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Design and Implementation of Brushless DC Motor Drive and Control System

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Abstract

The paper designs a high power brushless DC motor (BLDC) closed-loop control system, mainly including design of IR2130 drive circuit, H bridge drive circuit, Control of rotation direction for motor and speed detection circuit. in order to improve the performance of motor running, one adopts PID algorithm, through the tuning of parameters, the control exhibits very good performance. Experiments show that both hardware and software control algorithms are reliable, stable. The running performance of the system is robust before or after adding load.

Keywords: brushless DC motor; closed-loop control system; H bridge circuit; speed detection

1. Introduction

Here Brushless DC motors(BLDC) have some advantages over conventional brushed DC motors[1,2], which are mainly better speed versus torque characteristics, high efficiency, high dynamic response, long operating life, noiseless operation higher speed ranges, low maintenance. So BLDC rapidly gains popularity, BLDC motors have been widely used in the industries, especially in the areas of appliances production, medicine, aeronautics, Medical equipment, chemical, automotive, textile, industrial automation and so on. The small sized motors with external rotors are widely used in visual equipment such as computer disc drives, tape recorders and digital audio tapes[3]. The fine performance of BLDC obtains everybody's favor, but the control complexity and high cost of the dive hold back the widespread use of BLDC motors. Reduce cost controllers for BLDC motors are more in demand and many schemes

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and algorithms for reduced cost controllers have been reported in the literature [4-5], the cost reduction of controllers for BLDC drives can be accomplished by two approaches, namely topological approach and control approach, in the control approach, one should design and implement some new algorithms. Whereas, the number of switches, sensors and associated circuit should minimized, which replaces traditional integrated drive chip with expensive price. So the paper's main purpose is to design one kind of low-cost drive and control circuit, and one kind of stable reliable control algorithm, simultaneously , which can satisfy the need of high efficiency.

The paper is organized as follows. Section 2 introduces running principle of the BLDC motor Section 3 elaborates on the overall system block diagram. The main circuit design and implementation process in detail. Section 4 proposes a fuzzy PID control algorithm, section 5 analyses the experimental results. Section 6 draws a short conclusion about this paper.

2. The main circuit design and implementation of BLDC motor control system

The system is composed of multiple sub-circuits, mainly including：IR2130 drive circuit, the H drive circuit bridge, speed detection circuits, over current protection and the other peripheral circuits, for example, power circuit, keyboard circuit and so on. One uses STC89C52 single-chip microprocessor as controller. Now one gives elaboration for every main part in detail.

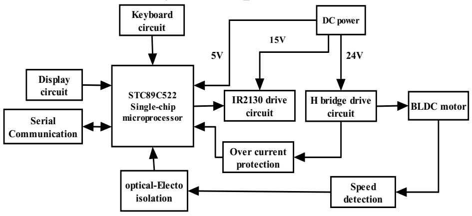

Fig. 1 The block diagram of overall system

2.1 IR2130 drive circuit

IR2130 belongs pre-drive chip, which has a bootstrap function. The external circuit design of IR2130 determines the performance of H-bridge drive circuit, so it is the key of the whole control system. In the design process, if the device selection is not appropriate, which may result in serious heat for H bridge drive circuit, as a result, this will cause the circuit burned. The circuit design shown in Fig 4, D1-D3 ultra-fast recovery diodes named uf4007, which avoid spike-wave of high-frequency to break down diode. C11-C13 are the bootstrap capacitors, which are used to Store energy for driving the power tubes of the top half-bridge. Through calculating, one can find the best value of capacitance. The formula is as shown in the following expression (1)

$$C \geq \frac{2\left[2Q_g + \frac{I_{qbs(\max)}}{f} + Q_{ls} + \frac{I_{Cbs(leak)}}{f}\right]}{V_{cc} - V_f - V_{LS} - V_{Min}} \tag{1}$$

Where Q_g = high-side FET gate charge, f = operating frequency, $I_{Cbs\,(leak)}$ = Bootstrap capacitor leakage current, $I_{qbs\,(max)}$ = maximum VBS Quiescent Current, V_{CC} =the voltage source of logic part e, V_f =positive voltage drop of bootstrap diode, V_{LS} = the voltage drop on load, V_{Min} =the minimum voltage between VB and VS, Q_{ls} = convert each cycle, the level required to charge.

