Approximate optimization design of high power LSM for thrust force ripple reduction using Kriging method

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Abstract — This paper presents the efficient method for thrust force ripple reduction of high power linear synchronous motor(LSM) by module phase set shift(MPSS). And propose a method that reduce thrust force ripple more by use of chamfering. The chamfering shape is optimized using Kriging method

I. INTRODUCTION

Rotating machines are using gears to change the rotary motion into the linear motion, on the other hand, linear motors have a accurate position control and excellent dynamic characteristics because of generating a thrust force directly. But the important problem, one of the linear motor is a high thrust ripple. Thrust ripple has a bad effect on the position accuracy and the dynamic characteristics, so it is necessary to reduce the thrust ripple. Cogging is one of the cause that affect thrust force ripple. Cogging has some connection with the GCD between pole pitch and teeth pitch.

It is proposed method to reduce a thrust ripple of the linear motor that chamfering, skew, and so on. In this paper, the module phase set shift(MPSS) is used to reduce a thrust force ripple that has a similar effect to skew. And propose a method that reduce a thrust force ripple more by use of chamfering.

II. LSM BASIC DESIGN

LSM was basically designed as following step. Because alignment torque is larger than reluctance torque in LSM, electric loading & magnetic loading is selected from (1) and calculate $X_r L_{stk}$.

$$F = \left(\frac{1}{2} K_w \hat{B}_{g1} ac \cos\beta\right) X_r L_{stk} \quad (1)$$

As magnetic loading was selected, magnetic flux density of air-gap is calculated from magnetic loading, and then ratio of shape size in field part is selected from magnetic flux density of air-gap. Turns per pole per phase is calculated from initial value of E_0, I_{ph} and determine the turns of stator. And then determine the ratio of shape size in stator part. Calculated R, L_d, L_q of stator's winding is used in voltage equation and find the new E_0, I_{ph}. Repeat the process until the new E_0, I_{ph} are converged on constant value. The basic design parameter by the flow is as shown Table 1. Basic design model is 10 poles per module and designed 20 modules.

TABLE I
Designed LSM Spec.

rated size (total / 1)		6.81 / 0.3405	MW
start thrust (total / 1)		81.7 / 4.085	kN
frequency		161.50	Hz
input line to line voltage		7794.23	V_rms
input phase voltage		4857	V_rms
input current		1583	A_rms
air-gap		10	mm
pole pitch		258	mm
section length		1200	m
number of poles (total / each)		200 / 10	
mover	teeth width	100	mm
	yoke width	100	mm
	core stack length	220	mm
	slot depth	100	mm
	coil turns	200	turns
	coil current	25	A
stator	number of slots per phase per pole	1	
	series turns per phase	100	turns
	yoke width	100	mm
	teeth width	46	mm
	slot depth	50	mm
	slot width	50	mm

III. BASIC MODEL ANALYSIS

To interpret 10 pole stator length is too long. Therefore it takes long time to analysis 10 pole. There is no problem that interpret 4 pole and convert to 10 pole. Therefore progress 4 pole analysis. Thrust from load angle makes largest thrust when load angle is 70 degree. Thrust is 4.21kN and thrust ripple is 4.50kN when convert to 10 pole. It is satisfied enough with the required thrust 4.085kN. And then teeth is cut for weight reduction as shown Fig. 2. When load angle is 70 degree in new shape, thrust is 83.75kN as shown Fig. 3 which is satisfied with the required thrust. But thrust ripple is 77.92kN, thrust ripple magnitude is 87% of thrust magnitude. It is too large and makes bad characteristic for dynamic characteristic and accuracy. Therefore it needs improvement.

