Brushless DC Motor Speed Control System of the Walking Aids Machine

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Abstract—In this paper, Brushless DC motor is preferred to be the motive force of the electric walking aids machine. We adopt Y connected three-phase full-bridge drive mode as control scheme. Based on the analysis of Brushless DC motor three closed-loop control scheme, a control system is designed. The core of the hardware of this system is TMS320F2812 and intelligent power module (IPM). TMS320F2812 of TI Company is used as Micro-controller chip and IPM of IR Company is used as driver chip. The program is written in the C language and assembly language. Based on the analysis of Brushless DC motor closed-loop control scheme, by combining PID algorithm with the mathematical model of BLDCM, a method of modularization design for BLDCM control system provided, which reach the simulation of current loop and speed loop control. This model offers a perfect experiment environment for analyzing and designing BLDCM control system.

Keywords-Brushless DC Motor (BLDCM); Y-connected three-phase full-bridge drive mode; three closed-loop control system; TMS320F2812; modeling and simulation.

I. INTRODUCTION *(HEADING 1)*

With the problem of the aging of the population is becoming more prominent, the old men and disabled people have the demand of the electric walking aids machine. The electric walking aids machine can use as a walking aids and functional training instrument. The motor is the key part of electric walking aids machine. It will directly affect the quality of the electrical performance of walking aids machines. Thus the study of motor drive controller has a very great significance.

The electric walking aids machine services the old men and disabled people, so security of the electric walking aids machine is vital. The motor of the electric walking aids machine must follow three requirements: acceleration characteristic, stable performance, long time service behavior. In this study, Brushless DC motor is preferred. Because of Brushless DC motor using electronic commutation replace machinery commutation, it overcomes the problems of the traditional DC motor and can work long hours without replacing brush. The traditional DC motor has brush friction and need replace electric brush timely. The Brushless DC motor also has four advantages: good performance of speed, small volume, high-efficiency and energy-saving. It has been widely applied in various fields such as economic production and People's Daily life. According to the requirement of the speed of electric walking aids machine, we add speed reducer to motor.

II. CONTROL SCHEME

In this study, Y connected three-phase bridge main circuit is preferred. The schematic diagram of three-phase Brushless DC motor Y connected full-bridge driving circuit is shown in Fig. 1. This circuit works in the mode of two phase conduction three-phase six-step state. In the motor running process, the motor hall position sensors detect motor current position continuously. According to the current position, controller judges the conduction timing of the next electronic commutator.

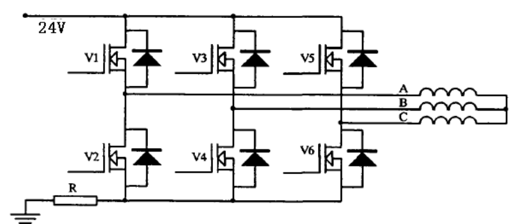


Figure 1. The schematic diagram of three-phase Brushless DC motor Y connected full-bridge driving circuit

In the non-commutation circumstances, any time only two stator windings electrify. At this time, the voltage balance equation is

$$u_s = 2e + iR = 2K_e n + iR. \tag{1}$$

The expression of speed can be obtained:

$$n = \frac{u_s - iR}{2K_e}. \tag{2}$$

Where, u_s is the voltage of electrified two-phase windings; e is the back EMF of motor phases; i is the current of motor phases; n is the speed of motor; R is the equivalent resistance of circuit, including the resistance of motor two-phase windings and the equivalent resistance of tube voltage drop; K_e is the back EMF coefficient of motor.

