Design and Research of under-Voltage Protection Circuit for Motor Driver Chip Based on Special Integrated Chip

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Abstract. Intelligent power integrated circuit chips play an increasingly important role in industrial automation, domestic medical appliances, automotive electronics, especially in modern military, aerospace and other fields. Based on the analysis of the current front-end verification problem of digital application specific integrated chip, the composition and working principle of motor drive chip, the design and composition technology of undervoltage protection function module and the perfect protection circuit not only ensure that the chip can work normally under some harsh conditions, but also play a vital role in the safety of the whole system sometimes. After the motor chip is verified by the flow sheet, packaging, testing and test result analysis are carried out to further predict and adjust the function and reliability of the motor chip. On the basis of analyzing the current front-end verification problem of digital application specific integrated chip, the circuit structure is simple, no additional bandgap reference circuit is needed, and the voltage comparator circuit is also omitted.

1. Introduction
Modern, efficient and accurate motor control is realized by computer. A complete motion control system is composed of motor chip, main processor, motor and incremental encoder [1]. The complexity of software naturally requires higher efficiency, reliability and maintainability of software. It also increases the complexity, cost and development cycle of SRM control system, and reduces its reliability, maintainability, anti-interference ability and stability [2]. Traditional under-voltage protection circuit is generally composed of input voltage sampling circuit, reference circuit and hysteresis comparator. The voltage sampling circuit and positive feedback hysteresis circuit mostly adopt resistance voltage dividing structure [3]. The combination of the current control circuit and the external reference voltage can be used to determine the current operation mode (fast attenuation mode, slow attenuation mode and mixed attenuation mode). At the same time, the motor drive chip also provides perfect protection measures. The power integrated circuit integrates power and information control into one chip, making it the interface between weak current and strong current in mechatronic system [4]. The average voltage is changed by changing the “duty ratio” of the voltage on the armature of the DC servo motor, thus controlling the rotating speed of the motor. Therefore, this device is also called a switch drive device. At this time, the power integrated circuit not only guarantees the power output capability, but also has the functions of logic, control, sensing, detection, protection and self-diagnosis, so the power integrated circuit has certain intelligence [5].

In the design of motor driver chip, many factors need to be taken into account, including whether the motor is unidirectional or bidirectional rotation and whether speed regulation is needed [6]. For one-way motor drive, only a high-power triode or field effect transistor or relay can drive the motor directly. As a conversion device of mechanical and electrical energy, the motor has been applied in all fields of national economy and people's daily life [7]. The main types of motor are synchronous motor,
asynchronous motor (also known as induction motor) and DC motor. The motor does not rotate and the instantaneous voltage at both ends of the armature is not zero, but the positive and negative pulse voltage with the same width. An alternating current flowing through the armature circuit makes the motor flutter at high frequency, which is beneficial to reducing static friction [8]. An application-specific integrated circuit, the main components of which include a rotor position sensor decoder circuit; Internal reference power supply with temperature compensation. The chip starts to output pulse signals to drive the switch tubes in the full-bridge drive circuit of the motor, so that the motor starts to run. After the speed increases continuously to a certain extent, the motor is started. Through hardware simulation kernel classes, these models can be directly compiled into lightweight executable simulation models without using a hardware simulator to debug hardware behavior [9]. It is necessary to add an undervoltage protection circuit inside the chip, which can ensure that when the power supply voltage is lower than the set working threshold, the external power tube and most modules inside the chip are in the off state. In this paper, the design of undervoltage protection circuit for motor driver chip based on ASIC is studied [10].

2. Research on Relevant Technology of Protection Circuit

2.1. Classification and Basic Characteristics of Protection Circuits

After the speed signal of the special integrated chip motor, the speed controller (speed servo control system) with negative feedback circuit is used to realize the stability control of the motor speed. Current flows longitudinally, so it has lower on-resistance with the same breakdown voltage. But at the same time, independent drain leads are needed, so there is an imperfect drain leads resistance. Capacitance can also be used to determine the invalid time of the output of current sensitive comparator in order to prevent the wrong overcurrent detection when the phase input is changed or the input of digital-to-analog converter is changed. In the under-voltage protection circuit of the existing technology, there is often a reference circuit to generate the reference voltage, and the comparator is used to sample the voltage signal of the power supply. The reference voltage signal produced by the reference circuit is compared with the reference voltage signal produced by the reference circuit. Resistors also need to occupy a large layout area. In addition, traditional undervoltage protection circuits often need external bias circuits, which makes the circuit less independent. Operating performance under over-set conditions (e.g. overpressure, undervoltage, overtemperature, overload, etc.). Only in this way can the motor drive chip work safely and reliably under any harsh conditions. In order to achieve this goal, the design must consider adopting countermeasures and measures that can protect the chip from failure and damage under the set over-specified conditions.

