DESIGN OF ANNULAR LINEAR INDUCTION PUMP FOR HIGH TEMPERATURE LIQUID LEAD TRANSPORTATION

JAE SIK KWAK*, HEE REYOUNG KIM
Ulsan National Institute of Science and Technology, UNIST-gil 50, Ulsan, Republic of Korea
*Corresponding author: sikjae10@unist.ac.kr

Abstract :The annular linear induction pump (ALIP) with the flowrate of 30 L/min and the developing pressure of 1 bar was designed for transportation of liquid lead which is used for neutron target. The characteristics of design variables are analysed by electrical equivalent circuit method taking into account hydraulic head loss in the narrow annular channel of the ALIP. The pump was divided into two parts, which consisted of the primary one with electromagnetic core and exciting coils, and secondary one with liquid lead flow. The design program, which was composed by using MATLAB language, was developed to draw pump design variables according to input requirements.

1. Introduction

Electromagnetic (EM) pumps have been employed to transport heavy liquid metals such as mercury, lead, and so on. That arise at their application in liquid metals cooled reactors and other plants, for example, neutron target or neutron spallation sources. Using of mechanical pumps for heavy liquid metals for these purposes are associated with problems of providing reliable mechanical propellers and seals operating at rather high loads and heavyduty mentioned above operation conditions. As an alternative solution, the EM pumps (Figure 1), which are thought to effectively overcome the disadvantages of mechanical pumps [1], are considered. The characteristics of design variables are analyzed by electrical equivalent circuit method taking into account hydraulic head loss in the narrow annular channel of the ALIP. The design program, which is composed by using MATLAB language, is developed to draw pump design variables according to input requirements of the flowrate, developing pressure and operation temperature.

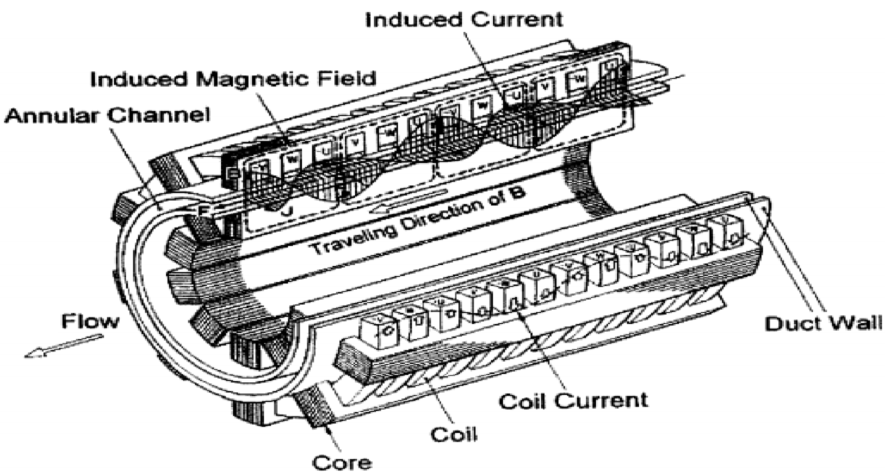

Figure 1: Schematic diagram of ALIP.

2. Structure of ALIP

2.1 Electromagnetic core

Structure of ALIP is shown in Figure 2. In this illustration, electromagnetic core can be divided into two parts, inner core and outer core which induce magnetic field to axial direction and radial direction. So material for core must be ferromagnetic body which has high permeability. It also maintains magnetic characteristics and mechanical strength in high temperature and fast neutrons. For blocking loss of magnetic field and heat generation caused by eddy current in core inside, stacking isolated ferromagnetic plane is recommended. Especially, inner core have to be placed radial form in the duct for considering direction of magnetic field.

Outer core is manufactured by stacking chain of E type core. And use a material silicon steel plate coated by insulation organic matter. Outer core bunch is fixed by stainless steel square pipe and bolts with nuts. Inner core is manufactured by stacking I type core, be placed in the inner duct and sealed by cone for preventing contact with liquid lead [2,3].

