

Research and Design of Electric Vehicle Controller Based on Brushless DC Motor

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Abstract: This article deals how to design a complete e-bike controller system by STM32 chip microcomputer. The circuit is mainly used for controlling the brushless DC motor, when we design the power inverted circuit, we usually check resistors voltage to detect the current and then send the data to CPU to complete the current closed loop system. However, when the controller is used in high power levers, the heavy current will cause some power loss. In order to improve this problem, we can detect the current according to the MOSFET tube resistance, and then we put the signal into the differential amplifier to make the signal accurate. Finally we may make the controller available on aluminum base board.

Key words: e-bike controller system; brushless DC motor; MOSFET tube resistance sampling; aluminum base board

0 Introduction

Brushless DC motor (BLDCM) is widely used in various industrial control occasions because of its advantages of large output torque, low noise, high efficiency and good stability^[1]. With the development of society, environmental pollution is more and more serious, in order to protect the environment, electric vehicles as a representative of new energy vehicles has become the first choice, but the brushless DC motor controller level of uneven, so the design of a Paragraph cost-effective, good stability of the electric vehicle controller is imminent^[2].

In this paper, the principle and control method of brushless DC motor are studied, and a brushless DC motor controller is designed and implemented^[3]. The main chip STM32F103C6T6, which is made by ST, has a flexible I/O port configuration^[4]. It integrates a wide range of motor interface controls to provide convenience for motor control. While discussing the controller circuit, a new method of internal resistance sampling for MOS transistors is proposed for high power circuit design^[5].

1 Basic principle of the system

Brushless DC motor basic control principle is based on the motor installed in the Hall sensor signal logic state, real-time access to the motor rotor position information and feedback to the microcontroller, the microcontroller according to the real-time Hall signal to the drive circuit to issue different PWM wave control Signal, through the inverter circuit to the motor coil to form a rotating magnetic field to drive the motor rotor continuous rotation^[6]. At the same time according to the detected current and speed value of double closed-loop control, change the size of the PWM to control the size of the current speed^[7].

The main circuit in this system is the power circuit, power inversion circuit, peripheral interface circuit, voltage detection circuit, current sampling circuit and protection circuit. Figure 1 shows the overall structure of the system block diagram.

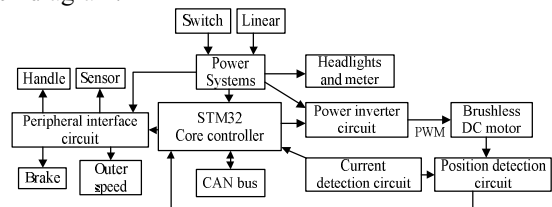


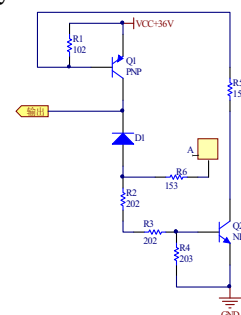
Fig.1 The overall structure of the system block diagram

2 Hardware Design of Brushless DC Motor

2.1 Power short-circuit protection design

The main power supply of the electric vehicle controller from lithium battery output +36 V voltage, it can be directly for the electric car headlights power supply, after the power supply circuit, respectively, output +15 V, +5.3 V and +3.3 V voltage^[8]. Taking into account the headlamp short circuit will lead to damage to the entire control system, the design of a headlamp work closed-loop system^[9].

Short circuit protection circuit shown in Figure 2, A port connected to the MCU control signal, issued after the high level, making Q2 conduction, Q2 conduction after Q1 turn, to provide current for the headlamp, when the output short circuit, the control side which after the diode signal is clamped to 0.7V, the voltage after R2, R3, R4 makes Q2 cut off, at the same time Q1 cut off, has played a protective role. Q1 normal working current value to ensure the normal operation of headlights, select the patch 2SA1013, diode selection Schottky diode.



