The Optimal Design of Thrust Density in Double Sided Coreless PMLSM for Considering Winding Temperature Rise

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Abstract — This work dealt with the optimal design which is a considering rising winding temperature of coreless PMLSM (Permanent Magnet Linear Synchronous Motor). The distribution temperature which was caused by copper loss in the coreless PMLSM was analyzed using FEM (Finite Elements Method). The thrust and current density which winding temperature reaches the allowable temperature were calculated. The optimal model which is the maximum thrust per unit weight was reduced.

I. INTRODUCTION

The coreless PMLSM does not generate detent force. So, it has not only no normal force but also no velocity ripple. Therefore, it has been widely used in superhigh speed precise industries such as manufacturing equipment of semiconductor wafers because of a fast response time[1]. The productivity of these devices depends on the acceleration and deceleration characteristics of Coreless PMLSM.

At coreless PMLSM, effective thrust to load grow bigger when the mover is lighter, because load installed directly on the mover. In other words, it could accelerate faster and it could increase productivity when the mover is lighter if two machines produce same thrust.

Number of turns and current density must be increased to produce more thrust because only winding exists in the mover. But weight of mover would be heavier if number of turns increased, and winding temperature would rise if current density increased. Consequently, the optimum point must be set.

It seems very simple to derive the optimal model which has maximum thrust per unit weight, if all design parameters are same except for winding height and current density. The optimal model would be derived when carry out finite element analysis with changing number of turns assuming current density through experience.

But thermal characteristic would be changed when number of turns and thickness of the mover changes. It means that current density changed if number of turns change. Accordingly, it would be complicated to derive the optimal model if it considered winding temperature.

Therefore, optimal design method of coreless PMLSM considering winding temperature through thermal analysis suggested in this paper. Namely, the optimal model that produce maximum thrust per unit weight was derived through calculate thrust by computed current density when winding temperature reaches allowable temperature. Validity was proven through comparing the result of calculation with the result of experiment.

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II. THERMAL ANALYSIS OF PMLSM

A. *Specification*

Table 1 represents principal specification of the Coreless PMLSM. The Continuous load test which determined the rating of machine was carried out by S5 (Periodic control including electrical break) like Fig. 1[2]. The test motor was installed on a test jig, the operating conditions which are acceleration 25(m/s2), maximum velocity 2.5(m/sec), moving distance 150(mm), and moving mass which include mover is 16(kg) were set up. The temperature Sensor was already inserted into mover to measure the winding temperature. The continuous operation was controlled to saturate the rising of winding temperature at 80(°C) by the waiting time while the winding temperature was recorded in this condition.

So result of experiment, the continuous thrust was 227(N) at natural cooling, the continuous current density was measured as 8.48(A/mm2).

TABLE I. PRINCIPAL SPECIFICATION

Item	Symbol	Value	Unit
Thickness of PM	t_m	7.5	mm
Length of PM	l_m	52.0	mm
Height of Winding	h_w	9.4	mm
Continuous Current Density	J_c	8.48	A/mm^2
Continuous Thrust	F_c	227	N
Limit of Temp. rise	ΔT	80	C

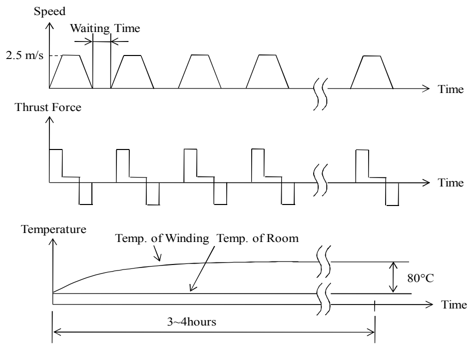


Fig. 1 Continuous load test pattern (duty type S5)

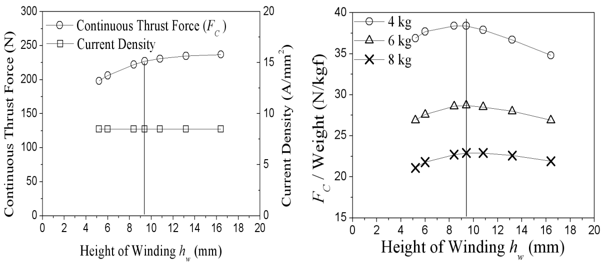
B. *Thrust per unit weight*

It seems very simple to derive the optimal model which has maximum thrust per unit weight, if all design parameters are same except for winding height and current density.

