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A SPECIAL EXCITATION SYSTEM FOR ANALYSIS OF COUPLING CHARACTERISTICS OF THRUST AND LEVITATION FORCE OF MAGLEV TRAIN

Background: In the maglev train propelled by long stator linear synchronous motor (LSLSM), the thrust characteristics are one of important points to evaluate the performance of the system. However, coupling effect exists between the propulsion and levitation system. Therefore, the interference from the levitation system must be considered when the propulsion system is designed.

Aim: The article focus on the analysis of coupling characteristics of thrust and levitation force of maglev train, and a special excitation system is designed for the study.

Methods: In order to study the thrust performance under the fluctuating air gap field under laboratory conditions, a rotating synchronous motor has been designed to imitate the long stator linear synchronous motor applied in high speed maglev train. And a special excitation system is designed for the rotating synchronous motor, which can simulate the fluctuation of the exciting current during the actual operation of maglev train. The air gap of the rotating synchronous motor is kept as constant, and the fluctuating excitation current is added to the excitation winding of the rotating synchronous motor, thus the simulation of air gap magnetic field variation is achieved.

Results: The special excitation system of the experimental motor is introduced in detail.

Conclusion: The relationship between thrust and levitation force of long stator linear synchronous motor (LSLSM) in maglev train is strong coupling, non-linear, and dynamic. Complete decoupling of thrust and levitation force is not easy to be achieved. The experimental platform has been built to study the coupling characteristics of thrust and levitation force of maglev train.

***Keywords*:** Excitation system, Coupling characteristics of thrust and levitation, Long stator linear synchronous motor (LSLSM), Performance of the propulsion, Maglev train.

INTRODUCTION

Maglev system utilizing long stator linear synchronous motor (LSLSM) propulsion and electromagnetic suspension has been applied in normal commercial operation [1–3]. The electromagnetic force that makes the train suspend upon the track is produced by the excitation magnetic field. The interaction between armature magnetic field and excitation magnetic field produces the thrust force. The thrust and levitation force are related to the

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excitation magnetic field. This maglev system offers many advantages. However, it also has some disadvantages. Coupling characteristics are very complicated between thrust and levitation force. The characteristic of propulsion control system is one of the important points to evaluate the performance of the maglev train. However, the wide range field excitation fluctuations caused by external interference make the performance of the propulsion even worse [9–12]. The operation principle of a long stator linear synchronous motor and a rotating synchronous motor are the same. It is a convenient and feasible scheme to verify the propulsion control characteristics of maglev train on rotating synchronous motor. The structure of the LSLSM and test rotating synchronous motor are shown in Fig. 1 and Fig. 2. The air gap, distribution of air gap magnetic field, stator pole pitch and rotor pole pitch of the rotating synchronous motor are the same or equal proportion with the LSLSM applied in high speed maglev train.

