Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

The Analysis of an End Effect according to the Input Frequency Change in the EM Pump

Hee Reyoung Kim, Jong Man Kim, Jae Eun Cha, Jong Hyun Choi, Ho Yoon Nam
Korea Atomic Energy Research Institute, Dugjindong 150 yuseong Daejeon, kimhr@kaeri.re.kr

1. Introduction

In general, an electromagnetic (EM) pump is considered to circulate a liquid sodium coolant for a Sodium Fast Reactor (SFR). The EM pump has an end effect at both ends basically due to its finite core length. The generated magnetic field across the flow gap is distorted at both ends of the pump. Consequently, there arises reduction on the developed force by the vector product of that magnetic field and its perpendicular induced current. Especially, it experiences even the opposite pumping force near the pump inlet. That causes low efficiency of the pump and resultantly brings about bad performance of a pump. The present study theoretically shows that this end effect can be lessened by control of input frequency. It is predicted that pump operates much more efficiently in the range of low frequency around teen hertz than in that of high frequency over 60 Hz. The force density is investigated in the narrow annular channel of the pump with the length of 84cm according to pump axial coordinates at various frequency.

2. Mathematical Model and Equations

Fig.1 shows a real EM pump of the annular type and the pump can be converted into the analytical model by using the equivalent sheet current method as is seen in the Fig. 2.

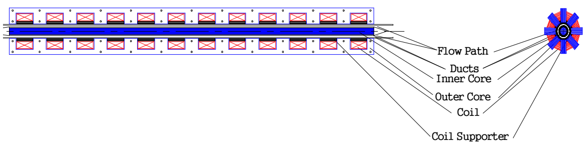

Fig. 1 Cross-Sectional View of the Annular Linear Induction EM Pump

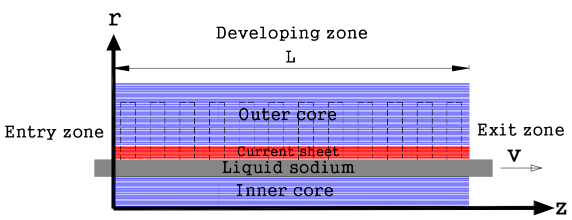

Fig. 2. Mathematical Model of the EM Pump of the Annular Type

MHD equations for the analysis of the sodium flow are described by using dimensionless parameters of Reynolds number, Re, Hartmann number, Ha, and magnetic Reynolds number, Rm as follows

$$\nabla \cdot V = 0$$

$$\nabla \cdot B = 0$$

$$\frac{\partial V}{\partial t} + (V \cdot \nabla)V = -\nabla P + \frac{1}{R_e}\nabla^2 V + \frac{Ha^2}{R_e} J \times B$$

$$\nabla \times B = R_m J$$

$$\nabla \times E = \frac{\partial B}{\partial t}$$

$$J = E + V \times B$$

where $R_e = \frac{\rho R_0 V_s}{\mu}$ $\quad H_a = \sqrt{\frac{\sigma}{\mu}} B_0 R_0$ $\quad R_m = \mu_0 \sigma R_0 V_s$.

Extending the above equations gives the solutions for the force densities in the pump inlet, region and outlet as follows

$$\frac{\partial P}{\partial z} = \frac{H_a^{\ 2}}{2R_e} \mathrm{Re}(J_\theta B_r)$$

$$f_{con} = -\frac{1}{2} V_s s \mu_0^{\ 2} \sigma \frac{k^2 J_m^{\ 2}}{R_0^{\ 2}\{k^4 + (s\omega\mu_0\sigma)^2\}}$$

$$f_{entry} = \frac{1}{2} V_s s \mu_0^{\ 2} \sigma (\frac{a_e}{b_e}) e^{-\gamma_{1r}(L-z)} \{c_{en} \cos[\gamma_i L - (\gamma_i - k)z] + d_{en} \sin[\gamma_i L - (\gamma_i - k)z]\}$$

