A Novel Back EMF Zero Crossing Detection of Brushless DC Motor Based on PWM

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Abstract: In order to solve the problem of the phase delay of the filter capacitor in the traditional back EMF zero crossing detection technology, In this paper, through the PWM pulse regulation of the new back-EMF zero-crossing detection method accurate and reliable commutation. The Brushless DC motor rotor positioning accuracy and commutation smooth has been achieved. The experimental results verify the validity of the new back-EMF zero-crossing detection method.

Key words: Brushless DC motor; New counter electromotive force zero - crossing detection; Phase delay; PWM pulse regulation**;**

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1. Introduction

Brushless DC motor using electronic switch device to replace the brush motor mechanical commutation, to avoid the carbon brush mechanical commutation to bring the sparks, noise, with a good speed characteristics, dynamic performance, and small size, simple structure , High power density [1].Especially brushless DC motor using Hall element position sensor, because of its no change in sparks, reliable operation, easy maintenance, simple structure, no loss and many other advantages, has been more and more extensive Application [2]. However, brushless DC motors require an additional position sensor to provide the necessary commutation signal to the inverter bridge, and its presence brings a lot of flaws and inconveniences to the application of the brushless DC motor: 1) The position sensor Increase the size and cost of the motor; 2) The position sensor will reduce the reliability of motor operation, even now widely used Hall sensor also has a certain degree of magnetic non-sensitive area; 3) Sensor installation accuracy will affect the motor running Performance, increasing the difficulty of the production process.

In recent years, the control of brushless DC motor without position sensor has been a more popular research topic at home and abroad. In this paper, a phase control method based on real-time PWM pulse control to control the RC time constant in the filter circuit at the terminal voltage is proposed for the phase delay of the filter capacitor in the traditional back-EMF zero-crossing detection technique. The experimental results show that the zero - crossing detection of the brushless DC motor based on PWM regulation can effectively solve the phase delay problem of the filter capacitor.

2. Back EMF Zero-Crossing Detection Technology

Three-phase six-star starter brushless motor, the back-EMF zero-crossing detection method of the basic principle: each phase winding single-phase positive and negative were 120 ° conduction, and at any time at any time three phases only two simultaneous , By measuring the potential of the three-phase winding terminal and the neutral point, when the other phase terminal potential and the neutral point potential is equal, that is, the non-conduction of the opposite electromotive force zero crossing, and then 30 ° electrical angle delay for electronic switching Phase [8]. Therefore, as long as the detection of each winding back electromotive force zero crossing, you can determine the motor rotor position and the next commutation time. As the back EMF is difficult to directly measure, usually through the detection of terminal voltage to obtain anti-backlash zero. Therefore, this method is also known as the terminal voltage detection method [9-10].

With a trapezoidal back electromotive force waveform brushless DC motor main circuit schematic, back EMF waveform shown in Figure 2-1,2-2。

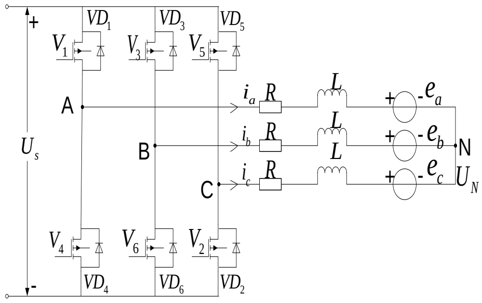

Figure 2-1 Equivalent model of brushless DC motor and three-phase full-bridge main circuit

In the figure, Us is the DC bus voltage and V_1-V_6 are the power switching devices. Currently, IGBT or MOSFET is used. VD_1-VD_6 are the freewheeling diode and U_N for the motor neutral point voltage. That is, the motor neutral point N corresponds to the DC bus negative voltage, the three-phase current direction of the motor and the polarity of the three-phase back electromotive force are shown in Fig 2-2.

