IOP Conf. Series: Materials Science and Engineering **392** (2018) 062168 doi:10.1088/1757-899X/392/6/062168

Controlling System Based on DSP for BLDC Motor

Zhou Yu[1], Bai-Na Su[2] and Yu-Shan Zhang[3]

[1,3]ZhengZhou Electric Power College, China

[2]State Grid KaiFeng Power Supply Company, China

[1]232689536@163.com,[2]subaina@126.com,[3]58585749@qq.com

Abstract. This paper researches the rotor position detection, presents a control system based on DSP TMS320F2812 for position sensor-less BLDC motor. Besides, the paper analyzes the control system and describes the composed hardware, software design and control strategy. This system can greatly simplify the hardware construction, and control the motor efficiently and stably.

1. Introduction
Brushless DC motor has many advantages like large output, excellent speed control performance, easy to control and energy saving, therefore, it has been increasingly and widely used in industrial field. With the rapid development of technology, the function of high performance SCM (Single Chip Microcomputer) and DSP used in motor controlling is more and more abundant, the operating rate also has a qualitative leap, and the price is getting lower. Therefore, excellent performance real-time control algorithms and comprehensive monitoring software can be achieved, such as Kalman filtering, adaptive control, fuzzy control and neuron control, etc., which can further improve the control precision and real-time performance.

2. Mathematical model of the brushless DC motor
Brushless DC motor is a complex system, which has characteristics like strong coupling, nonlinear, multi-variable, time-varying[1].To establish the correct mathematical model, the first step is making correct assumption for the model:

- The three phase windings of the stator is completely symmetrical in the space, and between any two the difference electrical angle is 120°;
- The waveform of the back electromotive force is ideal trapezoid wave;
- Ignore the cogging of the motor and the armature reaction
- Ignore the hysteresis loss and eddy current, the equivalent inductance of the phase winding is a constant, the magnetic circuit is not saturated;
- The inverter circuit power tube of the drive system and the internal resistance of freewheeling diode without taking into account, the performance requirements achieves the desired level[2].

2.1. Voltage Equation
The three phase stator voltages equations of brushless DC motor are as follows[3]:

IOP Conf. Series: Materials Science and Engineering **392** (2018) 062168 doi:10.1088/1757-899X/392/6/062168

$$\begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} P \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \quad (1)$$

Where, u_A、u_B、u_C——voltage of stator phase winding

e_A、e_B、e_C——back-EMF of stator phase winding

i_A、i_B、i_C——current of stator phase winding

L——inductance of each stator phase winding

M——mutual inductance between each stator phase winding

R——resistance of each stator

P——differential operator

If the self and mutual inductances of the stator winding is considered as constant, the connection of three phase windings is star-shaped and no leads to the midline, then the constraints are as follows:

$$i_A + i_B + i_C = 0 \quad (2)$$

and

$$Mi_B + Mi_C = -Mi_A \quad (3)$$

Using formula (2) and (3) to make equivalent transform of the matrix in formula (1), it becomes:

$$\begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} P \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \quad (4)$$

2.2. Torque equation

The electromagnetic torque of the brushless DC motor arising from the interaction of the magnetomotive force generated by the current in the stator winding and the rotor magnet, the electromagnetic torque generated by stator winding is as follow:

$$T_\sigma = \frac{1}{\omega}(e_A i_A + e_B i_B + e_C i_C) \quad (5)$$

Then the Electromagnetic power equation is:

$$P_\sigma = e_A i_A + e_B i_B + e_C i_C \quad (6)$$

At any moment, only two phase stator windings are working, therefore, the electromagnetic torque can be expressed as:

$$T_\sigma = \frac{P}{\omega} = \frac{2E_S I_S}{\omega} \quad (7)$$

Where E_S——the EMF magnitude of stator winding's each phase;

I_S——the current magnitude of stator winding's each phase.

As shown in formula (7), the electromagnetic torque of the brushless DC motor is proportional to the current, and the torque can be controlled by changing the output square wave current [4].

