The Research controller system of Brushless DC Motor Based on DSP

XiaoShuang Wang¹*, Jing Zhao² and Wei Li³

¹School of Information and Communication, National University of Defense Technology, Xi'an City, shanxi, No. 5 Guangming Road, Wangqu Town, Chang'an District, 710106, China

²School of Information and Communication, National University of Defense Technology, Xi'an City, shanxi, No. 5 Guangming Road, Wangqu Town, Chang'an District, 710106, China

³School of Information and Communication, National University of Defense Technology, Xi'an City, shanxi, No. 5 Guangming Road, Wangqu Town, Chang'an District, 710106, China

*Corresponding author’s e-mail: wxs163jundui@163.com

Abstract. Brushless DC motor (BLDCM) is a new type of motor which integrates power semiconductor and permanent magnet materials. In this paper, a sensorless brushless DC motor control system based on DSP and CPLD is proposed. The working principles of the control circuit, power inversion circuit and rotor position identification circuit with the core of TMS320F2812 and MAX7000 (EPM7032) are analyzed in detail. The test results show that the system has the characteristics of strong anti-interference, good robustness, fast starting and high efficiency.

1. Introduction

BLDCM is a new type of motor developed rapidly with the development of power electronics technology and new permanent magnet materials. It is widely used in aerospace, medical, computer, electric vehicle and other fields. BLDCM is divided into position sensor control and sensorless control. The control of position sensor is simple, but the existence of position sensor increases the cost and volume of motor. Moreover, in some special applications such as high temperature and humidity, the reliability of external position sensor is poor, which limits its application scope to a certain extent. Therefore, sensorless control has become a hot issue of domestic and foreign scholars in recent years[1].

Among the sensorless control methods, the zero-crossing detection of back electromotive force (EMF) is the most mature and widely used position detection method[2]. However, after detecting the zero-crossing of back electromotive force (EMF), the correct commutation time can only be obtained through complex and expensive digital or analog devices. In this paper, a kind of sensorless control of BLDCM is realized by detecting the three-phase voltage of the input end of the BLDCM and quickly obtaining the rotor position through simple filter circuit and comparison circuit.
2. Hardware Circuit Design of Control System

This control system adopts speed and current control and conventional digital PID control method. The specific measures are precise commutation according to the rotor position of brushless DC motor and calculating the current motor speed according to the rotor position signal, so that the current motor speed can be synchronized with the reference speed, forming a closed-loop speed control. Finally, the speed difference is processed as the current reference value of the current loop, thus constituting a double closed-loop brushless DC motor servo control system. The whole system structure is shown in ‘Figure 1’.

![System structure diagram.](image)

The system uses TI's TMS320F2812 as the main controller, which mainly completes the functions of speed calculation and PWM speed regulation, rotor position detection, over-current protection, motor operation status and speed display. In addition, CPLD is used to realize the logic control of the power switch of the inverters, so that the speed of DC motor can be controlled by only one PWM wave with adjustable duty cycle, which saves the memory of the DSP and improves the control accuracy.

2.1. Rotor position detection circuit

Brushless DC motor adopts special winding mode, which can produce ideal trapezoidal wave back EMF and current. Using three-phase inverters, the conduction angle of each phase winding is 120 degrees, and its equivalent schematic diagram is shown in ‘Figure 2’.

![The equivalent diagram of BLDCM.](image)
In the control of brushless DC motor, the upper arm PWM chopper and the lower arm constant-pass control are usually adopted. The waveforms of back EMF, current, commutation signal and switch control signal are shown in 'Figure 3'.

The position of the rotor is determined by detecting the three-phase terminal voltage. In a 360 electric angle period, the current of each phase stator winding has three states: positive, zero and negative. Taking phase A as an example, the terminal voltage is Va, assuming that the on-off voltage drop of each MOS and diode is 0, PWM = 1 indicates the on-off of the bridge arm, and PWM = 0 indicates the off-off of the bridge arm [3-4].

At the electric angle of \(30^\circ \sim 150^\circ\), the A-phase stator winding passes through positive current. When PWM = 1, \(S_1\) and \(S_4\) turn on, \(V_a = V_{dc}\); When PWM = 0, \(D_2\) and \(S_4\) turn on, \(V_a = 0\).

At the electric angle of \(210^\circ \sim 330^\circ\), the A-phase stator winding passes through negative current. When PWM = 1, \(S_2\) and \(S_3\) turn on, \(V_a = 0\); When PWM = 0, \(D_4\) and \(S_2\) turn on, \(V_a = 0\).

At the electric angle of \(-30^\circ \sim 30^\circ\) and \(150^\circ \sim 210^\circ\), Phase A stator winding current is zero. The expression of \(V_n\) is obtained when PWM = 1 and PWM = 0.