$$f_{exit} = -\frac{1}{2} V_s s \mu_0^{\ 2} \sigma (\frac{a_e}{b_e}) e^{\gamma_{2r} z} \{c_{ex} \cos[(\gamma_i - k)z] + d_{ex} \sin[(\gamma_i - k)z]\}$$

$$a_e = \frac{k J_m^{\ 2}}{R_0^{\ 2}\{k^4 + (s\omega\mu_0\sigma)^2\}} \qquad b_e = (\gamma_{2r} - \gamma_{1r})^2 + 4\gamma_i^{\ 2}$$

$$c_{en} = (\gamma_{2r} - \gamma_{1r})(k\gamma_{2r} + \omega s \mu_0 \sigma) + 2\gamma_i^{\ 2} k$$

$$d_{en} = \gamma_i k(\gamma_{2r} - \gamma_{1r}) - 2\gamma_i (k\gamma_{2r} + \omega s \mu_0 \sigma)$$

$$c_{ex} = (\gamma_{2r} - \gamma_{1r})(k\gamma_{1r} + \omega s \mu_0 \sigma) - 2\gamma_i^{\ 2} k$$

$$d_{ex} = \gamma_i k(\gamma_{2r} - \gamma_{1r}) + 2\gamma_i (k\gamma_{1r} + \omega s \mu_0 \sigma)$$

$$\gamma_{1r} = \frac{a_1}{2}\left(\sqrt{\frac{b_1 + 1}{2}} + 1\right) \qquad \gamma_{2r} = -\frac{a_1}{2}\left(\sqrt{\frac{b_1 + 1}{2}} - 1\right) \qquad \gamma_i = \frac{a_1}{2}\left(\sqrt{\frac{b_1 - 1}{2}}\right)$$

$$a_1 = \mu_0 V_s (1 - s) \qquad b_1 = \sqrt{1 + (\tfrac{4k}{a_1(1-s)})^2}$$

In the Fig. 3, the developing force acts reversely at the inlet region of the pump. The reversed force by end effect reduces the overall efficiency of the pump resultantly.

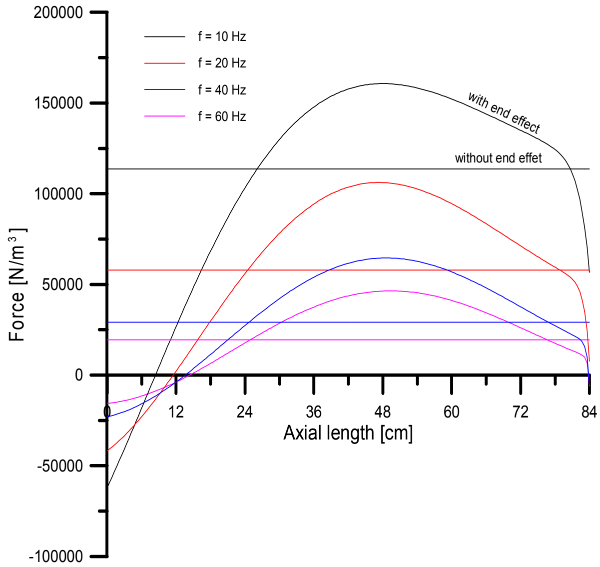

Fig. 3. Distribution of Force according to Axial Length of the Pump (Pump of diameter = 10 cm and length = 84 cm with 40 l/min)

Entry and exit end effect are graphically given in the Fig. 4 and Fig. 5. Entry end effect force affects on most region of the pump while exit end effect has little effect except extreme exit of the pump. Fig. 6 shows the ratio of the force with end effect to the force without end effect. The lower input frequency is, the smaller end effect is.