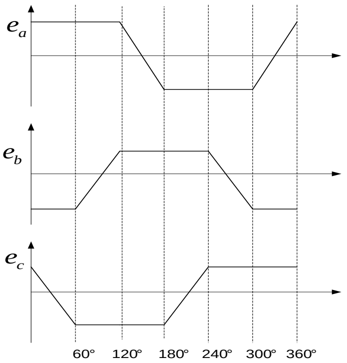

Figure 2-2 Three-phase back electromotive force waveform

U_a , U_b , U_c are the negative terminal voltages of the input terminals of each phase with respect to the power supply Us respectively. Assuming the system uses two-two way of conduction, three-phase and six-state 120 ° conduction mode, the adjustment of the bridge on the tube with PWM modulation, the other tube having been conduction.

The three-phase voltage balance equation of the motor is:

$$U_a = Ri_a + L\frac{di_a}{dt} + e_a + U_N \tag{2-1}$$

$$U_b = Ri_b + L\frac{di_b}{dt} + e_b + U_N \tag{2-2}$$

$$U_c = Ri_c + L\frac{di_c}{dt} + e_c + U_N \tag{2-3}$$

In this conduction mode, only two tubes are turned on for every 60 ° electrical angle. In the range of 60 ° ~ 120 ° in Fig. 1-2, the A and B phases are conducting and A positive B negative, this is, the A phase current flows into the neutral point of the motor, and the B phase current flows out of the motor neutral point. At this time A, B two-phase current equal size, the opposite direction, C phase current is zero, so the formula (2-3) can be simplified as:

$$U_c = e_c + U_N \tag{2-4}$$

or

$$e_c = U_c - U_N \tag{2-5}$$

As $i_a = -i_b$, $e_a = -e_b$, the formula (2-1) and (2-2)are added to obtain a neutral point voltage

$$U_N = \frac{U_a + U_b}{2} \tag{2-6}$$

Substituting formula (2-6) into formula (2-5) yields:

$$e_c = U_c - \frac{U_a + U_b}{2} \tag{2-7}$$

Similarly, the A-phase and the B-phase back-EMF zero-crossing detection equation are:

$$e_a = U_a - \frac{U_b + U_c}{2} \tag{2-8}$$

$$e_b = U_b - \frac{U_a + U_c}{2} \tag{2-9}$$

Through the back-EMF zero-crossing detection method, in the compensation of the back-EMF to the motor commutation time 30 ° phase shift. According to the calculated motor speed, real-time adjustment PWM pulse control terminal voltage filter circuit RC time constant, in order to achieve accurate and reliable 30 ° phase shift

3. New Zero Crossing Detection Method and Its Implementation

3.1Phase Compensation of The Filter Capacitor

When the back-EMF of the power-off phase winding after zero, and then after 30 ° electrical angle, analysis of the back EMF waveform shows that the place is the phase of the commutation point. However, in the practical application of the motor back EMF detection circuit, as shown in Figure 3-1, the filter capacitor on the one hand to filter the role of filtering, on the other hand the detection voltage has a certain phase shift [11-12].According to Figure 3-1, it is easy to calculate the phase shift of the detection circuit. Take the A phase as an example, where U_A is the A-phase voltage, U_{ao} is the filtered output voltage, and f is the back-electromotive force frequency. Calculated by base wave:

$$\frac{U_{ao}}{U_a}=\frac{R_2}{R_1+R_2+j2\pi fR_1R_2C_1} \qquad (3\text{-}1)$$

Phase angle delay is

$$\alpha=\arctan\frac{2\pi R_1R_2C_1f}{R_1+R_2} \qquad (3\text{-}2)$$

It can be seen from the above formula, the phase angle delay of the filter capacitor and the function of the motor speed need to be detected or calculated in real time. In this paper, a solution is adopted so that the controller can be compensated better when the motor speed is high or the speed is very low. The basic principles are as follows:

