Initial Design and Dynamic Performance of Linear Switched Reluctance Motor with Design Range considering Continuous Thrust Generation and Saturation according to Design Factor

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Abstract — This paper deals with initial design and dynamic performance of linear switched reluctance motor using design range for continuous thrust generation and saturation according to design factor. In the design range for continuous thrust generation, the initial design of LSRM was performed, and the saturation is then considered by finite element method. From the analyzed results, the dynamic characteristic simulation is performed to predict the operating characteristics as well.

I. INTRODUCTION

Since the winding of Linear Switched Reluctance Machine (LSRM) is only placed either primary or secondary, the structure is simple and durable per. In addition, the force characteristic is superior to other electrical machine per unit volume. However, thrust ripple cannot be avoided due to the operating method by pulse voltage. It usually causes the noise and vibration of machines, so the research on ripple reduction is actively and widely being performed [1]-[4]. Besides, LSRM has large air-gap as a characteristic of linear machine, and the amount of leakage flux is more than others. Since it causes the differences on performance, the accurate analysis and design is needed for the application of LSRM in industry.

This paper deals with initial design and dynamic performance of the LSRM using design range for continuous thrust generation and saturation according to design factor. At first, the ratio of the mover and stator teeth width is determined for continuous thrust generation, and the teeth height is calculated with the satisfaction of coil turns for the required thrust in terms of input current value. In the second place, from the design specifications, the circuit parameters are calculated, and they are applied to the simulation model for dynamic characteristic to analyze the operating characteristic of LSRM. The analyzed results are evaluated whether it is suitable for the required specifications, and the validity of the design process is demonstrated from the evaluation. It is considered that the suggested design range can contribute to the initial design of LSRM, which can be substituted by linear PM motors.

II. DESIGN RANGE ACCORDING DESIGN FACTOR

Fig. 1 shows the flow chart for continuous of LSRM. First, saturation is considered from finite element method for design factor to satisfy required thrust, and circuit parameter is calculated design factor considering saturation. Second, simulation model of the LSRM is made for dynamic characteristic analysis using circuit parameter, voltage equation. Finally, initial design process is performed repeatedly to satisfy required specification through dynamic simulation result.

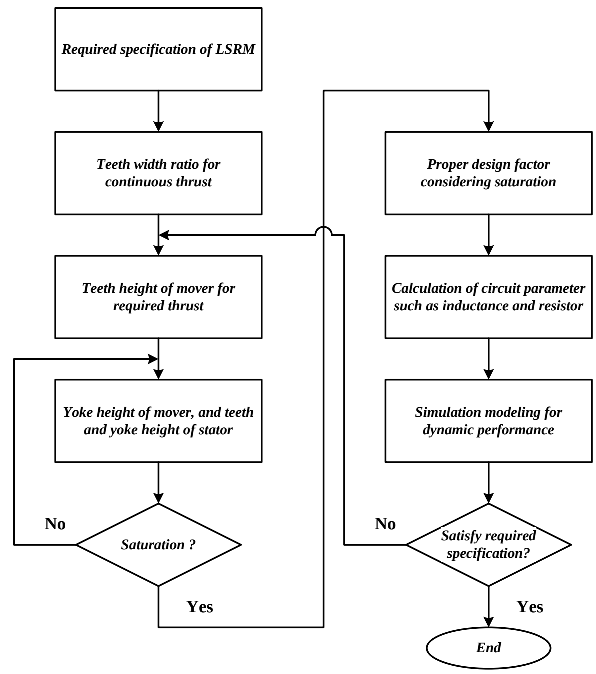

Fig. 1. Flow chart for continuous thrust of LSRM

A. Teeth width ratio for continuous thrust

The LSRM generate thrust in inductance rising slope range, and the mathematical expression for thrust of the LSRM is given by $F_x=(i^2/2)\cdot(dL/dx)$. In order words, since the electromagnetic thrust of LSRM is given by the product of the square of winding currents affected by inductance of windings and the rate of changing in inductance with respect is essential for the calculation of thrust for LSRM.

Fig. 2 shows the kind of teeth width of mover and stator, and inductance profile and predicted thrust of continuous each phase according to teeth width of mover and stator. We can derive a teeth width ratio of mover and stator continuous thrust generating from Fig. 2.

B. Teeth height of mover for required thrust

Teeth height of mover is provided slot area which is had number of coil turn to satisfy required thrust. Here, number of coil turn is defined current density and fill factor [5].

$$L = -jK_l\left(\frac{\mu_0 J e^{-2k_n Y_s} e^{k_n y} + \mu_0 J e^{-k_n y}}{e^{-2k_n Y_s} e^{k_n Y_m} - e^{-k_n Y_m}}\right) e^{-jk_n x} \quad (1)$$

$$K_l = \frac{(\tau_m - w_{mt}) h_{mt} f_f J_d S}{2i^2} \quad (2)$$

where $k_n=n\pi/\tau$ is the spatial wave number of the n^{th} harmonic, Y_s and Y_m are height of stator and mover, respectively. J is Fourier series expansion for current of mover winding, τ_m is the pole pitch of the mover, w_{mt} is teeth width of mover, h_{mt} is teeth height of mover, f_f is fill factor, J_d is current density, S is teeth area and i input current.

According to the position of aligned and unaligned of LSRM, the inductance can be calculated by (1), and it is applied to thrust equation for the thrust prediction of LSRM.

