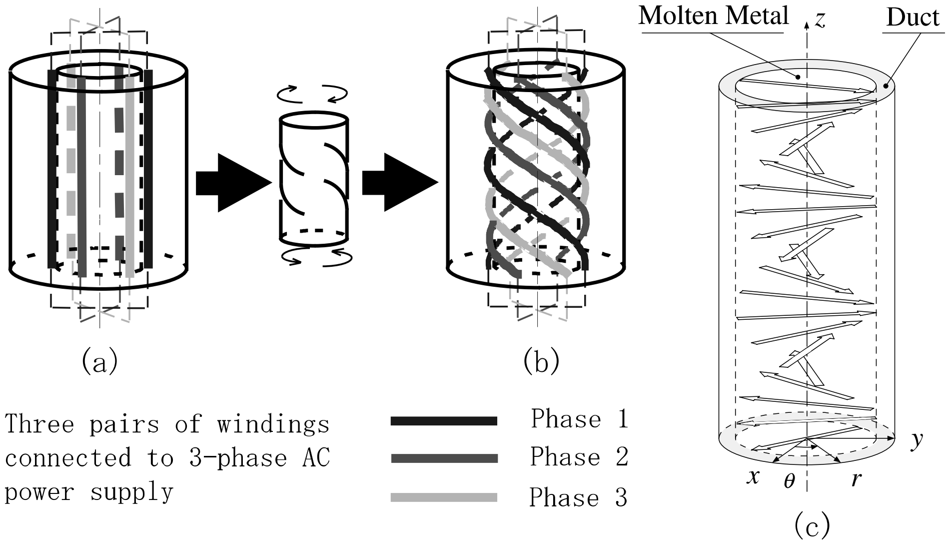


Fig. 1. Windings and magnetic field. (*a*) Stator of an ordinary three-phase induction motor. (*b*) Stator of the induction pump for high temperature molten metals: three pairs of helical windings. (*c*) Rotating twisted magnetic field.

We carried out a molten metal circulation experiment using molten gallium at 50°C. This paper reports on the results of the circulation experiment. In addition, we performed numerical simulation at the same condition as an experiment under the magnetic Stokes approximation for small shielding parameter. This paper also reports on the results of the numerical simulation.

1. Experimental apparatus.

1.1. Stator. A prototype stator with three pairs of helical windings has been fabricated for this molten gallium circulation experiment. The photographs of the stator are shown in Figs. 2*a*, *b*. This stator doesnt have any teeth and slots. This stator can continue to operate for long periods owing to water cooling.

1.2. Molten gallium circulation system. The molten gallium circulation apparatus is shown in Fig. 2*c*). This duct system has a needle valve at downstream of the flowmeter. This needle valve regulate pressure drop of duct system. The rotating twisted magnetic field creates an axial flow with swirl. To eliminate the swirl effect on the pressure measurement, perforated plate conditioner with 35 holes are mounted in this duct system [6]. Four of the perforated plates are mounted in a symmetrical configuration with respect to the longitudinal center of the stator between the inlet and the outlet pressure transducer.

2. Results of experiments.

2.1. Pressure for various input powers. The developed pressure Δp was then measured for various input powers P, where Δp is defined as the difference in the static pressure between the outlet and inlet of the pump. This result is shown in Fig. 3*a*. This experiment was performed at three frequencies: 50, 250 and 400 Hz. The needle valve in the duct system was at the full-open position. The error bar of the developed pressure shows the sample standard deviation. This

