A New Phase-Delay Free Method to Detect Back EMF Zero-Crossing Points for Sensorless Control of Spindle Motors

Quan JIANG, *Member, IEEE*, Chao BI, *Member, IEEE*, and Ruoyu HUANG

Abstract--**This paper introduces a new phase-delay free rotor position detecting method for the sensorless control of brushless DC spindle motors. It applies a digital filtering procedure to identify the true and false zero-crossing points of the phase back EMFs, the latter of which are caused by the terminal voltage spikes of the commutating freewheeling currents. The suggested method is inherently top speed-limitation free and independent of the motor parameters. It can be applied in all kinds of spindle motors from 1" micro drives to 3.5" high-speed enterprise server drives. The developed prototype of SpinBox based on the invented method has experimentally confirmed its correctness and effectiveness in wide-speed range.**

Index Terms--**brushless DC motors, hard disk drives, rotor position detection, sensorless control, spindle motors.**

I. Introduction

RECENTLY, hard disk drives (HDD) trend to be high spin-speed for servers and small form factor, e.g., 1" or sub-inch HDDs, for consumer appliances. The highest spin speed of commercial HDDs has been 15,000 rpm and will be higher in future. And the phase back EMF amplitudes of small factor HDD spindle motors are becoming lower. These tendencies bring new challenges to the sensorless brushless DC (BLDC) control of HDD spindle motors. The conventional sensorless control methods with the rotor position detection from the back EMFs will not work well when the terminal voltage spikes last relatively longer at the high motor speed or the phase back EMF amplitude is very low [1]-[3].

This paper introduces a new phase-delay free rotor position detecting method for the sensorless control of BLDC motors. This method invents a digital filtering procedure to identify the true and false zero-crossing points (ZCPs) of the phase back EMFs, the latter of which are caused by the terminal voltage spikes of the phase commutating freewheeling current. The proposed filtering method makes it possible that the sensorless BLDC motors can employ the simplest ZCP detecting circuit without the phase-delay and independent of motor parameters. Therefore, the true ZCPs of phase back EMFs and rotor position can be accurately detected in a very wide range of speeds for all sensorless BLDC motors.

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II. Typical Operations of Sensorless BLDC Motors

This paper employs a sensorless BLDC motor drive in Fig. 1 to illustrate the suggested method. The typical terminal voltages of a HDD spindle motor at high speed are shown in Fig. 2, which is driven in the constant voltage BLDC mode.

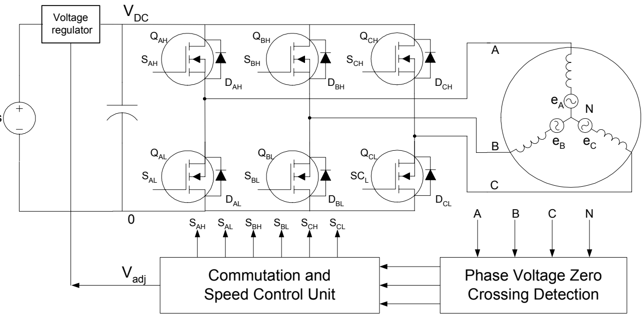

Fig. 1. System schematic of a typical sensorless BLDC motor drive.

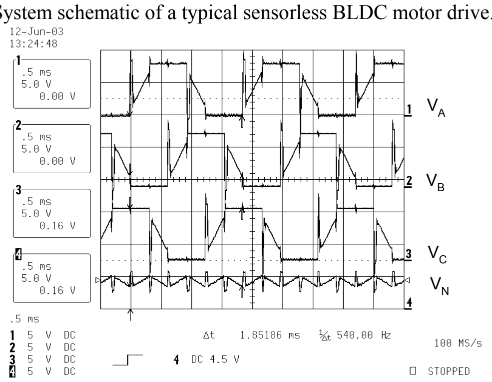

Fig. 2. Typical terminal voltages of a HDD spindle motor.

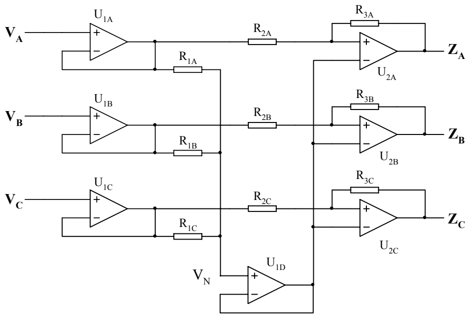

Fig. 3. ZCP detecting circuit without phase-delay.

Since the BLDC motors work with two excited phases and one unexcited phase except the commutation period, this provides the possibility to employ the back EMF of the unexcited phase to detect the rotor position. Usually the ZCPs of the back EMF are used because they are independent of the

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speed. The suggested ZCP detecting circuit is shown in Fig. 3 and it is phase-delay free. Moreover, the virtual neutral voltage in the circuit is equivalent to the real neutral voltage of the motor. Comparing the terminal voltages with the virtual neutral voltage, the ZCP level signals of the corresponding phases, Z_A, Z_B, and Z_C, are generated as shown in Fig.4. But these ZCP level signals contain the false ZCPs caused by the phase commutations.

