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Research on DSP-based Asynchronous Motor Control Technology

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Abstract

The Motor in a variety of electrical transmission and position servo system occupies an extremely important position. After the DSP technology being applied to the motor control, the unification of the hardware and the flexibility of the software can be combined. Take the brushless DC motor for example, studied the mathematical model and the structure of the motor control system, also obtained the design scheme of the DSP-based asynchronous motor control system. With TI's 32 bit fixed point DSPTMS320F2812 as the core design of the hardware system, we wrote the system software, debug the motor control system and the results show that the system achieves the expected effect. The results of the research can be applied to brushless DC motor and other motor control, it will have a wide application prospects.

Keywords*: DSP, motor, system design, control system*

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1. Introduction

The traditional digital control system often with single chip or microcomputer as the core, but with DSP as the core of the motor control system provides high precision and speed, has the logic control function and various interrupt processing and other more powerful processing and calculating ability. Because of its the Harvard structure or modified Harvard architecture, the control system which take DSP as the core improves the calculation ability of the data and program independent bus structure. It can realize complex control law, and the system has very strong flexibility. Take the brushless DC motor for example, studied the mathematical model and the structure of the motor control system, also obtained the design scheme of the DSP-based asynchronous motor control system [1]-[4]. With TI's 32 bit fixed point DSPTMS- 320F2812 as the core design of the hardware system, we wrote the system software, debug the motor control system and the results show that the system achieves the expected effect. The results of the research can be applied to brushless DC motor and other motor control, it will have a wide application prospects.

2. Brushless DC Motor's Mathematical Model

Brushless DC motor electrical part mainly comprises a motor body and a power inverter. We used The permanent magnet surface mounting type structure of three-phase brushless DC motor in this system, the stator armature winding is star type connection two excitation mode. Assumed that:

1) Three-phase stator winding completely symmetrical, spatial difference between 120 electrical angle, the same parameters;
2) Rotor air gap magnetic field is a trapezoidal wave, three-phase winding back EMF is a trapezoidal wave, wave crest width of 120 electric angle;
3) Ignore the stator core slot effect.

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2.1 Voltage Equation

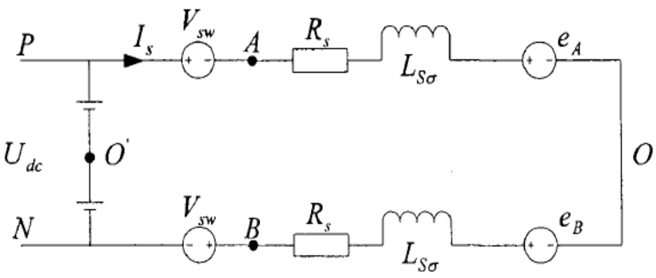
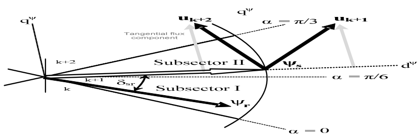


Figure1. A, B two-phase conduction equivalent circuit

The mathematic model of Brushless DC motor based on Figure 1 (A, B two-phase conduction) positive direction set can be obtained by winding of three-phase voltage equations [5], [6]:



(1)

In which:

R_S —The stator winding of each phase resistance;

L 、M —Each phase stator winding inductance and mutual inductance between two-phase winding；

u_{AO} 、 u_{BO} 、 u_{CO} —The stator winding phase voltage；

i_A 、 i_B 、 i_C —The stator winding phase current;

e_A 、 e_B 、 e_C —Stator three-phase windings each opposite potential;

p —Differential operator.

Because the three-phase windings adopt star type connection, so the phase winding current and is equal to 0, i.e.

$$i_A + i_B + i_C = 0 \tag{2}$$

Therefore

$$\begin{aligned} u_{AO} &= R_S i_A + L_S p i_A + e_A \\ u_{BO} &= R_S i_B + L_S p i_B + e_B \\ u_{CO} &= R_S i_C + L_S p i_C + e_C \end{aligned} \tag{3}$$

In which $L_S = L - M$, as the equivalent of one phase inductance.