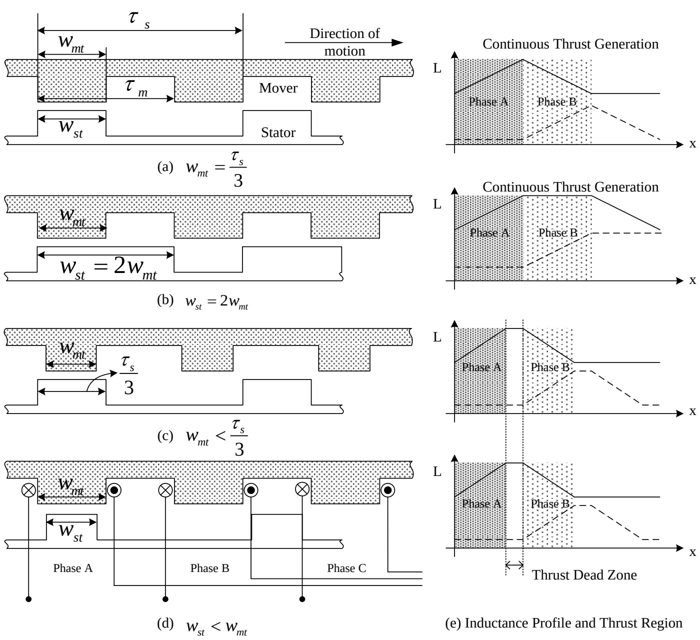

Fig. 2. Inductance and thrust according to teeth width of mover and stator

C. Design factor considering saturation

By using finite element method, the modified design specification is derived satisfying the required thrust through the specific analysis considering saturation in terms of the design specification of the mover and stator.

III. Results and Discussion

Fig. 3 presents the analyzed results of thrust characteristic according to the ratio of mover and stator tooth width, and the tooth width satisfying the required specification can be confirmed. Fig. 4 shows the analyzed thrust results obtained by the tooth height of the mover in terms of the tooth width ratio satisfying the required specification, and it presents the tooth width of the mover and tooth height satisfying the required thrust. Fig. 5 is the analyzed result of the saturation and flux path of the mover and stator, and Fig. 6 offers the dynamic characteristic analysis result. It is confirmed that the analyzed results meet the required thrust. In this paper, the initial design of LSRM is performed in the design range with continuous thrust, and the validity of the analysis process considering saturation is demonstrated by finite element method. Besides, the operating characteristic is predicted by the dynamic characteristic analysis. From the analyzed results, it is confirmed that the design range suggested in this paper can generate the continuous thrust.

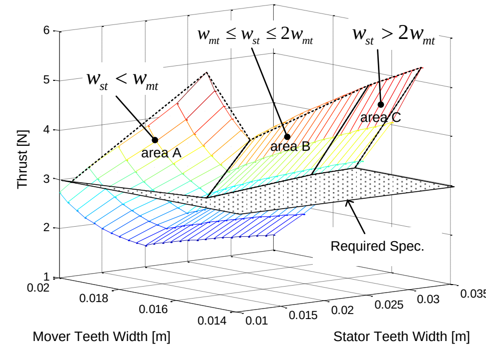

Fig. 3. Thrust characteristic by teeth width ratio

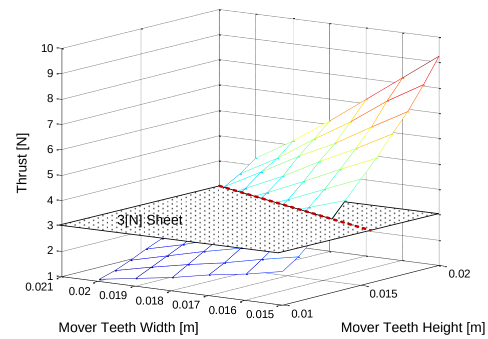

Fig. 4. Required thrust and thrust characteristic according to mover teeth width and height

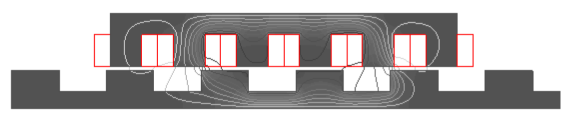

Fig. 5. Flux path and saturation according to design factor

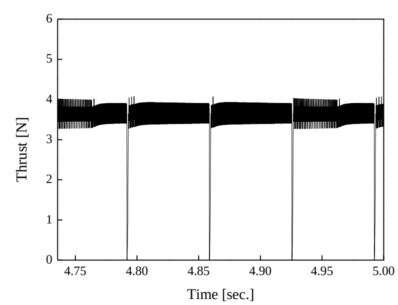

Fig. 6. Thrust characteristic by dynamic simulation

IV. References

[1] T. J. E Miller, *Switched Reluctance Motors and Their Control*, Oxford, 1993.

[2] Byeong-Seok Lee, Han-Kyung Bae, Praveen Vijayraghavan, and R. Krishnan, "Design of a linear switched reluctance machine," *IEEE Trans. Ind. Appl.*, vol.36, no.6, pp.1571-1580, 2000.

[3] Han-Kyung Bae, Byeong-Seok Lee, Praveen Vijayraghavan, and R. Krishnan, “A linear switched reluctance motor: converter and control,” *IEEE Trans. Ind. Applicat.*, vol.36, no.5, pp.1351-1359, 2000.

[4] Hong Sun Lim and R. Krishnan, “Ropeless elevator with linear switched reluctance motor drive actuation systems,” *IEEE Trans. Ind. Elec.*, vol.54, no.4, pp.2209-2218, 2007.

[5] Seok-Myeong Jang, Ji-Hoon Park, Jang-Young Choi and Han-Wook Cho, “Analytical prediction and measurements for inductance profile of linear switched reluctance motor,” *IEEE Trans. Mag.*, vol.42, no.10, pp.3428-3430, 2006.