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Fig.2 Short circuit protection circuit

Power supply circuit provides +5V power supply for a variety of peripheral devices (such as turn, Hall, sensors, etc.), this type of power supply also needs short-circuit protection circuit. The traditional power short-circuit protection circuit shown in Figure 3, when the load short-circuit, input current increases, Q1 conduction, Q2 off [10]. This circuit acts as a protection circuit only when the controller is static, rated and fully loaded. Although this circuit can play a protective role, but the circuit seems cumbersome, so the design of a new power short circuit protection circuit is necessary.

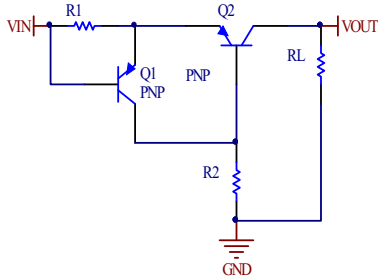


Fig.3 Traditional power short circuit protection circuit

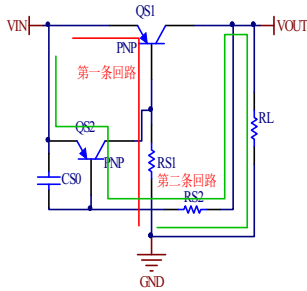


Fig.4 Improved power short circuit protection circuit

Improved power short circuit protection circuit Shown in Figure 4, the key lies in the transistor Q2 and Q1 conduction sequence. After the system is powered on, the first path is shown in red, from $V_{IN} \rightarrow Q_{S1} \rightarrow RS1 \rightarrow GND$, which establishes a potential faster than the second path $V_{IN} \rightarrow Q_{S2} \rightarrow RS2 \rightarrow RL \rightarrow GND$ so that Q_{S1} First through, Q_{S2} cut-off. The effect of C_{S0} is to extend the Q_{S2} turn-on time. Short circuit occurs, V_{OUT} is 0, Q_{S2} conduction, Q_{S1} off, V_{IN} is not output. Compared with Figure 3, its stability and reliability have improved. The circuit makes the reliability of the controller hardware work has been greatly improved. But the controller is often affected by the high speed, high peak current impact, the need to detect the circuit with the integrated protection of the microcontroller^[11].

2.2 Drive circuit design

Drive circuit is the MCU to receive information to reflect the rotor position of the HALL sensor signal issued by the switch to the PWM drive signal circuit. In order to meet the power requirements of the electric vehicle controller, the MOS tube with the advantages of high operating frequency, small conduction loss and so on is adopted as the switch tube. Using IR's integrated driver chip IR2103 and its peripheral circuit constitutes a drive circuit, A, B, C three-phase respectively, each using a IR2103. Taking into account the consistency of the

three-phase circuit to B-phase drive circuit shown in Figure 5 as an example to explain, taking into account the MOS tube drive loss problem, in order to ensure the MOS tube temperature is maintained in a stable state, the switch The frequency is set to 17K. Based on the above considerations, this paper selected 10uF / 50V chip capacitors.

Turn on the system power, $12V \rightarrow C_{1B} \rightarrow R_{20B}$ bootstrap capacitor to charge, adjust the R_{20B} resistance, change the size of the charge current. We can also use this control method. After the system is powered on, the PWM control signals are sent to the three-phase bridge respectively. At this time, the capacitor charging circuit is $12V \rightarrow C_{1B} \rightarrow$ the next bridge MOS. Before normal startup, the capacitor bootstrap can be completed. In consideration of the system-Non-conduction to the level of uncertainty, to avoid the emergence of three-state, the resistance R_{20B} connected to the next bridge DS.

