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SENSORLESS SELF-STARTING AND CONTROL STRATEGY OF RUSHLESS DC MOTOR

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Abstract:-

Brushless DC motor with sensors have problems, such as theirs large sizes, high costs, limited applications and so on.In order to solve them,based on STM32F103 MCU and taking it as the core,this essay uses position sensorless control based on square-wave drive,it realizes the switching of zero speed to the motor closed-loop state through three-step start technique,it checks rotor position and speed by back-EMF method.At last,it makes the motor run normally. The effectiveness and feasibility of the control scheme proposed are verified through experiments.

Key words:-*Brushless DC motor;sensorless; square-wave drive; three-step start; back-EMF method;STM32F103*

CLC number: TP217

0 INTRODUCTION

With the development of the microelectronics industry, brushless DC motor (BLDCM) has been able to replace the DC motor in many consumer and industrial applications with the advantages of small size, smooth operation, controllable and high efficiency. Since the electrical excitation must be synchronized with the rotor position, the traditional BLDCM usually has a position sensor to detect the position of the rotor magnet. However, with the cost, reliability, application range, mechanical robustness and other factors, the use of sensorless control technology becomes inevitable Choose trends.

In recent years, domestic and foreign researchers have found that there are many sensorless start-up and control methods for brushless DC motors. Reference [1] proposed to use the freewheeling diode method to detect the rotor position, which is more accurate than directly detecting the back-EMF zero-crossing point. However, the complicated detection circuit needs to be set up and the cost is high. In document [2], the flux linkage method is used to calculate the flux linkage by measuring the stator voltage and current, so as to obtain the rotor position information efficiently, documents [3-4] in-depth analysis of the back EMF starting point to make the brushless DC motor work properly, but did not specify which kind of back EMF method; document [5] proposed a new sensorless start-up method, that fixed frequency boost Start-up method, omitting the pre-positioning link, but reduces the robustness and stability of the system; documents [6-8] for position sensorless brushless DC motor proposed several different rotor position detection method, and made The advantages and disadvantages of comparison, with reliability.

Based on the above-mentioned method, a chip-based STM32F103-based sensorless control scheme based on square wave drive is proposed. The program adopts three-stage starting mode to realize self-starting of the motor. The position and speed of the rotor are determined by the back-EMF zero-crossing detection method. The single-closed PI speed controller realizes the stable control of the rotating speed of the motor and improves the anti-interference. Button control motor start, stop, accelerate, slow down and positive and negative. Finally, through experiments, the motor runs smoothly without a sensor, which proves the effectiveness of the scheme.

1 Working Principle of BLDCM Based on Square Wave Drive

1.1 Basic principles of BLDCM

Brushless DC motor is mainly composed of a motor body and a power electronic switch (inverter), which are electronically commutated. The stator is a winding, the rotor is a permanent magnet, and the energized coil generates a magnetic field that interacts with the permanent magnet field to generate a magnetic moment, So that the rotor rotation. In this paper, the stator winding phase winding with full length, the use of three-phase symmetrical star connection.

As shown in Fig. 1, the brushless DC motor is usually used as the schematic diagram.u_a、 u_b 、 u_c andi_a、 i_b 、 i_c are a、 、 c terminal voltage and phase current, R is the stator resistance， L is the stator phase inductance， e_a、 e_b 、 e_c is the opposite electric potential of three-phase;u_n is the Voltage in Neutral-point joint portion of stator winding。

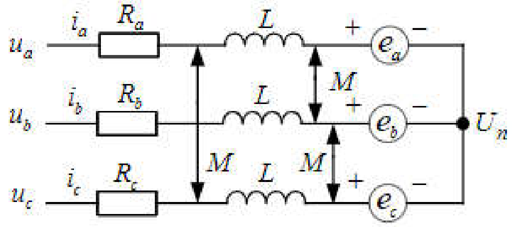

Fig.1 brushless DC motor schematict Voltage Balance Equation：

Voltage Balance Equation：

$$\begin{bmatrix} u_a - u_n \\ u_b - u_n \\ u_c - u_n \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1.1)$$

Neutral Voltage Equation：

$$U_n = \frac{u_a + u_b + u_c}{3} - \frac{e_a + e_b + e_c}{3} \quad (1.2)$$

1.2 BLDCM commutation control circuit

This article uses the second two-phase three-phase six-state control.

