The Design of the Annular Linear Induction EM Pump with a Sodium Flowrate of 35 kg/sec

Hee Reyoung Kim, Tae Ho Lee and Yong Bum Lee
Korea Atomic Energy Research Institute, Dugjindong 150 yuseong Daejeon, kimhr@kaeri.re.kr

1. Introduction

Generally, an electromagnetic (EM) pump has been employed to circulate liquid metal with a high electrical conductivity by the electromagnetic force (Lorentz force) which is the cross product of the magnetic field and its perpendicular current. Therefore, an EM pump has its advantages over a mechanical pump such as no noise, no rotating parts, and its simplicity. Actually, it can be used for the Sodium Fast Reactor (SFR) which uses liquid sodium with a high electrical conductivity as a coolant. In the present study, the annular linear induction EM pump with a flowrate of 2,265 L/min and a head of 4 bar is designed by using an electrical equivalent circuit method which is applied to linear induction machines. The designed pump will be used for the verification of the elements, which are IHX, AHX and DHX, in the component performance test sodium loop for the sodium thermo-hydraulic experimental facility. The pump is manufactured and fabricated to meet the requirements of the material and a functioning in high temperature-sodium environments. The P-Q characteristic is theoretically calculated on the designed pump according to the input currents and voltage.

2. **Method and Results**

2.1 The design analysis of an EM Pump

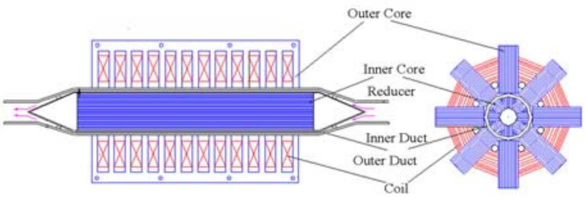


Fig. 1. Cross-sectional view of the annular linear induction EM pump

The cross-section of the annular linear induction EM pump to be designed is represented in Fig. 1. It is largely divided into two parts. One is the electromagnet made up of the inner and outer cores with a high magnetic permeability and exciting conductor coils. The other is a duct with a narrow annular channel gap for the sodium flow [1]. Firstly, the pump has the geometrical variables of the inter-core gap, diameters of the inner core, core length. Also, it has the electromagnetical variables of the input current, voltage, frequency, coil turns, the number of pole pairs and pole pitch. Therefore, the design variables are determined from the characteristic analyses on the developing force according to various variables by using the equivalent circuit method [1-3]. Fig.2 shows equivalent circuit on one phase of the EM pump.

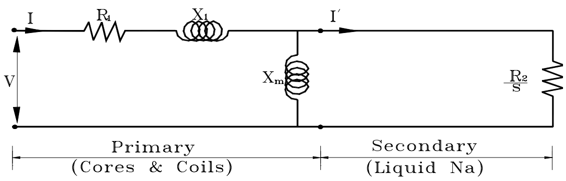


Fig. 2. The equivalent circuit for an EM pump design
(V : Input voltage I : Input current
R_1 : Primary resistance X_1 : Primary reactance
X_m: Magnetizing reactance I' : Secondary current
R_2 : Secondary resistance s : Slip)

It consists of two parts. The primary part is the electromagnet with cores and coils. The secondary one is the moving liquid sodium fluid inside the duct channel. From the balance equation on the developed power, the relationship between developing force and flowrate is obtained as follows;

$$\Delta P = \frac{3I^2}{Q}\frac{R_2^{\,2}(1-s)}{(R_2^{\,2}/X_m^{\,2}s^2+1)}$$

where ΔP is developing pressure and Q is the flowrate. Each equivalent resistance and reactance is given by Laithwaite's standard design formula.

$$R_1 = \frac{\pi\rho_c q k_p^{\,2} m^2 D_0 N^2}{k_f k_d p\tau^2},\quad X_1 \cong \frac{2\pi\mu_0\omega D_0\lambda_c N^2}{pq}$$

$$X_m = \frac{6\mu_0\omega\tau\pi D_0(k_w N)^2}{\pi^2 p g_e},\quad R_2 = \frac{6\pi D\rho_r'(k_w N)^2}{\tau p}$$

Using the above resistances and reactqances, the developing force is reduced to functions of pump variables;

$$\Delta P = \frac{36\sigma s f\tau^2(\mu_0 k_w N I)^2}{p g_e^{\,2}\{\pi^2+(2\mu_0\sigma s f\tau^2)^2\}}$$

The developing force can be calculated at various values of the pump's geometrical and operational variables. The length and diameter of the EM pump have the fixed values due to the loop structure. Therefore, the design variables are optimized according to the change of the other variables such as gap, pole pitch, coil turns except the length and diameter. On the other hand, the hydraulic head loss at the narrow annular flow gap is given by Darcy-Weisbach [4];

$$\Delta P_L = \frac{\rho\eta L v^2}{2g}$$

2.2 The Designed Specification of the EM Pump

The main design values for the EM pump are represented in Table 1.