The time when the power transistor in the power protection circuit plays is always later than the time when the power transistor closes. This time is called dead-time. The driving signals of the two power transistors on the same side of the dead-time are all low-level. The protection circuit is brought into the overall circuit simulation, and the output of the protection circuit is a logic control signal, a blocking circuit control signal when the protection circuit is in a high level, and a releasing circuit control signal when the protection circuit is in a low level. The delay and logic parameters of the power short circuit protection circuit are shown in Table 1 and Figure 1.

| Table 1 Delay and Logic Parameters of Power Short Circuit Protection Circuit |
|------------------------------------------|-------------------|-----------------|
| High-end Driver of Short Circuit Protection Output | No delay | 13.51±0.35 |
|                                                      | Delay of 0.5us   | 12.18±1.62     |
| Low-end Drive of Short Circuit Protection Output    | No delay | 12.30±0.36 |
|                                                      | Delay of 0.5us   | 13.19±0.98     |
2.2. Basic Structure of Traditional Protection Circuit

According to the reliability requirement of the chip, the motor driver chip of the special integrated chip protects the internal fault protection circuit of the chip, such as overheating, undervoltage, overcurrent, etc. The IC engineer will choose to design the circuit according to the need to prevent the medium-power devices of the inverting circuit from flowing too much current for a long time, and generate a large amount of heat energy to protect the motor or chip. A simple over-current protection circuit is designed inside the chip. Therefore, the function of over-current protection is to monitor the current flowing through the power transistor when the chip is working. Current signal is transformed into voltage signal through external resistance, and then voltage signal is fed back to the logic control circuit inside the chip after passing through the external control chip, so as to control the speed of the motor to change. Mirrored to the current mirror structure, the current mirror structure is compared and output through inverter shaping. This is the main function of the undervoltage protection circuit. The motor drive chip can quickly stop working when an undervoltage condition occurs so as not to cause damage, and on the other hand, the motor drive chip can quickly resume normal work after eliminating the undervoltage condition. However, when the temperature drops to a safe range, the protection mechanism is released and the chip works normally. At the same time, the thermal shutdown protection circuit needs hysteresis function to prevent the thermal oscillation phenomenon of repeated shutdown and startup near the overheat shutdown threshold of the circuit.

Collect the high-voltage side power supply voltage and compare the magnitude of the high-voltage side power supply voltage and the high-voltage side undervoltage threshold. If the high-voltage side power supply voltage is lower than the high-voltage side undervoltage threshold, then the input signal of the high-voltage side drive circuit of the motor drive chip in the low-voltage area is forced to become low level. The undervoltage protection flow chart of the motor drive chip is shown in Figure 2.
Under low power supply voltage, some sub-circuits of the motor driver chip of the special integrated chip will not work properly, especially the digital logic control circuit is prone to misoperation. Even if the chip can switch normally, its working efficiency will be greatly reduced. Driving current limitation and current sampling are used to detect the current of power transistors on four bridge arms. High temperature warning and protection are used to detect the overall temperature of the chip. Intelligence of power integrated circuits is embodied in that if abnormal phenomena such as load opening, over-current, output short-circuit, power short-circuit, power under-voltage, over-voltage and over-heating occur, the chip will be protected by internal circuit and output fault diagnosis signal to external control circuit. Sampling bridge circuit has a high continuous current on the bridge arm when it works, so it is necessary not only to limit the driving current, but also to monitor the current outside the chip at any time. If the chip enters a short undervoltage state during operation or at the instant of startup, it will not have serious consequences on the motor drive system. The potential low frequency vibration of the stepping motor is greatly weakened or eliminated, and the possibility that the stepping motor works in a resonance region is reduced. It can be said that subdivision drive technology is a leap forward in stepping motor drive mode and precise control technology. The drive circuit can be operated in a current fast attenuation mode, a current slow attenuation mode or a current mixed attenuation mode by controlling the drive circuit through a logic circuit. When the power supply voltage gradually drops, the logic level of the output is low. This output signal is provided to the subsequent circuit to turn on or off the key module circuit, thus playing the role of protection circuit.

