永磁同步馬達之電磁場分析與控制實驗規劃

吳育澤、陳盛基,葉競榮

E-mail: 319786@mail.dyu.edu.tw

摘 要

近年來，永磁同步馬達(Permanent Magnet Synchronous Motors, PMSM)在轉速控制的應用場合中已漸漸占有一席之地。其驅動方式一般採用六步方波驅動、弦波脈波寬度調變或空間向量脈波寬度調變。使用六步方波驅動永磁同步馬達可具有低切換損失以及不需精確的轉子位置回授等優點，但伴隨而來的是具有較大的轉矩漣波。若使用弦波脈波寬度調變驅動可獲得較小的轉矩漣波，但弦波脈波寬度調變驅動需要更為精確的轉子位置。空間向量脈波寬調變的工作原理是利用三相PWM換流器的基本電壓向量來合成所需的定子電壓向量，而此定子電壓向量在定子線圈上作用產生旋轉的定子磁通向量，再與轉子磁通相互作用產生轉矩使馬達旋轉。空間向量脈波寬度調變的諧波電流明顯比弦波脈波寬度調變小而分散，因此諧波損耗明顯較少，轉矩漣波也較小。並藉由合理安排000與111狀態的分配，以六個非零向量加上兩個零向量合成為圓形軌跡的電壓向量控制信號，同時可減少功率元件的開關次數與提升電壓利用率。 本研究針對永磁同步馬達進行電磁場分析與控制實驗的規劃。以TI TMS320 F2812數位訊號處理器(DSP)為控制器核心，搭配VisSim/ECD DSP快速發展系統完成嵌入式控制器實驗，並使用有限元素分析軟體JMAG進行馬達模型之有限元素分析與磁路模擬，將其模擬結果作為整個控制實驗規劃之參考依據。 最後，將模擬結果與實際量測之波形進行比對，驗證模擬與實測之準確性，且同時針對不同控制方法進行實驗，觀察調整控制器參數對系統響應的影響。

關鍵詞 : 永磁同步馬達、有限元素分析、永久磁鐵、磁路、永磁同、步馬達控制、VisSim、TI TMS320 F2812、數位訊號處理器(DSP)、正弦波脈波寬度調變(SPWM)、空間

目錄

參考文獻

[1] V. Petrovic, R. Ortega, A. M. Stankovic, and G. Tadmor,“ Design and Implementation of an Adaptive Controller for Torque Ripple Minimization in PM Synchronous Motors, ” IEEE Trans. Power Electron., vol. 15, no. 5, Sep. 2000.

