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Low Torque Ripple Controller for Spindle Motors

Kun XIA, Yusong TANG*, Bin DONG, Jing LU, and Chao BI

Department of Electrical Engineering, University of Shanghai for Science and Technology, Shanghai, China

Abstract— **This paper presents a new six-step driving method for the spindle motors. Traditional six-step driving methods have commutation torque ripple that affects the motor performance and generates mechanical vibrations and noise in application. To analyze the commutation torque ripple, a non-linear transient model of the phase current during the commutation interval is employed. In the transient-current model, a duty of Pulse Width Modulation (PWM) during the commutation interval is the most important parameter to produce a constant torque. The control strategy focuses on how to adjust the duty in the proper way. The results show that the proposed control strategy is reliability and efficiency without any extra hardware cost.**

Index Terms – spindle motor, torque ripple reduction, high efficiency, acoustic noise.

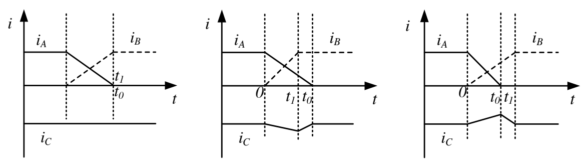
I. INTRODUCTION

The Space Vector PWM (SVPWM) control strategy is a common control strategy for spindle motor. It is a control strategy to make motor running with low acoustic noise and vibration for sinusoidal shape phase currents, but it is energy consuming and needs high performance micro-controller. High frequency PWM to achieve sine wave causes the losses on driving circuit and high performance MCU to detect zero-crossing points (ZCPs) are required.

Another control strategy with lower circuit losses and requirements is six-step driving method. Traditional six-step driving method has one main drawback, that the commutation current ripple has a lot influence on the motor output torque ripple [1]. This paper proposes a novel control strategy for HDD spindle motors based on the six-step driving method. Low torque ripple can be achieved with the improved control algorithm [2-3].

II. THEORY AND METHOD

The non-commutation phase current ripple generates torque ripple and acoustic noise when motor is running. Fig. 1 shows three different varieties of phase current during commutation.



(a) i_c stability (b) i_c convex (c) i_c concave

Fig. 1. Three phase currents during commutation.

In this paper, a transient model of the phase current during commutation period will be built to analyze the current. The duty of the PWM on conduction state is D_0 and the duty during commutation interval is D_1. While D_0 is decided according to the speed controller, and D_1 can be calculated by equation (1).

$$D_1 = (3D_0U_{dc} + E_m) / 2U_{dc} \quad (1)$$

where E_m is the Back-EMF amplitude and U_{dc} is the DC link voltage. For the limitation of PWM duty ratio, D_1 cannot maintain equation (1) with high value of D_0 while the speed of the motor is increasing. In this paper, D_2 is put on out-going phase switches to decrease the current falling rate at this situation. At high speed region, D_2 can be given as

$$D_2 = (3D_0U_{dc} + E_m) / 2U_{dc} - 1 \quad (2)$$

Fig. 2 shows the equivalent circuit of BLDCM driving system. U_{dc} is the direct-current voltage of the three-phase inverter.

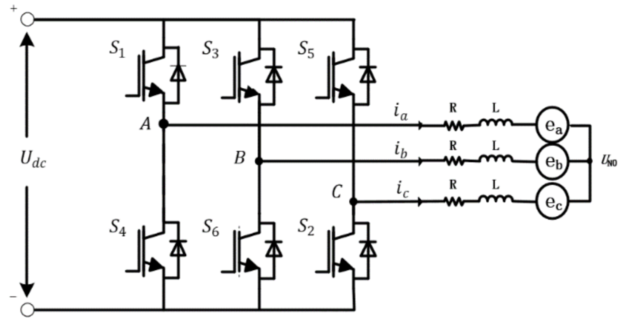
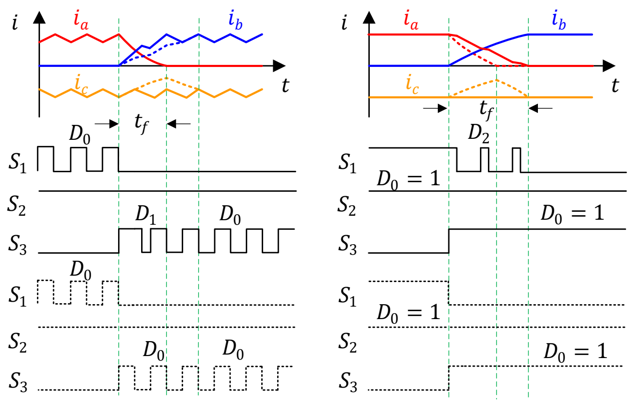


Fig. 2. typical driving circuit of the BLDCM

Fig. 3 shows the current waveform with the switch signals, when the phase current changes from phase-AC to phase-BC. The gate signal waveforms S1, S2, and S3 are shown in the figure;



(a) (b)

Fig. 3. Commutation current control strategy.
(a) Low-speed region. (b) High-speed region.