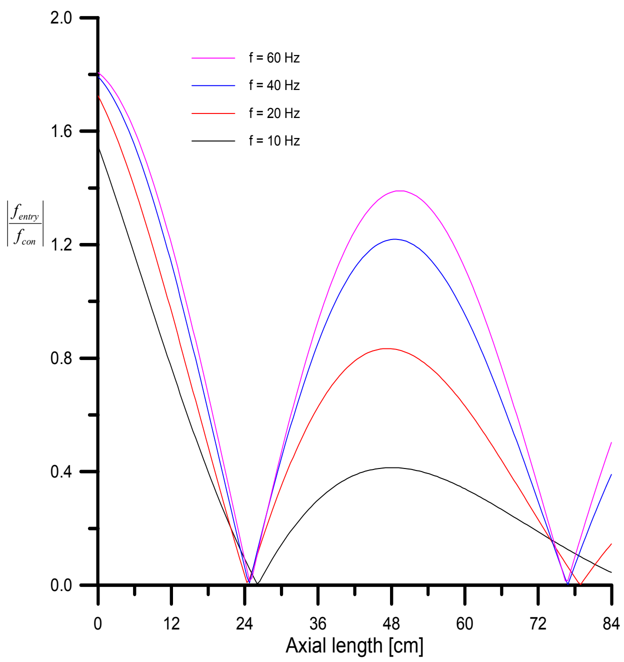

Fig. 4. Ratio of Entry End Effect to Conventional Force

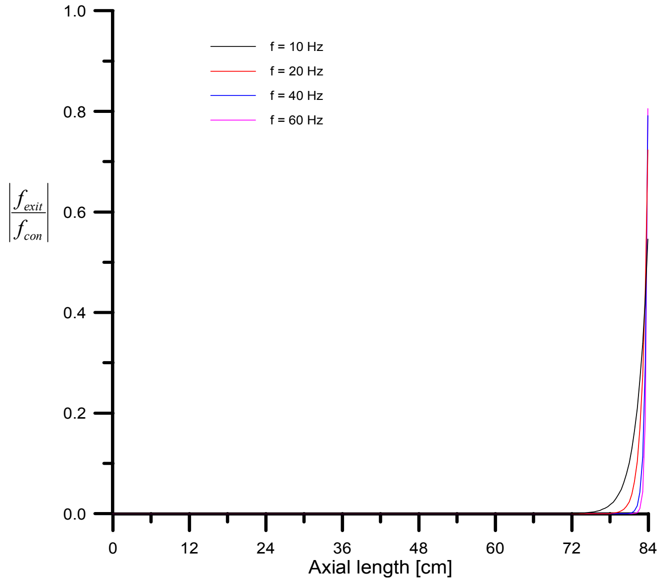

Fig. 5. Ratio of Exit End Effect to Conventional Force

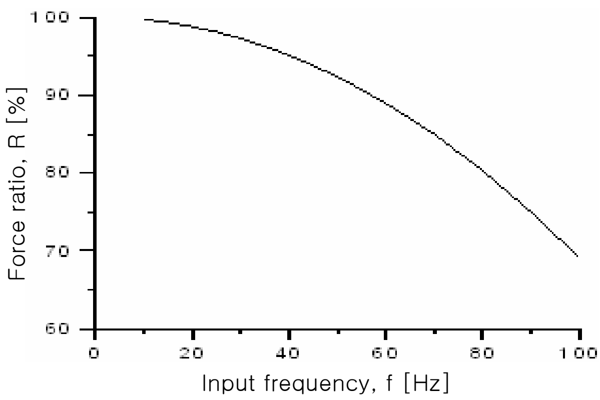

Fig. 6. Ratio of Both Forces in Case with and without End Effect according to Frequency Change

4. Conclusion

An EM pump is shown to have little end effect in the low input frequency of teen Hz from the analysis. Considering that the higher velocity of the EM pump is, the larger end effect is, low frequency operation is predicted to be feasible as far as developing force and efficiency are too much decreased.

REFERENCES

[1] R. S. Baker, "Electromagnetic Pump for Liquid Metals", Mech. Eng., p. 15, July(1964).

[2] S. A. Nasar, Linear Motion Electric Machines, John Wiley & Sons, New York (1976).