Determination of Parameters Considering Magnetic Nonlinearity in Solid Core Transverse Flux Linear Motors for Dynamic Simulation

Ji-Young Lee, Ji-Won Kim, Jung-Hwan Chang, Do-Hyun Kang and Jung-Pyo Hong*
Transverse Flux Machine Research Group, Korea Electrotechnology Research Institute, KOREA
*Dept. of Automotive Engineering, Hangyang University, KOREA
jylee@keri.re.kr, Hongjp@hanyang.ac.kr

Abstract — This paper presents a method to calculate motor parameters considering magnetic nonlinearity in solid core Transverse Flux Linear Motors (TFLM) for dynamic simulation. The magnetic field characteristics of the machine are calculated by using 3-dimensional Equivalent Magnetic Circuit Network (3D EMCN) method, and parameters for dynamic simulation such as inductance, electromagnetic force (emf), thrust, core loss, and mechanical load are calculated by using the magnetic field analysis results. The calculated parameters are used as a form of lookup-table in the dynamic simulation model. Therefore, the accuracy of the method is examined by the comparison of input currents which are calculated by using the dynamic simulation model and measured for an example TFLM.

I. INTRODUCTION

Transverse Flux Linear Motors (TFLMs) have a number of useful features distinguished from other motors. TFLM offers a very high force density, and it is suitable for direct drive applications because the mover can produce high flux density in air gap compared with other motor types. This high flux density, however, can cause considerable core losses, which affect the motor performances. When solid core is used for rigid and inexpensive fabrication, the saturation effect and core losses make the motor performance reduced a lot.

Therefore this paper deals with accurate characteristic analysis for solid core TFLM. First of all, mathematical model of dynamic simulation is made, then, motor parameter calculation methods are proposed considering magnetic nonlinearity and 3D magnetic path for reliable dynamic simulation. The parameters such as inductance, electromagnetic force (emf), thrust, core loss, and mechanical load are calculated after magnetic field analysis performed by using 3-dimensional Equivalent Magnetic Circuit Network (3D EMCN) method [1]. The calculated parameters are used as a form of lookup-table in the dynamic simulation model.

In order to verify the usefulness of the method, calculated by dynamic simulation and measured currents are compared for an example solid core TFLM.

II. ANALYSIS MODEL

A. Features of TFLM

Fig. 1 shows configurations of a permanent magnet (PM) type TFLM fabricated to test its application to a high power transportation system. Both the mover and stator have solid core for rigid fabrication, and PM and armature coils are in the mover.

The principle of force generation of objective model is shown in Fig. 2 which is the $\overline{AA'}$ section of Fig. 1. In the mover poles, the two magnetic polarities by PMs, N and S, are changed to one polarity, N or S, by offset one polarity against the polarity of current coil. Therefore, when the polarity of current coil is N, ideally there is only polarity N in the mover. Alternating current functions as a switch turning on and off the mover polarity, therefore, mover and stator generate the total thrust in one direction [2].

As roughly shown in Fig. 2 (a), sine wave source makes better output characteristics; the output power is higher, and the thrust ripple is lower if two more phases are used. In the aspect of drive, sine wave current control has also better response characteristics. Therefore, for industry application, sine wave source is considered to run TFLM, and the square wave source is dealt for static characteristic test [1].

B. Dynamic Simulation Model

The drive system for TFLM is composed of three main parts. Beside the motor there is the power electronic part and the controller. The converter consists of a switch-mode inverter that is coupled to the rectifier by a dc-link capacitor. Each phase is controlled by current controller that can be a PI or hysteresis band controller. The rough block diagram of control system is as shown in Fig. 3 (a)

The most inner part of this model is one single motor phase which is based on the following voltage equation:

$$V = Ri + \frac{d\lambda}{dt} = Ri + \frac{d\lambda}{dx}\frac{dx}{dt} + \frac{d\lambda}{di}\frac{di}{dt} = Ri + v\frac{d\lambda}{dx} + L\cdot\frac{di}{dt} \quad (1)$$

where, V, i, R, λ, and L are voltage, current, resistance, total linkage flux, and inductance, respectively. Because all phases of TFLM are separated, there are no mutual components of inductance.