2.2. Mathematical Model of Power Inverter

Power inverter two-phase conduction mathematical model can be described as the following voltage equation [7], [8]:

$$SU_{dc} = S_A u_{AO} + S_B u_{BO} + S_C u_{CO} + V_{SA} + V_{SB} + V_{SC} \tag{4}$$

U_{dc}—DC bus voltage;

S—A three-phase inverter high voltage side and the low voltage side of the power switch device in conducting state. If high pressure side and a low pressure side has at least one power switch conduction, then the status of switch S=1, or S=0.

S_A, S_B, S_C—Each phase of power switching device turned on. Assumption that high side conduction 1, low side switched to -1, high pressure side and a low pressure side is switched to the 0, the high pressure side and a low pressure side cannot be communicated simultaneously.

V_{SA}, V_{SB}, V_{SC}—Assumption of power switch device turn-on voltage drop for VSW,Power diode turn-on voltage drop for VD,the same phase of high and low voltage side turn-off voltage drop for 0.

2.3. The Potential Equation

Ignore the slot effect of brushless DC motor stator, permanent magnet is pasted on the surface of the rotor iron core, motor equivalent air-gap and that the gas gap specific permeance is uniform, the air-gap magnetic field is mainly composed of rotor permanent magnet to generate the magnetic induction intensity, as shown in figure 2. Map with rotor as the reference coordinate system, rotor quadrature axis as the coordinate origin, the rotor shaft of π/2 electric angle [9], [10].

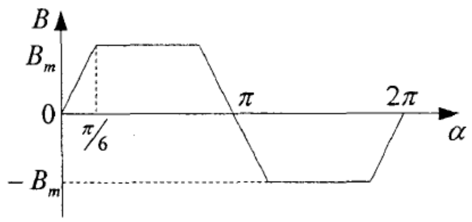


Figure 2. no-load air gap magnetic field waveform

When $0 \le \alpha \le \pi/6$, the air-gap magnetic field with uniform growth, it can be expressed as

$$B(\alpha) = \frac{6}{\pi} B_m \alpha \tag{5}$$

When $\pi/6 \le \alpha \le 5\pi/6$, the air-gap magnetic field is constant and the largest, it can be expressed as

$$B(\alpha) = B_m \tag{6}$$

When $5\pi/6 \le \alpha \le 7\pi/6$, the air-gap magnetic field of a uniform reduction, it can be expressed as

$$B(\alpha) = B_m(6 - \frac{6}{\pi}\alpha) \tag{7}$$

When $7\pi/6 \le \alpha \le 11\pi/6$, the air-gap magnetic field is constant and the negative maximum, it can be expressed as

$$B(\alpha) = -B_m \tag{8}$$

When $11\pi / 6 \le \alpha \le 2\pi$, the air-gap magnetic field of a uniform reduction, it can be expressed as

$$B(\alpha) = B_m(\frac{6}{\pi}\alpha - 12) \tag{9}$$

According to the magnetic field waveform periodicity and symmetry, using Fu Liye decomposition, we got the sum of the odd harmonic component.

$$B(\alpha) = \sum_{n=1}^{\infty} B_n \sin(2n-1)\alpha$$

In which

$$B_n = \frac{24B_m \sin[(2n-1)\pi / 6]}{\pi^2 (2n-1)^2}$$

EMF waveform in armature winding associated with air gap magnetic field waveform the rotor speed and the position of rotor relative to the stator armature winding. When the rotor speed is constant, brushless DC motor back EMF wave form is symmetrical three-phase trapezoid wave. Back EMF waveform origin of coordinates corresponding to the rotor shaft (N pole center line) and in opposite directions of A phase stator winding axis, that is to say the rotor position angle is equal to the electrical angle. The waveform of the average width is equal to 120 degrees angle when $\theta = \pi$, the waveform amplitude is proportional to the rotor speed, higher rotational speed, greater amplitude. Usually the ratio of the back EMF amplitude A and the corresponding mechanical speed B is called the back EMF coefficient C,i.e.

$$E_s = K_e \Omega \tag{10}$$

When the rotor is constant acceleration, back EMF waveform is no longer a flat-topped trapezoidal wave.Because the rotor turned each 360 degrees，back EMF waveform alternate from positive to negative once. Every 360 electric horn of the back EMF, the waveform can be regarded as equal to a constant initial speed EMF waveform superimposed a initial 0 speed constant acceleration back EMF waveform. Rotor constant acceleration running, angular velocity grow proportionally with time, rotor position angle is increased with Time Square, back EMF is proportional to the product of the angular velocity and the air gap magnetic field.