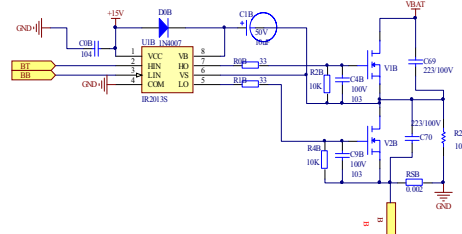


Fig.5 Drive circuit of B phase

2.3 Current Sampling Circuits design

In order to obtain the maximum torque and better real-time control of the brushless DC motor, the stationary three-phase stator coordinate system is transformed into the rotating coordinate system. HALL sensor real-time access to the rotor position, making the synthetic magnetic field and the rotor magnetic field difference of 90 degrees, that is, by changing the size of the stator winding current value to achieve closed-loop control. For the resistors R_{2B} and R_{4B} , when the MOS off, the parasitic capacitance of the discharge circuit through the drive chip to discharge the switch tube. In order to prevent the power tube of the shock, must be used 33Ω resistance termination, GS between the parallel capacitor can eliminate the chopping of the high-frequency interference, while conducive to MOS tube quickly over the "Miller platform" to reduce switching losses. Bootstrap diode in the D_{B0} opened, to withstand the corresponding reverse voltage. Figure 5 shows the location of point B, through the sampling resistor R_{SB} voltage detection to obtain the current value, but because the phase current peak is large, in order to reduce power consumption, the use of 2mΩ sampling resistor.

Sampling the voltage signal is short, the use of differential amplifier circuit provided to the microcontroller, as shown in Figure 6 for the current sampling circuit, still using B-phase circuit to illustrate. Figure, in order to further reduce the common-mode signal and high-frequency signal interference, select the two-level magnetic beads plus two capacitor filtering

method to ensure the accuracy of the signal.

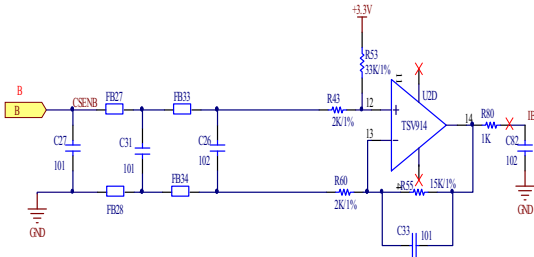


Fig.6 Current sampling circuit

2.4 Overcurrent Protection Circuit design

As the Hall logic signal error and dead-zone protection failure brought about by the MOS tube up and down through the high-current short-circuit damage to the controller greater. To ensure that the short circuit can be cut off after the PWM signal, you must use the MCU interrupt function. As shown in Figure 7 for the overcurrent protection circuit, A, B, C three-phase voltage amplifier through the op amp amplifier TRAP feet, the normal work TRAP pin is high, the current is too large, the transistor open, level Flip, trigger interrupts. The magnitude of the protection current can be set by changing the feedback resistance of the op amp.

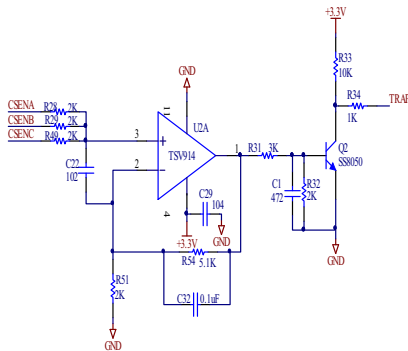


Fig.7 Overcurrent protection circuit

3 MOSFET internal resistance sampling

When the controller works, the phase current is 3-5 times of the bus current. When the motor power reaches 500W, the bus current limit of the controller can reach 18A to 20A. At this time, a larger current flows through the switch tube. For high power applications, taking into account the power loss problem, usually do not take the form of resistance sampling, the usual practice is to install high-power bus Hall or current transformer, and the sensor's high cost, bulky and inconvenient installation.

In this paper, the current feedback value obtained by detecting the internal resistance drop when MOSFET is on. This method has been studied before, the article's idea is to detect the power semiconductor conduction voltage drop and get the current feedback value, the article targeted for the object of a number of MOS tube in parallel, and discussed in this article the traditional The significance of the six tubes in the number of power tube some differences, but essentially the same principle. The detection method of the internal resistance sampling circuit is that the current signal is obtained by comparing

and amplifying the driving level of the lower bridge.