Table 1. The characteristic of the EM pump

	Design Variables		Design Values
Hydro dynamical	Flowrate	Q [l/min]	2,265
	Developing Force	ΔP [bar]	4.07
	Temperature	[oC]	550
	Velocity	[m/sec]	6.5
	Slip	s [%]	49.8
	Head loss	[bar]	0.16
Geometrical	Pump Length	L [m]	1.3
	Pump Diameter	D [m]	0.46
	Inter-core Gap	g [m]	0.02
	Flow gap	[m]	0.016
Electro-magnetical	Input Current	I [A]	125
	Input Voltage	V [V]	426
	Input VA	VI [VA]	92.2
	Turns/Slot	N [#]	32
	Frequency	f [Hz]	60
	Number of Pole Pairs	p [#]	6
	Pole Pitch	. [m]	0.11
	Goodness factor		0.9

The length and diameter of the pump are 1.3 m and 0.46 m, respectively, due to its loop geometry. The inter-core gap is 0.02 m by consideration of the diameter and thickness of the commercially-produced pipe. Accordingly, the flow gap is 0.016 m. For the high goodness factor and P-Q characteristic, the pole pitch (or number of pole pairs) is 0.11m (or 6). The three phase alternating current and voltage are applied to the pump and the input frequency is 60 Hz of the commercial frequency. The head loss in the flow gap is 0.16 bar by calculation at the nominal operation point. It is negligible compared with the nominal developing pressure of 4 bar.

P-Q curves at designed values are shown in Fig. 3. In Fig. 3, the pumping flowrate reaches the synchronized one when it is over 4,000 L/min much more than the nominal one of 2,265 L/min.

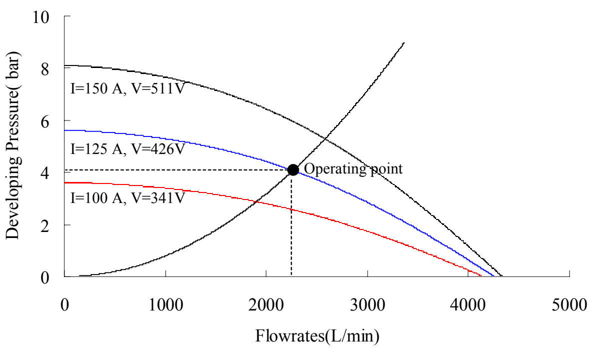
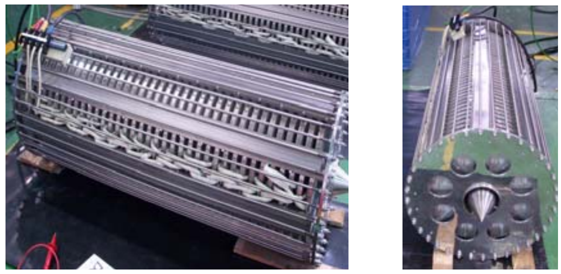


Fig. 3. P-Q characteristic of the designed EM pump by the theoretical calculation

According to the designed specifications, the pump was actually manufactured and fabricated by a consideration of the operational environment such as a high temperature of 550 ℃, chemically reactive sodium fluid, magnetic field distortion, etc. Fig. 2 shows the completed three-phase annular linear induction electromagnetic pump for the liquid sodium circulation in the loop.



(a) The front view (b) The side view

Fig. 2. The completed annular linear induction EM pump

3. Conclusion

The annular linear induction electromagnetic pump was designed and manufactured by the electromagnetic and hydraulic calculation. In the near future, the experiments will be carried out with an experimental uncertainty analysis for the pump thermo-hydraulic performance.

Nomenclature

D = mean diameter of the fluid
D_0 = diameter of the inner core
g = inter−core gap
g_e = effective inter−core gap(= K_c x g)
K_c = Carter's coefficient
k_d = t/w (t : slot depth)
k_f = slot−filling factor (0.5−0.6)
k_p = t_c/w (t_c : slot pitch, w : slot width)
k_w = winding coefficient
m = number of input phases
N = number of turns of coils per slot
p = number of pole pairs
q = number of slots per pole per phase
λ_c =1/12 x $k_d(1 + 3\alpha)$, α = chording factor
ρ_c = resistivity of the coil conductor
ρ_r = surface resistivity of the fluid
τ = pole pitch
μ_0 = magnetic permeability of vacuum
ω = $2\pi f$ (f : input frequency)

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