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Electromagnetic Pump Optimization for Micro URANUS Reactors

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1. Introduction

Micro URANUS is a SMR with a rated output of 60 MWt, abbreviated as 'Micro Ubiquitous, Rugged, Accident-forgiving, Nonproliferating, and Ultra-lasting Sustainer' as shown in fig. 1[1]. Micro URANUS has a six-angle grid core as a pool type fast reactor using LBE, which is chemically stable as a coolant and can achieve a fast neutron spectrum. To achieve high safety, the primary system is designed to run without pumps and 40 years of full power operation without replacing and redeploying the fuel to ensure nuclear non-proliferation [2].

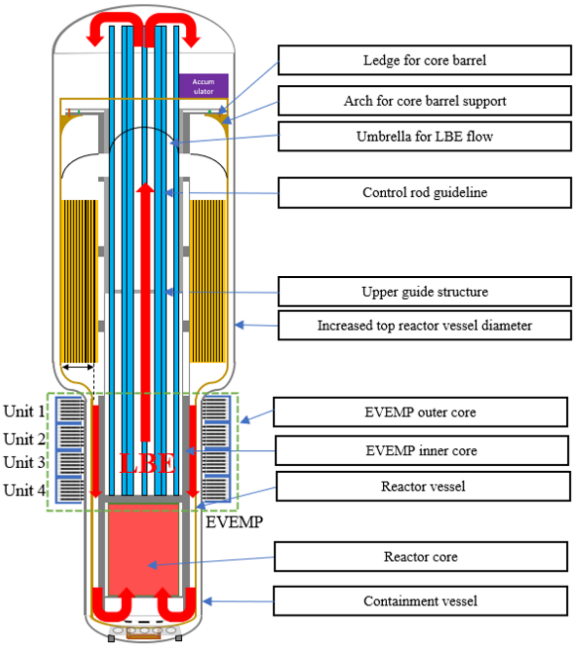


Fig. 1 Micro URANUS design

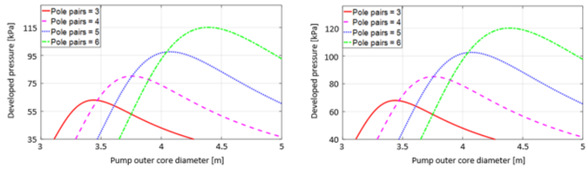
For MicroURANUS, forced circulation devices such as pumps are essential to maintain flow rates during operation. However, it is necessary to utilize natural circulation for the reactor to run without pumps, not only during the accident situations but also during the normal operation. Micro URANUS is a structure that places heat source (nuclear reactor core) at the bottom of the reactor vessel and heat sink (steam generator) at the top of the reactor vessel to maximize the natural circulation of the LBE. Natural circulation from these temperature differences and height differences removes heat from the core and supplies it to the steam generator to produce power. The pressure drop that occurs in the coolant flow area is very important because the size of the power source is very small compared to that given by the natural circulation.

In order to install pumps for enhanced output in Micro URANUS with these very small sizes and special structures, installation of EVEMP (Extra-vessel electromagnetic pump) using the concept of an electromagnetic pump that is easy to free up space and operates in contactless ways is essential, and this is used to design enhanced power up to 60 MWt. This paper discusses the optimization analysis of the EVEMP according to the geometrical variables and electromagnetic variables.

2. Methods and Results

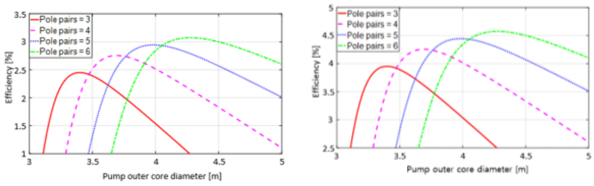
The design variables in EVEMP include geometric variables such as pump outer core diameter and pump inner core thickness, and electromagnetic variables such as the number of pole pairs and frequency. The effects and performance of EVEMP in Micro URANUS according to changes in geometric and electromagnetic variables were analyzed.

Fig. 2 and 3 show the graphs of developed pressure and efficiency according to the changes in the number of pole pair and pump outer core diameter analyzed at 5 and 10 Hz. A low input frequency was used to reduce the end effect of the electromagnetic pump [2]. As the diameter of the outer core of the pump increased, the efficiency increased and then decreased above a certain point. If the diameter is too short, it is difficult to form an induced magnetic field due to the reduction of the size of core tooth cross section. If the diameter is too large, the resistance increases, resulting in ohmic loss. Therefore, it is essential to determine the optimal diameter, and the optimal values of the two graphs were between 3600 and 3700 mm. Therefore, in consideration of the coil thickness and reactor size, the optimal pump outer core diameter was 3683 mm. In addition, as pole pairs increased, efficiency and developed pressure values increased in both graphs. However, since the electromagnetic pump was located between the steam generator and the core, the maximum pump height was limited to 2500 mm. This indicates that a maximum of four pole pairs can be used because the height of the pump corresponding to one pole pair was 544.6 mm.



