Journal of the Korean Institute of Illuminating and Electrical Installation Engineers Vol. 19, No.5, pp. 68~73 July 2005 논문 19-5-10

선형유도전동기를 이용한 전자기펌프의 설계 및 해석

(Design and Analysis of Electromagnetic Pump Using Linear Induction Motor)

김창업* · 전문호
(Chang-Eob Kim · Mun-Ho Jeon)

요 약

본 논문은 선형유도전동기를 이용한 전자기펌프의 특성해석에 대하여 연구한 것이다. 전자기 펌프는 선형유도전동기의 추진력에 의하여 용융 금속을 이송할 수 있다. 추진력을 높이기 위해 유전 알고리즘을 사용하여 최대 추력을 가지는 선형유도전동기를 설계 하고, 선형유도전동기를 이용한 전자기 펌프의 특성해석을 유동해석에 의하여 분석하였다.

Abstract

This paper presents the characteristics analysis of an electromagnetic pump using the linear induction motor (LIM). The electromagnetic pump can be used to transfer the molten metals by the electromagnetic force of LIM. The characteristics of the pump are analyzed solving a hydrodynamic equation with an electromagnetic one.

Key Words : Electromagnetic Pump, linear induction motor, MHD

1. Introduction

The linear induction motors are widely used in different applications : high-speed ground transportations, passenger elevators, sliding doors, etc.[1]. The LIM can also be used for transporting molten metals by electromagnetic pump. Fig. 1. shows the system for this process. In this system, the LIM is used for transferring molten metal by electromagnetic force.

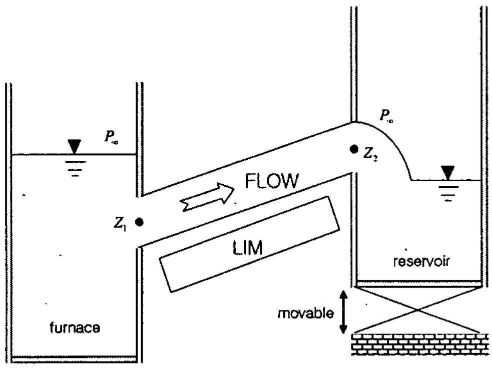


Fig. 1. Electromagnetic pump using LIM

* 주저자 : 호서대학교 전기정보통신공학부 부교수
Tel : 041-540-5657, Fax : 041-540-5693
E-mail : cekim@office.hoseo.ac.kr
접수일자 : 2005년 4월 13일
1차심사 : 2005년 4월 20일
심사완료 : 2005년 5월 9일

The molten metal is treated as the secondary part of the LIM. Since the LIM produces an electromagnetic force in the duct, the molten metal can flow from the furnace to the reservoir.

2. Optimum Design of LIM

Fig. 2. is the analysis model of the LIM. The molten metal is the secondary part of the LIM. Fig. 3. shows the equivalent circuit for LIM.

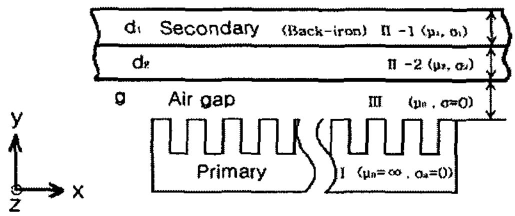


Fig. 2. Analysis model of LIM

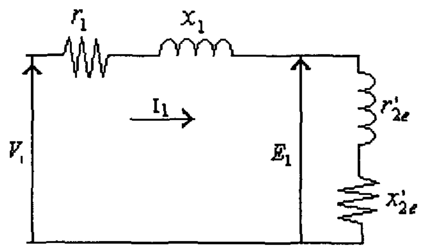


Fig. 3. Equivalent circuit for LIM

M-number of phase, V_1-applied voltage[V], r_1, x_1-primary resistance and leakage reactance [Ω], r'_{2e}, x'_{2e}-secondary resistance and leakage reactance considering the end effect[Ω]. Based on the equivalent circuit, the characteristics of LIM are given as follows[2].