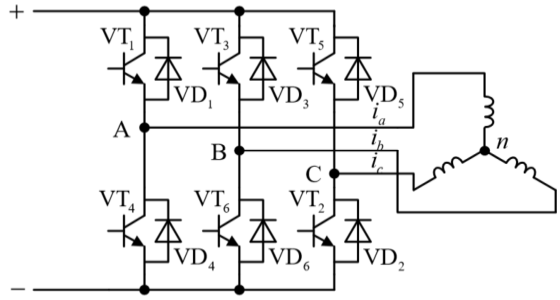

Fig. 2 Control system circuit

As shown in Figure 2, for the control system circuit, VT1—VT6 is the Power FET， VD1—VD6 is the Anti-diode, playing a role in freewheeling In an electrical cycle, there are totally 6 trigger states of these switches, and each switch turns on the electrical angle each time only two switches are on, that is, only two phases are on. For example, when the AB phase is conducting, the switch tubes VT1 and VT6 are opened, and C is the floating phase, that is, the non-conducting phase. The current flowing path is: positive power supply VT1 → phase a winding → phase B winding → VT6 → negative power supply. And so on, with the continuous rotation of the motor rotor, turn on the corresponding power FET turn-on sequence in Table 1.

Tab.1 Conduction sequence of power transistor and direction of winding current

State	Current direction	The switch turned on
1	A^+ B^-	VT_1、VT_6
2	A^+ C^-	VT_1、VT_2
3	B^+ A^-	VT_3、VT_4
4	B^+ C^-	VT_3、VT_2
5	C^+ A^-	VT_5、VT_4
6	C^+ B	VT_5、VT_6

2 Position Sensorless Self-Start Based on Square Wave Drive

In this system, the brushless DC motor adopts the position sensorless control. When the motor is at zero speed or low speed, the back electromotive force is zero or very small, and the rotor position cannot be detected. Therefore, an effective starting technique is needed. The study found that how to switch from zero speed to detect the zero crossings of the counter electromotive force and then switch the motor to the closed loop state is the most difficult to solve. In addition, the system is based on square wave driving, The traditional, currently more mature three-stage start-up method, namely rotor positioning, acceleration and switching.

2.1 Rotor pre-positioning

The initial position of the rotor determines which of the two power switches the inverter first conducts to allow the motor to start, making it more difficult to determine the rotor position without a sensor. Therefore, before starting, any two phases can be turned on and on for a certain period of time. Under the effect of the stator magnetic field, the rotor will turn to a position corresponding to conduction, that is, the axis of the composite magnetomotive force of the two-phase winding Position, then the rotor positioning end.

In the process of pre-positioning, due to the inaccuracy of six-step control, it usually takes long enough to ensure that "jitter" stops before proceeding to prevent the motor from pre-positioning inaccuracies.

2.2 External synchronization acceleration (forced open-loop)

After the pre-positioning, according to the motor steering, you can know which two power switches should be triggered, if the pre-positioning process is turned on the AB phase, so when the motor positioning, the commutation sequence can be conducted according to the next phase sequence , and so on. The motor should gradually reduce the energizing time of each phase sequence during acceleration. In fact, it is to realize an acceleration curve similar to exponential type, and the motor must be continuously rotated.

2.3 External synchronization to self-synchronization switch (get into the closed-loop)

Continue to accelerate the motor until it can detect the steady-state back-EMF zero-crossing signal, so as to realize the closed-loop operation of the motor, and the position sensorless algorithm based on the back-EMF detection. At this moment, the trigger signal is no longer issued according to the approximate acceleration curve, but the corresponding switch tube is triggered according to the detected rotor position signal.

Switching process is the key to sensorless operation, need to meet: the general choice of motor speed of 20% of the maximum speed as the switching speed; smooth switching requires brushless DC motor commutation in the best phase commutation operation, the external synchronous commutation signal And self-phase commutation signal is fully synchronized.