Equation (2) shows that motor speed regulation can be achieved by changing u_s. The main advantages of this method are: (1) the voltage drop characteristic curve is a

978-0-7695-3852-5/09 $26.00 © 2009 IEEE
DOI 10.1109/ICINIS.2009.155

cluster of line which parallel to the inherent characteristic line. Regardless of full loaded or unloaded, this method has obvious effect of speed regulation. (2) The hardness of voltage drop characteristic curve is constant. The speed fluctuation is low in low-speed circumstances. Static stability is high, and speed range is large. Motor voltage can be smoothly changed, thus speed can be smoothly regulated. So we can realize stepless speed regulation and low armature terminal voltage dissipation. Therefore, this method has been widely applied in the occasion of high performance requirements of motor speed regulation [1].

In this paper, in order to control the motor speed, pulse width modulation (PWM) is preferred to regulate motor armature terminal voltage. From the above brushless DC motor speed control principle we can know that the motor speed regulation is realized by changing the DC voltage, and the change of DC voltage can realized by adjusting the duty ratios of PWM waves namely PWM technology. That is to say, in the constant DC power supply, we change the DC voltage by adjusting the pulse width of PWM waves to realize the control of motor speed [2].

III. CONTROL STRATEGY

Single closed-loop control system of Brushless DC motor speed feedback can realize speed without static error under the condition of guaranteeing the stability of system. But it cannot completely control the dynamic process of current or torque according to need. So it commonly used in the occasions of low dynamic performance requirements. If the dynamic performance requirements are high, such as start-stop fast, low dynamic speed-drop when adding load suddenly etc, single closed-loop control system cannot meet the requirements. In order to improve the dynamic performance of brushless DC motor control system, it is necessary to introduce the current negative feedback loop to control current and torque of system dynamic process on the basis of single speed closed-loop control system. In order to meet the requirements of without overshoot and good ability of anti-disturbance, good real-time performance and rapid response, this system adopts speed loop, current loop and position loop three closed-loop control strategy. One important role of current loop is to ensure that the armature current in the dynamic process is no more than allowable values. That is to say, current loop firstly can restrain overshoot. Without steady state offset is the most fundamental requirement to speed loop. Position loop mainly play the role of phase conversion. The frame of control principle is shown in Fig.2.

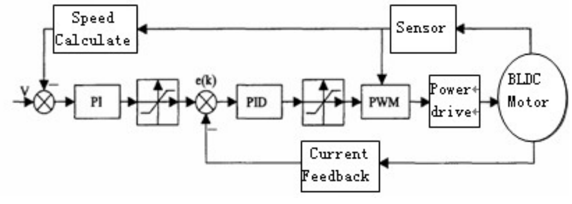


Figure 2. Frame of control principle

Control objectives are brushless DC motor position and speed, belonging to the first and second order systems. Here we choose the typical PID algorithm can satisfy the requirements of control. PID control algorithm commonly has two kinds: the position control algorithm and incremental control algorithm.

The typical PID incremental control algorithm is

$$u(k) = u(k-1) + (K_{Pi} + K_{Ii} + K_{Di}/T_i)e(k) - (K_{Pi} + 2K_{Di}/T_i)e(k-1) + K_{Di}e(k-2)/T_i \quad (3)$$

Where, u(k) is output, K_{Pi} is proportionality coefficient, K_{Ii} is integral coefficient, K_{Di} is differential coefficient, T_i is sampling period, e(k) is error.

IV. THE SYSTEM HARDWARE CIRCUIT

In this study, the main chips of control circuit are digital signal processor (DSP) and intelligent power module (IPM). DSP sends PWM signal to IPM to make three-phase conducted by turns, thus to control the motor rotation. And IPM produces current feedback to DSP to realize current closed-loop control. The CAP ports of DSP receive the motor hall-effect sensor. We get motor speed feedback by calculating and realize speed closed-loop control. The Diagram of DSP control BLDC motor is shown in Fig.3.