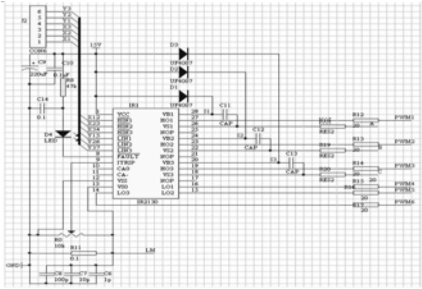

Fig. 2 IR2130 drive circuit

R12-R17 resistors are used to prevent parasitic oscillation of power tube, moreover, the value of resistors is 20 ohm resistors. R18-R20 are used to limit Current when generating the negative voltage, one need to debug the value of resistance according to the system. R11 is used as the current sampling resistor, which is 0.1ohm. C6-C10 is filter capacitor of the circuit, which are used to filter spikes of LM signal.

2.2 Design of H-bridge drive circuit

The design of H-bridge driver circuit is shown in Figure 5. Where, supply voltage of the Power is 24v, the model of MOSFET tube is IRF540, which integrates the diode. D5 is the Zener diode P6KE24CA, which is used to limit voltage. C1-C3 is used to absorb the voltage spikes on the DC bus, and C4-C5 are used to filter 24V supply voltage, taking 0.1uf ceramic capacitor, which is used to prevent peak voltage. R1-R6 is used to protect drive bridge, which prevents static electricity to burn power MOSFET.

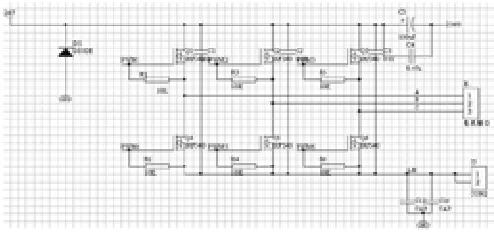

Fig. 3 H-bridge driver circuit

2.3Control of rotation direction for motor

One can use STC89C522 single-chip microprocessor to control the rotation direction of motor through program. When Hall sensor detects a new position, the program changes the turn-on sequence of H reversible bridge to achieve commutation. Because BLDC use pairwise conduction control method, so when the rotation direction of BLDC commutes, there are only two power MOSEFT which are on. When Hall sensor detects next new position, which tells port P2 of STC89C522 single-chip microprocessor to give new control signal. The control word is shown in table 1.and table 2.

Table 1 Positive rotation

Ha	Hb	Hc	conduction tube	P2.5	P2.4	P2.3	P2.2	P2.1	P2.0	Control word
1	0	1	Q1、Q6	1	0	0	0	0	1	21H
0	0	1	Q6、Q2	1	0	0	0	1	0	22H
0	1	1	Q2、Q4	0	0	1	0	1	0	A0H
0	1	0	Q4、Q3	0	0	1	1	0	0	C0H
1	1	0	Q3、Q5	0	1	0	1	0	0	14H
1	0	0	Q5、Q1	0	1	0	0	0	1	11H

Table 2 Negative rotation

Ha	Hb	Hc	conduction tube	P2.5	P2.4	P2.3	P2.2	P2.1	P2.0	Control word
1	0	1	Q4、Q3	0	0	1	1	0	0	C0H
0	0	1	Q2、Q4	0	0	1	0	1	0	A0H
0	1	1	Q6、Q2	1	0	0	0	1	0	22H
0	1	0	Q1、Q6	1	0	0	0	0	1	21H
1	1	0	Q5、Q1	0	1	0	0	0	1	11H
1	0	0	Q3、Q5	0	1	0	1	0	0	14H

23.4 Speed detection

For a closed-Loop control system, one must acquire the practical rotation speed of BLDC. So it requires to design a equipment which can detect current speed. According to the maximum speed of motor, we design an optical encoder disk, as shown in Fig 6