3 Control Strategy of Position Sensorless Based on Square Wave Drive

3.1 Back-EMF zero-crossing detection

3.1.1 EMF commutation principle

The BLDCM with position sensor uses the Hall sensor to determine the position of the rotor so that the phases of the windings of the stator are switched on in a sequential manner to achieve phase commutation. The sensorless BLDCM determines the position of the rotor by detecting the back-EMF zero-crossing point generated during motor operation phase.

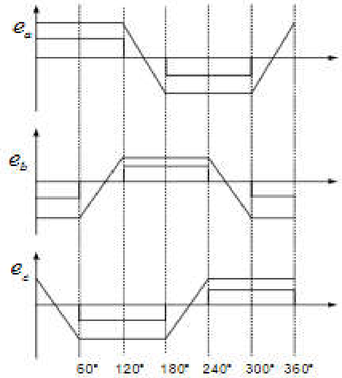

Fig. 3 Three phase EMF waveform

As shown in FIG. 3, the back EMF always passes through the horizontal axis (zero cross point) once during the 60□ electrical angle. At this point, the delayed electrical angle is the corresponding commutation time.

3.1.2 Back EMF zero-crossing program

When the motor is running, only the two-phase windings are conducting at any one time, the current of the non-conducting phase windings is zero. It can be seen from equation (1.1) that the moment when the voltage of the non-conducting phase windings equals the neutral voltage is The moment of non-conduction phase winding back EMF zero crossing. Therefore, the non-conducting phase winding terminal voltage can be compared with the neutral voltage to obtain the zero cross point of the winding back-EMF. However, the BLDCM generally does not induce a neutral point, and the terminal voltage signal usually contains some interference signals. Therefore, it is impossible to directly compare the winding terminal voltage and the motor neutral voltage. Therefore, this paper uses the back-EMF zero-crossing detection method: sampling three-phase voltage of the AD signal sampling, the voltage after low-pass filter, and then use the virtual neutral voltage comparison method.

At any one time, the currents in the two-phase windings are equal in magnitude and opposite in direction, and the non-conduction phase current is 0, which can be obtained according to formula (1.1)

$$u_a + u_b + u_c = e_a + e_b + e_c + 3u_n \qquad (3.1)$$

And because the conduction of the two-phase winding back EMF equal size, the opposite direction, the type can be changed to

$$3u_n = u_a + u_b + u_c - e_x \qquad (3.2)$$

Where x indicates the non-conducting phase. Also because

$$e_x = u_x - u_n \qquad (3.3)$$

So get it

$$2e_x = 3u_x - (u_a + u_b + u_c) \qquad (3.4)$$

Figure 1 winding terminal voltag u_x（x□a、b、c) low-pass filtered to obtain the detection signal, equation (3.4) is converted into

$$2e_x' = 3u_x' - (u_a' + u_b' + u_c') \qquad (3.5)$$

In the formula $e_x' = \frac{u_x'}{u_x} e_x$, the voltage of the virtual neutral is $u_0 = \frac{1}{3}(u_a' + u_b' + u_c')$ (3.6)

From (3.5) and (3.6)

$$\frac{2}{3} e_x' = u_x' - u_0 \qquad (3.7)$$

By comparing the value of u_x' and u_0, we can determine the zero crossing point of the winding back EMF.

3.2 Speed control after starting

The speed is determined by the zero-crossing point: Because the interval between two zero-crossing points of the two back EMFs corresponds to the time when the rotor turns to the electrical angle, the timer can be used to determine the interval and the rotor speed can be calculated.

Because the motor studied in this paper is in the conduction mode, PWM control is used to control the speed of the motor. The PWM modulation of the upper tube in the single-tube modulation mode is used to control the lower tube. Shown in Figure 4, for the speed control block diagram. Because the motor is open-loop running during start-up, the motor needs to switch to single-loop speed control when the motor reaches a certain speed after starting and the back EMF is valid.