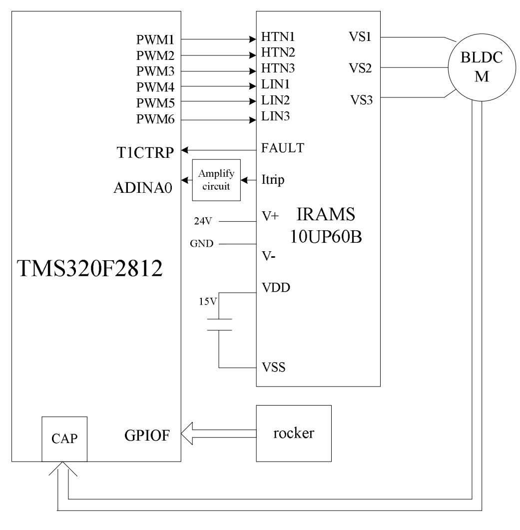


Figure 3. Diagram of DSP control BLDC motor

TMS320F2812 takes a high performance DSP nuclear, large capacity on-chip memory and special movement control devices (PWM produced circuit, programmable dead band, SVPWM produced circuit, capture unit etc.), as well as peripheral circuits of other function (16 channels ADC unit, serial communication interface, CAN controller module, etc.) integrated on a single chip, keeping the advantage of traditional microprocessor, such as programmable, integration, high flexibility, good adaptability, upgrade convenience, etc. At the same time, its internal DSP can provide the ability of higher arithmetic speed, accuracy and processing large amounts of data. By means of improving the structure of Harvard, TMS320F2812 respectively use independent bus access to program and data space. Cooperating internal hardware multiplier, optimized pipeline set of instructions, DSP controller can satisfy the requirement of real-time, and realize complex control algorithm such as fuzzy control and neuron control etc [3].

IRAM10UP60B is intelligent power chips of IR Company. It has three-phase inverter circuits and drive chip, and it can be used for driving three phase AC induction motor and brushless DC motor. This module integrates IR low voltage NPT IGBT technology and the three phase voltage, high-speed drive technology of industry standard. Built-in temperature monitoring, over-current protection and short-circuit capacity of IGBT and UVLO function provides the protection and safe working functions of high level. This module integrates bootstrap diode for the high side drive, as well as the polarity power supply for the inside driver circuit. These attributes simplify the use of modules, and greatly reduce the cost.

V. SOFTWARE PROGRAMMING

The main body of the program is sequential structure. Hall signals capture module and AD convert module adopt interrupt control mode. The main system flowchart is shown in Fig. 4. The main achievement of the procedure is system initialization and settings of software variable. Reading the CAP1, CAP2 and CAP3 Hall position signals make the electronic switching tube conduction to complete the start of motor (At this point, set this three-port as I/O port function).

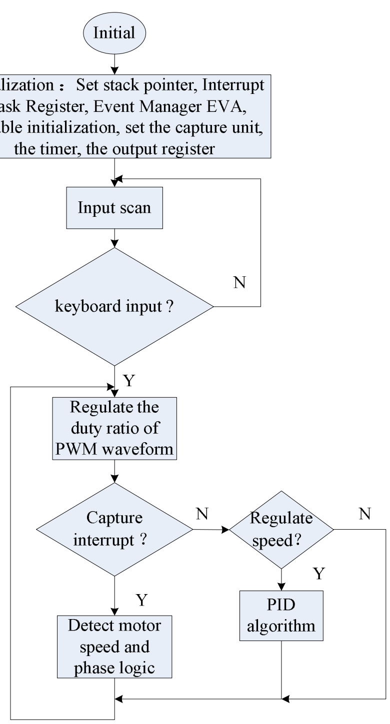


Figure 4. The main system flowchart

VI. EXPERIMENTAL RESULTS

According to the above, the simulation model of the BLDCM control system has been established in Matlab/Simulink environments [4]. A three closed-loop control scheme is adopted in this control system, wherethe outer loop is speed loop with PI controller. The inner loop is current ones with current hysteresis controller and position ones. The simulation block diagram of the total control system is shown in Fig. 5.