$$P_{g1} = mV_1^2 r'_{2e}/Z_1^2 \text{ [W]} \quad (1)$$

$$P_0 = (1-s)mV_1^2 r'_{2e}/Z_1^2 \text{ [W]} \quad (2)$$

$$P_1 = mV_1^2(r_1 + r'_{2e})/Z_1^2 \text{ [W]} \quad (3)$$

$$P_{c1} = mV_1^2 r_1/Z_1^2 \text{ [W]} \quad (4)$$

$$P_{c2} = smV_s^2 r'_{2e}/Z_1^2 \text{ [W]} \quad (5)$$

$$P_A = mV_1^2/Z_1 \text{ [W]} \quad (6)$$

$$\eta = P_0/P_1 = (1-s)r'_{2e}/(r_1 + r'_{2e}) \quad (7)$$

$$F_x = mV_1^2 r'_{2e}/V_s Z_1^2 \text{ [N]} \quad (8)$$

where, V_s is synchronous speed [m/s] and Z_1 is equivalent circuit impedance [Ω].

Genetic algorithm (GA) is used to get the optimum variables, because GA can reduce the chance of searching local optima. The GA consists of three operators - reproduction, crossover, and mutation[3]. Fig. 4. shows the design parameters - teeth width, slot width, slot depth and stack height. The constraints are shown in Table 1 - teeth width, slot width, slot depth, stack height, primary current density and maximum flux density in teeth. The molten metal flows through the duct which its length and depth are 600[㎜], 30[㎜], respectively.

The optimized design variables can be obtained by solving the problem[4,5].

Find X which minimize $f(X)$ (9)

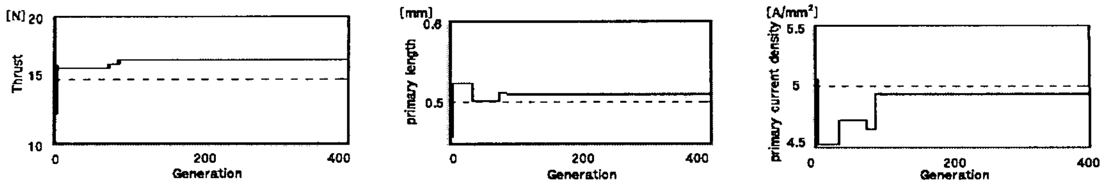
subject to $g_j(X) \leq 0 \quad (j = 1, 2, \ldots, m)$

where X={$X_1, X_2, \ldots X_n$} are independent design parameters, n is the number of parameters, j is the number of constraints, $f(X)$ is object function, $g_j(X)$ are restrictions of object function. Using the sequential unconstraint minimization technique (SUMT), the optimization problem is transformed as follows.

Find X which minimize Φ_k

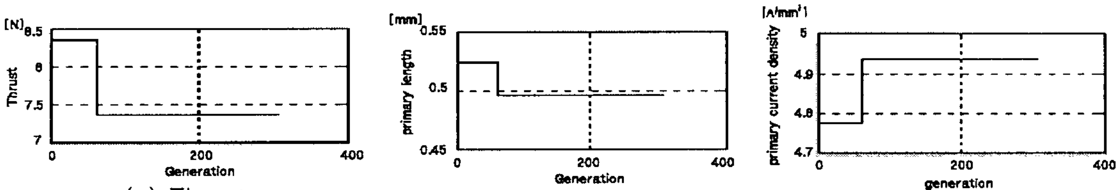
$$\Phi_k = \Phi(X, r_k) = -f(X) - r_k \sum_{j=1}^{n} [1/g_j(X)] \quad (10)$$

where, r_k is penalty parameter ($k = 1, 2, \ldots$).



