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Optimal Design of Slotless-type PMLSM Considering Multiple Responses by Response Surface Methodology

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***Abstract*-- This paper deals with the optimal design of a slotless-type permanent magnet linear synchronous motor (PMLSM). Response surface methodology, one of the optimization methods, is used to consider multiple responses of the PMLSM. That is, it is applied to obtain more average thrust and less thrust ripple than a prototype PMLSM. Characteristic analysis of the PMLSM is performed by space harmonic method for fast analysis, and the final results of an optimized PMLSM are compared with those of the prototype PMLSM by finite element analysis.**

I. Introduction

Permanent magnet linear synchronous motors (PMLSMs) have been used in a wide variety of industrial applications. Especially, a slotless-type PMLSM is suited for precision instruments requiring accurate position control due to low thrust ripple. However, it has low power density because of a large air-gap structurally [1]. Therefore, this paper proposes optimal design of the PMLSM to obtain larger thrust and smaller thrust ripple than already fabricated prototype PMLSM.

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful to find the "best fitted" representation of the response of the physical system under investigation. It has recently been recognized as an effective optimization approach for design of electrical devices when used in combination of the numerical method for product performance simulation [2]. In RSM, a polynomial model is generally to be constructed to represent the relationship between the performance and the design parameters. Thus, this model can be used to predict the product performance as a function of design variables, and design optimization considering multiple responses can be carried out with much ease.

II. Analysis Model

Fig. 1 shows the prototype PMLSM fabricated for high precision driving.

III. Preparation for Optimization

A. Defining the design variables

All parameters related to average thrust and thrust ripple in the PMLSM are described in Fig. 2. If all of them are employed in optimization process, the analysis time is very long due to a number of experiments, and accuracy of the optimization is low on account of interaction of each variable. Accordingly, important design parameters concerning the average thrust and the thrust ripple must be investigated. Fractional factorial designs are suitable for solution of this problem. Fig. 3 and Fig. 4 show the importance and interaction effect of each parameter. From the result, three control factors, B, C, and D, are selected. Description of each variable is shown in Table I.

B. Design area

In general, design area is set by past experiment data, experimenter's experience and a response aspect by changing design variables through factorial design. In this paper, design area by fractional factorial design is determined, and the area is shown in Table II.

Fig. 1 Prototype PMLSM

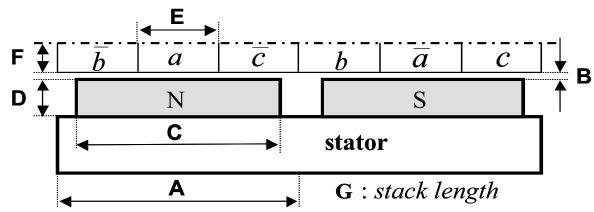


Fig. 2 Design parameters

IV. Optimization of Multiple Responses

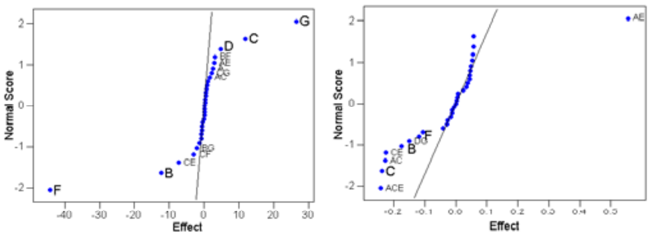
RSM is a very powerful method searching optimal condition in interest area through statistical fitting method, which is based on observed data from system [3]. However, in multiple responses, it is not easy to find optimal conditions simultaneously satisfying each response by RSM. Therefore, this paper seeks optimal points satisfying special area of each response.

In RSM, a polynomial approximation model is commonly used for a second-order response and can be written as follows:

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x^2{}_j + \sum_{i \neq j}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad (1)$$

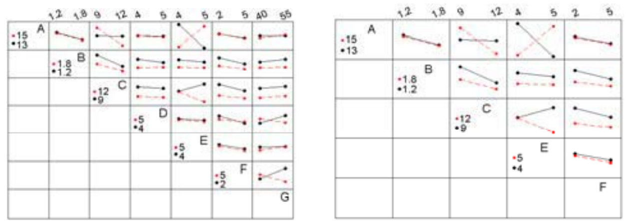
where β is regression coefficients, and ε is a random error treated as statistical error. The fitted coefficients and the fitted response model by least square method used to estimate unknown coefficients and central composite design based on space harmonic method are obtained respectively. Then, objective area of each response is determined as follows:

$$126 \le \hat{\mathbf{Y}}_{\text{Average thrust}} \le 126.5 \qquad 0.49 \le \hat{\mathbf{Y}}_{\text{Thrust ripple}} \le 0.5$$



(a) Average thrust (b) Thrust ripple

Fig. 3 Normal probability plot of the effect



(a) Average thrust (b) Thrust ripple

Fig. 4 Interaction effect of each parameter

V. Results and Discussion

The optimal condition of multiple responses is shown in Table III. Average thrust and thrust ripple of optimized PMLSM by FEM is increased 18.9[%] and reduced 55.4[%] than prototype PMLSM respectively. Graphic performance comparison between optimized PMLSM and prototype PMLSM is given in Fig. 5.

VI. Conclusion

In order to increase performance of the prototype PMLSM, optimization design considering multiple responses by RSM is introduced in this paper. It is accomplished by the proposed method that performance of the optimized PMLSM is improved as compared with that of the prototype PMLSM. Therefore, this proposed approach concerning multiple responses is considered as an appropriate optimization method for optimal design of PMLSM and other machines.

TABLE I
PARAMETERS DESCRIPTION

Parameters	Description	Parameters	Description
A	Pole pitch	E	Width of coil
B	Air-gap	F	Height of coil
C	Width of magnet	G	Stack length
D	Height of magnet		

TABLE II
DESIGN AREA

Design variables	min	max
B : Air-gap [mm]	0.8	1.6
C : Width of magnet [mm]	9.8	12.6
D : Height of magnet [mm]	3.5	6.5

TABLE III
OPTIMAL POINT OF MULTIPLE RESPONSES

Parameters	Prototype	Optimized
B : Air-gap [mm]	1.2	1.2
C : Width of magnet [mm]	9.8	12.6
D : Height of magnet [mm]	5	6.5

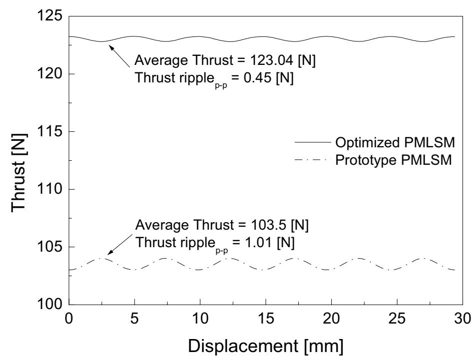


Fig. 5 Performance comparison between prototype and optimized PMLSM

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