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The Optimum Design Analysis of the Small DC Electromagnetic Pump with Loop-Supported Type

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1. Introduction

Electromagnetic pumps have been employed to the liquid metal experiments including transportation of liquid sodium in a sodium fast reactor (SFR). Recently, the approach to the heat exchange between sodium and carbon dioxide, which is known to be less reactive with sodium than water, is being attempted in Korea. In the present study, the conceptual design of the DC electromagnetic (EM) pump, which has the flowrate of 3L/min and the developed pressure of 0.2 bar in the temperature of 500℃, for circulating liquid sodium in the test loop for sodium-carbon dioxide reaction experiment is carried out.

2. Analysis

The DC electromagnetic pump is divided into liquid sodium fluid with the high electrical conductivity, metal duct, magnet and electrode for generating electromagnetic force as shown in Fig.1.

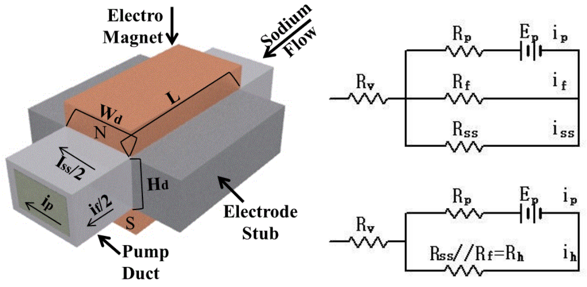

Fig.1. Schematic of the DC EM pump and its equivalent circuit

In Fig. 1, the equivalent circuit of the pump includes the electric potential (electro motive force), the resistance by liquid sodium and stainless steel duct, contact resistance, and fringe resistance.

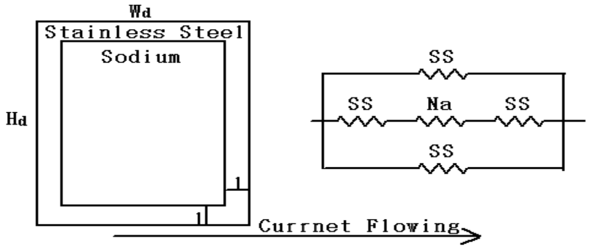

Fig.2. The cross-sectional view of the DC EM pump

Actually, the liquid sodium flows through the duct with the stainless steel as represented in Fig. 2, and so the resistance by it should be considered. Applying Kirchhoff's law for the circuit and balancing the electric input and hydraulic output, the relation between the input current and developed pressure including geometric variables was obtained in the Eq. (1).

$$i_t = \frac{\Delta P\left(R_h + R_p\right)(H_d - 2l)}{BR_h} + \frac{BQ}{R_h(H_d - 2l)} \qquad (1)$$

Where

$$R_p = \frac{\rho_{Na}(W_d - 2l) + 2\rho_{ss}l}{(H_d - 2l)L}$$

$$R_f = \frac{\rho_{ss}(\rho_{Na}(W_d - 2l) + 2\rho_{ss}l)}{k[(W_d)H_d\rho_{ss} + 2l\{\rho_{Na}(W_d - 2l) + 2\rho_{ss}l\}]}$$

$$R_{ss} = \frac{\rho_{ss}(W_d - 2l)}{2Ll}$$

$$\frac{1}{R_h} = \frac{1}{R_f} + \frac{1}{R_{ss}}$$

In Eq. (1), the input current is calculated on the change of the variables such as the length, width and height of the pump under the requirement of the flowrate of 3L/min and the developed pressure of 0.2bar. The height of the pump ($\mathrm{H_d}$) could be expressed by the width of the pump duct ($\mathrm{W_d}$) using $\mathrm{U} = \mathrm{Q}/(\mathrm{H_d} - 2l)(W_d - 2l)$. Using the MATLAB, finding optimized value for DC EM pump.

3. Result

The maximum length of the electrode stub (or pump length) was 0.10 m considering the space of the pump occupied at the test loop where the geometrical variables of the stainless steel duct thickness had the value of 0.001 m, and $\mathrm{H_d}$ is adopted minimized value which is 0.004m. The permanent magnet with the magnetic flux density of 0.3T was considered for generating electromagnetic force. In the DC EM pump, current is most powerful factor which decide cost problem. In order to make reducing cost, minimize current is needed. Fig. 3 shows the input current on the change of the width and length of the pump duct which are impacted on total current. As a result, the optimum width and length of the pump duct was found from the lowest point in Fig. 3. The fringe factor of the pump was 0.5272. Consequently, the DC EM pump had the geometrical and electrical design values with the width of the pump duct of 0.03311 m, the height of the pump duct of 0.004 m, the length of the pump of 0.10 m and the input current of 337.6 A, respectively.

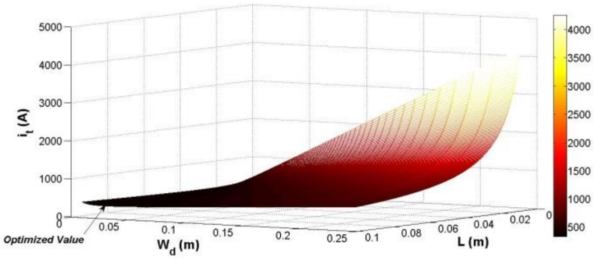

Fig.3. Input current according to change of duct width

On the other hand, the viscous effect by the flow of liquid sodium in the pump was negligible compared with the produced electromagnetic force. The calculated viscous pressure drop was numerically 373.9Pa for the velocity of the order of 0.8036 m/sec in the duct channel where the produced electromagnetic force was order of 2×10^4Pa.

4. Conclusion

The DC electromagnetic pump with the flowrate of 3 L/min and the developed of 0.2 bar was conceptually designed using the equivalent circuit. It was understood that the pump could be geometrically optimized and that the viscous effect was negligible. It was thought that the present design analysis would be used to design and manufacture the DC electromagnetic pump for the sodium and carbon dioxide experimental test loop.

NOMENCLATURE

B = Magnetic field strength
E_p = Electromotive force
H_d = The height of the pump duct
i_t = Total current
i_p = Pump current
i_f = Fringe current
i_{ss} = Stainless steel current
i_h = Current parallel to pump
J = Current density
J_{max} = Maximum allowed current density
k = Fringe factor
L = Electrode stub length
l = Duct wall thickness
ΔP = Pressure head
Q = Volumetric flow rate
R_h = Resistance parallel to pump
R_p = Pump duct resistance
R_v = Resistance perpendicular to pump
R_{ss} = Stainless steel resistance
R_f = Fringe resistance
U = Fluid velocity
W_d = The width of the pump duct
ρ_{Na} = Sodium resistivity
ρ_{ss} = Stainless steel resistivity

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