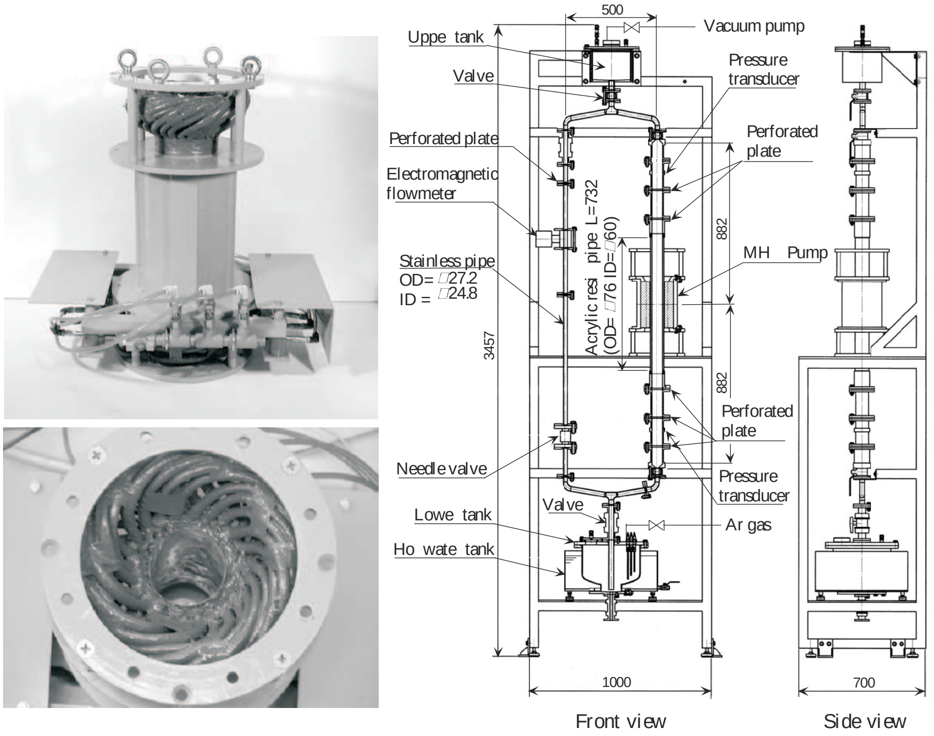
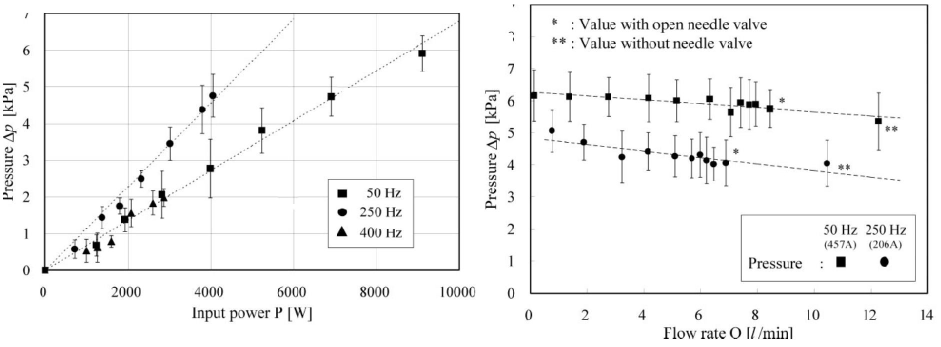


Fig. 2. Experimental apparatus.