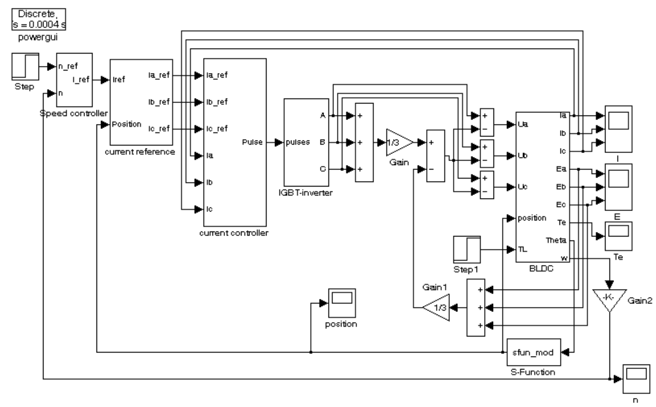


Figure 5. Structural diagram of simulation model

The system starts in the state of unloading, add the load equals 5(N·M) in 0.3 second. In speed PI controller block, Kp equals 10, Ki equals 8.6. The given speed N equals 1000 r/min, the simulation curves of the speed waveforms are shown in Fig. 6.

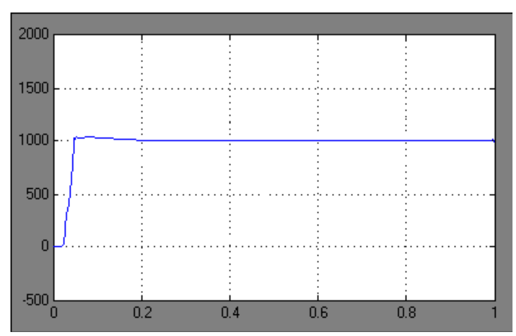
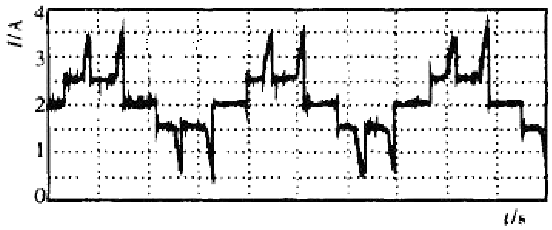
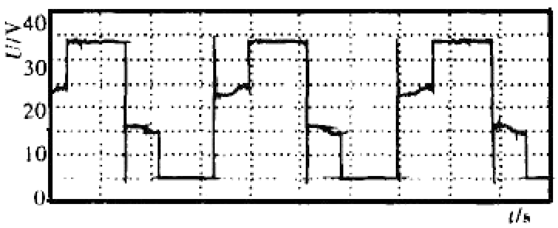


Figure 6. Speed waveform

According to the above， a controller of permanent magnet brushless DC motor is designed. The Parameter of brushless DC permanent magnet motor: number of pole-pairs P=4, normal rated power is 120W. PWM chopping frequency is 20 kHz, current-loop's Sampling Cycle is 50µs, and the speed-loop's is 1ms. Measured waveform of phase current and phase voltage is showed in figure 5.



(a)



(b)

Figure 7. The measured waveform: (a) A-phase current waveform(0.5A/div),(b) A-phase voltage waveform(5V/div)

The measured waveforms show that There is greater volatility in the phase current waveform. This is due to the current commutation. To eliminate the cause for the torque (current) fluctuations in the problem, further work needs to be done. From the experimental results point of view, this problem does not preclude us from verifying the feasibility of the control strategy.

VII. CONCLUSION

From the study of the control principle and process of brushless DC motor, this system adopts speed loop, current loop and position loop three closed-loop control strategy. TMS320F2812 and IPM further simplify the circuit of control system. Selection of components will reduce and the reliability of the system will improve. The modeling and simulation of the control system are presented in this study. The simulation results demonstrate that the simulated waveform fits theoretical analysis well.

ACKNOWLEDGMENT

We are grateful for the support of National High Technology Research and Development Program (HTRDP)(2008AA022407)

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