Encoder consists of two parts: shade component and light component, one install them on rotation haft of the motors. When haft rotates, code disk rotates in same speed. Then one install a pair of infrared tubes on both sides of encoder which one can send light signal and the one can receive light signal. When motor rotates, code disk rotates to certain position, then infrared light transmit the receiving tube through light component, while receiving tube gives a pulse signal. If motor rotate to next position, the light is covered, the receiving tube cannot receive the infrared light, then receiving tube doesn't send any signal. So the cycle continues. One can calculate the speed of motor rotation through counting the number of pulses in the unit time. The circuit of detecting speed is shown as follow Fig 7

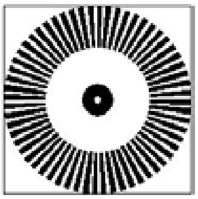

Fig 4 optical encoder disk

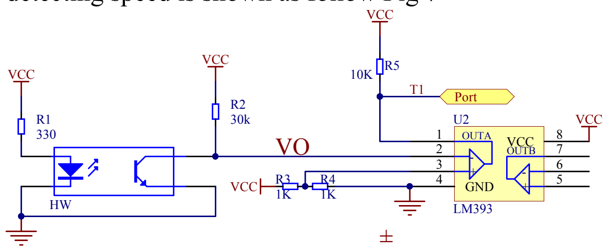

Fig 5 the circuit of detecting speed

When the light is blocked, the infrared receiver resistance is greater, assuming 300K, while R2=30K, according to the top circuit, one can calculate the voltage of V0.

$$V_o = 300K/(30K + 300K)*5V = 4.55V \tag{2}$$

For comparator, $V_+ = V_{cc}/2 = 2.5V$, $V_- = V_o = 4.55V$, then $V_+ < V_-$, so the output of comparator is "0", Similarly, when the light transmit the receiving tube, the infrared receiver resistance is smaller, assuming 3k, then

$$V_o = 3K/(30K + 3K)*5V = 0.45V \tag{3}$$

Obviously, $V_+ > V_-$, so the output of comparator is "1" , t through counting the number one can achieve speed detection. Fig 7 can achieve speed detection in theory, when the rotation speed is low, one can detect the speed correctly. Hower, when the rotation speed is very high, the circuit is not feasible, one can compare the following two figures, the former is resistance signal of receiving tube in low speed, the latter is resistance signal of receiving tube in high speed. Abviously, the latter leads to error output signal of comparator easily, that is to say, the speed detected is incorrect. So one requires improve the top circuit.

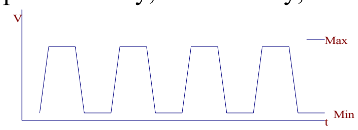

Fig 6 resistance signal of receiving tube in low speed

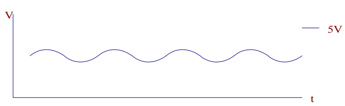

Fig 7 resistance signal of receiving tube in high speed.

Fig 10 and Fig 11 show the improved circuit, among them, the infrared detection beam tube is used detect the speed of rotation encoder on the motor shaft.P8 is an interface, as shown below in Fig 10. Beam pipe connects the amplifier circuit connections (P8 -> P7). R15 (330Euro) is a current limiting resistor of the IR LED. R6_0 and R6_1 are resistances for sharing the voltage with the infrared receiver.

Similarly, the R7-0, R7_1; R8_0, R8_1 are so. Fig 11 shows the design of amplifier circuit. The signal amplified through the amplifier circuit is as follows in Fig 12. The output waveform through the comparator is as follows in Fig 13.

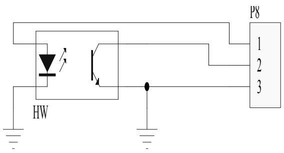

Fig 8 the infrared detection beam tube

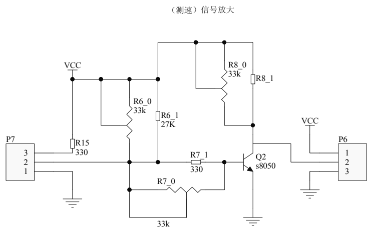

Fig 9 Signal amplification circuit

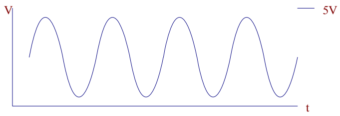

Fig10 the amplified signal

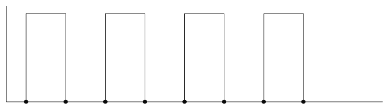

Fig 11 the output waveform through the comparator

3. PID algorithm for speed control

For BLDC motor, the speed control is very important. In order to meet all kind of control requirements, there is a need for implementing effective controller for digital control of the BLDC, the most commonly used controllers include PID controller, fuzzy logic controller, and the combination between them: fuzzy-neural network, fuzzy-genetic algorithm and so on, according to the actual application requirements and the principles of stability and reliability, one select the PID controller as the core control algorithm, the basic controller structure is shown in Fig 14.

