반응표면법을 이용한 양측 철심형 영구자석 선형 동기기의 구조 최적화

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Structure Optimization of Double-Sided Iron-Core Type Permanent Magnet Linear Synchronous Machine Using Response Surface Method

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Abstract - The inherent drawback of iron-core type permanent magnet linear synchronous motor (PMLSM) is detent force that is dependent on several major factors such as PM length, slot clearance, and skewing. To minimize the detent force, this paper proposes a structure optimization using the combination computation of two dimensional (2-D) finite element analysis (FEA) and response surface methodology (RSM). The RSM, that is a collection of the statistical and mathematical techniques, is utilized to predict the global optimal solution based on the FEA calculated results of the detect forces for different combinations of factors. With the help of the combination computation the high capacity iron-core type PMLSM with more than 12000 N propulsion forces only contains less than 3 N detent forces.

1. 서 론

The permanent magnet linear synchronous motor (PMLSM) has superiority to be used in vertical transmission system, such as multi-car ropeless elevator system and deep mine transmit system, because of high power density and good motion ability. Some vertical propulsion systems utilizing the coreless type PMLSM was investigated to achieve the detent force and normal force suppression [1]. However, to make the vertical transmission system become practical, one of the most important requirements is the high force density [2]. Therefore, in this paper we propose a long armature double-sided iron-core type PMLSM model to realize the vertical ropeless transportation system.

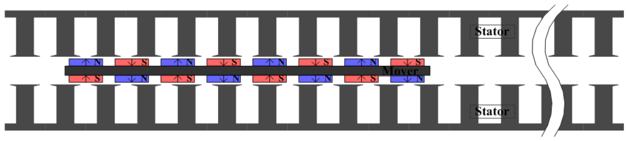
The inherent drawback of an iron-core type PMLSM is the detent force that is generated by the interaction between the permanent magnet (PM) and the slotted iron-core. The optimal structure design of PMLSM is an effective means to reduce the detent force. Since the amplitude of detent force is generally dependent on several major factors, for instance, slot opening length, airgap length, PM length, skewing of either stator or magnet poles [3]. We can minimize the detent force by optimal design of some factors. However, it is difficult to predict the optimal values of the factors by finite element analysis (FEA). Even all characteristics of detent force versus each factor can be calculated without considering the time consuming, we cannot obtain a global optimal solution. Therefore, the combination of the FEA and response surface method (RSM) is necessary. The RSM is a collection of statistical and mathematical techniques [4]. In RSM a quadratic approximation model is commonly used to predict the optimal value. Since there is error in the fitted quadratic approximation model in comparison with the real model, the window-zoom-in method is employed to obtain more accurate and near-optimum response value.

2. 본 론

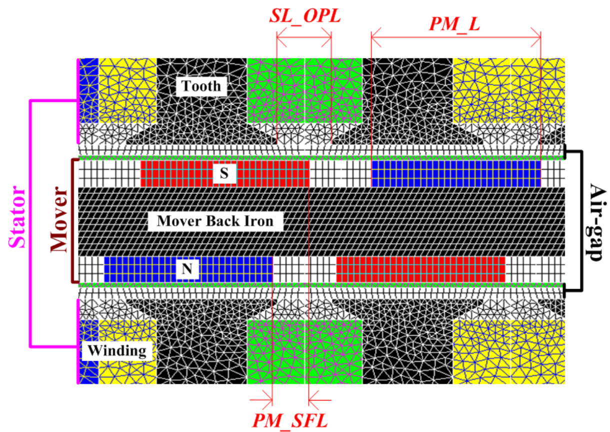
2.1 PMLSM Model

Fig. 1 illustrates the structure of the long armature double-sided iron-core type PMLSM. The stator side that consists of two group of semi-closed slot iron core with concentrated windings faced to each other in a 9-slot/8-pole fractional-slot pitch structure is fixed to the hoist way. The mover side that is composed of two group of permanent magnet mounted on the surface of the iron yoke is fastened to the mover cage.

In this paper, the two-dimensional (2-D) finite element method (FEM) is used to analyze the PMLSM model that is partially shown as Fig. 2. The three optimal factors: PM relative displacement SKL, PM length PML, and slot opening length SL_OPL, are screened as variables. According to the basic design requirements the three factors range are given as the values shown in the first calculation column of Table 1.



<Fig. 1> Structure of a long armature double-sided iron-core type PMLSM



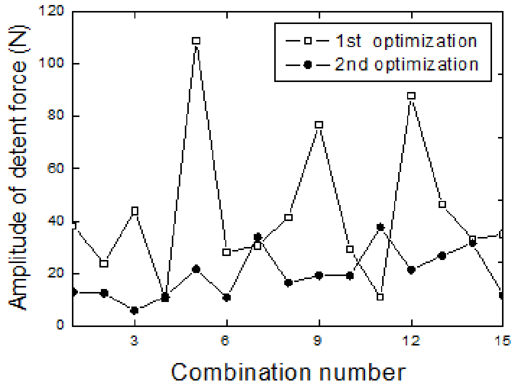
<Fig. 2> PMLSM Meshed partial structure with optimal factors.