[2] M. Boussak, “ Implementation and Experimental Investigation of Sensorless Speed Control With Initial Rotor Position Estimation for Interior Permanent Magnet Synchronous Motor Drive, ” IEEE Trans. Power Electron., vol. 20, no. 6, Nov. 2005.
[3] D. Shibeshi, “ Dsp Based Field Weakening Control of PMSM, ” Oct. 2007.
[4] J. Simanek, R. Dolecek, O. Cerny, V. Schejbal, “ Processor TI 2812 as Control Base of Permanent Magnet Synchronous Motor, ” Sep. 2009.
[5] J. Wisniewski, W. Koczara, “ Sensorless Control of the Axial Flux Permanent Magnet Synchronous Motor at Standstill and at Low Speed, ” in Proc. IEEE Power Electron. Special Conference, Sep. 2009.
[6] J. Salomaki, M. Hinkkanen, and J. Luomi, “ Influence of Inverter Output Filter on Maximum Torque and Speed of PMSM Drives, ” IEEE Trans. Ind. Appl., vol. 44, no. 1, Jan./Feb. 2008.
[7] M. Bodson and J. Chiasson, “ Differential-Geometric Methods for Control of Electric Motors, ” Int. J. Robust Nonlinear Control, Aug. 1998, pp. 923-954.
[8] L. Ying and N. Ertugrul, “ A Novel, Robust DSP-Based Indirect Rotor Position Estimation for Permanent Magnet AC Motors Without Rotor Saliency, ” IEEE Trans. Power Electron., vol. 18, no. 2, Mar. 2003.
[9] C. C. Hwang, S. M. Chang, C. T. Pan, T. Y. Chang, “ Estimation of Parameters of Interior Permanent Magnet Synchronous Motors, ” Journal of Magnetism and Magnetic Materials, 239, 2002,pp. 600-603.
[10]C. C. Hwang, J. J. Chang, “ Design and Analysis of a High Power Density and High Efficiency Permanent Magnet DC Motor, ” Journal of Magnetism and Magnetic Materials, 209, 2000,pp. 234-236.
[11]D. C. Hanselman, Brushless Permanent Magnet Motor Design New York: McGraw -Hill, 1994.
[12]D. C. Hanselman, Brushless Permanent Magnet Motor Design Second Edition, The Writers ’ Collective, 2003.
[13]Ansoft Maxwell 2D Field Simulator, Getting Started - A 2D Parametric Problem, 1995.
[14]A Permanent Magnet Brushless DC Motor Problem, Ansoft RMxprt Application Note, 2004.
[15]H. Qingxin, L. Hui, “ DSP Control System of Brushless DC Motor Without Position Sensor, ” Beijing, China.
[16]Lee, T. S., Lin, C. H., and Lin, F. J. “ An Adaptive H Controller Design for Permanent Magnet Synchronous Motor Drives, ” Hualien, Taiwan, Apr. 2004.
[17]P. Pillay, and R. Krishnan, “ Modeling of Permanent Magnet Motor Drives, ” IEEE Trans. Ind. Electron., vol. 35 , no. 4, Nov. 1988.
[18]M. A. Jabbar, Z. Liu and J. Dong, “ Time-Stepping Finite Element Analysis for the Dynamic Performance of a Permanent Magnet Synchronous Motor, ” IEEE Trans. Magnet., vol. 39, no. 5, Sep. 2003.
[19]G. Cvetkovski and L. Petkovska, “ Performance Improvement of PM Synchronous Motor by Using Soft Magnetic Composite Material, ” IEEE Trans. Magnet., vol. 44, no. 11, Nov. 2008.
[20]S. Bouchiker, G. A. Capolino, and M. Poloujadoff, “ Vector Control of a Permanent-Magnet Synchronous Motor Using AC-AC Matrix Converter, ” IEEE Trans. Power Electron., vol. 13, no. 6, Nov. 1998.
[21]K. Nakamura, K. Saito, T. Watanabe, and O. Ichinokura, “ A New Nonlinear Magnetic Circuit Model for Dynamic Analysis of Interior Permanent Magnet Synchronous Motor, ” Journal of Magnetism and Magnetic Materials 290-291, 2005, pp. 1313-1317.
[22]A. Meroufel, A. Massoum, and B. Belabes, “ Fuzzy Adaptive Model Following Speed Control for Vector Controlled Permanent Magnet Synchronous Motor, ” Leonardo Electronic Journal of Practices and Technologies, Issue 13, Jul./Dec., pp. 19-33, 2008, ISSN 1583-1078.
[23]A. Loukdache, J. Alami, M. Belkacemi and A. Imrani, “ New Control Approach for Permanent Magnet Synchronous Motor, ” Int. J. Electrical and Power Engineering, 2007.
[24]F. Aghili, M. Buehler, and J. M. Hollerbach, “ Optimal Commutation Laws in the Frequency Domain for PM Synchronous Direct-Drive Motors, ” IEEE Trans. Power Electron., vol. 15, no. 6, Nov. 2000.
[25]NEC Application Note, “ 8-Bit Single-Chip Microcontroller Permanent Magnet Synchronous Motor Control, ” NEC Electron., 2008.
[26]J. X. Xu, S. K. Panda, Y. J. Pan, T. H. Lee, and B. H. Lam, “ A Modular Control Scheme for PMSM Speed Control With Pulsating Torque Minimization, ” IEEE Trans. Ind. Electron., vol. 51, no. 3, Jun. 2004.
[27]M. A. Rahman and M. A. Hoque, “ On-line Adaptive Artificial Neural Network Based Vector Control of Permanent Magnet Synchronous Motors, ” IEEE Trans. Energy Conversion, vol. 13, no. 4, Dec. 1998.
[28]L. Zhong, M. F. Rahman, W. Y. Hu and K. W. Lim, “ A Direct Torque Controller for Permanent Magnet Synchronous Motor Drives, ” IEEE Trans. Energy Conversion, vol. 14, no. 3, Sep. 1999.
[29]J. Nerg, M. Niemela, J. Pyrhonen, and J. Partanen, “ FEM Calculation of Rotor Losses in a Medium Speed Direct Torque Controlled PM Synchronous Motor at Different Load Conditions, ” IEEE Trans. Magnet., vol. 38, no. 5, Sep. 2002.
[30]H. T. Moon, H. S. Kim, and M. J. Youn “ A Discrete-Time Predictive Current Control for PMSM, ” IEEE Trans. Power Electron., vol. 18, no. 1, Jane. 2003.
[31]K. T. Chang, T. S. Low, and T. H. Lee, “ An Optimal Speed Controller for Permanent-Magnet Synchronous Motor Drives, ” IEEE Trans. Ind. Electron., vol. 41, no. 5, Oct. 1994.
[32]C. C. Chan and K. T. Chau, “ An Advanced Permanent Magnet Motor Drive System for Battery-Powered Electric Vehicles, ” IEEE Trans. Vehicular Technology, vol. 45, no. 1, Feb. 1996.