The control strategy for spindle motor without position sensor need to detect the Back-EMF ZCPs. They could be detected by the terminal voltage every 120 electric degrees. Speed control loop is also contained in the algorithm to ensure the spindle motor speed could be controlled precisely.

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III. Experiment

Simulation and experiment results will be discussed in the final paper in detail. The key parameters are shown in table 1.

TABLE I
Parameters of the Spindle Motor

Parameter	Value
Resistance (Ω)	0.75
Inductance (mH)	1.03
Poles	4
Ramp (r/min)	7200
Input Voltage (V)	12

A. Computer Simulation

The simulation model is established in MATLAB/Simulink circumstance. Fig. 4 shows the torque and phase current waveforms when the target rotor speed jumps from 500 r/min to 1000 r/min in 0.2 s. The current is square and the torque ripple is small in the constant-speed region. The figure indicates that the proposed driving strategy can significantly reduce the torque ripple and quickly adjust the motor speed.

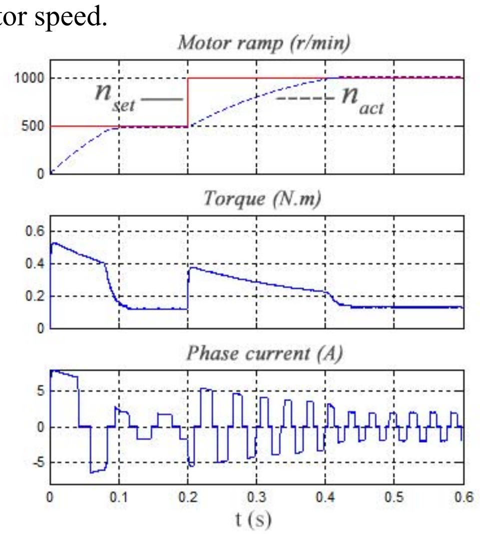


Fig. 4. Simulation waveforms while the speed is adjusted.

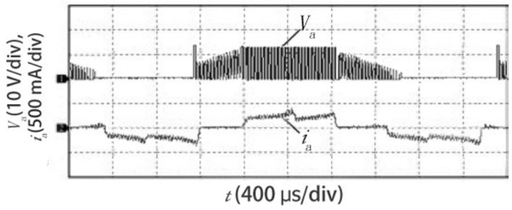
B. Acoustic noise experiment

The sound pressure level (SPL) meter is employed to measure the acoustic noise and one anechoic chamber is applied to construct the noise test system. Altogether, three different control strategies are tested, including traditional square voltage, proposed low torque ripple and senseless SVPWM driving methods. The stator terminal voltage and current waveforms of each control strategies are shown in Fig. 5.

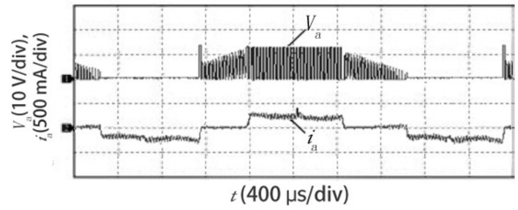
In the final paper, the result shows that the input power of spindle motor driving circuit using the proposed control strategy is smaller than that of SVPWM driving method at the same speed. And the acoustic noise spectra of three different control strategies from 1 kHz to 20 kHz which mainly indicates the EM forces are given. Result shows that the EM noise of spindle motor under SVPWM driving strategy is the lowest. The PWM frequency in this experiment is 35 kHz and the driving circuit loss would be much higher while the PWM frequency increases.

IV. Conclusion

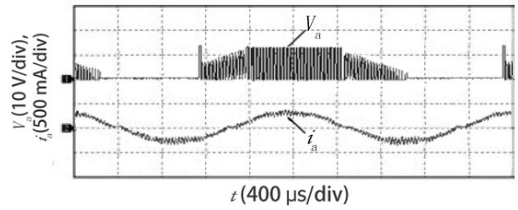
A high-efficiency and robust driving strategy for spindle motor to suppress commutation torque ripple is proposed. A simulation with the proposed control system is developed and proves the better performance of the speed control. In experiments, the input power and acoustic noise of the spindle motor with three driving methods are compared.



(a) Traditional driving method



(b) Proposed driving method



(c) SVPWM

Fig. 5 Experiment waveforms of spindle motor.

The results show that the proposed driving method has higher efficiency than the SVPWM method and lower acoustic noise than the traditional six-step driving method.

Acknowledgment

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