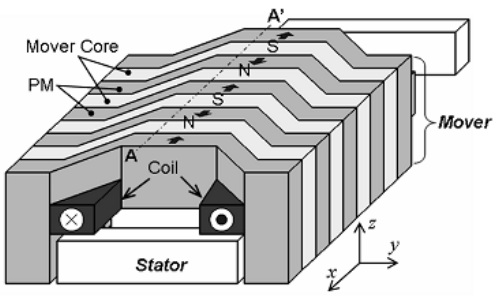
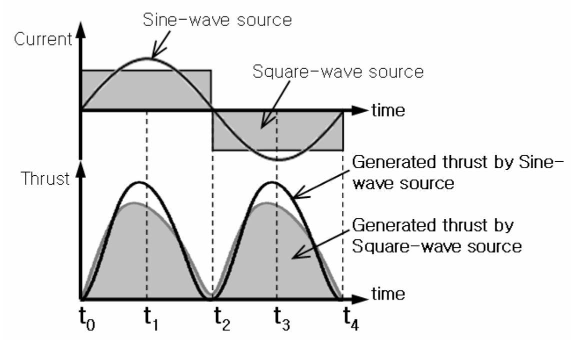
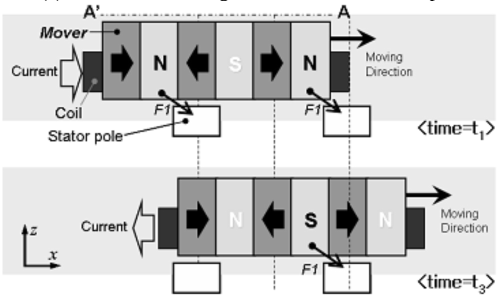


Fig. 1. Configuration of one-phase TFLM



(a) current mmfs and generated thrusts for one phase



(b) variation of mover polarity

Fig. 2. Principle of force generation

To this equation, (1), the mechanical equation is added.

$$F_x - F_l = M \cdot a = M \cdot \dot{v} = M \cdot \ddot{x} \qquad (2)$$

where F_x, F_l, M, a, v, and x are thrust, load, total mover's mass, acceleration, velocity, and distance, respectively. The (1) and (2) are expressed by block diagrams as shown in Fig. 3 (b) and (c). To reduce calculation time, core losses are considered as lookup table in the block diagram of mechanical equation instead of using 3D transient analysis with voltage equation

C. *Parameter determination*

Basically, all parameters are calculated using the magnetic field analysis results obtained by using 3D EMCN. Although in the dynamic simulation the current source is considered as sine wave, in the magnetic filed analysis the current source is square wave to make lookup table according to input current and mover displacement. After that, each parameter is calculated as follows;

1) inductance and emf : with flux variation depending on current and displacement as shown in (1), inductance and emf are calculated. If the coil is in the stator, the inductance calculation method is in [1]

2) thrust : it is calculated by using Maxwell Stress Tensor.

3) core losss : the process used in this paper is the traditional method introduced in [2]. To get accurate results, the magnetic field analysis for the first step of core loss calculation should be performed with running current source. Therefore sine wave source should be considered in magnetic field analysis.

4) mechanical load : in the linear motor, the product of perpendicular load and friction coefficient is mechanical load in steady state [3]. Not only total mover's mass but also attraction or normal force can be perpendicular load.

III. RESULTS AND DISCUSSION

The specifications and magnetic material characteristics, which are B-H curve and core loss data obtained by Epstein frame test, are the same as those of the solid stator core model in [2] except number of turns. With those conditions, Fig. 4 shows the calculated parameters according to current and displacement.

