Analysis and Verification of the Reduction of Detent Force in a Permanent-Magnet Linear Synchronous Motor

莊杰霖、陳盛基

E-mail: 9607741@mail.dyu.edu.tw

ABSTRACT

Linear permanent magnet synchronous motors have advantages of high speed, high dynamic response and direct drive. And hence they have been gradually applied for factory automation and numerical motion control systems. However, the detent force in linear permanent magnet synchronous motors due to the end-effect and the interaction between the permanent magnet and the armature teeth generally causes the undesired vibration and noise. Particularly, the detent force may cause an adverse disturbance for the system at low speeds. This study analyzes the detent force in a linear permanent magnet synchronous motor and proposes four detent force minimization techniques, which include adding shoes in the armature teeth, decreasing slot width, modulating the permanent magnet width, choosing the suitable armature length, and modifying the permanent magnet surface shape etc. We discuss the simulation results by finite element method using the Ansoft Maxwell-2D software. Then according to the results a linear motor with lower detent force is designed. Finally, a detent force measuring device is established to measure the detent force of linear permanent magnet synchronous motor. The measured data together with the simulation results verify the accuracy of the analysis process.

Keywords : linear permanent magnet synchronous motor ; detent force ; finite element method analysis ; end-effect ; permanent magnet

Table of Contents

REFERENCES

[1] R. P. Deodhar, D. A. Staton, T. M. Jahns and T. J. E. Miller,“ Prediction of Cogging Torque Using the Flux-MMF Diagram Technique ”, IEEE Trans. on Industry Applications, vol.32, no.3, pp. 569-576, 1996.
[2] K. C. Lim, J. P. Hong and G. T. Kim,“ The Novel Technique Considering Slot Effect by Equivalent Magnetizing Current ”, IEEE Trans. on Magnetics, vol.35, no.5, pp. 3691-3693, 1999.
[3] T. Yoshimura, H. J. Kim, M. Watada, S. Torii, D. Ebihara,“ Analysis of the Reduction of Detent Force in a Permanent Magnet Linear Synchronous Motor ”, IEEE Trans. on Magnetics, vol.31, no.6, November, pp.3728-3730, 1995.
[4] I. S. Jung, S. B. Yoon, J. H. Shim, D. S. Hyun,“ Analysis of Forces in a Short Primary Type and a Short Secondary Type Permanent Magnet Linear Synchronous Motor ”, IEEE Trans. on Energy Conversion, vol.14, no.4, December, pp.1265-1269, 1999.
[5] M. Inoue, K. Sato,“ An Approach to a Suitable Stator Length for Minimizing the Detent Force of Permanent Magnet Linear Synchronous Motors ”, IEEE Trans. on Magnetics, vol.36, no.4, July, pp.1890-1893, 2000.
[6] K. C. Lim, J. K. Woo, G. H. Kang, J. P. Hong and G. T. Kim,“ Detent Force Minimization Techniques in Permanent Magnet Linear Synchronous Motors ”, IEEE Trans. on Magnetics, vol.38, no.2, March, pp.1157-1160, 2002.
[7] N. Bianchi, S. Bolognani and A.D.F. Cappello,“ Reduction of Cogging Force in PM Linear Motors by Pole-Shifting ”, IEE Procceedings Electronic Power Applications, vol.152, no.3, May, pp.703-709, 2005.
[8] R. Akmese, J. F. Eastham,“ Design of Permanent Magnet Flat Linear Motors for Standstill Applications ”, IEEE Trans. on Magnetics, vol.28, no.5, September, pp.3042-3044, 1992.
[9] 沈德洋，“ 單側式永磁同步馬達之動態分析及頓動力與力量漣波補償 ”，中正大學機械工程研究所碩士論文，2000年。
[10] 陳盛基，“ 影響永磁無刷直流線性馬達頓動力之電機參數分析 ”國家科學委員會個人型研究計劃報告，NSC94-2213-E-212- 027 ，2006年。
[11] 粘鐿耀，“ 無鐵心式永磁線性無刷直流馬達之設計與分析 ”，大葉大學電機工程研究所碩士論文，2007年。
[12] 戴信能，“ 永磁式線性伺服馬達控制與磁路之整合最佳化設計 ”，中正大學機械工程研究所碩士論文，2000年。
[13] K. K. Tan, S. N. Huang and T. H. Lee,“ Robust Adaptive Numerical Compensation for Friction and Force Ripple in Permanent Magnet Linear Motor ”, IEEE Trans. on Magnetics, vol.38, no.1, pp.221-228, 2002.
[14] K. K. Tan, H. Dou, Y. Chen and T. H. Lee,“ High Precision Linear Motor Control Via Relay-Tuning and Iterative Learning Based on Zero-Phase Filtering ”, IEEE Trans. on Magnetics, vol.9, no.2, pp.244-253, 2001.
[15] A. P. Hu, A. Register, N. Sadegh,“ Using a Learning Controller to Achieve Accurate Linear Motor Motion Control ”, International Conference on Advanced Intelligent Mechatronics, Atlanta, USA, September, pp.611-616, 1999.
[16] G. Otten, T. J. A. de Varies, J. V. Amerongen, A. M. Rankers and E. W. Gaal,“ Linear Motor Motion Control Using a Learning Feed-Forward Controller ”, IEEE/ASME Trans. on Mechatronics, vol. 2, no.3, pp. 179-187, 1997.
[17] D. C. Hanselman, Brushless Permanent Magnet Motor Design, second edition, The Writers ’ Collective, 2003.
[18] C. Studer, A. Keyhani, T. Sebastian, S. K. Murthy,“ Study of Cogging Torque in Permanent Magnet Machines ”, IEEE IAS Annual Meeting, New Orleans, Louisiana, USA, October, pp.42-49, 1997.
[19] 黃國華、陳鴻誠，“ 永磁電機頓轉轉矩之分析 ”，馬達電子報，第七十二期，2004年。
[20] Z. Q. Zhu, D. Howe,“ Influence of Design Parameters on Cogging Torque in Permanent Magnet Machines ”, IEEE Trans. on Energy Conversion, vol.15, no.4, December, pp.407-412, 2000.
[21] M. S. Islam, S. Mir, T. Sebastian,“ Issues in Reducing the Cogging Torque of Mass-Produced Permanent-Magnet Brushless DC Motor ”, IEEE Trans. on Industry Applications, vol.40, no.3, May/ June, pp.813-820, 2004.
[22] T. Mizuno, H. Yamada,“ Magnetic Circuit Analysis of a Linear Synchronous Motor with Permanent Magnets ”, IEEE Trans. on Magnetics, vol.28, no.5, pp.3027-3029, 1992.
[23] 詹宜彬，“ 線性同步馬達的設計與製作 ”，清華大學動力機械工程研究所碩士論文，1996年。
[24] I. Boldea, S. S. Nasar,“ Linear Electric Actuators and Generators ”, Cambridge University Press, 1997.
[25] 廖聰明，“ 線性馬達高功率驅動器研製 ”，中山科學研究院委託學界研究報告，1998年。
[26] 涂銘河，“ 線性馬達強健控制器設計 ”，大葉大學電機工程研究所碩士論文，2005年。
[27] Catalog:Linear motion products, Baldor Electric Company, Fort Smith, AR, USA, 2000.
[28] Boldea, and S. A. Nasar, Linear motion electromagnetic systems, John Wiley & Sons Inc., 1985.
[29] G. W. Mclean,“ Review of recent progress in linear motors ”, IEE Proceedings, vol. 135, Pt. B, no.6, pp.380-416, November, 1988.
[30] Catalog:Platinum DDL, Kollmorgen, Radford, VA, USA, 2001.
[31] D. K. Cheng, Field and Wave Electromagnetics, second edition, Addison Wesley, 1992.
[32] P. Famouri,“ Control of a linear permanent magnet brushless DC motor via exact linearization Methods ”, IEEE Trans. on Energy Conversion, vol.7, no.3, September, pp.544-551, 1992.
[33] 張富均，“ 線性馬達驅動系統之研製 ”，逢甲大學自動控制工程研究所碩士論文，2001年。
[34]“ 精密馬達機電科技研發人材培訓課程講義 ”，The University of Sheffield，2006年。
[35] 陳盛基、粘鐿耀，“ 永磁直流無刷馬達改變磁極弧長降低頓轉轉矩之分析 ”，馬達電子報，第209期，2006年。