[33]A. Lidozzi, L. Solero, F. Crescimbini, and A. D. Napoli, “ SVM PMSM Drive With Low Resolution Hall-Effect Sensors, ” IEEE Trans. Power Electron., vol. 22, no. 1, Jan. 2007.
[34]E. Schmidt and A. Eileberger, “ Calculation of Position-Dependent Inductances of a Permanent Magnet Synchronous Machine With an External Rotor by Using Voltage-Driven Finite Element Analyses, ” IEEE Trans. Magnet., vol. 45, no. 3, Mar. 2009.
[35]P. Pillay, and R. Krishnan, “ Modeling, Simulation, and Analysis of Permanent-Magnet Motor Drives, Part I: The Permanent-Magnet Synchronous Motor Drive, ” IEEE Trans. Ind. Appl., vol. 25, no. 2, Mar./Apr. 1989.
[36]P. Mattavelli, L. Tubiana, and M. Zigliotto, “ Torque-Ripple Reduction in PM Synchronous Motor Drives Using Repetitive Current Control, ” IEEE Trans. Power Electron., vol. 20, no. 6, Nov. 2005.
[37]K. H. Kim, I. C. Baik, G. W. Moon, and M. J. Youn, “ A Current Control for a Permanent Magnet Synchronous Motor With a Simple Disturbance Estimation Scheme, ” IEEE Trans. Control Systems Technology, vol. 7, no. 5, Sep. 1999.
[38]Z. Q. Zhu, “ Influence of Design Parameters on Cogging Torque in Permanent Magnet Machines, ” IEEE Trans. Energy Conversion, vol. 15, no. 4, 2000, pp. 407-412.
[39]N. Bianchi and S. Bolognani, “ Design Techniques for Reducing the Cogging Torque in Surface-Mounted PM Motors, ” IEEE Trans. Ind. Appl., vol. 38, no. 5, 2002, pp. 1259-1265.
[40]許潔一, 「內藏式永磁同步馬達之設計與同動控制」, 大葉大學 電機工程學系碩士班, 碩士論文, 2007。
[41]卓源鴻, 「表面附著型永磁同部馬達之設計與特性分析」, 逢甲大學電機工程學系, 碩士論文, 2001。
[42]簡旭佑, 「嵌入型永磁馬達的設計與分析」, 逢甲大學電機工程學系, 碩士論文, 2004。
[43]林浤偉, 王寶鋒, 張永華, 陳功, 「田口法應用於永磁同步馬達之控制器設計」, 長庚大學電機系, 國防大學中正理工學院電機系, 中正嶺學報, 第三十三卷, 第一期, 2004。
[44]張浚溢, 「表面型與內藏型永磁同步機特性比較」, 逢甲大學電機工程學系, 碩士論文, 2002。
[45]林玄坤, 「以DSP為基礎之永磁同步馬達驅動器設計及主動式前轉向系統之模擬」, 南台科技大學電機工程研究所, 碩士論文, 2006。
[46]江伯崧, 「應用數位信號處理器於永磁同步馬達速度控制之研究」, 成功大學工程科學系, 碩士論文, 2002。
[47]陳泓傑, 「直接轉矩控制於永磁同步馬達之轉矩漣波改善研究」, 中央大學電機工程研究所, 碩士論文, 2007。
[48]池怡德, 「應用直接轉矩控制法於具有空間電壓向量脈寬調變之永磁同步馬達的研究」, 成功大學工程科學系, 碩士論文, 2005。
[49]陳盛基, 莊杰霖, 「永磁無刷馬達設計與分析流程驗證」, 機械月刊, 381期, 2007, pp. 6-18。
[50]吳大偉, 王漢?, 謝宗煌, 吳清章, 「電機機械」, 文京圖書有限公司, 1995。
[51]劉昌煥, 「交流電機控制:向量控制與直接轉矩控制原理」, 東華書局, 2005。
[52]趙凱華, 陳熙謀, 「電磁學」, 第二版, 曉園出版社, 2007。
[53]卓傑企業有限公司, 「DSP電機控制發展系統(DMD2000)」。
[54]陳盛基, 葉競榮, 吳育澤, 「高效率永磁無刷直流馬達之電磁場分析」, 第八屆台灣電力電子研討會, 中壢, 台灣, 9月4日, 2009, pp. 1043-1048 。
[55]孫清華, 黃昌圳, 「最新無刷直流馬達」, 全華科技圖書股份有限公司, 2001。