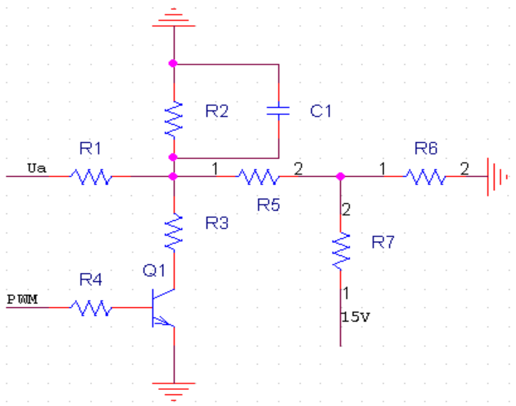

Figure 3-1 Phase shift compensation circuit

To A phase, for example, as shown in Figure 3-1, Terminal voltage U_a by the resistance R_1, R_2 partial pressure, and then by the capacitor C_1 filter, PWM pulse control transistor Q_1 off. When the PWM pulse is high, the transistor saturation open, the resistance R_3 equivalent ground, and the resistance R_2 in parallel; when the PWM pulse is low, the transistor cut-off, the resistance R_3 does not work. Changing the PWM pulse width can be equivalent to change the resistance R_2, and then change the RC time constant, that is, change the phase shift of the filter circuit. As the PWM pulse width adjustment is simple and convenient and can be continuous, it can achieve 0 ° ~ 90 ° phase shift. In this scheme, a constant 30 ° phase shift is required in the full speed range of the low speed to high speed motor, and the pulse width of the PWM can be adjusted in real time according to the motor speed calculated by the CPU detection. When the resistance $R_2 > R_1$ (in the actual application circuit, take $R_2 >> R_1$, the purpose is to increase the PWM regulation effect), adjust the PWM pulse width, so that it is proportional to the motor speed, so the motor speed range to a constant 30 ° phase shift. At the same time, When the motor in the quiescent state, an increase of three resistors R_5, R_6, R_7 and a 15V power supply, so that the back electromotive force is zero and the position signal detection circuit comparator has a stable output. R_5, R_6, R_7 selection principle is: $R_5 >> R_1$, $R_7 >> R_6$, $R_5 >> R_7$.

3.2 New Back EMF Zero-Crossing Detection of The Hardware Circuit

At present, the counter-electromotive force zero-crossing detection uses hardware circuit to achieve [13-14]. The basic structure of the hardware detection circuit is shown in Figure 3-2. In this circuit, the comparator forward input and three-phase detection voltage is connected and the reverse input and three-phase detection voltage of the neutral point voltage U_{N1} connected.

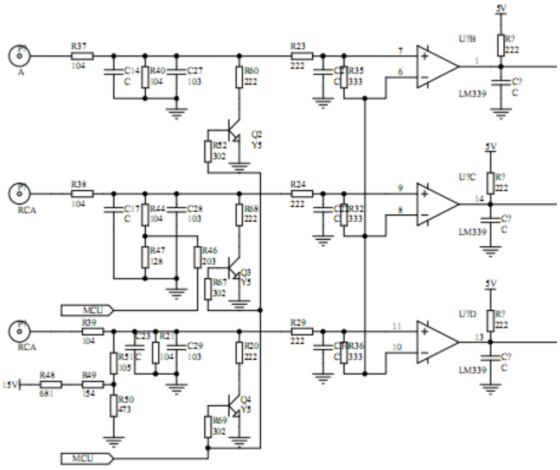

Figure 3-2 Counter-electromotive force zero-crossing detection hardware circuit

The following shows the comparator output signal H_a , H_b , H_c and the motor back electromotive force diagram (which has been 30 ° phase shift processing). As shown in Figure 3-3.

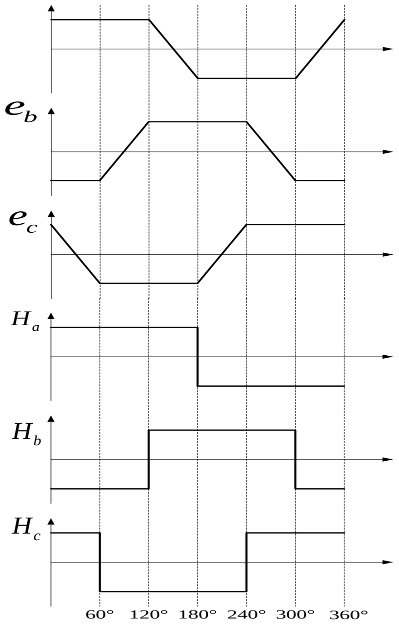

Figure 3-3 Counter electromotive force and the corresponding comparator output waveform