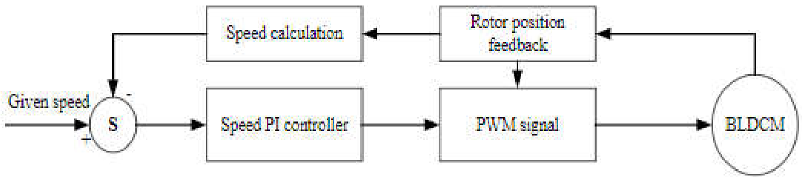

Fig.4 Control block diagram of speed regulation system

4 System experimental platform

4.1 Experimental hardware platform

The experiment is based on STM32F103 chip as the core of brushless DC motor controller, using sensorless square wave control strategy. Peripheral circuits are provided with drive circuit, sampling circuit, ST-Link communication circuit, DC power supply, brushless DC motor, PC PC, the overall structure of the system block diagram shown in Figure 5.

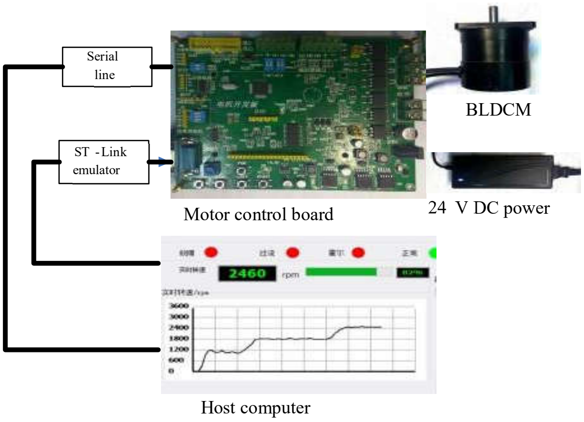

Fig.5 The overall block diagram of the system

Turn on the power, when the motor is completed after the start, through the key control motor start, stop, accelerate, and slow down, through the host computer real-time observation of motor speed.

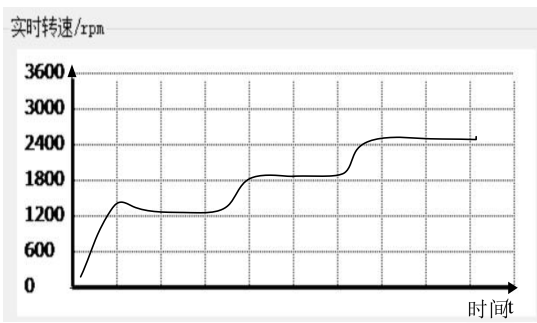

Fig.6 PC real-time observation of motor speed

As shown in FIG. 6, when the speed reaches a certain value, although there is a slight jitter within the allowable range of the error, no great fluctuation occurs and the rotation speed is stabilized from low to high. It can be seen that the speed control in this system has made more Good results.

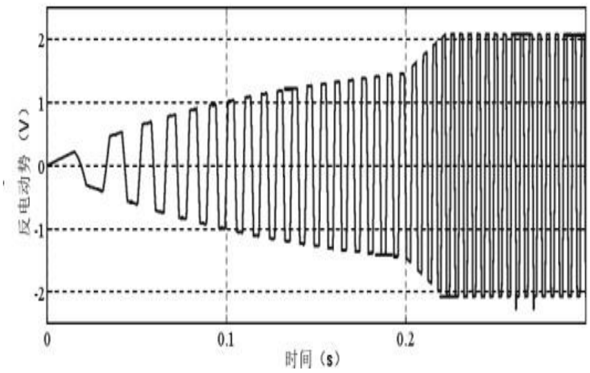

Fig.7 Back-EMF waveform

As the speed increases, the back EMF also increases, as shown in Figure 7, the back EMF waveform is approximately trapezoidal.

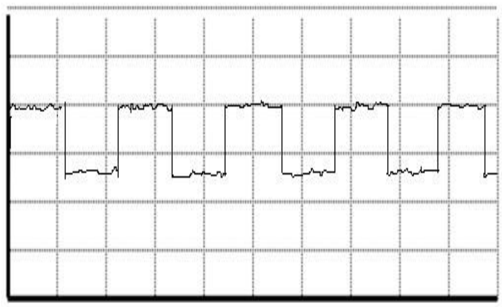

Fig.8 Position signals detected by Back-EMF

As shown in Figure 8, the back-EMF zero-crossing signal delayed electrical angle of the signal, the rotor position signal. It has been verified that the rotor position signal detected by the back-EMF has almost no lead or lag relative to the ideal position signal.

