The Design of Controller for PMSM Based on DSP and IPM

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Abstract. In this paper, according to the characteristics and operation principle of Permanent Magnet Synchronous Machine (PMSM), a controller of PMSM is designed from the aspects of hardware and software. The electric motor controller is taken as the design target. Firstly, the TMS320F28035, which has a working clock frequency of 60MHz, is used as the core and the drive. Secondly, the feedback circuits are designed for controller using Cadence. Thirdly, the FOC control strategy is used to design a PMSM motor controller for verification. The controller uses the PWM signal as the main driving signal, and the DSP's A/D sampling module and QEP module are the main feedback signals. It adopts the combination of FOC vector control and PI loop control strategy of speed loop and current loop double closed loop to realize motor control. Finally, the CCS software is used for testing to make the motor stable and operate at a higher efficiency, which can achieve better speed regulation.

1. Introduction
Motor drive system is the heart of new energy vehicles, which will directly affect the performance advantages and disadvantages mileage, torque output of electric vehicles, safety and reliability overall performance. According to the requirements of the drive system for the motor, the drive motor can be divided into: DC brush motor, switched reluctance motor, permanent magnet brushless DC motor, permanent magnet synchronous motor and AC asynchronous motor. Electric vehicles have experienced the development of switched reluctance motors, AC asynchronous motors and permanent magnet synchronous motors in terms of motor selection. At present, switched reluctance motors have applications in buses due to factors such as vibration and noise, in passenger cars. In the field, domestic and foreign products mainly use permanent magnet synchronous motors, which have the advantages of small size, light weight and easy layout on the vehicle, so they are widely used [1-2].

2. Overview of PMSM Control Strategy
At present, there are three mainstream control strategies for permanent magnet synchronous motors, namely voltage regulation and frequency modulation control, vector control and direct torque control [3-4]. The vector control method is the most widely used in modern motor control theory. The controller adopts the vector control method for control. The basic idea is to decouple the voltage, current, magnetic flux and other factors that are coupled together, which affect the running state of the motor, and make the AC motor through appropriate transformation equivalent. The control effect is the same as that of a DC motor. It establishes the equivalent relationship between the three-phase AC winding current, the two-phase AC winding current and the DC winding current in the rotating coordinates by generating the same rotating magnetic field. The mathematical equivalent conversion is used to simulate the DC motor. Control the law to control the AC motor [5].
In the motor control, due to the need to accurately measure and control the various operating parameters, the closed-loop control is implemented, and the measured parameters are compared with the given parameters, so that the control effect is approaching and finally achieves the desired effect. Therefore, PI control [6] is adopted.

3. Hardware system design

The permanent magnet synchronous motor controller designed in this thesis is designed to achieve high precision and high efficiency of motor control. It adopts the closed-loop control mode, that is, the control core has the function of driving output, and also has the functions of detecting various operating parameters. It is mainly composed of five parts, namely power module, control core module, three-phase inverter module, current detection module and position detection module [7]. As shown in Figure 1, the system provides bus voltage BUS+ from an external switching power supply or battery pack. After rectification and filtering, the system is divided into two paths. One of them is used to step down the voltage to supply the DSP core, and the other output is high voltage DC. The power supply directly acts as the bus voltage of the inverter; the three-phase inverter has a PWM output function of the DSP, and outputs a PWM signal, which is driven after isolation and amplification; the current detection part uses a resistance sampling method to detect the current when the motor is running. The size is input to the ADC interface of the DSP; the position detection part uses an incremental encoder to collect the pulse vector and practice of the encoder, and the M/T speed measurement method is used to calculate the actual running speed of the motor.

3.1 DSP minimum system design

When designing the controller in this project, TMS320F28035 is used as the control core. Firstly, the minimum system of DSP is designed. The purpose is to make the control core of the system work stably and orderly. The system uses 20MHz crystal oscillator as the clock source. In order to ensure the oscillation frequency of the crystal oscillator is stable, 12pF capacitor is used as the load capacitance of the crystal oscillator to form the crystal oscillator circuit. Then the software is six times frequency and two frequency division, so that the DSP finally works at 60MHZ clock. When the minimum system is in normal working condition, it should satisfy the stable motor control signal output and sampling feedback signal acquisition operation. The minimum system introduces 3.3V, 1.8V peripheral and core power supply, which consists of clock circuit, BOOT circuit and JETAG debug interface circuit. Among them, the correct configuration of the DSP configuration pin is a key factor for the normal operation of the DSP. The BOOT pin is divided into two states: pull-up and pull-down. They can be controlled by software or by hardware switch. Different combinations of states determine the start mode of the DSP, such as booting from FLASH, running from ROM, and
so on. The controller increases the hardware start switch while ensuring that the boot mode can be controlled by software, making the controller more flexible.

3.2 Power circuit

The power supply of the controller is mainly composed of a high-voltage peripheral power supply and a low-voltage core power supply, wherein the high-voltage peripheral mainly refers to the permanent-magnet synchronous motor driven by the controller, and the low-voltage core power supply is responsible for supplying power to the DSP and the detection circuit. Because the motor controller has its particularity, that is, the motor it is connected to is an inductive load, the coil in the load will store energy, and the high voltage will be released when the power is turned on and off, which will cause voltage oscillation, endanger the stability of the system, and even burn out the control core and other devices. Therefore, when designing the circuit and PCB, attention should be paid to the isolation of the power supply and the high and low voltage sub-area arrangement to ensure a safe creepage distance. The controller is mainly powered by 24V DC bus voltage. The TPS54331 is used as the core to make a switching power supply. It can be used to reduce the DC 24V to 15V DC, supply power to the IPM module, and prepare for the subsequent step-down. There are a variety of options for controlling the core power supply, such as the use of a highly integrated dual-channel LDO, a one-time output of 3.3V and 1.8V, and a multi-stage buck solution. The controller selects the latter from the cost consideration, adopts the hierarchical and multi-stage step-down mode, and gradually adjusts the voltage to supply power to the DSP and the feedback circuit. The selected buck strategy is to make 15V with the 7805 linear regulator chip as the core. The 5V step-down circuit uses AMS1117-3.3 and AMS1117-1.8 as the core to make 5V to 3.3V and 3.3V to 1.8V step-down circuits, and arranges a large number of capacitors between the step-down circuits. Coupling, in which a small capacitor is used to filter out high-frequency noise, and a large capacitor is used to filter out low-frequency noise, thereby reducing ripple and stabilizing power supply, and their circuits are as shown in Figure 2.