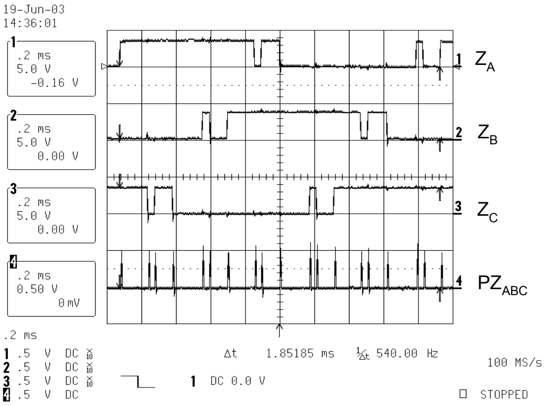

Fig. 4. ZCP level signals and the edges of ZCP level signals.

III. New Back EMF ZCP Detecting Method

In order to get the true ZCPs from ZCP level signals and eliminate the false ones, firstly, all the rising and falling edges of ZCP level signals are generated to obtain a ZCP edge pulse signal, PZ_{ABC} as shown in Fig. 4, as follows,

$$PZ_{ABC} = (Z_A \oplus Z_{A\_delay1}) + (Z_B \oplus Z_{B\_delay1}) + (Z_C \oplus Z_{C\_delay1}), \quad (1)$$

where "*delay1*" is a predetermined width about 1 μs to form the delays of all three ZCP level signals. Through analyzing the signals of Z_A, Z_B, Z_C and PZ_{ABC} in Fig. 4, it could be found that all the false ZCPs are caused by the phase commutations and each commutation produces a noise pulse on a terminal voltage with two false ZCPs of one rising edge and one falling edge, i.e., two false ZCP pulses in PZ_{ABC}. Because the commutation happens according to the phase control signals, which switch off the relative switch devices of the inverter, the false ZCPs appear exactly after these switch-off signals. Therefore, the falling edges of device switching signals in Fig. 1 can be employed to form a masking signal correspond to the 1st edges of the false ZCPs. This signal M_Z can be obtained through the following logic,

$$\begin{aligned} M_Z = [&(S_{AH} \oplus S_{AH\_delay2}) \cdot \overline{S}_{AH} + (S_{AL} \oplus S_{AL\_delay2}) \cdot \overline{S}_{AL} \\ &+ (S_{BH} \oplus S_{BH\_delay2}) \cdot \overline{S}_{BH} + (S_{BL} \oplus S_{BL\_delay2}) \cdot \overline{S}_{BL} \\ &+ (S_{CH} \oplus S_{CH\_delay2}) \cdot \overline{S}_{CH} + (S_{CL} \oplus S_{CL\_delay2}) \cdot \overline{S}_{CL}], \end{aligned} \quad (2)$$

where *"delay2"* is the width of M_Z pulse and needs to be a little bigger than *"delay1"* in (1). It is described in Fig. 5.

Then, masking the 1st edges of the false ZCPs with the signal M_Z, the masked ZCP signal PZ_M in Fig. 6 is obtained through the following,

$$PZ_M = PZ_{ABC} \cdot \overline{M}_Z. \quad (3)$$

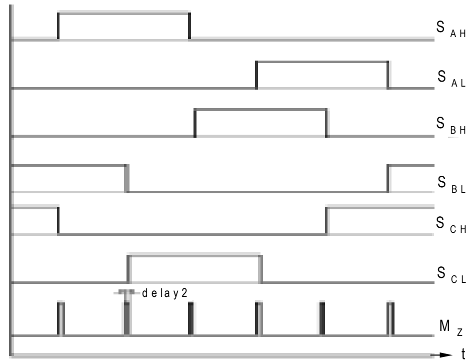

Fig. 5. The mask signal M_Z generated from switching signals.

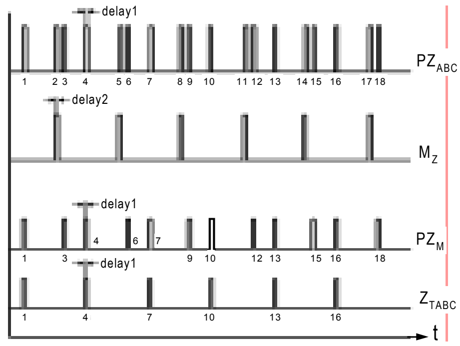

Fig. 6. The masked signal PZ_M and true ZCP Z_{TABC} after digitally filtering.

Comparing the logic values of ZCP level signals, a pulse of the masked signal PZ_M is identified as a true ZCP when the logic values of the present PZ_M pulse are different from those of a preceding PZ_M pulse. This could also be expressed as,

$$\begin{aligned} Z_{TABC}(i) = PZ_M(k), \text{ if } [&(Z_A, Z_B, Z_C) \text{ at } PZ_M(k-1) \oplus \\ &(Z_A, Z_B, Z_C) \text{ at } PZ_M(k) = \text{"}true\text{"}] \end{aligned} \quad (4)$$

In this way, all true ZCPs can be obtained as Z_{TABC} in Fig. 6.

IV. Conclusion

The proposed method is low-cost and easy to be implemented through hardware logic circuits, CPLD, FPGA firmware or DSP firmware. Based on this method, a universal digital sensorless control system suitable for all kinds of BLDC motors has been successfully developed with the speed stability of 0.01% and its top speed will be no longer limited by the rotor position detecting method. Experimental results have confirmed that this method can be applied to both high spin-speed spindle motors with multi-platters and low back EMF spindle motors for small factor and sub-inch HDDs in all three BLDC modes, including PWM chopping, MOSFET on-resistance variable and voltage constant BLDC modes.

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