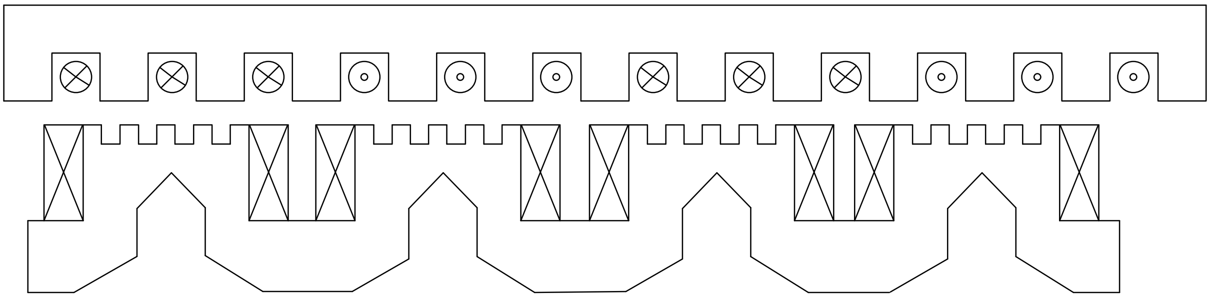

Fig.1. The structure of LSLSM

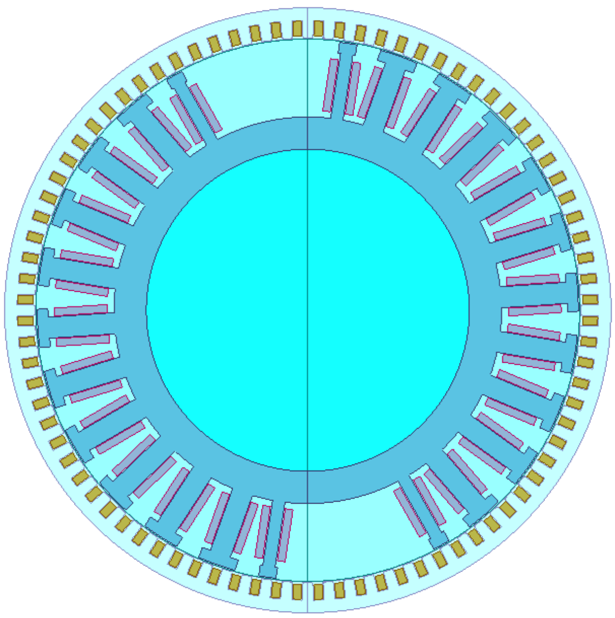

Fig. 2. The structure of the rotating synchronous motor

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The air gap magnetic field variation of the synchronous motor can affect the thrust performance. The air gap of the LSLSM of the maglev train is variable, and the air gap magnetic field of the LSLSM is influenced by air gap and the excitation current. The suspension system of high speed maglev train must adjust the exciting current to keep the air gap as constant in actual operation. Therefore, no matter the fluctuating air gap or the change of levitation force can be reflected by the fluctuation of the excitation current. Considering the influence of excitation field fluctuation on propulsion control, a special excitation system of the rotating synchronous motor is introduced in this paper. The excitation system is designed to generate the constant DC current for the field excitation, and it also can generate the alternating current at different frequencies to simulate the fluctuation of the exciting current during the actual operation. By this way, the complex coupling relationship between thrust and levitation force can be simplified. Although the air gap length of the rotating synchronous motor is constant, the change of air gap magnetic field can be same with that in actual operation by this special excitation system.

SIMULATION AND EXPERIMENT

In order to simulated the excitation current of the maglev train, the reference value of the special excitation system is set according to the excitation current of the maglev train. The control system diagram is shown in Fig. 3.

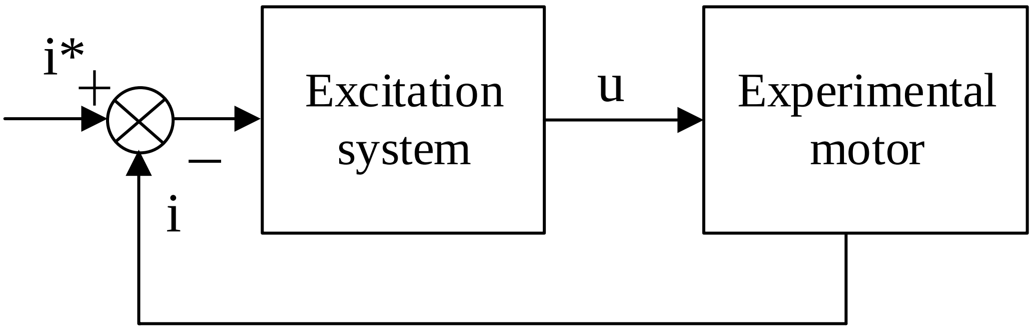

Fig. 3. The control diagram of the excitation

Current closed-loop feedback control is employed in the control the voltage source inverter for the special excitation system. The excitation winding of the motor is resistance-inductance load, thus high voltage is needed to produce the required wave current because of the large inductance of the excitation winding. Therefore, a boost circuit is designed in this excitation system. The topology structure of excitation source is shown in Fig. 4. L_2 and R is the excitation winding load.

In the simulation analysis of the excitation source, voltage closed loop control is used in the boost circuit unit, and current closed loop feedback control is used in the single phase full bridge inverter unit. When the reference of

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excitation current is 12.5 A, the output current waveform of the excitation source is shown in Fig. 5. When the reference of excitation current is 12.5 A, besides, the sinusoidal fluctuation with amplitude 2.5 A and 3 Hz frequency is added. The output excitation current waveform of the excitation source is shown in Fig. 6.

