End Effect in Tubular Transverse Flux Permanent Magnet Linear Motor

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Abstract — This paper presents the end effect of tubular transverse flux permanent magnet linear motor (TFPMLM), which is the special topology of linear motor. Due to the end effect, the unbalanced magnetic field distribution in the tubular TFPMLM has been generated. This is the significant drawback which will deteriorate the performance of the TFPMLM drive system. In order to improve the performance of TFPMLM, the auxiliary cores model is carried out by using 3-D finite element method (FEM), and compared to the basic model.

I. Introduction

The higher specific force density of a tubular transverse flux permanent magnet linear motor (TFPMLM) in comparison to a conventional linear machine makes it a promising many linear motion field [1]-[3]. In linear motors, end effects occur entering or exiting the magnetic field because of the stator or the mover having finite length. The tubular TFPMLM is no exception. Many papers focus on the reduction of the end effect in permanent magnet linear synchronous motor (PMLSM). Jung *et al.* [4] and Inoue and Sato [5] provided the method of the modification of the end teeth length and shape, and the optimization of the iron core length. In [6]-[7], the novel method with the auxiliary poles was proposed to reduce the end effect. These methods have good effect on the reduction of the end effect in PMLSM. However, there are few literatures about the end effect in TFPMLM.

II. Analysis Model

The end effect in the tubular TFPMLM will be serious, while the mover of is located at the edge of stator. Fig.1 shows the basic structure of tubular TFPMLM.

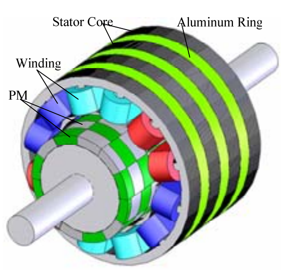


Fig. 1. The basic structure of the TFPMLM.

The three-phase TFPMLM are decoupled from each other, so the computation model can be analyzed by just a single phase [8]-[9]. The end effect of phase A computation model shown in Fig. 2 is a simplified model of TFPMLM considering the end effect. In the same way, the other two phase computation model can be developed (given in Fig. 3), which the phase differences exist in the permanent magnet (PM).

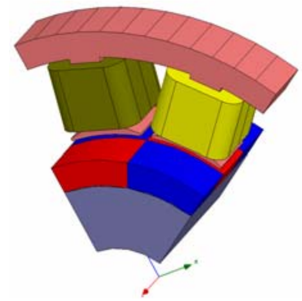
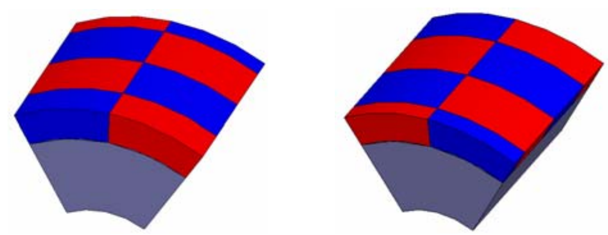


Fig. 2. Computation model of phase a with edge effect considered



a) Mover model of phase b b) Mover model of phase c
Fig. 3. Mover models of phase b and phase c with end effect

The single phase winding flux in an electrical period can be achieved by 3D finite element method (FEM) via utilizing FLUX3D software from Cedrat. Fig. 4 shows that the waveform of winding flux linkage with and without the end effect. As can be seen, the higher winding flux linkage is made considering the end effect, and further analysis will be presented in the finial paper.

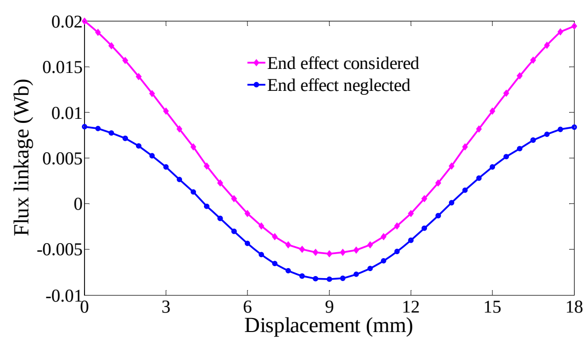


Fig. 4. Comparison of no-load flux linkage in phase

III. Influence of End Effect on Performance

A. Cogging Force

Based on the above 3-D FEM model, the waveform of three phases and total cogging force without and with the end effect in the TFPMLM are respectively presented in Figs. 5 and 6. It can be seen that the three phase cogging force are not symmetrical in an electrical period due to the end effect in the TFPMLM. For further analysis, the larger resultant three phase cogging force responsible for vibration and noise is produced due to end effect.

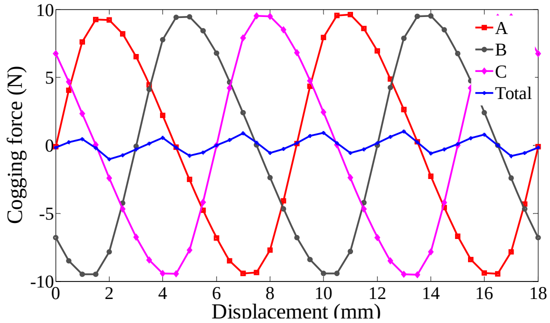


Fig. 5. Cogging forces of three phases and total cogging force without end effect