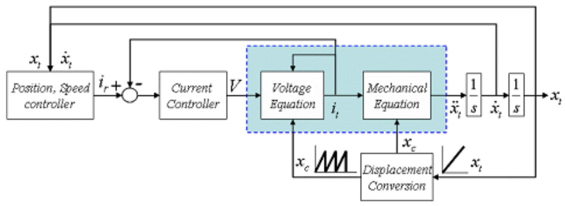
The verification of the usefulness of the method will be shown in extended paper by comparing simulated and measured currents.

IV. REFERENCES

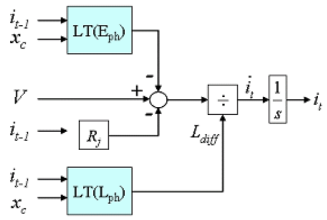
[1] Ji-Young Lee, Jung-Pyo Hong, Jung-Hwan Chang, and Do-Hyun Kang, "Computation of Inductance and Static Thrust of a Permanent-Magnet-Type Transverse Flux Linear Motor," *IEEE Trans. on Industry Application*, vol.42, No.2, pp.487-494, 2006

[2] Ji-Young Lee, Do-Hyun Kang, Jung-Hwan Chang, and Jung-Pyo Hong, "Rapid Eddy Current Loss Calculation for Transverse Flux Linear Motor," *IEEE Industry Applications annual meeting*, CD, 2006

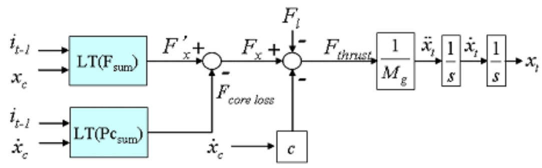
[3] Jacek F. Gieras, and Zbgniew J.Piech, *Linear Synchronous Motors – Transportation and Automation Systems*, CRC Press, 2000



(a) block diagram of control system



(b) block diagram of voltage equation



(c) block diagram of mechanical equation

Fig. 3. Block diagram for dynamic simulation of TFLM

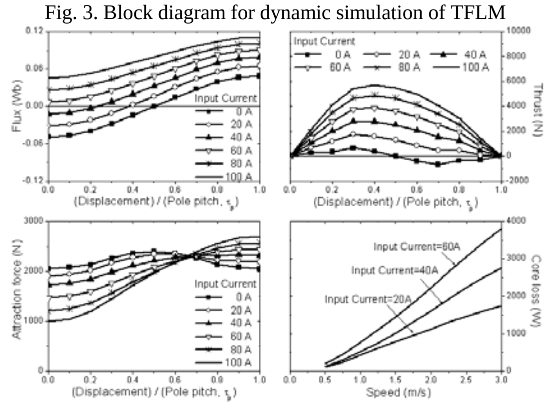


Fig. 4. Magnetic parameters for dynamic simulation

Compumag 2007
Aachen, Germany

IEM RWTH

INSTITUTE OF ELECTRICAL MACHINES
CHAIR OF ELECTROMAGNETIC ENERGY CONVERSION
RWTH AACHEN UNIVERSITY

Proceedings of the

16th Conference on the Computation of Electromagnetic Fields

COMPUMAG 2007

June 24th - 28th

Aachen, Germany

ITG INFORMATIONSTECHNISCHE GESELLSCHAFT IM VDE

IET
The Knowledge Network

Wednesday, June 27th

OC1 – Optimisation - Software Methodology EUROPA SAAL

08:30–10:10 Session chair: **Gabriela Ciuprina, Jan Sykulski**

PC1 – Electrical Machines and Drives BALUSTRADE

10:30–12:10 Session chair: **Erich Schmidt, Yoshihiro Kawase**

PC2 – Numerical Techniques BALUSTRADE

10:30–12:10 Session chair: **Igor Tsukerman, Georg Wimmer**