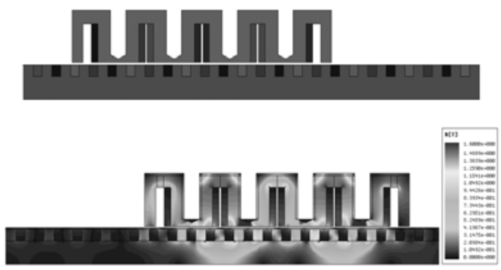

Fig. 2. Transformed Design Result

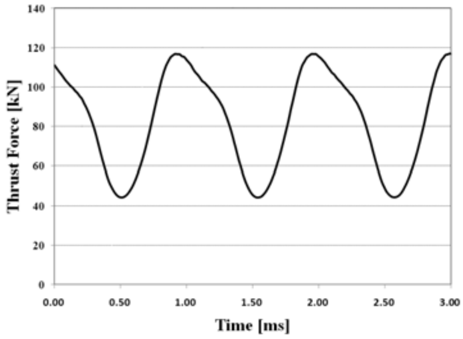

Fig. 3. Transformed LSM Thrust at 70degree Load Angle

IV. MPSS

MPSS is applied because the thrust force ripple is too large as a result of above model's analysis. MPSS(Module Phase Set Shift) is a method that shift initial location of each module. Therefore summation of total thrust force ripple can be reduced like as skew effect at rotary type motor.

Theoretically MPSS can reduce the thrust force ripple most when shift one teeth length of stator as skew. Shift one teeth length is 100% and it can be represented from percent. Thrust force ripple is reduced continuously but thrust force is reduced rapidly when cross the MPSS 60%. Maglev train design demand a large average thrust force and little thrust force ripple. Average thrust force reduction have to be within 3% for satisfying initial goal of average thrust force. MPSS 70% is selected to satisfy average thrust force 81.31kN. Average thrust force is reduced 3% but thrust force ripple is reduced 33.36% when select the MPSS 70%.

V. OPTIMAL DESIGN AND RESULT

A. Selecting variable

Thrust force ripple is reduced 63.3% through MPSS and perform a optimal design to reduce thrust force ripple more. Air-gap magnetic flux distribution influence on thrust ripple. The parts that can great influence on air-gap magnetic flux distribution are variable Core tip, h and Cut. Therefore Core tip, h and Cut are selected as shown Fig. 4. Variable Cut and variable Core tip influence on thrust force and thrust force ripple more.

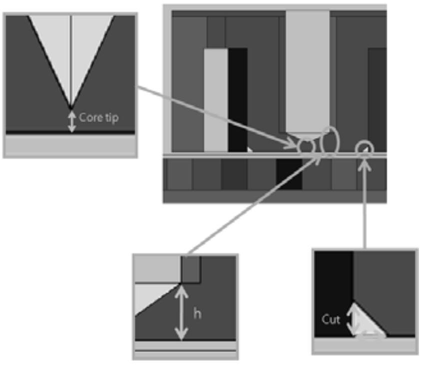

Fig. 4. Selected Variable for Optimum Design

B. Approximate optimization design using Kriging method and result

Kriging method is predicting the characteristic value that want to know around the value already known through the linear combination of weighted value. Ripple is more weighted in approximate optimization design because ripple reduction is larger than thrust reduction at each of the variable. Optimized values are Core tip=21.7, h=25, Cut=12 using Kriging method as shown Fig. 5 and modeling is shown as Fig. 6. Thrust force is 79.07kN and ripple is 18.67kN at optimized model analysis result as shown Fig. 7. Thrust force is reduced 2kN and ripple is reduced 9kN by MPSS 70% model.

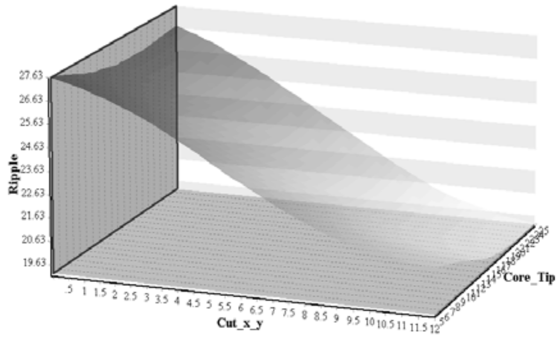

Fig. 5. Ripple according to variables using Kriging method

Fig. 6. Final Model

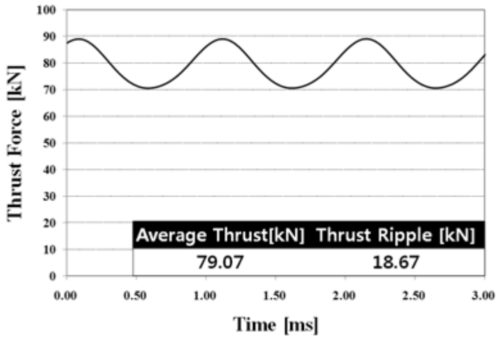

Fig. 7. Thrust at Final Model

VI. REFERENCES

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