(a) Thrust (b) Primary length (c) Primary current density

Fig. 5. Optimum design variables for 4-pole LIM



(a) Thrust (b) Primary length (c) Primary current density

Fig. 6. Optimum design variables for 6-pole LIM

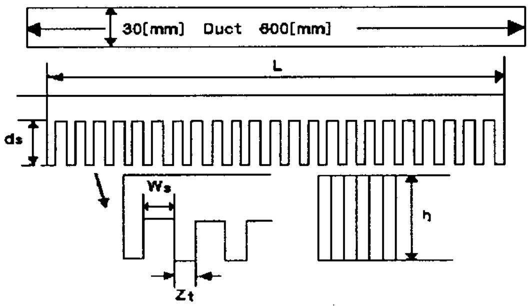


Fig. 4. Design parameters of LIM

Table 1. Design parameters and constraints

Design parameters	Constraints
$X_1 : Z_t$ (Teeth Width)	g_1: primary current density $J_1 \le 5[A/mm^2]$
$X_2 : W_s$ (Slot Width)	g_2: maximum flux density in teeth $B_{tm} \le 1.5[T]$
$X_3 : d_s$ (Slot depth)	$g_3 : 5.0 \le Ws \le 12.5[mm]$
	$g_4 : 2.5 \le Zt \le 8[mm]$
$X_4 : h$ (Stack height)	$g_5 : 30 \le ds \le 60[mm]$
	$g_6 : 60 \le h \le 100[mm]$

Fig. 5. and Fig. 6. are the simulation results of the optimization when the object function is thrust F_x. In the optimization, the molten zinc is used for the air gap 20[㎜] and slip 0.99.

3. The Characteristics Analysis of Electromagnetic Pump

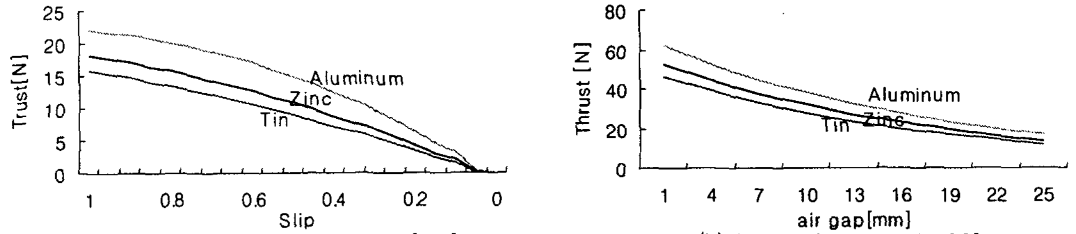
Fig. 7. and Fig. 8. are the characteristics for optimum model 1 and 2 : the trust-slip and thrust-air gap for three molten metals. The thrust is strong for high conductivity and small air gap. Table 2 shows the optimized design parameters of LIM.

Table 2. Optimized design parameters of LIM

	Model 1	Model 2
Number of Poles	4	6
Primary Voltage[V]	220	220
Pole Pitch[㎜]	108	72
Slot Depth[㎜]	47	47
Slot Width[㎜]	8.8	8.8
Teeth Width[㎜]	3.2	3.2
Primary Length[㎜]	519.2	495.2
Air gap[㎜]	20	20
Back-iron Thickness[㎜]	15	15
Primary Resistance[Ω]	3.3575	3.0967
Stack Height[㎜]	80	100
Primary Weight[Kg]	18.99	22.96
Depth of duct[㎜]	30	30
Molten metal conductivity[1/Ωm]		
Aluminum	4.02	
Zinc	2.7	
Tin	2.2	

Fig. 9. is the simulation result of thrust versus duct depth for LIM Pump at air gap 20[㎜], flow velocity 0.2[m/s]. The maximum thrust is obtained around 20[㎜] of duct depth.