4. Experimental Results and Analysis

The signal output of the back-EMF zero-crossing detection circuit is shown in Figure 4-1 when the motor is at rest. Figure 2, 3, 4 channel waveforms corresponding to A, B, C phase, 2-channel waveform for the high and low levels of 250ms each square wave, 4-channel waveform amplitude constant 0,3 channel waveform amplitude constant 5V. This is consistent with the design of this program. In the case where the motor counter electromotive force is zero, in order to stabilize the back electromotive force detection circuit, in the C phase detection circuit superimposed on a small signal, the small signal makes the detection circuit output stable, which is easy to determine the motor to run the motor status. In order to make the above judgment more reliable, in the A phase to increase a high and low levels of 250ms each square wave signal, The program on the back EMF detection circuit output signal within 250ms to determine whether the motor running to ensure that the motor can be reliable start.

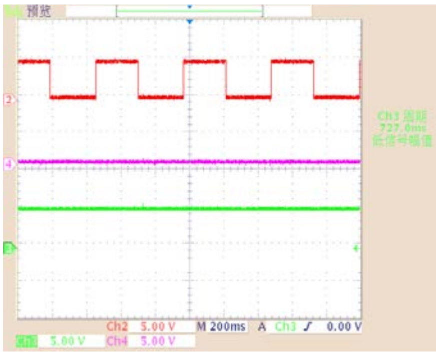

Figure 4-1 output waveform of the counter electromotive force detection circuit when the motor is at rest

The phase compensation waveform for the filter capacitor is shown in Figure 4-2. 2-channel waveform is the detection circuit output waveform and 3-channel for the corresponding phase of the terminal voltage waveform. It can be seen that the rising and falling edges of the signal output waveform of the detection circuit correspond to the commutation point of the terminal voltage waveform, and the 30 ° phase shift of the backlash point to the commutation point is accurately realized. This fully proves the validity of the method used to control the phase shift of the RC constants of the PWM control filter circuit used in this paper. The sharp pulse on the slope of the midpoint voltage waveform is due to the sudden change in voltage caused by the freewheeling diode.

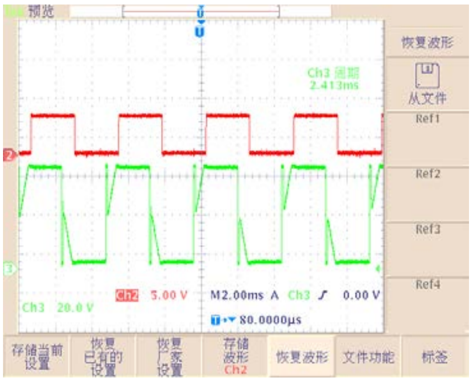

Figure 4-2 Phase compensation waveform

By controlling the PWM for phase compensation, over-compensation can also be achieved, as shown in Figure 4-3. Figure 2-channel waveform for the detection circuit output waveform and 3-channel for the corresponding phase of the terminal voltage waveform. In the process of over-compensation, the motor noise is very large, serious heat and almost no normal operation, we can see the importance of phase compensation.

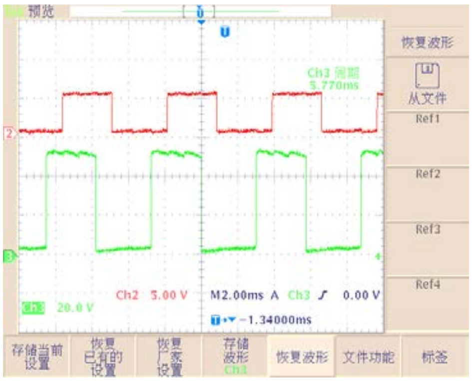

Figure 4-3phase over compensation waveform

5. Conclusion

In this paper, a new back EMF zero - crossing detection circuit is designed for the phase delay of the filter capacitor in the traditional back EMF crossing zero detection technology. When compensating the backlash of the back electromotive force, the RC time constant of the filter circuit at the control terminal voltage is adjusted by real-time adjustment of the PWM pulse to achieve an accurate and reliable 30 ° phase shift.

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