Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

The Status of Development of Electromagnetic Pumps for Space Application

J. S. Kwak, K. H. Kim, J. S. Jeong*, Hee Reyoung Kim
Ulsan National Institute of Science and Technology, Banyeon-ri, Eonyang-eup, Ulju-gun, Ulsan, Korea
[*]Corresponding author:amour8458@unist.ac.kr

1. Introduction

The electromagnetic pump has simple geometrical structure without rotation parts contacting coolant, and so, property of little maintenance and hydraulic stability over mechanical pumps for liquid metal cooled nuclear reactor. The electromagnetic pump can be applied to spaceship which uses small nuclear power generator. Actually, the various nations including USA are researching on electromagnetic (EM) pumps for space application. Also, Korea lunched this research as a part of the small nuclear power generation technology development for space. In this study, investigated are the basic principle and types of electromagnetic pump and the trend of electromagnetic pump technology development in foreign nations. The survey and analysis give the understanding of the suitability and prospect of electromagnetic pumps as space application technology in Korea.

2. Basic Principle and Types of Electromagnetic Pump

2.1 Basic Principle

Main function of an EM pump is to force electrically conductive liquid metal fluid to flow through a pipe in the liquid metal reactor system [1]. External current flows in the coil of the EM pump. It produces magnetic field along the electromagnet iron core and current is induced in the liquid metal perpendicular to the produced magnetic field. As a result, Lorentz body force is generated from the cross product of the induced current and magnetic field. Liquid metal fluid flows through a pipe by this force [2] where the pressure gradient of fluid caused by Lorentz body force can be written as Eq. (1).

$$\nabla p = j \times B \qquad (1)$$

where j and B are current density and magnetic flux density, respectively [1].

According to the way of generating the force, EM pump can be divided two main groups: conduction types and induction types [3].

2.2 Types of EM pump

In conduction pumps, current is fed to the liquid metal from an external sources, magnetic field is supplied with permanent magnets or electromagnets. According to the way of power supply, the pumps are divided into direct current (DC) and alternating current (AC) conduction pumps [2]. In induction pumps, the current is induced from time varying magnetic field by Faradays' law, the direction of which is perpendicular to magnetic field in the liquid metal. According to the geometric shape of channel, the pumps can be divided into annular and flat linear induction pump. On the other hand, another kind of the EM pump, thermoelectric (TE) pumps are similar to DC conduction pumps. but it doesn't require external electrical power to operate because deriving power directly from the hot liquid metal flow by the mechanism called Seebeck effect [2].

2.3 Efficiency Analysis of EM pumps

In the Table 1, performance characteristics for several different types of liquid metal pumps are represented where they are predicted or measured [2].

Table 1. Comparison between various types of EM pumps [2]

Pump Type		Input Power (kWe)	ΔP (kPa)	Flow Rate (L/min)	Pump Efficiency (%)	Liquid (℃)
Conduction Pump	DC	14.2	276	1,136	**44**	NaK (250)
	DC	649	517	31,420	**~50**	Na (410)
	AC	-	69	76	**-**	NaK (400)
	AC	1.8~3.6	90	76	**3~6**	NaK
Induction Pump	ALIP	8.6	97	1,590	**36**	NaK (175)
	ALIP	29	345	1,510	**36**	Na (500)
	ALIP	721	517	31,420	**45**	Na (400)
	FLIP	70	276	4,542	**36**	Na (370)
TE Pump	TE	15.9	7.6	50	**39.7**	NaK (540)

From the Table 1, AC conduction pump has relatively low pump efficiency. In this type, input electrical power is consumed to produce both current and magnetic field. Except this type, there is little difference between efficiency values where they have the efficiency of two digit percentage. As a result, the pump suitable for space environment should be decided by other characteristics of pumps such as pump specific power, development cost or safety [2]. From the Table 1, DC conduction pump looks better than others in the point of efficiency which are more than 40% .