(a) 10 Hz (b) 5 Hz

Fig. 2 Developed pressure of the EVEMP with a change in the pump outer core diameter at different number of pole pairs ((a) f = 10 Hz, (b) f = 5 Hz)



(a) 10 Hz (b) 5 Hz

Fig. 3 Efficiency of the EVEMP with a change in the pump outer core diameter at different number of pole pairs ((a) f = 10 Hz, (b) f = 5 Hz)

Fig. 4 and 5 show the pressure drop and input power of the electromagnetic pump according to the frequency change under the pump outer core diameter 3683 mm, four pole pairs, and 1250 A input current conditions. The pump specification increases as the input current increases, but 1250 A is used based on the maximum allowable current of the coil. The higher the frequency, the lower the electrical conductivity of the flow due to the skin effect, so the input power increased as the frequency increased (Fig. 4). The optimal developed pressure value was achieved at a frequency of about 8 Hz. The optimal developed pressure was achieved at about 8 Hz (Fig. 5), but the optimal efficiency was achieved at about 5 Hz because it is the efficiency corresponding to the ratio of hydraulic force to input power. As the frequency was increased to 5 Hz, the developed pressure value was increased, and thus the efficiency was increased, but as the frequency exceeding 5 Hz was further increased, the increase in pressure drop value was decreased, and thus the efficiency was decreased. These results indicate that the optimum frequency (5 Hz), input voltage (875 V), and input power (675 kW) of the pump have been achieved at 1250 A. The optimized design specifications for electromagnetic pumps are shown in Table I.

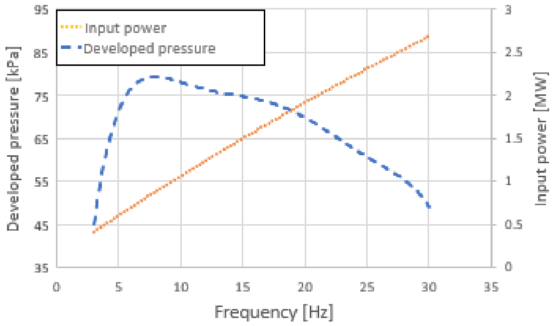


Fig. 4 Efficiency of the EVEMP with a change in the pump outer core diameter at different number of pole pairs ((a) f = 10 Hz, (b) f = 5 Hz)

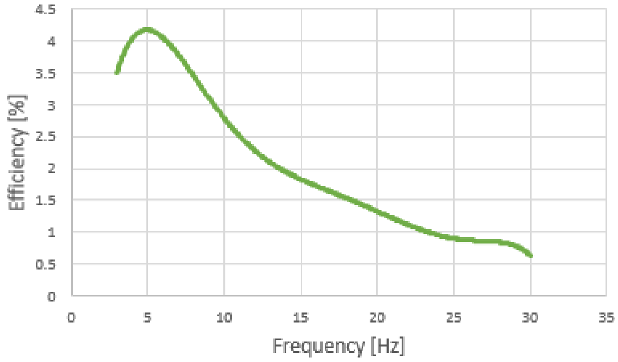


Fig. 5 Efficiency of EVEMP as a function of frequency

Table I: EVEMP specification

	Design variables	Unit	Value
Requirements	Mass flowrate	[kg/s]	4196
	Developed pressure	[kPa]	73
	Temperature	[°C]	250
	Velocity	[m/s]	0.5
	Reynolds number	[#]	1463035
Geometrical	Core length	[mm]	2178
	Pump outer core diameter	[mm]	3635
	Pump inner core diameter	[mm]	2500
	Flow gap	[mm]	100
Electrical	Input voltage	[V]	875
	Input current	[A]	1250
	Input frequency	[Hz]	5
	input VI	[kVA]	1894
	Coil turns	[#]	20
	Input power	[kW]	675
	Hydraulic Efficiency	[%]	4.15

3. Conclusions

In this study, an EVEMP with a mass flow of 4196 kg/s and a developed pressure of 73 kPa at an operating temperature of 250°C was optimally designed. As a result, the optimal EVEMP outer core diameter and pump height of the electromagnetic pump were derived. And the optimal input frequency and pole pair were shown at 675 kW of input power. The optimized EVEMP is expected to be used appropriately to meet the required heat output (60 MWt) of Micro URANUS.

REFERENCES

[1] H.R. Kim, Y.B. Lee,. A design and characteristic experiment of the small annular linear induction electromagnetic pump. Ann. Nucl. Energy, 38(5), 1046-1052 ,2011.

[2] H. R. Kim, J.S. Kwak, MHD design analysis of an annular linear induction electromagnetic pump for SFR thermal hydraulic experimental loop. Ann. Nucl. Energy, 92 2016, 127-135.