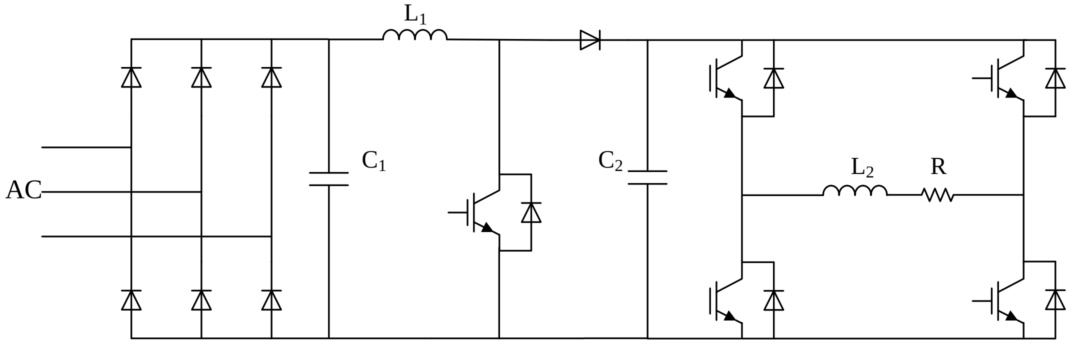

Fig. 4. Topology structure of excitation source

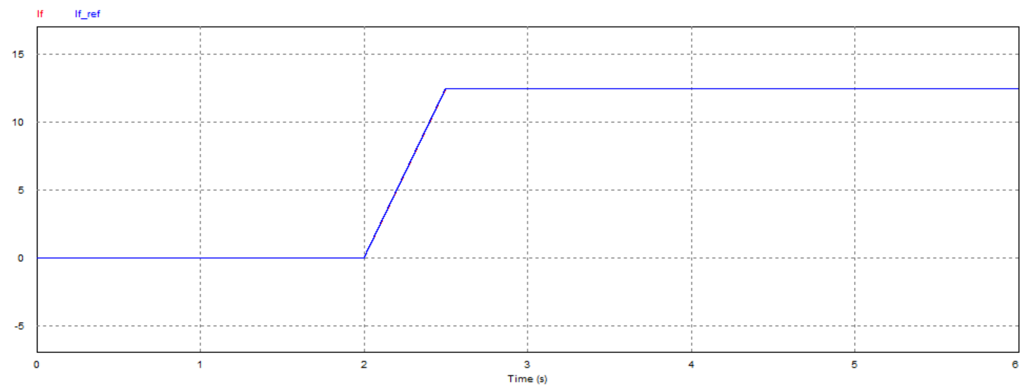

Fig. 5. Normal excitation current waveform

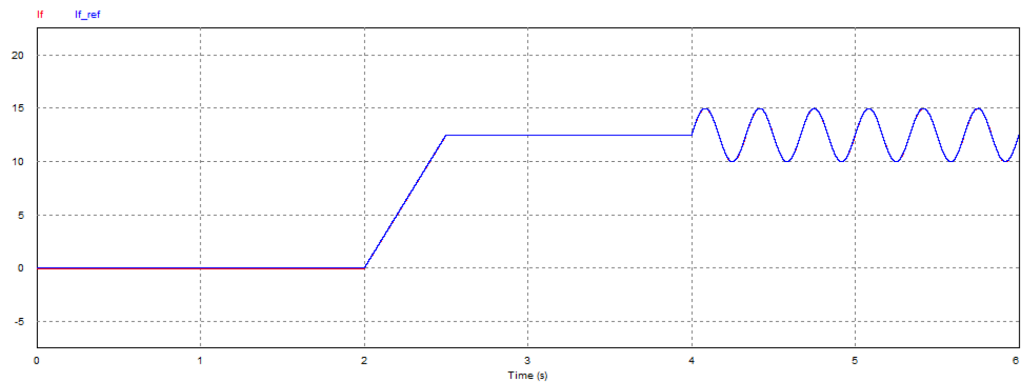

Fig. 6. Excitation current waveform with harmonic wave

In this experiment, the voltage reference value of voltage closed-loop of the boost circuit is 300 V. The output current reference is 12.5 A, the harmonic with frequency 3 Hz and amplitude 2.5 A is added to the output current reference at 5 seconds. At 10 seconds, the frequency and amplitude of the harmonic are changed. The output excitation current waveform is shown in

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Fig. 7. Considering that the actual harmonics in the excitation current of maglev train are not sinusoidal, then random fluctuations are added to the excitation current reference in the experiment. Output voltage of the boost circuit and the excitation current waveform are shown in Fig. 8. The voltage reference value of voltage closed-loop of the boost circuit is still 300 V. The random fluctuations with frequency 3.33 Hz are added to the output current reference at 5 seconds.