MOSFET small conduction resistance, fast switching speed, no secondary breakdown and other characteristics make it a mainstream power switching devices. MOSFET flows through the on-state current, its internal resistance on the pressure drop. With the development of semiconductor process technology, the value of the resistance is often only a few milliohms. The smaller the internal resistance, MOSFET can withstand the pressure is lower. So a reasonable choice of MOSFET parameters help to improve our design quality. As mentioned earlier, the internal resistance of the MOSFET varies with temperature. Different temperature corresponding to different resistance, that is, different sampling current, as shown in Figure 8 for the temperature and current resistance diagram.



Fig.8 Temperature and current resistance diagram

Ignoring the impact of temperature changes on the internal resistance of the MOSFET, for the time to sample the temperature information, MOSFET internal resistance voltage data processing can be obtained from the switch current information to achieve the current closed-loop feedback, the key to the entire system is how to collect the MOSFET Of the internal resistance voltage, shown in Figure 9 for the MOSFET internal resistance sampling circuit, is still a phase to explain.

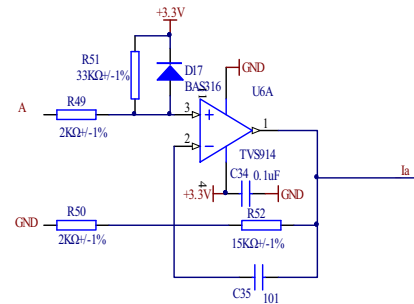


Fig.9 MOSFET internal resistance sampling circuit

Figure 9 shows that A and GND, respectively, from the down tube of the MOSFET to take the differential signal, and the previous differential resistance sampling. PWM phase before the arrival of the corresponding phase if the A-phase and B-phase of the lower tube conduction, then enter the op amp from the A-phase voltage of the bus voltage, the design is +36 V, if the voltage directly amplified will burn Bad op amp. In Figure 9, a diode is used to clamp it. And when the current cycle of the PWM tube to open the opening, because the signal is weak, this time the diode is disconnected. R₄₉ and R₅₁ in addition to previously mentioned to provide static bias voltage to avoid signal distortion, and in order to eliminate the amplifier static error, to ensure that the positive and negative both ends of the equivalent resistance connected to the same. In fact, the internal resistance of the MOSFET will increase with increasing temperature. A change in temperature can lead to inaccurate sampling.

Will reflect the temperature changes in the thermistor on the circuit, the way through the partial pressure to the MCU port, sensing the temperature of the signal changes in real-time compensation. The current sampling waveform is shown in Fig.10.

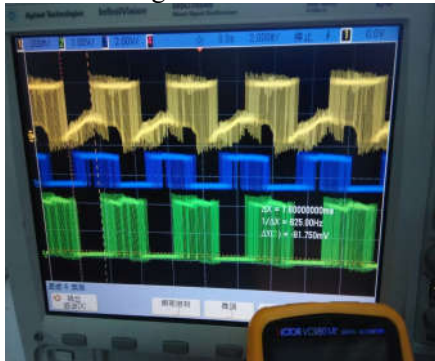


Fig.10 Current Sampling Waveform

As shown in Fig. 10, the order of pictures from top to bottom is defined as 1, 2, and 3, respectively. Still take three-phase motor A phase analysis. 1 for the A-phase bridge MOSFET internal resistance voltage signal is amplified by the op amp after the waveform, 2 for the A phase on the bridge DS waveform, 3 for the A phase under the bridge DS waveform.

Analysis of 1,2, the bridge conduction, the bridge into the op amp voltage clamped by the diode, amplified to a certain value. On the bridge off, the bridge under the voltage amplification, the voltage changes with the current changes. The analysis of 3, the bridge after the MOSFET conduction voltage drop to a certain value. It can be seen that the circuit can be current detection, and the structure is simple.