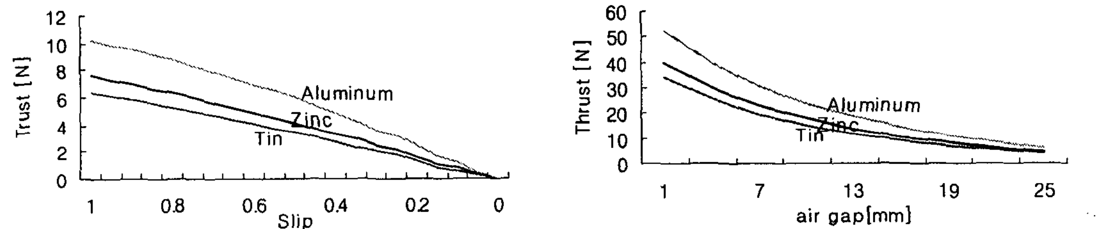
Fig. 10. is the simulation result of thrust versus back-iron thickness for LIM Pump at air gap 20 [㎜], duct depth 30[㎜] and flow velocity 0.2[m/s]. It is found that the thrust is saturated at 3[㎜] of



(a) Thrust-slip at air gap 20[mm]

(b) Thrust-air gap at slip 0.99

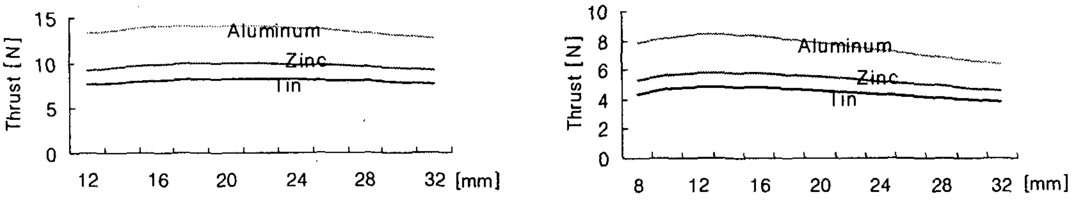
Fig. 7. Thrust-slip, thrust-air gap for 4-pole LIM



(a) Thrust-slip at air gap 20[mm]

(b) Thrust-air gap at slip 0.99

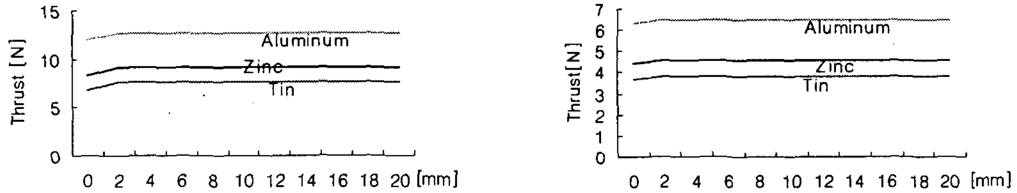
Fig. 8. Thrust-slip, thrust-air gap for 6-pole LIM



(a) Thrust-duct depth for 4-pole LIM

(b) Thrust-duct depth for 6-pole LIM

Fig. 9. Thrust versus duct depth for LIM Pump(air gap 20[㎜], flow velocity 0.2[m/s])



(a) Thrust-thickness of back-iron for 4-pole

(b) Thrust-thickness of back-iron for 6-pole

Fig. 10. Thrust versus thickness of back-iron for LIM Pump

back-iron thickness.

4. Magneto Hydrodynamic(MHD)

MHD refers to the interaction between an applied electromagnetic field and electrical conductive fluid. The FLUENT MHD code is used for analyzing the behavior of electrically conducting fluid flow under the influence of constant electromagnetic fields[6]. In this paper, a constant flux density is given 0.2[T] to find the flow velocity in the duct. Fig. 11 shows the simulation model for the furnace and duct model.

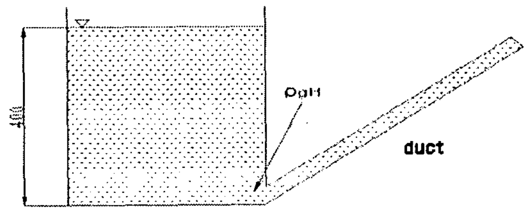


Fig. 11. Furnace and duct model

Fig. 12. and 13 are the simulation result for the flow velocity in the duct and the center of duct of molten zinc with 6-pole LIM. As a result, the velocity of the center of duct is about 0.34 [m/s]. Table 3 is simulation result for three different molten metals. The velocity and the mass flow are affected by the conductivity of molten metal.

