2009년도 대한전기학회 하계학술대회 논문집 2009. 7. 14 - 17

스파이럴 이동자 코어를 가지는 영구자석여자 횡자속 선형전동기의 등가자기회로망법을 이용한 특성해석

이지영*, 김지원*, 우병철*, 강도현*, 호앙트룽키엔**, 김광운**
한국전기연구원*, 과학기술연합대학원대학교**

Characteristic Analysis using Equivalent Magnetic Circuit Network Method for Permanent Magnet Excited Transverse Flux Linear Motor with Spiral Core in a Mover

Ji-Young Lee*, Ji-Won Kim*, Byung-Chul Woo*, Do-Hyun Kang*, Trung Kien Hoang**, and Kwang-Woon Kim**
Korea Electrotechnology Research Institute* ,University of Science & Technology**

Abstract - This paper presents an analysis method for a permanent magnet excited Transverse Flux Linear Motor (TFLM) with spiral core in a mover. The spiral core is used as mover core in order to make 3-dimensional magnetic flux path at the TFLM which has 3-dimensional magnetic flux flow. Magnetic field is analyzed by three-dimensional Equivalent Magnetic Circuit Network (EMCN) method. And an imaginary part, 'flux barrier,' is introduced to consider the spiral core characteristic. The computed thrust forces is compared to the measured results to show the effect of presented analysis method.

1. INTRODUCTION

In the factory automation system, there is a great demand for linear direct drives to avoid drawbacks of traditional drives with rotary motors and mechanical motion conversion devices such as gearbox, belt, etc. Permanent Magnets (PMs) excited Transverse Flux Linear Motors (TFLMs) have been improved in transportation and high power systems. This kind of motors promise far-reaching applications in the factory automation system and especially for linear direct drives.

PM excited TFLM has 3-dimensional flux paths. Flux path by PM is on x-z plane and flux path by winding is on y-z plane in rectangular coordinate system. This characteristic makes difficult to use general laminated core, which lamination direction is in one straight direction, in the structure of TFLMs. [1] and [2] show examples of making stator cores with laminated silicon steel at a rotary type transverse flux machine. Tooth of the stator core are bent not to interrupt 3-dimensional magnetic flux flow. In the mover, soft magnetic composite (SMC) core is used instead of laminated silicon steel core. When PMs are inserted between cores, SMC core is one solution in the most cases for 3-dimensional magnetic flux path and easy fabrication. SMC has a good alternative for 3-dimensional flux path, but its magnetic permeability is significantly lower than silicon steel, and the material cost is high.

Therefore, in this paper spiral core is used as compromise between general laminated core and SMC core. Material is silicon steel, and the B-H characteristics are better than SMC. The lamination is in a 'spiral' direction as the core name, and it makes not to interrupt 3-dimensional magnetic flux path compared with general laminated core.

3-dimensional Equivalent Magnetic Circuit Network (EMCN) method is applied to analyze this model [3]. There is a fact that, with the use of EMCN, the objects are modeled as solid state in place of laminated state which they should be in order to save analysis time, so that the flux barrier will be introduced to consider the laminated core characteristics. In term of thrust force, the results for the cases with and without flux barrier will be compared to each other and also compared to the measurement to show the effect of analysis method.

2. ANALYSIS MODEL

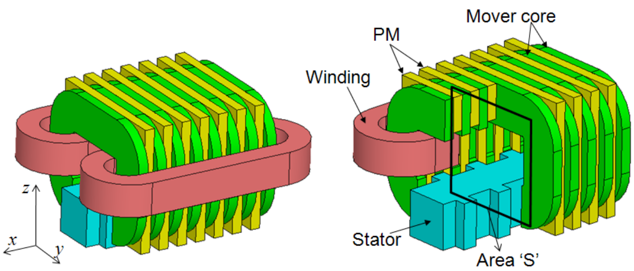
2.1 TFLM configuration

Fig 1 (a) shows a 3-dimensional analysis model of a PM excited TFLM with spiral core in a mover. As shown in Fig 1 (b) in detail the mover has a structure in which each of PM is interposed between adjacent two mover cores in order to form a high magnetic flux. This type of TFLM has salient poles on both stator and mover, and the excitation winding is carried by mover. Stator poles are skewed compared to the opposite one. The laminated directions of stator and mover cores are shown in Fig. 2, and the specifications of analysis model are briefly described in table 1. The principle of operation is explained in [4].

2.2 Analysis method.

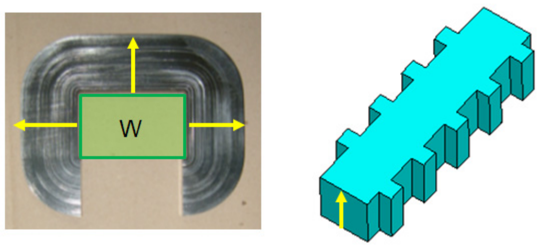
The magnetic characteristics of the analysis model are calculated by 3-dimensional EMCN. However, one should be noted that in order to save simulation time, either mover or stator are modelled as solid object thus enabling magnetic flux to flow in any direction. This is different from actual state with laminated core.

So that, with the intention of getting high accuracy of analysis in comparison with experimental result, here introduces an imaginary part, 'flux barrier.' Magnetic flux is hard to flow to the lamination direction because of low permeability. In the analysis model, the winding window 'W' as shown in Fig. 2 (a) is the area where flux hardly flow because of both mover and stator core lamination direction.