2.3. Equations of rotor motion

$$T_\sigma - T_L - B\omega = J\frac{d\omega}{dt} \quad (8)$$

Where T_L——load torque ($\mathrm{N \cdot m}$);

B——viscous damping coefficient ($\mathrm{S^{-1}}$);

J——rotary inertia of the system ($\mathrm{kg \cdot m^2}$)

IOP Conf. Series: Materials Science and Engineering **392** (2018) 062168 doi:10.1088/1757-899X/392/6/062168

2.4. Potential equation

If there is a single conductor moving in the air-gap of magnetic field, the induced MMF(Magnetic Motive Force)is as follow:

$$e = B_\delta l v \tag{9}$$

Where B_δ——the flux density size in the air-gap magnetic;

l——the effective length of conductor;

v——the relative line speed of the conductor and the magnetic field

$$v = \frac{\pi D}{60} n = 2 p \tau \frac{n}{60} \tag{10}$$

Where n——the rotate speed of the motor (rpm)

D——the inside diameter of the armature

τ——the polar distance

p——the number of pole-pair

Assuming the series turns of each phase winding of the stator armature is W_ϕ, then the size of each phase winding induction potential is:

$$E_\phi = 2 e W_\phi \tag{11}$$

Put formula (10) into formula (9):

$$e = 2 B_\delta l p \tau \frac{n}{60} \tag{12}$$

Each pole flux is as follow:

$$\phi_\delta = B_\delta a_i l \tau \tag{13}$$

Where a_i is pole arc coefficient, then:

$$e = 2 p \phi_\delta \frac{n}{60 a_i} \tag{14}$$

Put formula (14) into (11), then the induction potential of each phase winding is as follow:

$$E_\phi = \frac{p}{15 a_i} \phi_\delta W_\phi n \tag{15}$$

And the line potential is:

$$E = 2 E_\phi = \frac{2p}{15 a_i} \phi_\delta W_\phi n = C_e \phi_\delta n \tag{16}$$

Where, $C_e = \frac{2p}{15 a_i} W_\phi$ is potential constant.

3. Detection method for the back electromotive terminal voltage

Based on the mathematical model of BLDCM, the equation of back electromotive force is derived as below [5].Since the operating mode of the motor is two-two conduction with 120° and only two phase windings work at any one time, so the third phase winding is disconnected. According to equation (4), the balance equation of three phase terminal voltage, each phase voltage has neutral point voltage u_N. The equation of each phase is as follow:

$$u_A = R i_A + (L - M) \frac{di_A}{dt} + e_A + u_N \tag{17}$$

$$u_B = R i_B + (L - M) \frac{di_B}{dt} + e_B + u_N \tag{18}$$

$$u_C = R i_C + (L - M) \frac{di_C}{dt} + e_C + u_N \tag{19}$$

IOP Conf. Series: Materials Science and Engineering **392** (2018) 062168 doi:10.1088/1757-899X/392/6/062168

See from Figure 1, assuming that phase C is not conducting, the current flows into phase A and outflows from B, during this period, the back electromotive force of phase A is positive, phase B's is negative, the zero crossing point of phase C's back electromotive force is to be detected.

Take N, which is the neutral point of Y pattern winding, as the reference potential, the phase C winding is out of work since the switch tube VT2 is disconnect, that means $i_C = 0$, therefore $i_A = -i_B$, and formula 19 can simplified as follow:

$$u_C = e_C + u_N \tag{20}$$

When the back electromotive of phase C cross zero point, $e_A = -e_B$, voltage of the neutral point can be obtained by adding formula(17) and (18):

$$u_N = \frac{1}{2}(u_A + u_B) \tag{21}$$

Put (21) into (20),then:

$$e_C = u_C - \frac{1}{2}(u_A + u_B) \tag{22}$$

Similarly:

$$e_A = u_A - \frac{1}{2}(u_B + u_C) \tag{23}$$

$$e_B = u_B - \frac{1}{2}(u_A + u_C) \tag{24}$$

From above projections, we can obtain:

$$e_X = \frac{3}{2}u_X - \frac{1}{2}(u_A + u_B + u_C) \qquad X = A, B, C \tag{25}$$

In fact, the conclusion is the same. From the equation of back electromotive force, we can see that the detection of the motor rotor position based on back electromotive force, is essentially by measuring the phase voltage of three phase or the terminal voltage of three phase, and deducing the zero crossing point of back electromotive force, so as to achieve the motor commutation accurately.

