

Design of High Efficiency and Low Torque Ripple Controller for HDD Spindle Motors

Kun Xia, Bin Dong*, Jing Lu, Chao Bi

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

Abstract— This paper presents a novel senseless control method based on square voltage driving strategy for spindle motors used in hard disk drive. The novel control strategy can improve the efficiency of the driving circuit with low torque ripple, which induce the vibration and noise in HDDs. The generation of the torque ripple and the derivation of the control strategy would be introduced in the final paper. SPL spectrums are used in experiment to analyse the acoustic noise of spindle motor. The results of Simulation and experiment show the reliability and efficiency of the control strategy.

Index Terms – Hard Disk Drives (HDDs), spindle motor control, torque ripple reduction, acoustic noise.

I. INTRODUCTION

The common control strategy for spindle motor used in the HDDs is based on SVPWM (space vector PWM) technology [1]. The SVPWM control strategy has advantage on low acoustic noise and vibration for sinusoidal shape phase currents, while the SVPWM control method is energy consuming and require for high performance micro-controller [2]. In the SVPWM control strategy, inverter switches are complementary controlled with high frequency PWM causing the losses on driving circuit, and the high performance MCU with high speed ADC is required to detect zero-crossing points (ZCPs).

Six-step driving methods usually used in BLDCM driving system have lower circuit losses and requirement for controller. This paper proposed a novel control strategy for HDDs spindle motor based on six step driving method. This driving method has one main drawback, that the commutation current ripple has a lot influence on the motor output torque ripple [3]. In this paper, the PWM technology is used to suppress the current ripple and adjust the spindle motor speed.

II. TORQUE RIPPLE REDUCTION

The Back-EMF and the phase current waveform of the tested spindle motor under the traditional six-step driving strategy are shown in Fig. 1. The current ripple during commutation interval general the EM torque ripple.

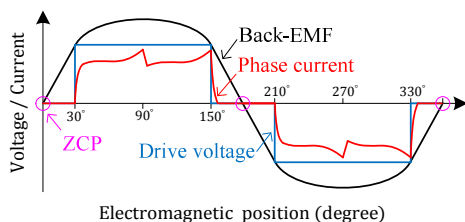


Fig. 1 Phase current under square driving voltage.

A. Commutation current ripple

The commutation process and the phase current characteristic would be analyzed clearly in the final paper. By building the transient model of the phase current during commutation period, the control parameters can be got. The duty of the PWM on conduction state and commutation interval is D_0 and D_1 respectively. The D_0 is decided according to the speed controller, and the D_1 can be calculated as (1). The end of commutation t_f when the falling current decrease to zero, is

$$D_1 = 1.5D_0 + 0.5E_m / U_{dc} \quad (1)$$

$$t_f = \frac{3i_a L}{D_1 U_{dc} + e_{ab} + 3Ri_a} \quad (2)$$

where E_m is the Back-EMF amplitude during commutation interval. As the increasing of the motor ramp, D_1 cannot maintain (1) when D_0 is high, for the limitation of PWM duty ratio. In this paper, one PWM D_2 is put on out-going phase switch to decrease the current falling rate at this situation. Then at high speed region, D_2 and t_f can be got as

$$D_2 = 1.5D_0 + 0.5E_m / U_{dc} - 1 \quad (3)$$

$$t_f = \frac{3i_a L}{U_{dc} (1 - D_2) + e_{ab} + 3Ri_a} \quad (4)$$

B. Low torque ripple control strategy

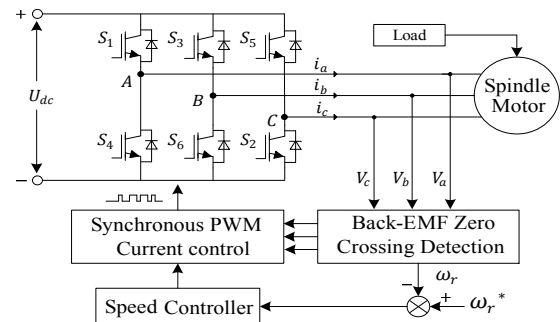


Fig. 2 Configuration of spindle motor driving system.

The configuration of spindle motor driving system is shown in Fig. 2. The spindle motor used in HDDs do not have position sensor and need to detect the Back-EMF ZCPs as shown in Fig. 1. The method of ZCPs detection would be introduced in final paper. With the speed control loop, the spindle motor speed can be precise controlled. The PWM generator produces the driving signal on inverter switches according to reference duty ratio and rotor position.

III. EXPERIMENT

In this paper, both simulation and experiment are done based on the novel control strategy for spindle motor driving system. The key parameters are shown in table 1.

TABLE I
PARAMETERS OF SPINDLE MOTOR

Parameter	Value
Input Voltage (V)	12
Ramp (r/min)	7200

A. Simulation experiment

The simulation model is built in Matlab/Simulink simulation environment. The Back-EMF waveform of spindle motor simulation model is trapezoidal and the flat area is 100 degrees.