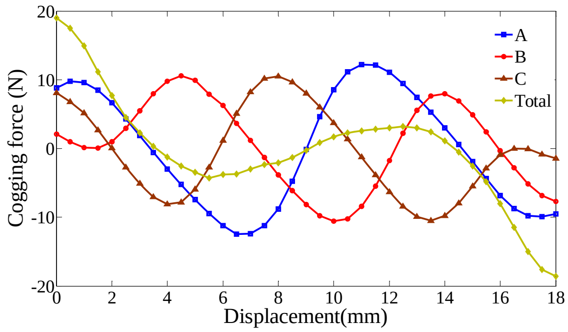


Fig. 6. Cogging forces of three phases and total cogging force with end effect

B. Back-EMF

Figs. 7 and 8 show that the three phase back-EMF of tubular TFPMLM at the speed of 1m/s without and with the end effect respectively. It can be seen that the higher back-EMF is made in the A-phase than other phases because of the difference size of permanent magnet due to end effect. In the result, the distortion of flux linkage and back-EMF in three phase result in the vibration of operation due to unbalanced phase.

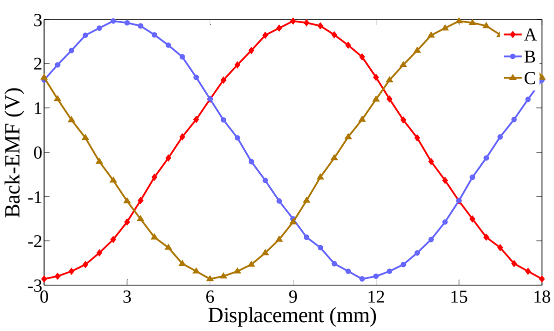


Fig. 7. Back-EMF of three phases without end effect

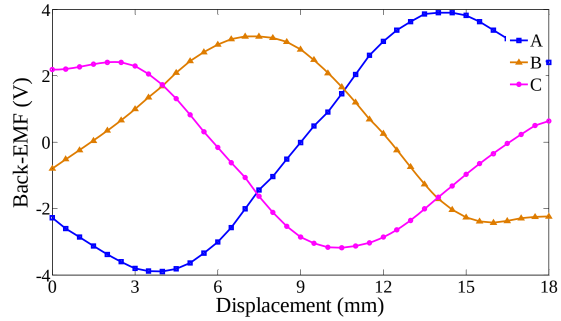


Fig. 8. Back-EMF of three phases with end effect

IV. The Influence of Auxiliary Cores

To eliminate unbalanced phase caused by the end effect, the auxiliary cores is carried out as shown in Fig. 9. Further more results and discussion will be presented in the final paper.

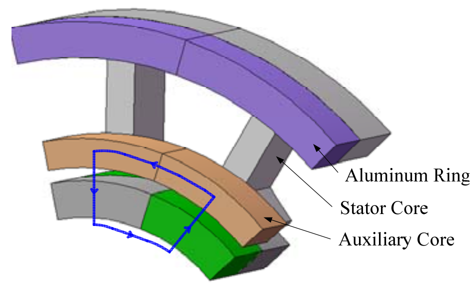


Fig. 9. Single-phase structure with auxiliary cores

V. References

[1] J.-H. Chang, D.-H. Kang, J.-Y. Lee, and J.-P. Hong, “Development of transverse flux linear motor with permanent magnet excitation for direct drive applications,” *IEEE Trans. Magn*, vol. 41, pp. 1936–1939, May 2005.

[2] Zou, J., Wang, Q., Xu, Y., “Influence of the Permanent Magnet Magnetization Length on the Performance of a Tubular Transverse Flux Permanent Magnet Linear Machine Used for Electromagnetic Launch,” *IEEE Trans. on Plasma Science*, vol.99, pp.1-6, 2010.

[3] Do Hyun Kang, “Increasing of thrust force in transverse flux machine by permanent-magnet screen,” *IEEE Trans. on Magn.*, vol.41 no.5, pp. 1952-1955, 2005.

[4] I. S. Jung, S. B. Yoon, J. H. Shim, and D. S. Hyun, “Analysis of forces in a short primary type and a short secondary type permanent magnet linear synchronous motor,” *IEEE Trans. Energy Convers.*, vol. 14, pp.1265–1270, Dec. 1999.

[5] M. Inoue and K. Sato, “An approach to a suitable stator length for minimizing the detent force of permanent magnet linear synchronous motors,” *IEEE Trans. Magn.*, vol. 36, pp. 1890–1893, Jul. 2000.

[6] Yu-wu Zhu, Sang-Gun Lee,Koon-Seok Chung, Yun-Hyun Cho, “Investigation of Auxiliary Poles Design Criteria on Reduction of End Effect of Detent Force for PMLSM,” *IEEE Trans. on Magn.*, vol.45, no.6, pp. 2863-2866, 2009.

[7] Jang, K-B, Kim, J-H; An, H.-J, Kim, G.-T, “Optimal Design of A Auxiliary Teeth to Minimize Unbalanced Phase due to End Effect of PMLSM,” *IEEE Trans. on Magn.*, vol.46, no.99, pp. 903-906, 2010.

[8] J. F. Gieras and M. Wing, *Permanent Magnet Motor Technology; Design and Applications*, 2nd ed. Marcell Dekker Inc., New York, 2002, pp. 353-387.

[9] R. Blissenbach, I. A. Viorel and G. Henneberger, “On the single-sided transverse flux machine design,” *Electrical Machines and Power Systems*, vol. 31, no. 2, pp. 109-128.