[36] N. Bianchi and S. Bolognani,“ Design Techniques for Reducing the Cogging Torque in Surface-Mounted PM Motors ”, IEEE Trans. on Industry Applications, vol.38, no.5, pp.1259-1265, 2002.
[37] J. F. Gieras,“ Analytical Approach to Cogging Torque Calculation of PM Brushless Motor ”, IEEE Trans. on Industry Applications, vol.40, no.5, pp.1310-1316, 2004.
[38] Z. Q. Zhu, X. P. Xia, D. Howe and P. H. Mellor,“ Reduction of cogging force on slotless linear permanent magnet force ”, IEE Procceedings Electronic Power Applications, vol.144, no.4, pp. 277-282, July 1997.
[39] 黃昌圳，“有限元素法在電機工程的應用”，全華科技圖書股份有限公司，初版一刷，2005年。
[40] 陳雙穩，“永磁無刷馬達之繞線結構對性能影響之研究”，成功大學機械工程研究所碩士論文，2001年。
[41] D. Howe, Z. Q. Zhu,“ The Influence of Finite Element Discretisation on the Prediction of Cogging torque in Permanent Magnet Excited Motors ”, IEEE Trans. on Magnetics, vol.28, no.2, March, pp.1080-1083, 1992.
[42] 陳文川，“精密直流無刷馬達之頓轉扭矩量測設備的建置及應用研究”，長庚大學化工與材料工程研究所碩士論文，2005年。
[43] J. F. Gieras and Z. J. Piech, LINEAR SYNCHRONOUS MOTORS Transportation and Automation Systems, CRC Press, 2000.