3. International and Domestic Status of Electromagnetic Pump Research

3.1 USA

Atomic International set out to develop liquid metal EM pump for reactor coolant supply in 1985 and fabricated and tested helical pump of which flow rate was about 10~2000 gpm [4]. Annular Linear Induction Pump (ALIP) was developed, which works without outside cooling source when transporting hot molten metal by Dow Chemical Company in 1987 [5]. In 1990s, Research of EM pump was carried out actively because Fast Breeder Reactor (FBR) had been reevaluated as next generation power source. Main research in 21st century in America is spaceship and FBR, and research of EM pump with elevated reliability, stability and many other advantages was hotting up. In 2007, NASA MSFC compared pumping technologies for the purpose of development of small nuclear reactor for space and concluded that TE pump is the best option. In 2010, Marshall Space Flight Center developed space nuclear reactor for supply of electric power on the planetary surface and used annular linear induction type. Today the study of EM pump for space is actively being done and space EM pump is in experimental and fabrication step in NASA.

3.2 Japan

From 1960s, Japan started research of EM pump. Toshiba fabricated many kinds of EM pump and developed the pumps with the flowrate of 10 ~ 10,000 L/min in 1970s [6]. In 1990s, EM pump instead of mechanical pump was researched actively with start of study of fast reactor. In 2006, ALIP was chosen for fast reactors and many experiments were carried out about efficiency and safety of ALIP. Japan today focuses on verification of developed technologies about transfer of liquid metal and generator. In Japan the research of EM pump for space is not so active and it does not seem to focus on EM pump for space.

3.3 Europe

In 1970s, France's NOVATOME produced conduction and induction pump with the flowrate of 2 ~ 140 m^3/hr [1]. In 1982, UK's Atomic Energy Authority fabricated helical pump and Efrenov Electric Equipment Research Institute in the Soviet Union made a center return type pump which had the flowrate of 3500 m^3/hr for secondary coolant system of BN-350 in 1988 [7]. In 1983 France started to make a program called ERATO which is nuclear reactor for space system.

In 2000s, France studies actively EM pump for liquid metal fast breeder reactor and Russia's Efremov Institute of Electrophysical Apparatus focused on study of ALIP. Nowadays many European countries such as UK, Italy, and so on are researching induction pump. A few countries such as France and Russia are studying on space nuclear reactor, but it is hard to grasp the research of EM pump for space.

3.4 Korea

In 1980s, Korea Institute of Energy Research examined research about concept of flow coupler for method of liquid metal transfer. In 1990, Seoul National University finished concept and design of ALIP for the development of small liquid-sodium EM pump and got result of fundamental experimental data by using Wood's metal as a fluid [3]. From 1997 until now, KAERI finished basic design of ALIP and have carried out basic magnetohydrodynamic characteristic experiment for construction of Korea Advanced Liquid Metal Reactor (KALIMER). In Korea, KAERI today is starting to research space nuclear reactor and EM pump in space. But the research on EM pump for space in Korea is planning stage. And ALIP which has been mainly studied is an experimental stage.

4. Conclusion

The analysis on the status of the development of electromagnetic pumps was carried out for the application to space environment. It was found that USA was approaching the research and development of electromagnetic pumps for space application. Most electromagnetic pumps surveyed have the efficiency between 35% and 50% where that of AC conduction pump is less than 6%. Further study was thought to have to be given for the mechanical and material characteristics, and the applicability of electromagnetic pumps for space nuclear reactor.

REFERENCES

[1]R.S. Baker, M.J. Tessier, Handbook of Electromagnetic Pump Technology, Elsevier Science Publishing, New York, 1987.
[2]K. A. Polzin, Liquid metal pump technologies for nuclear surface power, Proc. Space Nuclear Conference, Boston, MA, USA 2007.
[3]S.H. Hong, K.H. Jeong, H.Y. Nam, H.R. Kim, D.W. Kim, Development of Electromagnetic Pumps for Sodium Coolant of Fast Breeder Reactor, pp 36, 1993.
[4] R.S.Baker, "Electromagnetic pump for liquid metals", Mech, Eng, p.15, 1964.
[5] H.C. Behrens, US Patent 4,828,459, 1987.
[6]M.Namba, "Electromagnetic pumps for LMFBR", Toshiba Review, 116, 17, 1978.
[7] A.M.Anreev, "The TsLIN-3/3500 electromagnetic pump", Magn. Gidro. 25, 61, 1988.