Reducing the Output Torque Ripple of Permanent Magnet Synchronous Machine Drive System Caused by Cogging Torque

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Abstract — This paper presents a method of signal injection to counteract the cogging torque in permanent magnet synchronous machine to reduce the output torque ripples. Finite element magnetic field analysis is conducted to calculate the cogging torque, which is stored in a look-up table for determining the inject signals. Analysis results show that the proposed method can reduce the output torque ripple of a PMSM prototype below 5%.

I. INTRODUCTION

Permanent magnet synchronous machine (PMSM) is widely used in AC servo system because of the characteristics of exact control, durable performance, quick response and small-size. SVPWM is the most common kind of motor control method, and has the advantages of low current ripple, high DC voltage utilization ratio and easy digital realization. By combining FOC (field oriented control) theory and SVPWM technique, PMSMs can achieve the similar performance as DC motors [1], [2].

At present, scholars have already finished some research on the cogging torque issues of PMSM. For example, Takeo found that the cogging torque contains a substantial component with a period of one half of the slot pitch and proposed the shifting angles of PM to eliminate this component for 4-pole and 6-pole PM prototype motors [3]. The method of shifting one pair of poles by half a slot pitch relative to the other pair was studied for a 4-pole PM motor and found that the fundamental components of both cogging torque and ripple torque can be eliminated [4]. There also many other methods used such as a fractional number of slots per pole [5], slot or tooth pairing [6], and pole-arc optimization [7].

This paper examines the effects of the signal injection method. Cogging torque is calculated by the finite element method in advance and stored in a two-dimensional lookup table. Based on the calculated result, a signal to counteract the cogging torque is injected in time.

II. KEY TECHNIQUES

This article concentrates on calculation and simulation of SVPWM control system for PMSM for reducing or eliminating the cogging torque which affects the control system much especially at low speed condition.

Firstly, we focus on the analysis and simulation of SVPWM control operations, and the cogging torque of PMSM. Algorithm with id=0 has been the most effective control method. By this kind of control method, stator current is the minimum when the electromagnetic torque is confirmed. The mathematical SVPWM control model of PMSM usually includes the voltage equation and the stator flux linkage equation, and the model is built based on these equations as follow:

Voltage equation:

$$\mathrm{u}_d = \mathrm{R}_s \mathrm{i}_d + \frac{d\psi_d}{dt} - \omega_r \psi_q$$

$$\mathrm{u}_q = \mathrm{R}_s \mathrm{i}_q + \frac{d\psi_d}{dt} + \omega_r \psi_d$$

Stator flux linkage equation:

$$\psi_d = L_d i_d + \psi_f$$

$$\psi_q = L_q i_q$$

Electromagnetic torque equation:

$$T_e = 1.5 p \psi_f i_q$$

Mechanical movement equation:

$$J \frac{d\omega_m}{dt} = T_e - T_L - B\omega_m$$

Cogging torque is the negative derivative of magnetic co-energy with respect to position angle. Direct torque control (DTC) can stabilize the current but hardly remove cogging torque. Finite element analysis (FEA) can take into account the detailed structure and dimensions of the motor, and hence can accurately compute the motor parameters. The magnetic field distribution at a rotor position is illustrated in Fig. 1. From the magnetic field distribution, the cogging torque curve can be obtained by the finite element analysis in advance. For a 3-phase 4-pole motor prototype, the maximum torque is calculated of 0.25 Nm, about 5% of electromagnetic torque as shown in Fig. 2. Based on the exact expressions, a signal is injected in order to counteract the cogging torque.