2.4. Expressions of Electromagnetic Torque

The electromagnetic torque generated by square wave current drive brushless DC motor relates to phase current amplitude and phase difference between the phase voltage and phase current , nothing to do with the phase voltage amplitude. When phase voltage and phase current amplitude under the condition of invariable, the phase current rectangular wave and phase voltage trapezoidal overlap on flat, it can produce the maximum electromagnetic torque the electromagnetic power expression of brushless DC motor is

$$P_{em} = e_A i_A + e_B i_B + e_C i_C \tag{11}$$

EMF associated with mechanical angular velocity Ω the Motor pole pairs P_p the effective series turns per phase W the armature diameter D_a the effective length of axial conductor L the air gap magnetic flux density distribution $B(\alpha)$ and the Rotor position angle θ, that is

$$e_A = -B(\theta) p_p W L D_a \Omega \tag{12}$$

$$e_B = -B(\theta - 2\pi / 3) p_p WLD_a \Omega \quad (13)$$

$$e_C = -B(\theta - 4\pi / 3) p_p WLD_a \Omega \quad (14)$$

Minus sign show EMF direction are opposite to provisions directions. The electromagnetic torque is equal to the ratio of electromagnetic power and rotor mechanical angular velocity.

$$T_{em} = P_{em} / \Omega \quad (15)$$

3. Brushless Brushless DC Motor Control Based on the Holzer Sensor

Position sensorless brushless DC motor can obtain the rotor position directly through the position sensor.

Figure 3 is a three-phase brushless DC motor star type connection full bridge drive circuit. As an example, analysis the brushless DC motor 's working principle and control mode based on a Holzer sensor.

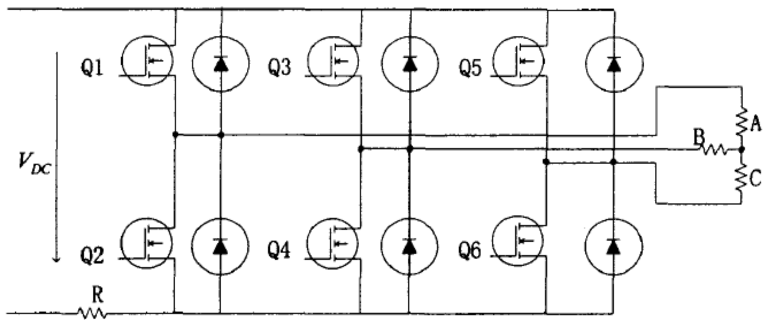


Figure 3. A three-phase star type connection full bridge drive circuit

Assuming a rotor only has one pair of magnetic poles, stator winding A, B, C three-phase symmetry, each pole and phase of 60 degrees phase distribution. The rotor in the space turned 60degrees, inverter energized in sequence on switch. Regulations for electric motor is rotating clockwise direction, then the turn-on logic of power switch tube is:

QI, Q4~QI, Q6~Q3, Q6~Q3, QZ~QS, QZ~QS, Q4~QI, Q4

Conversely, when the motor is reversed, the logic of power switch conduction is on the contrary. When rotor rotates through 60 degrees, the stator winding on a stator commutation, the synthesis of magnetic state on a single jump. So, in each machinery rotor, motor has six magnetic state, each magnetic conducting state only two phase, each phase winding turn-on time corresponding to the rotation of the rotor 120 electrical degrees degrees. According to the motor work can get Table 1 and Table 2.

In the table, six working state refers to the rotor position, each state corresponds to 60 degrees angle. HA, HB and HC respectively corresponding to A, B, C three-phase winding on the edge of the Holzer sensor status.