<Table. 1> Ranges of three optimal factors and optimal values

Factors	Ranges of factors (mm)		Optimal values (mm)
	first calculation	second calculation	
PM_L	28-38	28-34	**28**
PM_SFL	0-17	0-12	**6**
SL_OPL	3-19	5-14	**9**

2.2 Optimization Calculations

Based on the preliminary range of the three optimal factors, fifteen independent combinations of factors generated by RSM can be obtained, which are the mathematical models representing the best fit of the data [4]. Then the detent forces are calculated in one slot pitch 34 mm by means of geometry construction of the fifteen corresponding 2-D FEA models. Fig. 3 illustrates the amplitudes of detent forces of the FEA models. In this first optimization calculation the range of detent force is from12 N to 109 N shown as the rectangular dotted line.



<Fig. 3> Peak values of detent forces versus different factor combinations.

Next the fractional factorial method, known as face-centered central composite design that offers the advantage of requiring fewer runs, is utilized to predict the global optimal point. In RSM a quadratic approximation model is generally used and can be written as follows:

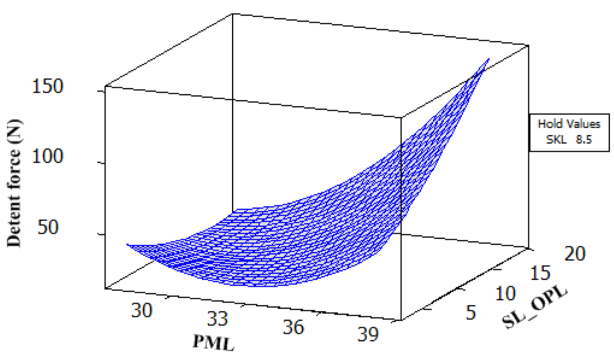
$$y = \beta_0 + \sum_{i=0}^{k} \beta_i x_i + \sum_{i=1, j \leq i}^{k} \beta_{ij} x_i x_j + \varepsilon$$

where y is the RSM predict value, $\beta(\beta_0, \beta_i, \beta_{ij})$ are the coefficients of the optimal factors $x(x_i, x_j)$, and ε is the estimate error.

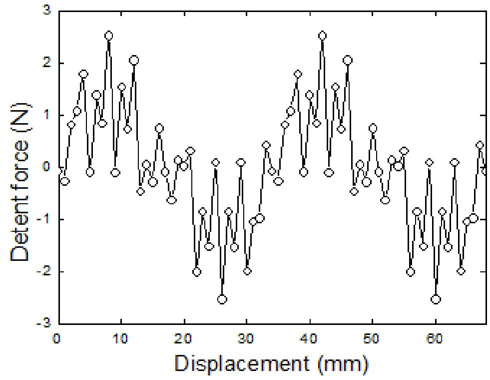
The coefficients $\beta(\beta_0, \beta_i, \beta_{ij})$ are very easy to estimate and one of the results of RSM is shown as Fig.4.

Finally, the global optimal point can be predicted in RSM. However, in the first optimization the estimate error ε is too large to predict the correct global optimal value exactly due to the large range of the amplitude of the detent force. Therefore, the window-zoom-in method is employed to reduce the factors region to achieve more accurate response value.

The computation using the combination of FEA and RSM is implemented once again. The ranges of optimal factors are reduced to the regions shown in the second calculation column of Table I by using the window-zoom-in method, and calculated amplitudes of detent forces are illustrated as the circle dotted line in Fig.3. Finally, the optimal values of three factors are predicted as the rightmost column of Table I. The detent force of the optimized long stator double-sided iron-core type PMLSM is shown in Fig. 5. The amplitude of detent force 2.52 N is only 0.02% of that of propulsion force 12000 N. This large capacity PMLSM with very high propulsion force and ultra small detent force satisfied the design requirement of the vertical transportation system allowing smooth motion.



<Fig. 4> Predicted response surface of detent force versus the PM length PML and slot opening length SL_OPL.



<Fig. 5> Detent force of optimized iron-core type PMLSM model.

3. 결 론

This paper had investigated the long-armature double-sided iron-core type PMLSM for vertical transportation system. The detent force was minimized to 8.4N utilizing the optimal structure design of PMLSM with the adjustment of PM length, PM group shifting length, and slot opening length by the combination of FEA and RSM. Furthermore, using the PM shift method that was similar to the skewing magnet technique, together with the consideration of output thrust, the detent force was reduced to 2.52N. This detent force could be neglected in comparison with the rated thrust 12000N and assured smooth motion drive. This high force density slotted iron-core type PMLSM with ultra low detent force made the ropeless elevator system become more practical.

감사의 글

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[참 고 문 헌]

[1] M. Platen, G. Henneberger, “Examination of leakage and end effects in a linear synchronous motor for vertical transportation by means of finite element computation”, IEEE Trans. on Magn., vol. 37, no. 5, pp. 3640-3643, 2001.
[2] T. Ishii, “Elevator for skyscrapers”, IEEE Spectrum, vol. 31, no. 9, pp. 42-46, 1994.
[3] I.S. Jung, J. Hur, and D.S. Hyun, “Performance analysis of skewed PM linear synchronous motor according to various design parameters”, IEEE Trans. on Magn., vol. 37, no. 5, pp. 3653-3657, 2001.
[3] J.H. Kwon, S.M. Hwang, C.M. Lee, K.S. Kim, and G.Y. Hwang, “Application of Response Surface Methodology (RSM) in Microspeaker Design Used in Mobile Phones”, IEEE Trans. on Magn., vol. 45, no. 10, pp. 4550-4553, 2009.