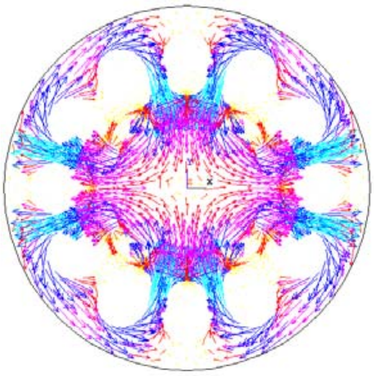


Fig. 1. Plot of no-load magnetic flux density vectors

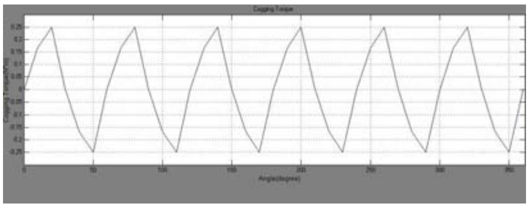
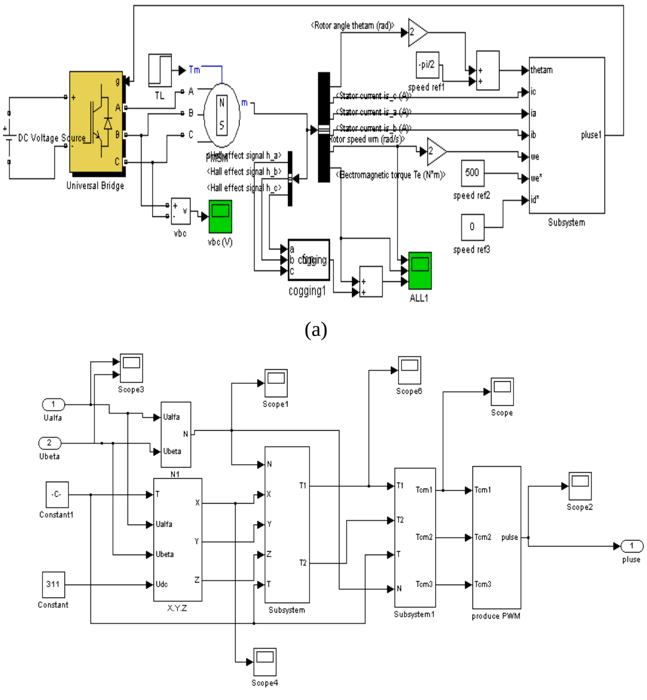


Fig. 2. Cogging torque versus rotor angle

Finally, to verify the theory an SVPWM control system with cogging torque model is built as shown in Fig. 3.



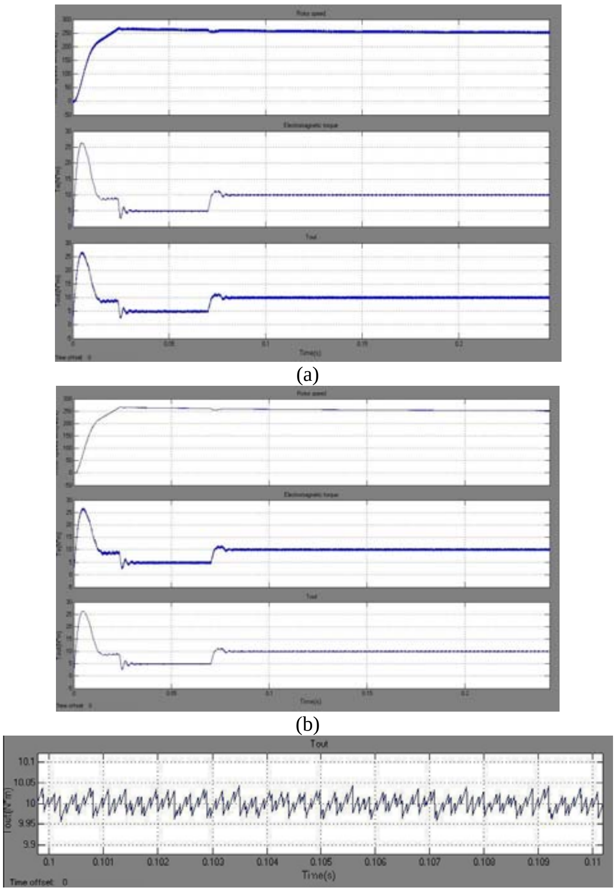
(a)

(b)

Fig. 3. SVPWM control system with cogging torque: (a) Overall system block diagram, (b) SVPWM module

III. MAJOR ANALYSIS RESULTS

Some important analysis results are given here. The comparative result of the traditional system and a new system with signal injection is shown as follows. In Fig. 4(a) the output torque ripple caused by cogging torque has effect on the performance in control system, Fig. 4(b) is the result of the system when signal is injected to the electromagnetic torque to counteract the cogging torque, and Fig. 4(c) shows the detail of output torque, where the ripple is below 5%. Detailed analysis will be given in the full paper.



(a)

(b)

(c)

Fig. 4. Rotor speed and electromagnetic torque: (a) Without the signal injection, (b) with signal injection, and (c) details of output torque.

IV. REFERENCES

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