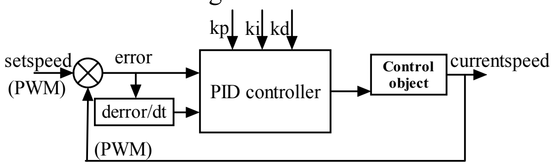

Fig12 the basic controller structure

The basic process of tuning parameters is shown in Fig 15 and Fig 16. where the green line is on half of PWN parameter(0 - 255), and red line stands for the current speed(50ms pulse number), white line stands for the desired speed(50ms pulse number), through Fig 15 and Fig16, we can find when the expectations changes, the measured values(the output of PID control) is better to follow the expectations. Generally speaking The last measured value should coincide with expected coincidence, but in fact due to measurement accuracy and output precision of PWM and other factors, the value measured can not be completely consistent with the expectations, which fluctuates around with the expectations. That is, the red line fluctuates a little around with the white line. Overall, the average is almost close to expectations.

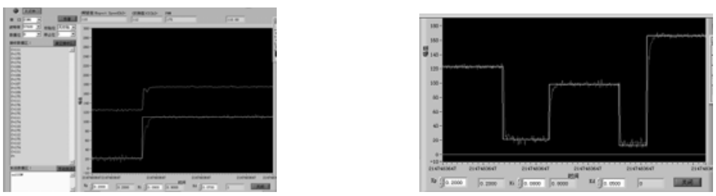

Fig 13 parameters tuning of PID

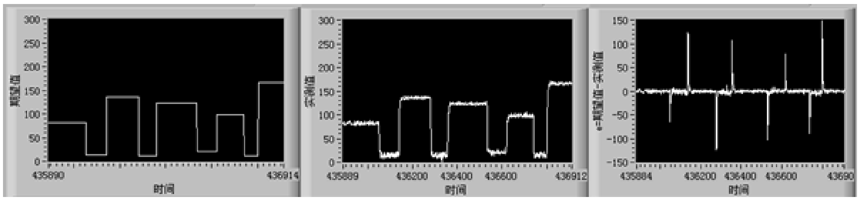

Fig 14 the expectation ,the actual value and deviation 's comparison

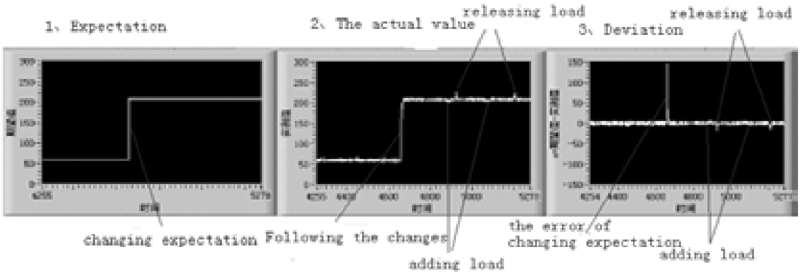

Fig15 The adjusting process of adding load, releasing load and changing expectation

From the three figures above, one can find: the BLDC control system is reliable, stable. That is to say, the design of drive circuit is feasible, at the same time, the PID algorithm is robust

4 Conclusion

In this paper, one designs and implements a High power BLDC motor closed-loop control system. On this basis, one uses PID control algorithm, Through tuning every parameter of PID controller, that is, Kp, Ki, Kd. We get the reliable and stable speed. Experiments show that both hardware and software control algorithms are reliable, the running performance of the system is robust before or after adding load. The system can be further extended to other application areas, which has a very broad application prospects.

Acknowledgements

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