B. Acoustic noise experiment

The acoustic noise is obtained through the sound pressure level (SPL) meter and the data would be analyzed with PC software. One anechoic chamber is used to build the noise test system. Fig. 3 show the HDD with spindle motor in the anechoic chamber. The test microphone is placed 20 cm away from the tested motor.

The spindle motor is drive with three different control strategies including traditional square voltage, proposed low torque ripple and senseless SVPWM driving methods. The current and stator terminal voltage waveforms under each control strategies are shown in Fig. 4.

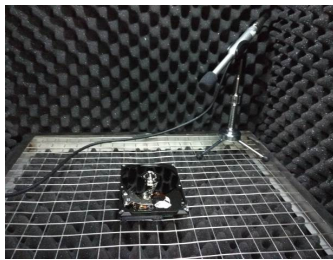


Fig. 3 Acoustic noise test environment

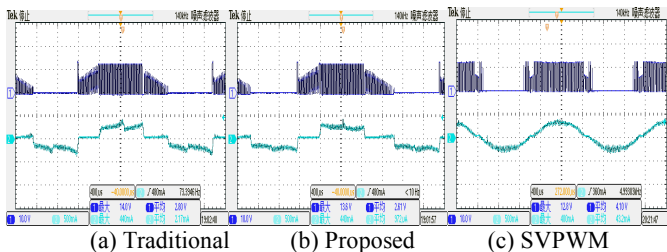


Fig. 4 Experiment waveforms of spindle motor.

The input power of spindle motor driving circuit under the proposed control strategy is slightly small than SVPWM driving methods as shown in Fig. 5. The PWM frequency used in these driving methods is 35 KHz. And the driving circuit loss of SVPWM control strategy would be much higher, when the PWM frequency increases.

Fig. 6 shows the acoustic noise spectra from 1 kHz to 20 kHz where the acoustic noise is mainly from the EM forces. The typical motor used for test is one FDB spindle motor which can eliminate most of the mechanical noise produced by rolling of bearing [4]. The EM noise of spindle motor under SVPWM driving strategy is lowest.

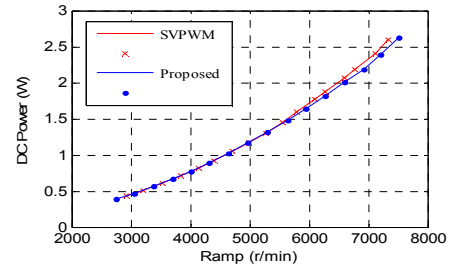


Fig. 5 Measured input power at different speeds.

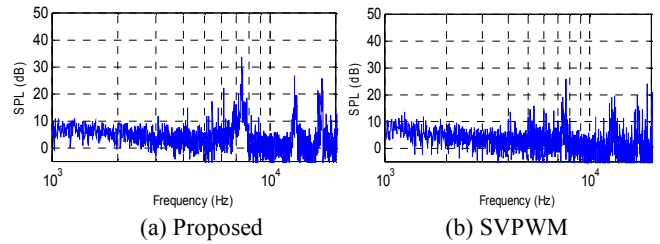


Fig. 6 Acoustic noise spectra of spindle motor.

IV. CONCLUSION

This paper proposed a high efficiency and low cost driving strategy for HDD spindle motor with low torque ripple. The novel commutation current control method using PWM technology is introduced. Simulation experiment with the proposed driving system shows the performance of the speed control. The input power and acoustic noise of the spindle motor under three driving methods are compared in the experiments. The results show the efficiency of the proposed driving system. Further research would be carried out to reduce the HDDs noise and inspect the influence of non-ideal Back-EMF on torque ripple and find the way to eliminate it.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of CHINA under Grant 51207091, also by the National Engineering Laboratory of Energy-saving Motor & Control Technique Foundation of CHINA under Grant KFK201509.

REFERENCES

- [1] S. Lin, C. Bi, Q. Jiang et al, "Analysis of three synchronous drive modes for the starting performance of spindle motors", IEEE Transaction on magnetics, vol. 43, no. 9, 2007, pp. 3734-3737
- [2] S. J. Sung, G. H. Jang, J. W. Jang et al, "Vibration and noise in a HDD spindle motor arising from the axial UMF ripple", IEEE Transaction on magnetics, vol. 49, no. 6, 2013, pp. 2489-2494
- [3] V. Viswanathan, S. Jeevanathan, "Approach for torque ripple reduction for brushless DC motor based on three-level neutral-point-clamped inverter with DC-DC converter", IET Power Electronics, vol. 8, no. 1, 2015, pp. 47-55
- [4] Bi. C, Jiang. Q, Lin. S et al, "Reduction of acoustic noise in FDB spindle motors by using drive technology", IEEE Trans. On Magnetics, vol. 39, no. 2, 2003, pp. 800-805