3. Simulation of Protection Circuit for Motor Drive Chip

3.1. Analysis of Power Supply Undervoltage Protection
In order to prevent motor blockage caused by low power supply voltage, special integrated chip motor driver chip should add power supply under-voltage protection circuit, so the power supply under-voltage protection circuit is based on the critical voltage which causes motor blockage. The voltage, current and heat in the driver chip are converted into voltage signals and transmitted to the comparison circuit and the internal reference. Then the results of the comparison are transmitted to the
phase logic separator of the core control circuit in the chip. After the logical conversion, the switch of the power transistor in the inverter is directly controlled. In order to realize that the chip can control the motor to enter the energy-saving state automatically after the clock control signal is stopped for about one second, the half-current locking function needs to be decomposed into a timing part of about one second and a phase current reduced proportionally. The armature resistance or back electromotive force of the motor changes, causing the rotation speed to change. Since the tachogenerator can immediately capture the change in rotation speed, the stability of the rotation speed of the motor can still be ensured by comparing the above-mentioned adjusting effects of the amplifier. From the dynamic performance point of view, increasing the switching frequency can enlarge the bandwidth of the system and improve the rapidity of the system, but the increase of the switching frequency will increase the dynamic loss of the transistor and reduce the transmission efficiency of the amplifier.

3.2. Analysis of Current Sampling Circuit
In order to avoid switching oscillation caused by the change of the current flowing through the power transistor near the current threshold set by the current protection, it is necessary to design the delay time of the over-current protection circuit from the turn-off state to the turn-on state, as well as the delay time of the over-current protection circuit from the turn-on state to the turn-off state. By adjusting the size of capacitor and current source, the circuit can get square wave signal with wide duty cycle, and can flexibly adjust the oscillation period and duty cycle. When the power supply voltage is below the normal operating range of the chip, some circuits inside the chip may not work properly, which may cause internal logic errors and make the external switches in an uncertain state. After the speed ramp-up phase is completed, the motor speed has reached a higher level. Therefore, in order to control the motor speed in a closed loop at this stage, the control system must increase the initial given speed. The signal generated by the torque position sensor, which causes the motor to generate continuous torque, is subjected to certain logic processing and then controls the logic switch unit to further determine the turn-on sequence and time of each phase winding. The signal generated by the torque position sensor, which causes the motor to generate continuous torque, is subjected to certain logic processing and then controls the logic switch unit to further determine the turn-on sequence and time of each phase winding. The power tube is controlled to be cut off so as to prevent the generation of overcurrent.

According to the function of the overheat protection circuit, the key of module design is to accurately measure the temperature inside the chip. Therefore, the output voltage or current of the temperature detection circuit is required to reflect the temperature change of the chip. At the same time, the parameters of other modules of the overheat protection circuit are required not to change with the temperature. Detecting whether the reference voltage generated by the power supply voltage is under-voltage or not, the under-voltage circuit can ensure that the drive motor will not be blocked if it considers the output of the reference source at the power supply voltage as the critical point of under-voltage and the output of the low level. The layout of analog integrated circuits is mainly designed by hand, and the layout design of analog integrated circuits has a great impact on the electrical performance of the chip. The potential is raised, the output of the protection circuit is reversed, the under-voltage protection state is triggered, the output signal is fed back to the control logic, and the logic control circuit sends out corresponding control signals to stop the chip. The feedback detection module needs to output the motor inversion flag signal to the feedback pulse counter. The feedback pulse counter changes the internal algorithm to calculate the accurate coordinate value of the motor load in real time under the motion state with direction change. The structure of the current mirror formed by the tube changes, and the current mirror structure positively feeds back the inversion of the output signal from low to high, thus realizing the hysteresis function of the protection circuit.

4. Conclusion
In this paper, the design of undervoltage protection circuit for motor driver chip of special integrated
chip is studied. In many cases, in order to prevent power tube and load from being damaged by overcurrent, the current value needs to be strictly controlled. For example, when controlling DC motor and stepper motor, if the current is too large to burn out, the value of reverse voltage applied by the motor is maximized, then the motor will decelerate at the fastest speed until it is close to stationary, because the feedback pulse frequency of the rotary encoder of the DC motor is proportional to the speed of the motor. By integrating the power tube and control circuit, the total silicon area consumed by the chip is greatly reduced, the external circuit design of the chip is simplified, and the cost of the chip is reduced. The internal integrated charge pump circuit can directly supply power to the drive circuit of the high-side power grid. In order to improve the yield, it is necessary to consider the impact of all process errors, that is, the circuit can achieve functions under various process angle combinations. An external hysteresis feedback comparator is used to prevent the thermal protection threshold from being affected by temperature, and a zener reference voltage source and a resistor voltage divider are used to provide a reference for the comparator to eliminate the influence of the power supply voltage. A current sampling circuit and an overcurrent protection circuit which need to be connected with a high-end power tube are arranged below a low-end driving circuit, and two current sampling circuits taking a reference source circuit as a midpoint are symmetrically arranged; The oscillator circuit needs to control two charge pump circuits. Considering the temperature characteristics of the device, the circuit introduces temperature compensation to reduce the adverse effects of temperature changes on the accuracy of circuit flip threshold and hysteresis.

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