Under the control of the single-tube PWM modulation mode, the phase current is adjusted by the current regulator, and the simulation waveform appears smoother. As shown in FIG. 9, it is similar to the square wave.

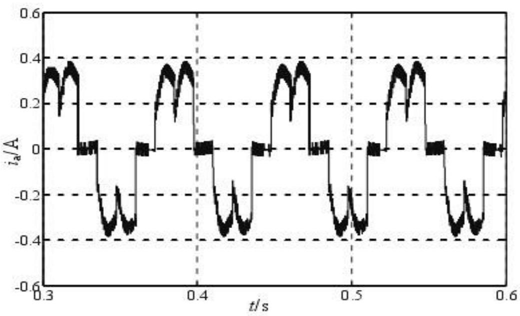

Fig.9 Phase current of steady state

4.2 Experimental software platform

Software programs include: the main program, the initialization subroutine, start the program, the back EMF detection program, speed control programs, Figure 10, Figure 11 are the main program and back EMF detection program flow chart.

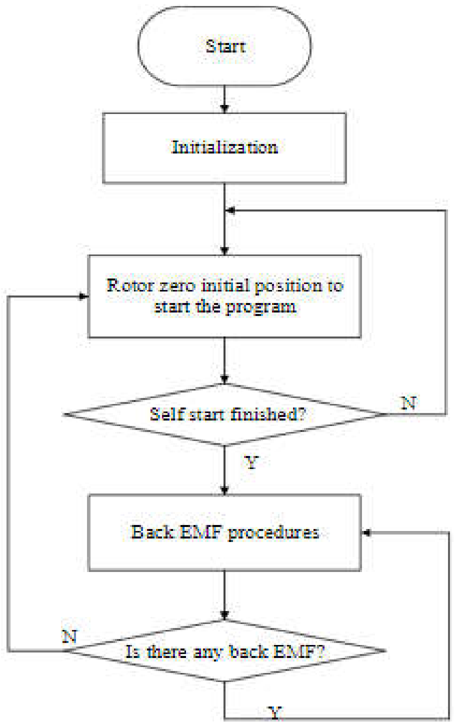

Fig. 10 Main program flow chart

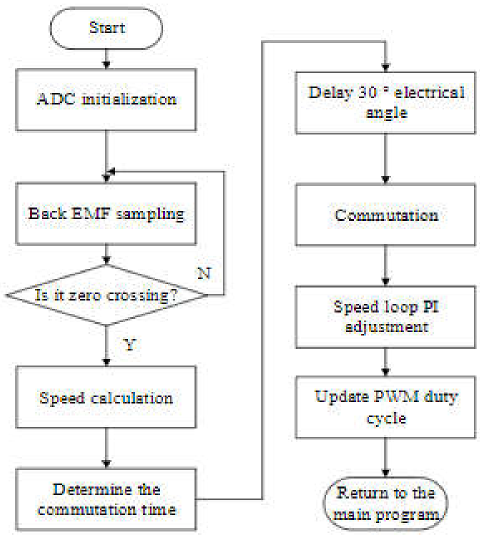

Fig. 11 Back-EMF detection program flow chart

When the software completes initialization of PE, A/D and so on, it will enter into the start-up program. When the motor is self-starting, it will start to enter the back electromotive force detection program. When the position of the rotor is detected and the speed is calculated, Speed control.

5 Conclusion

In this paper, based on the brushless DC motor and its control technology, the principle of brushless DC motor is studied, the square wave driven position sensorless self-starting is realized by the three-stage method, and the virtual neutral point The voltage comparison method monitors the position of the rotor without position sensor driven by the square wave. The PWM control duty cycle combined with the speed PI controller regulates the speed of the motor. The experimental results show that the sensorless control strategy of BLDCM based on square wave drive in this paper can make the system reliable Running, has a certain practical value.

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