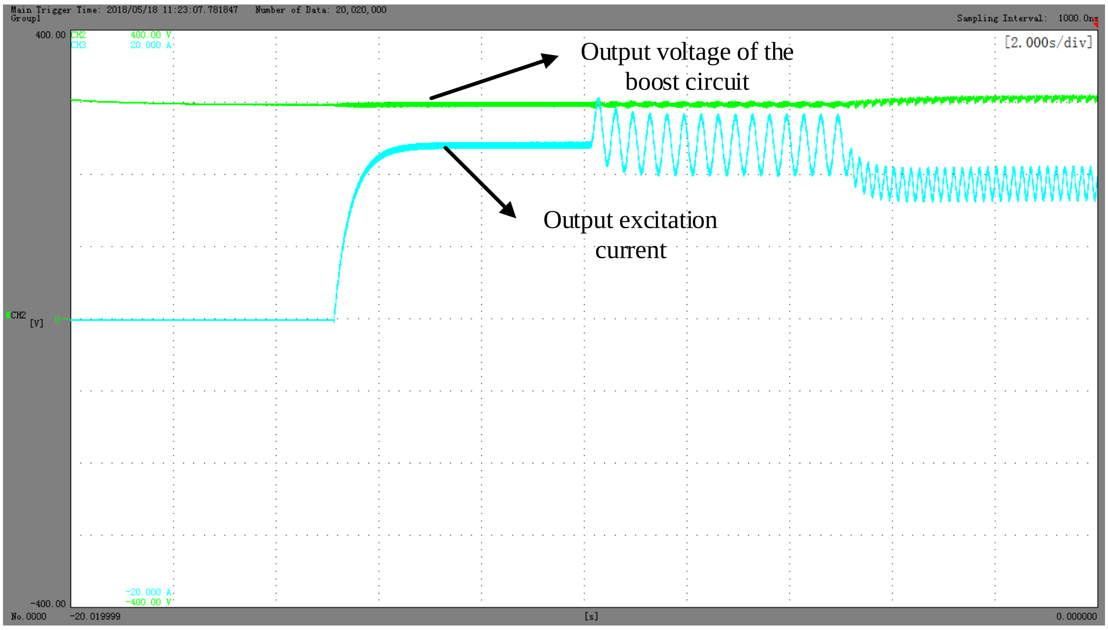

Fig. 7. Output voltage of the boost circuit and excitation current waveform

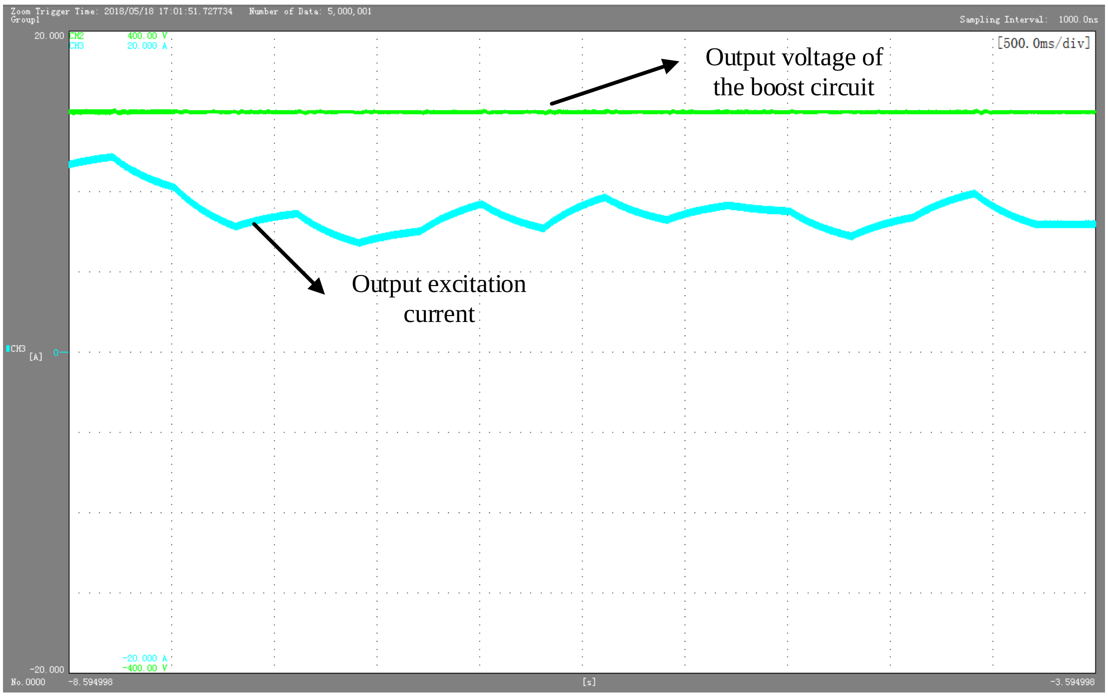

Fig. 8. Output voltage of the boost circuit and excitation current waveform

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CONCLUSION

The excitation special device can not only provide normal excitation current, but also simulate the fluctuation of excitation current very well. The fluctuation of excitation current of maglev train can be got from the levitation system. And combined with the experimental motor and experimental platform, the traction characteristics of maglev train under fluctuating excitation current can be analyzed.