4. Design for the hardware circuit of BLDC motor

In this paper, the main control chip is TMS320F2812, F28x series control chip contains event management module for motor control, because the module contains a PWM generator, and the dead-time control performance to avoid the up-and-down bridge arm of driving circuit shorting. F2812 is the DSP control chip that contains double event manager, which can simultaneously control multiple motors or inverters [6].

The hardware circuit is mainly composed of four parts: the DSP main control circuit, the control signal is issued from the embedded development board SEED-DSK2812; the designed drive circuit and signal detection circuit, the optocoupler isolation circuit for the voltage and current protection of the driver chips; the signal detection circuit containing filtering circuit and the circuit to detect the zero crossing of the virtual neutral point; the 24V switching power supply for the motor, the ±15V and 5V auxiliary switching power supply for the drive plate and signal detection plate. The concrete block diagram is shown as Figure 1:

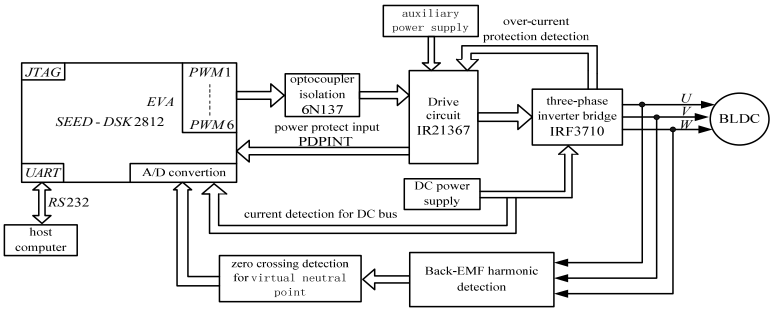

Figure1. Hardware block diagram of the BLDCM overall control system

5. The overall design of the system software

In the main control chip TMS320F2812, the EVA general-purpose timer T1 is used as the clock reference for the PWM comparator unit, T2 is used as the interrupt clock of the system, the perform frequency of the interrupt service routine is 40KHz . The flow chart of the main routine and interrupt routine is shown in Figure 2, Figure 3:

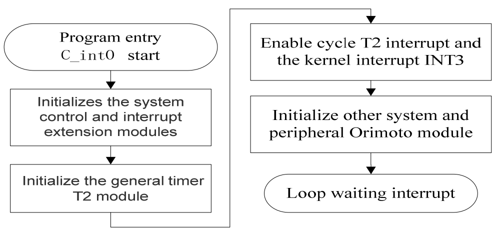

Figure 2.the flow chart of the main routine

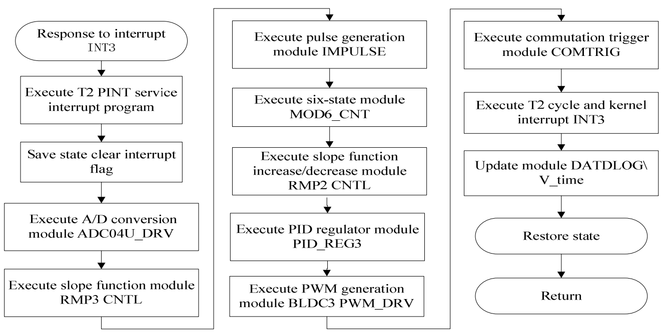

Figure 3.the flow chart of the interrupt service routine

The primary task of the main routine is to initialize the various modules of the system, then enter the interrupt service routine according to the predefined interrupt frequency, and implement the various modules, thus achieving the corresponding module functions to ensure the main routine capable of real-time monitoring and the purpose of control[7].