4 Fabrication of PCB for Aluminum Substrate

In this paper, the aluminum substrate with better heat dissipation is selected to place the heating element, and the common signal traces are designed with ordinary FR4 plate. The MOSFET, power resistor, LM317 these heating components placed in the aluminum plate, the drive chip, MCU and other chips together on the board, as shown in Figure 11 PCB design physical map.



Fig.11 PCB design physical map

5 Software design

The system uses the current speed of the dual closed-loop control of the motor speed to adjust in real

time. System power, first by determining the A, B, C three-phase voltage through the op amp amplified bias voltage, Hall signal voltage feedback value is normal to decide whether to start. The MOSFET turn-on sequence is determined by the rotor position information , and the speed is detected by the speed loop and compared with the set speed. An output is obtained by fuzzy PID as a given signal of the current loop, and the detected current value is compared with the given signal to obtain the final value by PI algorithm. The measurement and control curve of the controller is shown in Fig.12.

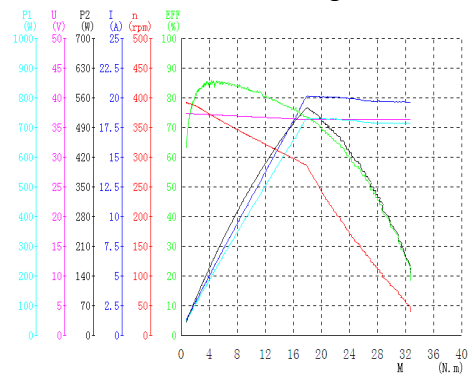


Fig.12 Measurement and control curve

6 Concluding remarks

In this paper, designed a high-performance electric vehicle controller which is based on STM32, and gives a detailed hardware design circuit. For the traditional high-power field, the circuit for the new MOSFET internal resistance sampling is improved, which makes the circuit peripheral equipment simple and easy to implement. Finally, based on these principles PCB, and tested, from the measurement and control curve, prove that the controller can be used in industrial production.

References:

- [1] Chun Hu, Guolong Xiao, Zhengping Gong, Guo Wu, Zhuanglong Guo. Design of Short Circuit Protection Circuit for LED Power Supply [J]. Mechanical & Electrical Engineering Technology, 2013, (05):71-73.
- [2] Donghua Zhang, Jun Liang, Chenghui Tu. New Technology of Current Detecting for Brushless DC Motor[J]. Electrical Measurement & Instrumentation ,2011,(06):19-22.
- [3] Dayong Wu,Minzhi Jia. Application of STM32 in Three Phase Brushless DC Motor Control System[J]. Micromotors,2014,(03):47-51.
- [4] Liu G, Cui C, Wang K, et al. Sensorless Control for High-Speed Brushless DC Motor Based on the Line-to-Line Back EMF[J]. Power Electronics IEEE Transactions on, 2016, 31(7):4669-4683.
- [5] Lee A C, Wang S, Fan C J. A Current Index Approach to Compensate Commutation Phase Error for Sensorless Brushless dc Motors with Non-ideal Back EMF[J]. IEEE Transactions on Power Electronics, 2015:1-1.
- [6] Shi J T, Pan F, Luo F L. Modeling and Simulation Analysis of Brushless DC Motor Control System[J]. Mechanical Engineering & Automation, 2014, 30(2):494-499.
- [7] LI, Gengxiang, Wang, Lei, Yang, Kuilin. LOCATING STRUCTURE BETWEEN PRINTED CIRCUIT BOARD AND INSULATING BOBBIN IN A BRUSHLESS MOTOR[J]. 2017.

- [8] Lu Y. Hybrid controller for brushless dc motor[J]. 2016.
- [9] Kim M, Oh J, Suk J H, et al. Motor driving module and brushless DC motor system[J]. 2016.
- [10] Andrieux G, Tafer T. Drive a Brushless DC Motor like a Standard DC Motor[J]. Atzelektronik Worldwide, 2016, 11(5):58-63.
- [11] Tsay C Y, Chi C H. Generating a coil switching signal for a brushless DC motor[J]. 2016.