References

1. Weh H. Linear synchronous motor development for urban and rapid transit systems. *IEEE Transactions on Magnetics.* 1979;15(6):1422-1427. doi: 10.1109/TMAG.1979.1060438
2. Wang X, Liu H, Zhang S. High Performance Propulsion Control of Magnetic Levitation Vehicle Long Stator Linear Synchronous Motor. Proceedings of the International Conference on Electrical Machines and Systems. 2011; doi: 10.1109/ICEMS.2011.6073798
3. Rao J, Wang K. Study on Dynamic Coupling Characteristics of Thrust and Levitation Force of Long Stator Linear Synchronous Motor for Maglev Train. Proceedings of the 20th International Conference on Electrical Machines and Systems. 2017; doi: 10.1109/ICEMS.2017.8055995
4. Yang G, Wang K, Zhang Z. Study on electromagnetic force ripple reduction of long stator linear synchronous motor based on unequal pole pitch. Proceedings of the 20th International Conference on Electrical Machines and Systems. 2017; doi: 10.1109/ICEMS.2017.8055994
5. Perreault BM. Control Strategies for Linear Synchronous Motors. Proceedings of the International Electric Machines & Drives Conference. IEEE; 2007;2:969-971. doi: 10.1109/IEMDC.2007.382806
6. Jin J, Zheng L, Xu W, Guo Y, Zhu J. Experimental study on thrust and normal force of a permanent magnet linear synchronous motor. Proceedings of the International Conference on Electrical Machines and Systems. 2011; doi: 10.1109/ICEMS.2011.6073660
7. Lu B, Tan X, Li Q, Luo J. The Analysis of Excitation Current Changes in Long Stator Linear Synchronous Motor of Maglev. Proceedings of the Prognostics and System Health Management Conference (PHM-2014 Hunan). 2014; doi: 10.1109/PHM.2014.6988204
8. Ge QX, Li Y, Kong L. A Comparative Study of FOC for Long Stator Linear Synchronous Motor Control. Proceedings of the International Conference on Electrical Machines and Systems. 2007; p. 398–402.
9. Valluvan M, Ranganathan S. Modeling and control of magnetic levitation system. Proceedings of the International Conference on Emerging Trends in Science, Engineering and Technology (INCOSET). 2012; p. 545–548. doi: 10.1109/INCOSET.2012.6513963
10. Su K-H, Li C-Y. Supervisory Fuzzy Model Control for Magnetic Levitation System. Proceedings of the 13th International Conference on Networking, Sensing, and Control (ICNSC). IEEE 2016; doi: 10.1109/ICNSC.2016.7479025
11. Venghi LE, Gonzalez GN, Serra FM. Implementation and Control of a Magnetic Levitation System. *IEEE Latin America Transactions.* 2016;14(6):2651-2656. doi: 10.1109/TLA.2016.7555233

Received: 07.07.2018. Accepted: 20.07.2018.

doi: 10.17816/transsyst20184245-51

12. Kim C-H, Ahn C, Park G-W, Park DY. Levitation and Guidance Control of Passive Magnetic Levitation Tray System. *IEEE ISR 2013*. 2013; p. 1–2. doi: 10.1109/ISR.2013.6695692
13. Boldea I, Tutelea LN, Xu W, Pucci M. Linear Electric Machines, Drives, and MAGLEVs: An Overview. *IEEE Transactions on Industrial Electronics*. 2018; 65(9):7504-7515. doi: 10.1109/TIE.2017.2733492
14. Ho E, Sen PC. High-performance decoupling control techniques for various rotating field machines. *IEEE Transactions on Industrial Electronics*. 1995; 42(1):40-49. doi: 10.1109/41.345844
15. Chen Y, Jin JX, Zhao HB. Simulation and analysis the thrust force of a permanent magnet linear synchronous motor. Proceedings of the International Conference on Applied Superconductivity and Electromagnetic Devices. 2011; p. 235–238. doi: 10.1109/ASEMD.2011.6145109

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