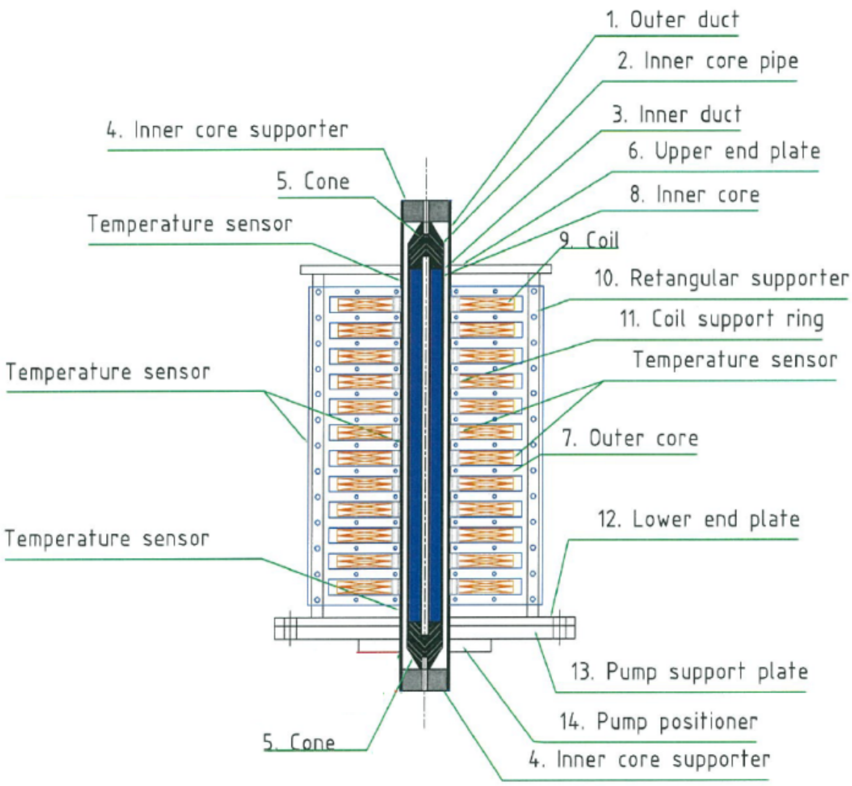

Figure 2: Structure of ALIP.

2.2 Electromagnetic coil

Materials for electromagnetic coil must have heat-resisting and low electrical resisting properties in the environment of high temperature and neutron irradiation. In the case of ALIP, electromagnetic coils are twined circularly and flowing electric current directly. So insulation between coils is essential.

2.3 Insulating material

Insulating materials must block electrical contact not only gap of coils but also between coil and outer cores. Because of filling factor, thin insulating materials are better as electrical insulation is allowed. It must be twined circularly with electromagnetic coil, have flexibility and heat-resisting properties.

2.4 Structural material

Structural material means components of pump except core, coil, and insulating material. These fix components (plates and supporters), protect from high temperature liquid lead (duct), helps flow of liquid lead (cone) and so on. Structural material must protect pump from high temperature lead in the aspects of heat and chemical reactivity. And it should not distort magnetic field. So austenite stainless steel is recommended because which is nonmagnetic material.

3. Analysis on the design parameters of ALIP

Basically ALIP changes driving power and efficiency by geometrical shape, size, and operating variables. The driving power and efficiency function can be derived by electrical equivalent circuit method. The pump was divided into two parts, which consisted of the primary one with electromagnetic core and exciting coils, and secondary one with liquid lead flow. The main geometrical variables of the pump included core length, inner diameter, flow gap, and so on while the electromagnetic ones covered turns of coil, number of pole pairs, input current, input frequency, and so on.

3.1 Electrical equivalent circuit method

The ALIP can be illustrated like Figure 3as electrical equivalent circuit. In the Primary one,R_1 is wire wound resistance in the coil, X_1 is leakage reactance from the core, X_m is magnetization reactance from the core, andR_2 is equivalent resistance of liquid metal. And function between developed pressure ΔP and average flow rate Q express like below [4, 5].

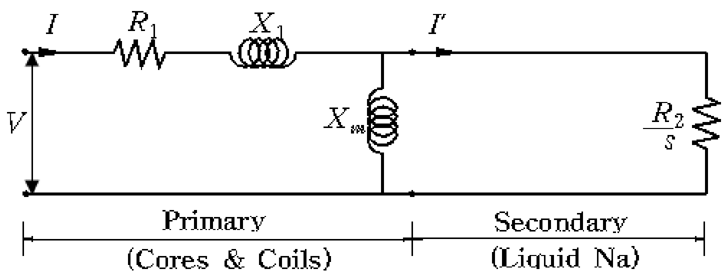

Figure 3: Electrical equivalent circuit of ALIP.

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

Equivalent resistance and equivalent reactance are knownfrom Laithwaite standard design formula calculated by magnetic circuit composed of geometrical and operational variables.As a result, below formula can be derived.

$$\Delta P = (3\,6\sigma s f \tau^2\,([(\mu_0\,k_w\,NI)]^2)/(p g_e^2\,\{\pi^2 + (2\,\mu_0\,\sigma s f \tau^2)]^2\,) \quad (2)$$

From the formula (2), correlation between developed pressure and pump design variables which are frequency, pole pairs flow gap, pole pitch, and so on can be known. Like above, efficiency formula can be also derived.

3.2 Characteristics of design parameters

From the developed pressure and efficiency formula by electrical equivalent circuit method, derive relations of design parameters. These are simplified in Table 1.