6. System experiments and results analysis

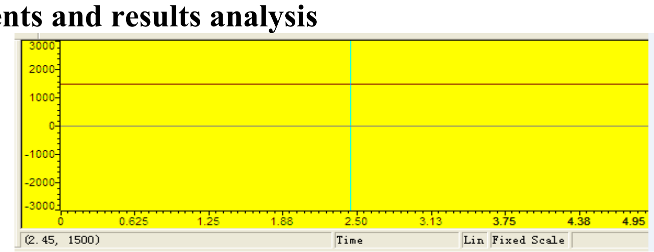

Figure 4. waveform of the position sensor-less closed loop speed control

The waveform corresponding to the rotational speed of the motor working without position, it can be seen that the waveform jitter smaller in this control mode, therefore the control effect is better.

Figure 5. the waveform diagram of the position sensor-less motor starting speed

The motor starting process when CCS run in the real-time simulation mode is shown in Figure 5, switching when the speed is 600rpm, and the speed fluctuation is smaller, which is better than position starting.

In this paper, software CCS is used to debug the hardware circuit of the experimental platform of the entire control system, the experimental waveform shows that the designed control system is able to run smoothly.

7. Summary and outlook

Based on the study of BEMF (back electromotive force), this paper designed a control system for position sensor-less BLDC motor, which is based on DSP TMS320F2812. This control system has rich chip resources, efficient processing ability, thereby the system structure is greatly simplified, and the motor is controlled efficiently and stably[8].

The key to control of the position sensor-less is to obtain rotor position signal, i.e. the traditional position sensor is replaced by the reliable rotor location signal, which is indirectly obtained from the two aspects of the software and hardware [9]. The position sensor-less BLDC motor has many advantages, such as simple structure, small size, high reliability and maintainability, therefore, it has been fully utilized in many areas [10].

There are still some issues about the control system based on DSP for BLDC motor. The control system proposed in this paper is able to operate stably, but the calculation bout of the control algorithm is large, the execution speed is slow, and the cost of DSP is high, these disadvantages need to be improved.

References

[1] J. Cao and B. Cao, “Fuzzy-logic-based sliding-mode controller design for position-sensorless electric vehicle,” IEEE Trans. Power Electron, 2009,24(10): 2368–2378

[2] J iang Haibo , Cui X inyi , Zeng Lingbo , Zhou Hui jun. Modeling and Simulation of Brushless DCMotor Fuzzy Control System[J]. Journal of XI’AN JIAO TONG University, 2005, 39(10): 1119-1120.

[3] Yaonan Wang. Position-Sensorless Hybrid Sliding-Mode Control of Electric Vehicles With Brushless DC Motor[J],IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS，2011.60(2):421-432.

[4] J ian g Haibo, Cui Xiny i, Zen g Lingbo, Zhou Hui jun, Modeling and Simulation of Brushless DC Motor Fuzzy Control System[J], JOURNAL OF XI′ AN JIAOTONG UNIVERSITY, 2005,39(10)：1119-1120.

[5] CaoJianbo, CaoBinggang, WangBin, XuPeng, Position-Sensorless Control for Brushless DC Motor of Electric Vehicle,Journal of XI AN JIAOTONG University,2008,42(5), 5979-6019

[6] Tan Jinrong ,Zeng Yuenan, Simulation of Control System for Sensorless Brushless DC Motor, Explosion-Proof Electric Machine, 2008，43(145)：32-36.

[7] Lin C T，Hung C W，Liu C W．Position sensorless control for four-switch three．phase brushless DC motor drives[J]．IEEE Transactions on Power Electronics，2008，23(1)：

438-444.

[8] Yaonan Wang, Xizheng Zhang. Position-Sensorless Hybrid Sliding-Mode Control of Electric Vehicles With Brushless DC Motor[J]. IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, 2011,60(2),:421-430.

[9] Buja G S, Kazmierkowski M P, Direct torque control of PWM inverter-fed AC motors-A survey, IEEE Trans Ind Electro, 2004, 51(4):744-757.4038.

[10] Damodharan P.,Vasudevan K. Indirect back-EMF zero crossing detection for sensorless BLDC motor operation. in:Proceedings of International Conference on Power Electronics and Drives Systems. Kuala Lumpur, 2005,1(11):1107-1111.