Fig. 2(a) shows the continuous thrust of the changes according to increasing or decreasing the height of winding.

The current density of each model, the same applied current density of basic model. When the increasing winding height, Air gap flux density is decreased because both PMs(Permanent Magnets) interval draft apart. But in this model, thrust was increased by more largely increased winding electromagnetic force. Fig. 2(b) shows thrust per unit weight by experiment result of continuous thrust.

In Fig. 2(a), as winding height is increased, the continuous thrust is also increased, although the mover weight is heavier. Therefore maximum point of thrust per unit weight is existed in the middle. In this figure, it is the basic model that winding height is 9.4(mm) when it weights 4~8(kg) includes the mover and load.



(a) continuous thrust (b) thrust per unit weight

Fig. 2 Thrust calculation result according to coil height

C. *Thermal transfer analysis*

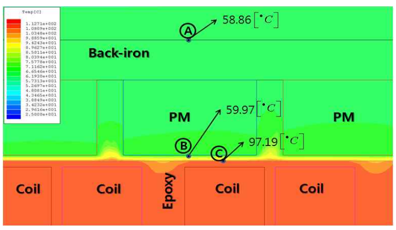


Fig. 3 Distribution temperature of analysis model

The convection heat transfer coefficients are the hardest thing to determine in heat analysis. The convection heat transfer coefficient is not property of material. It is determined by surface shape and flow property which took place convection heat transfer[3]. Fortunately, the winding height which selected among the design parameters in this paper does not change convection surface shape and flow property. Also, the convection heat transfer coefficient does not alter as well. The convection heat transfer coefficient was estimated by the experiment result of basic model.

D. *Considering the thrust winding temperature*

As a result of the thermal transfer analysis, the more winding height was increased, the more winding temperature was rised when same current density was applied regardless of winding height. Cooling effect decreased because if winding height is higher, it has disadvantage of radiate heat. Continuous current density was recalculated until winding temperature does not exceed the limit according to winding height. And Fig. 4 shows the result.

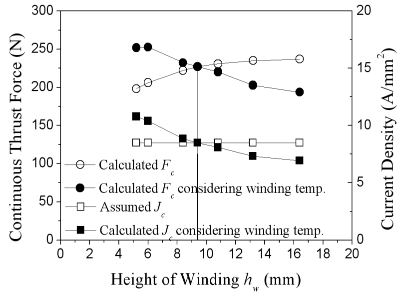


Fig. 4 Continuous thrust considering winding temperature

In case of without considering winding temperature, thrust was increased when winding height is higher. But in case of considering winding temperature, the result could computed that lower winding height would get more thrust as Fig. 4. It means, as much as winding height is lower, the heat transfer characteristic is improving and higher current density can be allowed.

E. *Comparison of thrust per unit weight*

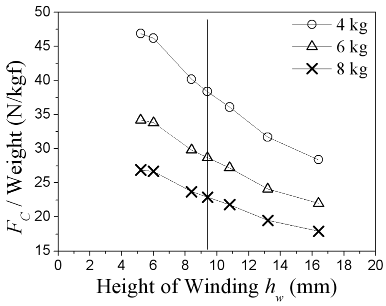


Fig. 5 Thrust per unit weight by considered the temperature rise

The optimal model is the basic model that winding height is 9.4(mm), without considering winding temperature in Fig. 2(b). However, as winding height is lower, thrust per unit weight was increased when considering winding temperature. As a result winding height of the optimal model must be lower than the basic model.

The three models which were different winding height were manufactured and compared experimental results with analysis results in this paper.

As for this work, it will be dealt with in full-paper for details.

III. References

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