Table 1: Characteristic of structure elements [3]

Structural Elements		Action Characteristics
Size of Outer Core	Increase	• Leakage reactance increase • Allowed Turns of coil increase
	Decrease	• By the decrease of leakage reactance, efficiency increase • Allowed turns of coil decrease
Duct Width	Increase	• For same output, need more current and efficiency decrease • Flow gap decrease
	Decrease	• output and efficiency increase • Flow gap increase
Pole Pitch	Increase	• Synchronous speed increase • Length of Inner core and weight, size of pump increase
	Decrease	• Size of pump decrease • Body force increase in same input
Number of Pole	Increase	• Dispersion of fluid thrust • Pump size increase
	Decrease	• Leakage reactance increase (in secondary part)
Size of Inner Core	Increase	• Pump weight increase • Area of duct increase (in same duct width)
	Decrease	• Pump weight decrease • Area of duct decrease (in same duct width)
Number of Coil	Increase	• Input current decrease in same output
	Decrease	• Input current increase in same output

4. Design program based on MATLAB

In the MATLAB code, sections for calculation are divided into 10 sections which are 'Required specification', Electromagnetic variables', Geometrical variables', Electro-geometrical variables', 'Hydro dynamical variables', 'Equivalent impedance', 'Power factor and goodness factor', 'Developed pressure', 'Electrical input and efficiency', 'Design Specification'.

In the Required specification section, input 3 main outputs of pump,pressure, temperature, and flow rate. And the code calculates other outputs for reaching to goal of 3 main outputs. In the electromagnetic variables section, input current, turns of coils, frequency, pole pairs, electrical resistivity of materials based on temperature, and so on. In the geometrical variables section, input basic size of pump like core length, flow gap, thickness of ducts, ratio of slot width to slot pitch, and so on. Then the equipped formulas calculate the detailed sizes of pump components. So I don't have to do detail design for each components of pump.In the other sections except last section, the code calculates outputs based on equipped formulas which are derived by equivalent circuit method. Also, hydrodynamics factors are considered. The pump input and output variables by using the code were represented in table 2.

5. Conclusions

The analysis on the design of ALIP for high temperature liquid lead transportation was carried out by using the electrical equivalent circuit method and taking the hydraulic loss into account. The design variables for the pump with the required flow rate and developed pressure were analyzed from the induced formulae. The computer code based on the present analysis was developed for the design of the small ALIP and applied to the design of pump for transportation of liquid leads with the flow rate of 30 L/min, the developed pressure of 1 bar and operation temperature of 500 . The material of the pump core, coil and structure was determined taking into consideration of the operation environment of the high temperature of 500 . The design analysis of the pump and developed computer code was thought to be effectively employed to design and manufacture the small ALIP.

Table 2: Pump variables using the MATLAB design code

	Design variables	Values
Hydrodynamic	Flow rate [L/min]	30
	Developed pressure [bar]	1.01
	Temperature [ ]	500
	Velocity [m/sec]	0.535
	Slip [%]	96.3
	Reynolds number	19218
	Head loss [Pa]	17471.959
Geometrical	Core length [mm]	480.0
	Outer core diameter [mm]	524.5
	Inner core diameter [mm]	37.1
	Inter core gap [mm]	12.70
	Flow gap [mm]	6.10
	Inner duct thickness [mm]	2.80
	Outer duct thickness [mm]	2.80
	Slot width [mm]	19.20
	Slot depth [mm]	206.00
	Core depth [mm]	231.00
	Core thickness [mm]	25.00
	Stacked coil think [mm]	186.00
	Coil support ring [mm]	10.00
	Space in slot depth [mm]	10.00
	Tooth width [mm]	19.20
	Slot pitch [mm]	38.40
	Conductor width [mm]	12.00
	Conductor thickness [mm]	6.00
	Insulator thickness [mm]	0.20
Electrical	Input current [A]	38.0
	Input voltage [V]	427
	Impedance [Ohm]	11.2
	Input VA [kVA]	28.1
	Input power [kW]	8.5
	Power factor [%]	30.1
	Goodness factor	0.3
	Pole pitch [cm]	12.00
	Number of slot [#]	12
	Turns/slot [#]	60
	Number of pole pairs [#]	2
	Slot/phase/pole [#]	1
	Hydraulic efficiency [%]	5.70

REFERENCES

[1] I.Bucenieks, J.Freibergs, E.Platacis.:Evaluation of Parameters of Powerful Electromagnetic Induction Pumpson Permanent Magnets for Heavy Liquid Metals, IV International Workshopon Materials for HLM-cooled Reactors and Related TechnologiesROMA, ITALY, May 21-23, (2007).
[2] Hee-Reyoung. K.:MHD Dynamic Analysis and Development of Design Method of an Annular Linear Induction Electromagnetic Pump, Ph. D. Dissertation, Seoul National University, (1998).
[3] Tae-Bong. P.:A Study on the Magnetic Fluid Flat Distribution in MHD Field, MSc. Dissertation, Changwon National University, (2003).
[4] Borghi, C. A.:Cristofolini, A.;Fabbri, M.;Study of the Design Model of a Liquid Metal Induction Pump, IEEE Trans. Magn., vol.34, no.5, (1999), pp.2956-295.
[5] Naser, S. A.: Linear motion electromagnetic systems, John Wiley &Sons, (1998), 131-263.