When PWM = 1, it is obtained from phase B:
\[
V_n = iR + L \frac{di}{dt} - E_b
\]
(1)

From phase C:
\[
V_n = V_{dc} - iR - L \frac{di}{dt} - E_c
\]
(2)

Add Formula (1) to Formula (2) to obtain:
\[
V_n = \frac{1}{2} [V_{dc} - (E_b + E_c)]
\]
(3)

When PWM = 0, it is obtained from phase B:
\[
V_n = iR + L \frac{di}{dt} - E_b
\]
(4)

From phase C:
\[
V_n = -iR - L \frac{di}{dt} - E_c
\]
(5)

Add formula (4) and formula (5) to obtain:
\[ V_n = \frac{1}{2} (E_b + E_c) \]  

(6)

for \( E_b = -E_c \), So from formula (3) and formula (6):

When \( PWM = 1 \), \( V_a = \frac{1}{2} V_{dc} + E_a \); When \( PWM = 0 \), \( V_a = E_a \).

The method of calculating the voltage of phase B and C is the same as that of phase A.

In summary, the expressions of terminal voltage \( V_a, V_b \) and \( V_c \) at different stages can be obtained, as shown in Table 1. D is the duty cycle of PWM wave.

| Condition | \( V_a \) | \( V_b \) | \( V_c \) |
|-----------|---------|---------|---------|
| \(-30^\circ \sim 30^\circ\) | \( D(\frac{1}{2}V_{dc} + E_a) \) | 0 | \( DV_{dc} \) |
| \(30^\circ \sim 90^\circ\) | \( DV_{dc} \) | 0 | \( D(\frac{1}{2}V_{dc} + E_a) \) |
| \(90^\circ \sim 150^\circ\) | \( DV_{dc} \) | \( D(\frac{1}{2}V_{dc} + E_a) \) | 0 |
| \(150^\circ \sim 210^\circ\) | \( D(\frac{1}{2}V_{dc} + E_a) \) | \( DV_{dc} \) | 0 |
| \(210^\circ \sim 270^\circ\) | 0 | \( DV_{dc} \) | \( D(\frac{1}{2}V_{dc} + E_a) \) |
| \(270^\circ \sim 330^\circ\) | 0 | \( D(\frac{1}{2}V_{dc} + E_a) \) | \( DV_{dc} \) |

Because \( E_a, E_b \) and \( E_c \) is less than or equal to \( \frac{1}{2} V_{dc} \), the waveform of three-phase terminal voltage can be obtained, as shown in ‘Figure 4’.

As can be seen from Figure 4, the waveform of terminal voltage is exactly the same as that of back EMF, but the amplitude is larger than that of back electrodynamic force. After measuring the terminal voltage, the rotor position signal can be obtained by low-pass filter and comparison circuit. The position detection circuit is shown in ‘Figure 5’.
The comparator LM339 can output the rotor position signal, then input the rotor position signal into CPLD, and carry out logical operation to get the control signal of the switch tube. The relationship between $V_a$, $V_b$, $V_c$ and rotor position signals $S_1$, $S_2$ and $S_3$ is shown in Table 2.

### Table 2. Rotor position signal.

|       | $S_1$ | $S_2$ | $S_3$ |
|-------|-------|-------|-------|
| $V_c>V_a>V_b$ | 0     | 0     | 1     |
| $V_a>V_c>V_b$ | 1     | 0     | 1     |
| $V_a>V_b>V_c$ | 1     | 0     | 0     |
| $V_b>V_a>V_c$ | 1     | 1     | 0     |
| $V_c>V_b>V_a$ | 0     | 1     | 0     |
| $V_c>V_a>V_b$ | 0     | 1     | 1     |

As can be seen from Table 2, the rotor position signals $S_1$, $S_2$ and $S_3$ output by the rotor position detection circuit are identical with the rotor position waveform in Figure 3, so the circuit can accurately measure the rotor position.

### 2.2. Overcurrent and overvoltage detection circuit

In order to prevent the bus current of the control system from exceeding the maximum current when the motor is rated, the DSP adjusts the bus current by collecting the bus current in real time, and sets the upper limit in the software. Considering the special conditions (abrupt load change and long-term blockage, etc.) that may occur when the motor is running, the hardware current limiting circuit is added to the system design, which enables the system to turn off the output of PWM wave in time.

### 3. Design of system software program

After the system is powered on and reset, the watchdog and various peripheral interrupts are shut down and initialized. Initialization includes system clock, interrupt vector and variable space allocation, etc. The system then opens the interrupt to allow the watchdog to enter the motor starter subroutine. After the motor is started, it is automatically switched to the main program for double closed-loop control[5]. The flow chart of the main program is shown in 'Figure 6'.

![Figure 6. The main flowchart program.](image-url)
4. System Performance Testing
In order to test the fast response and precise control of the system, a square wave speed signal is given, and the speed and current of the whole process are recorded by the DSP.

Electrical parameters for experiment:
Motor rated power: \( P = 220 \text{W} \).
Rated motor speed: \( n = 6000 \text{r/min} \).
Motor rated torque: \( T = 0.375 \text{N·m} \).

The experimental results are shown in ‘Figure 7’ and ‘Figure 8’.

5. Conclusion
In this paper, the sensorless brushless DC servo system is composed of TMS320F2812 and CPLD (EPM7032). It improves the operation ability of the system, completes more complex control algorithm, makes the system have good expansibility and widens the application scope of the system. At the same time, the new position detection circuit simplifies the design of software and hardware, shortens the development cycle and reduces the cost.

References
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