(a) 3D Full model for one phase (b) 3D insight view

Fig. 1 Configuration of a TFLM with spiral core in a mover



(a) Mover core (b) Stator core

Fig. 2 Mover and stator core (arrow is lamination direction)

The flux barrier is modeled with low relative permeability of 0.01 (the smallest value for used software) to prevent magnetic flux flowing in undesired direction. As shown in Fig 3, the flux barriers (red color) are attached to the mover core in both sides.

3. ANALYSIS AND MEASUREMENT RESULTS

The non-linear simulation results by EMCN method focus on thrust force for two cases: 4000 ampere-turns (AT) which is the rated magneto-motive force (MMF) or 100% MMF, and 2000 AT which is 50% MMF.

The analysis results are shown in the Fig. 4 for 100% and 50% MMF with and without flux barrier on the mover. It can be seen that in case of 100% MMF, flux barrier shows its effect strongly at displacements from 10mm to 16mm. This difference reflects the high saturation in the mover core at high values of MMF. When MMF reaches and beyonds the threshold causing magnetic saturation, the flux will flow to undesired direction exceeding the mover core and that results in higher thrust force if there is no flux barrier. There is almost no difference between with and without flux barrier in case of 50% MMF due to very low saturation at this point.

The comparison between analysis results with flux barrier and measured results is shown in Fig. 5 at 50% and 100% MMF, and the results for average thrust force are summarized in table 2. Less than 6% in differences are seen in the average thrust force between analysis and experiment. As shown in Fig 5, however, the analysis results have much more ripple than measured ones in the thrust force profile. This error includes both measurement error and modeling error, however, the flux barrier modeling contributes to reduce the analysis error.

4. CONCLUSION

This paper dealt with PM excited TFLM with spiral core in the mover. The magnetic characteristics of the analysis model were analysed based on 3-dimensional EMCN method. Flux barrier was introduced to prevent flux flow in undesired direction especially at high MMF. It is in order to consider lamination effect by laminated stator and mover cores. The measurement results confirmed the accuracy of the simulation with less than 6% difference in average thrust force.

REFERENCES

[1] A. Babazadeh, N.Parspour, and A.Hanifi, “Transverse Flux Machine for Direct Drive Robots: Modeling and Analysis,” *Proceeding of the 2004 IEEE conference on Robotic*, Automation and Mechatronics, pp.376-380, December, 2004

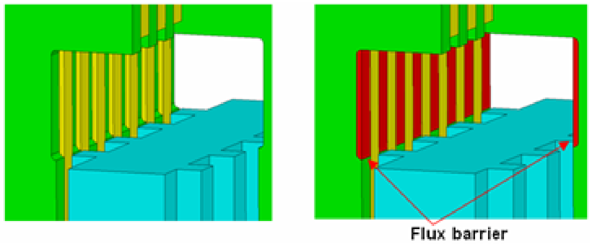
[2] Wihelm Hackmann, *Comparison of Different Gear Hub Drive of Rail Transport: Asynchronous Machine, Permanent Magnet Sysnchronous Machine, Transverse Flux Machine,* Technical University of Darmstadt, PhD dissertation, 2003, pp. 113

[3] 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

[4] Ji-Young Lee, Ji-Won Kim, Jung-Hwan Chang, Si-Uk Chung, Do-Hyun Kang, and Jung-Pyo Hong, "Determination of Parameters Considering Magnetic Nonlinearity in Solid Core Transverse Flux Linear Motor for Dynamic Simulation," IEEE Trans. on Magnetics, Vol. 44, No. 6, pp. 1566-1569, June 2008

Table 1 Specifications of the PM excited TFLM

Stator core material	50A470	No. of pole/phase & phase	Pole =12, Phase =3
Mover core material	35JN440	No. of turns/phase	42
PM material	NdFeB-sintered (N40H)	Rated magnetomotive force	4000 (AT)



(a) Without flux barrier (b) With flux barrier

Fig. 3 Introduction of flux barrier on the mover (Zoom in on Area 'S' in Fig. 1 (b))

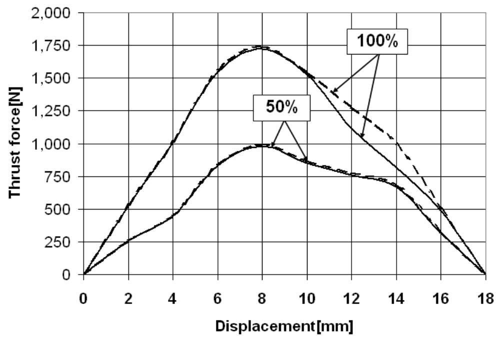


Fig. 4 Comparison of calculated thrust force depending on flux barrier consideration at mmf 50% and 100% (solid line: with flux barrier, dotted line: without flux barrier)

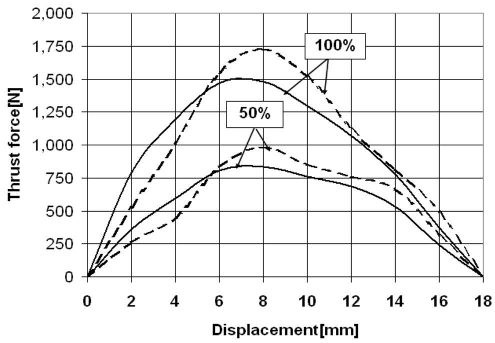


Fig. 5 Comparison of calculated and measured thrust force at mmf 50% and 100% (solid line: measured results, dotted line: calculated results)

Table 2 Summary of comparison

	Analysis results		Measured results
	Without flux barrier	With flux barrier	
50% MMF	577.62 N (107%)	568.55 N (106%)	538.10 N (100%)
100% MMF	1019.03 N (108%)	973.00 N (103%)	944.31 N (100%)