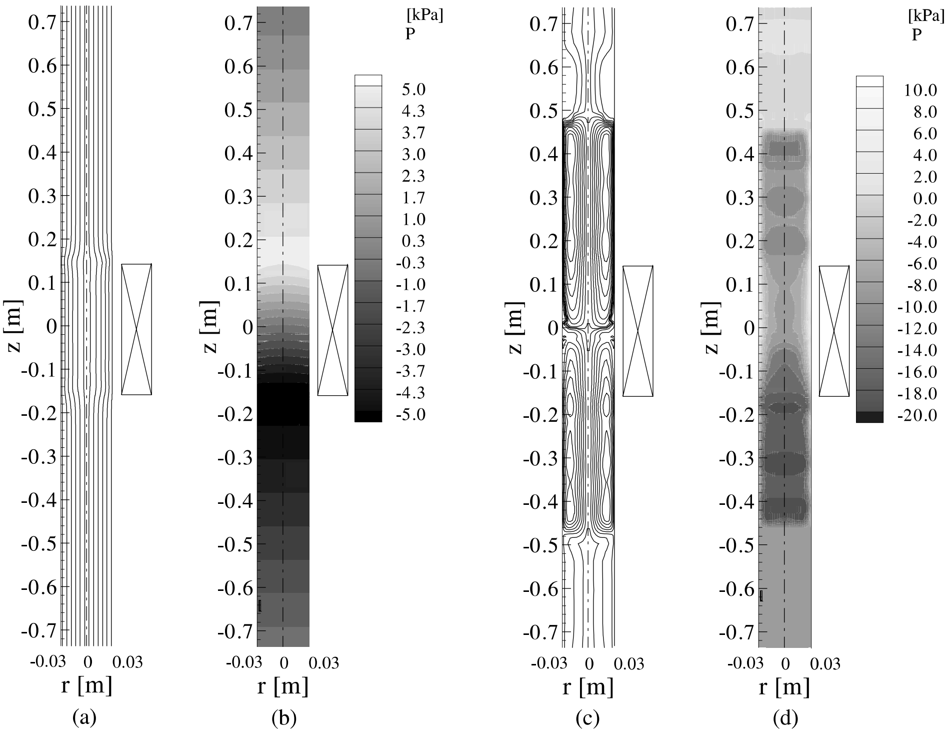


(*a*) (*b*)

Fig. 3. Experimental results. (*a*) Developed pressure for various input power. (*b*) Pump characteristics.

result shows that the developed pressure is nearly proportional to the input power for each frequency.

2.2. Pump characteristic. The pressure-flow rate characteristic of the proposed MHD pump is shown in Fig. 3*b*. This figure shows results at 50 and 250 Hz. Phase current, line voltage and power factor were 457 A, 18 V, 65% at 50 Hz and 206 A, 29 V, 39% at 250 Hz, respectively. This measurement has been performed for various open states of the needle valve. The maximum flowrate points (**) of each frequency were measured by replacing the needle valve with a straight duct. These values were almost constant through the measurements.



b

Fig. 4. Streamtube and pressure distribution at $t = 0.01$ s (*a*),(*b*) and at quasi-steady state (*c*),(*d*).

Table 1. Result of numerical simulation at 50 Hz.

	Current I, A	Flow rate Q, l/min	Pressure Δp, kPa	Maximum Velocity U_θ, m/s
Measurement	457	$8.46 \pm 0.3\%$	$5.91 \pm 8\%$	(3.55)
Numerical simulation	457	10.2	9.31	5

3. Results of numerical simulations.

3.1. Results at a starting condition. Fig. 4 show the streamtubes and the pressure distribution of molten gallium in the duct at $t = 0.01$ s. Fig. 4*a* shows that Lorentz force practically acts on the range of the height of the stator. Fig. 4*b* shows that pressure rise is generated between the inlet and the outlet of the pump and the proposed machine works as a pump.

3.2. Results at quasi-steady state. Table 1 shows the results at quasisteady state of 50 Hz obtained by the present simulation. The flow rate of the numerical result agrees with the experimental result within an error of 21%. This overestimation is caused by the fact that the numerical simulation does not accurately take account of the energy dissipation in turbulence. Besides, the result of the maximum circumferential component of velocity U_θ agrees with the predicted value obtained from the measurement within an error of 40%. This result suggests the validity the slip-pressure function given in the previous paper [5].

The streamtubes of molten gallium at quasi-steady condition are shown in Fig. 4*c*. From Fig. 4*c*, it is confirmed that the excessive spiral flow produces a secondary inward flow in the boundary layer [7] along each perforated plate. This secondary flow forms a pair of upper and lower big torus recirculating flows between two perforated plates. Because the torus circulation dominates the molten gallium flow in the longitudinal cross section, the streamline going through the pump is passing complicated course.

The pressure distribution in the duct is shown in Fig. 4*d*. Since the excessive swirl flow develops, its centrifugal force produces high pressure at the duct wall and low pressure around the central axis. This pressure distribution is similar to that of a centrifugal pump, however the proposed system functions as an axial pump producing an axial flowrate.

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