When the motor is in a counterclockwise direction, in the table the same working condition, Holzer sensor signal conduction and conduction of the power switch tube will change, as shown in Table 2.

It can be found, in positive or reversal of every switch control logic is on the contrary "anti".As shown in Table 3.

Table 1. Clockwise winding is energized in sequence and position signals control logic

Working state	I	II	III	IV	V	VI
HA	1	0	0	0	1	1
HB	1	1	1	0	0	0
HC	0	0	1	1	1	0
Conductive phase	A→B	A→C	B→C	B→A	C→A	C→B
The guide pipe	Q1, Q4	Q1, Q6	Q3, Q6	Q3, Q2	Q5, Q2	Q5, Q4

Table 2. Counterclockwise winding energized in sequence and position signals control logic

Working state	I	II	III	IV	V	VI
HA	1	1	0	0	0	1
HB	0	0	0	1	1	1
HC	0	1	1	1	0	0
Conductive phase	B→C	A→C	A→B	C→B	C→A	B→B
The guide pipe	Q3, Q6	Q1 ,Q6	Q1 ,Q4	Q5, Q4	Q5, Q2	Q3, Q2

Table 3. Rotating power control logic comparison

Power tube	Q1	Q2	Q3	Q4	Q5	Q6
Clockwise	$H_B\overline{H_C}$	$\overline{H_A}H_B$	$\overline{H_A}H_C$	$\overline{H_B}H_C$	$H_A\overline{H_B}$	$H_A\overline{H_C}$
Counterclockwise	$\overline{H_B}H_C$	$H_A\overline{H_B}$	$H_A\overline{H_C}$	$H_B\overline{H_C}$	$H_A\overline{H_B}$	$\overline{H_A}H_C$

After the sensor obtained the rotor position signal, it can be convenient to achieve the motor commutation control. At the same time we can get the speed control generated by the position signal, achieve the motor closed-loop control.

4. Design of Motor Control System

The motor control system belongs to the digital control system. The hardware circuit is mainly composed of a power supply circuit, power electronic circuit, signal processing circuit, a DSP controller circuit, every part of the circuit on a circuit board. System block diagram as shown in Figure 4 below.DSP main control circuit (control panel) takes TMS320 F2818 as the core, to complete a variety of signal processing and system control. It makes the controller and PC communication through the SCI interface. The controller has various debug interface circuit, it can output up to 12 PWM signal, which can simultaneously control two motor drive board.

5. Circuit Design of DSP Control

The main control circuit take the United States TI (TexasInstruments) produced by TMS32O Series in making fixed-point DSP chip TMS320F2812 as the core. This series of DSP architecture design for real time signal processing, and the controller take the real-time processing ability and controller peripheral function at a suit, Peripherals via the peripheral bus (PBUS) connects to the CPU internal memory interface. The structure shown in figure 5.All peripherals including the watchdog and CPU clock, must corresponding configuration control register before use.

The control circuit is to complete the following functions: (l) The output of the motor control PWM modulation signal, nor mal-rever se signal and brake control signal. Provide chopping signal and the strobe signal for the drive circuit (regardless of the configuration for H bridge or three-phase full-controlled bridge) of each switch tubes ,realize the control of motor speed, torque and reversible. (2) Generate PWM modulated signal, so that the motor voltage automatically change with a given speed signal, realize motor open loop speed control. (3) Acquisition of various sensors and feedback signal, the motor speed regulation and current regulation. (4) Realize fault protection function as short circuit, over current, overvoltage or under voltage. (5) The control circuit board based on TMS320F2 812,Including the DSP oscillating circuit, power supply reset circuit, the memory circuit.