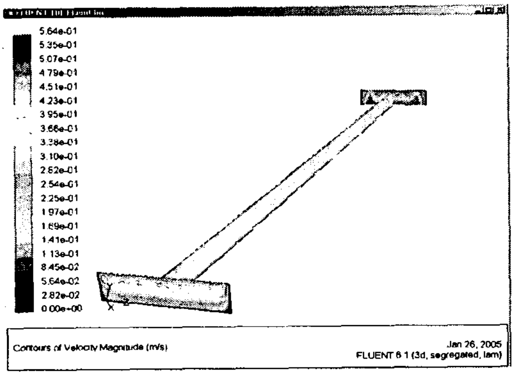


Fig. 12. Flow velocity in the duct

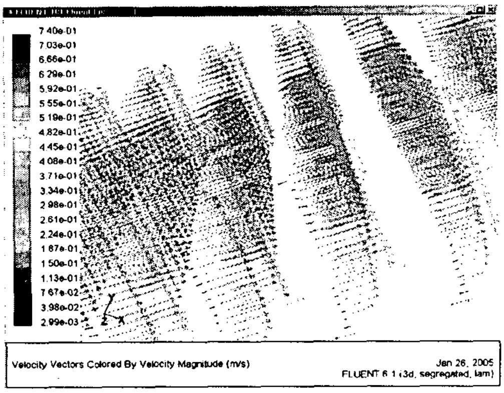


Fig. 13. Flow velocity field at the center of duct

Table 3. Flow Simulation with MHD

	Zn	Sn	Al
Maximum flow speed ([m/s])	0.42	0.45	0.48
Speed of duct at center of duct([m/s])	0.02	0.02	0.17
Mass flow rate(kg/m)	-0.266	-0.268	-0.429

5. Results and Discussion

This paper presents the electromagnetic pump using LIM for transferring molten metals. The LIM is designed by optimization using GA. The characteristics of the pump are simulated by FLUENT MHD code. The velocities in the duct are simulated for three molten metals : zinc, tin and aluminum. It is confirmed that for three molten metals, the flow velocity more than 0.3[m/s] can be obtained for electromagnetic field of 0.2[T].

본 연구는 산업자원부의 지원에 의하여 기초전력연구원 (과제관리번호:R-2004-B-128) 주관으로 수행된 과제와 2004년 호서대학교 학술연구조성비로 수행된 연구 결과임.

References

[1] Jacek F. Gieras, Linear Induction Drives, Oxford, 1994.

[2] M. Mirsalim, A. Doroudi, J.S.Moghani, "Obtaining the Operation Characteristics of Linear Induction Motors: A New Approach," IEEE Trans. Magn., vol. 38, no.2, pp.1365-1370, 2002.
[3] David E. Goldberg, Genetic Algorithm in Search, Optimization, and Machine Learning, Addison-Wesley, 1989.
[4] Dal-ho Im, Seung-Chan Park, Jee-Woo Im, "Design of Single-Sided Linear Induction Motor Using the Finite Element Method and SUMT," IEEE Trans. Magn., vol. 29, no. 2, pp.1762-1766, 1993.
[5] Chang Eob Kim, "Optimum design of a Linear induction Motor Using Genetic Algorithm, Niching GA and neural Network," KIEE Trans., vol. 3-B, no. 3, pp.128-132, 2003.
[6] Fluent Inc, Magnetohydrodynamics (MHD), 2003.

◇ 저자소개 ◇

김창업(金昌業)
1960년 1월 1일생. 1983년 서울대학교 전기공학과 졸업. 1990년 동대학원 전기공학과 졸업(석사). 1995년 한양대학교 대학원 전기공학과 졸업(박사). 2000~2001년 Post doc.(University of Southampton). 1997년~현재 호서대학교 전기정보통신공학부 부교수.

전문호(全汶鎬)
1976년 12월 11일생. 2002년 2월 호서대학교 전기공학과 졸업. 2004년 동 대학원 전기공학과 졸업(석사). 현재 동대학원 전기공학과 박사과정.