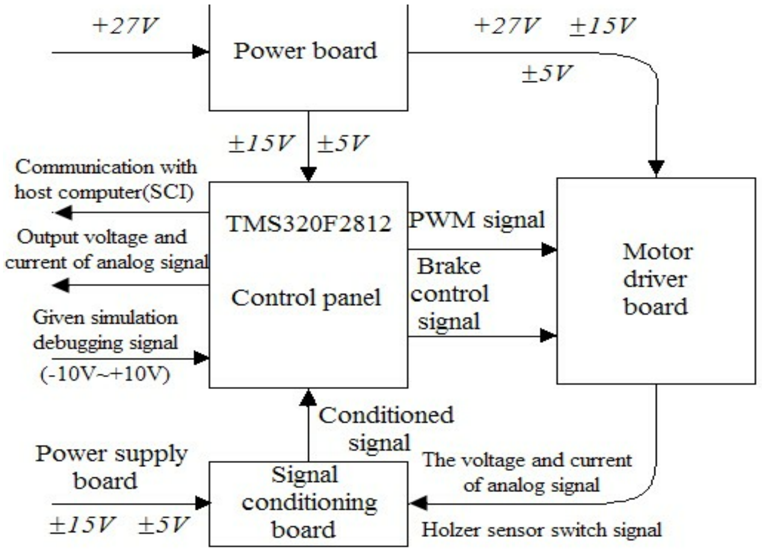


Figure 4. Motor control system block diagram

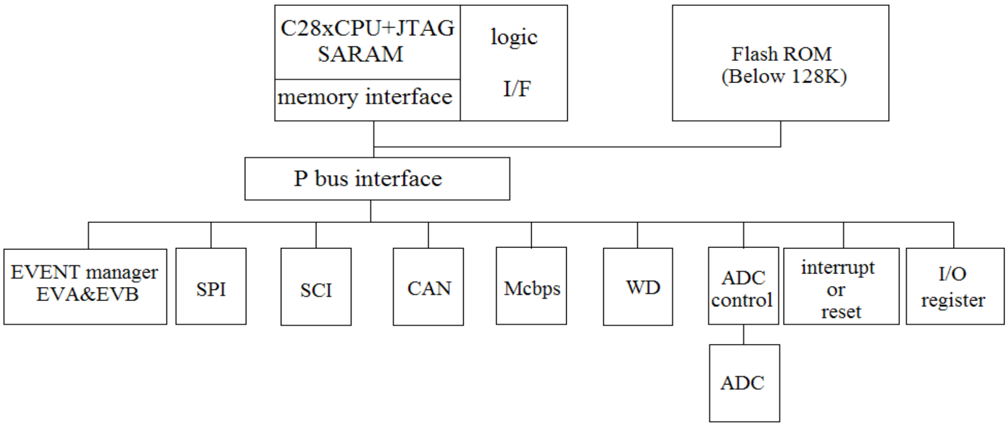


Figure 5. TMS320F28l2 function block diagram

6. Software Design Motor Control System

System DSP development environment using TI's new CCS3.1.The software integrates editing, debugging, simulation, monitoring and other functions in one, be convenience of real-time, embedded signal processing procedures for the preparation and testing. It can speed up the development process, improve work efficiency. Use the commonly used project management pattern, support C language and assembly language compilation or mixed compilation. Support all stages of the development cycle as shown in Figure 6.

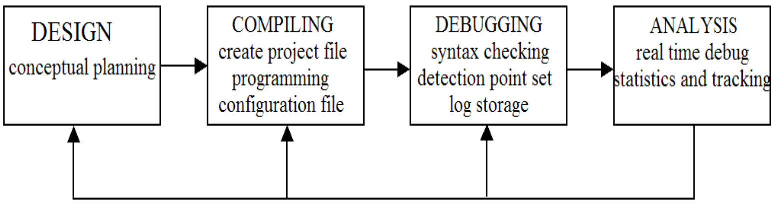


Figure 6. DSP system development process in four stages

The system software includes system initialization module, ADC sampling module, switch signal capture module, the PID algorithm design module, PWM output module and SCI communication module.

7. System Debugging

After the whole control system hardware and software design are initially completed, we has carried on the system debugging, including the hardware system in various circuit board module and the software module test function test. Then adjust and continuously improve the debugging problems arising in the course according, to make the whole system achieve the expected requirements and performance indicators. The research results can be applied to brushless DC motor and other motor control, it has a broad application prospects.

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