3.3 PWM drive isolation circuit

When the controller drives the motor, it basically controls the on-off of the three-phase inverter by outputting six PWM signals, so that the power devices of the inverter generate different switch combinations. However, due to the limited output current of the DSP pin, its driving capability is not enough to drive the next-level power device, and if it is directly connected, it is easy to introduce many noise and unstable voltage into the control core, increasing instability, so in the DSP and Signal amplification and local devices are added between the power devices. The controller adopts an eight-way buffer and line driver with three-state output. While improving the driving capability, its internal
one-way transmission design can effectively isolate, and its bus control capability can simultaneously
turn off six channels in the event of system failure. Output, play a role in protection.

3.4 IPM circuit
Power drive is a very important part of the motor controller, which determines the drive capability and
drive effect of the controller. The power drive portion is generally realized by a power device
comprising a three-phase inverter, wherein the three-phase inverter is composed of a total of six bridge
arms, and each of the bridge arms is composed of one or more power devices. There are several
options for selecting a power device. Depending on the power of the motor being driven, a choice of
MOSFET, IGBT or IPM intelligent power module. The controller selects Infineon's IRAM136 module
from the perspective of control strategy verification, small and medium power and high integration. It
integrates six IGBT power devices to form an inverter, and has current feedback, temperature and fault
alarm. The status monitoring circuit interface can read or control the high and low states of the FLT
and EN pins by reading the voltage output from the VTH pin, thereby realizing the effect of
monitoring its working state and quickly performing fault control.

3.5 Current detection circuit
The purpose of the current detection circuit is to obtain the working current under the working state of
the motor, and provide feedback data for the closed-loop control to achieve higher precision and
higher efficiency motor control. Common current detection is divided into direct detection methods for
small and medium currents, such as resistance sampling; and non-contact sampling methods for large
currents, such as Hall sampling. The controller adopts the method of direct resistance sampling, and
uses a small resistance value and a high-precision sampling resistor arranged on the lower arm of the
inverter to obtain a very small voltage signal through the principle of resistance division, and then the
operation is performed by an operational amplifier circuit. The signal is amplified and input to the
ADC pin of the DSP. Since the ADC pin of the DSP can withstand a voltage range of 0-3.3 during
normal operation, and the feedback signal may have a negative value, the operating circuit sets a bias
voltage of 1.65V to adjust, so that the sampled voltage can be obtained.

In addition, an overcurrent warning circuit is also set by using a comparator. When the amplified
feedback value is higher than the threshold value that is set, an overcurrent warning is triggered, and
the DSP core that receives the overcurrent warning signal can adopt a series of Safeguard. The
controller uses the LM358 as the core to design the operational amplifier circuit, and uses the LM393
as the core to design the comparison circuit.

3.6 Position monitoring circuit
The position monitoring circuit is an important part of the speed closed-loop control. The controller
uses the TXB0104 chip as the core to design the encoder circuit. The chip is a 4-bit bidirectional
voltage level converter with automatic direction sensing and ESD protection. When the motor is
working, the continuous pulse signal generated by the 1000-line encoder connected to the motor shaft
is processed by the encoder circuit and input to the QEP module interface of the DSP to obtain the
rotation angle and speed of the motor.

3.7 Power-on protection circuit
The stability of the controller is an important indicator of the controller design. In order to ensure that
the motor is accurately controlled and avoid the IPM part receiving the wrong signal indication, design
the power-on protection circuit, set the hardware start and power supply sequence, and join at the same
time. A wire wound resistor is used to limit current flow to prevent overcurrent during operation.
During the power-on process of the controller, the DSP core is first powered. When the core is
powered on and the hardware detection and initialization are completed, the IPM is powered, so that
the IPM can receive stable and clear immediately after power-on, control signal. The power-on
protection circuit consists of two parts, which are respectively realized by independent relays. One of
the relays controls the power supply of the IPM, and the other one controls whether the winding resistance is connected to the circuit.

Figure 3. Power-on protection circuit

4. PCB design and system testing
The production of hardware circuit boards is divided into two main stages: schematic design drawing and PCB drawing. The controller is designed and manufactured by Cadence software. The schematic link includes main steps such as component selection, component package drawing, circuit schematic drawing and export netlist. The PCB link includes constraint setting, component layout planning, and layout. Main steps such as routing, optimization, plate making and debugging. The controller is designed to be separately manufactured by using the control board and the driving board. The control core circuit and the power driving circuit are placed on the upper and lower PCBs, and the terminals are firmly and stably connected through the terminals. The benefits of this design are reduced peripheral interference to the core and reduced controller integration, improving controller serviceability. The two parts of the controller are the upper PART1 and the lower PART2, respectively, as shown in Figure 4. After PCB production and welding debugging, all components of the final motor control system are shown in Figure 5.

Figure 4. PCB design
After all the control system hardware is built, use the CCS software and JTAG emulator to download the motor control program to the chip FLASH to realize the offline operation of the controller. At this time, the external potentiometer knob can be used to control the running speed of the motor. When the motor controller is running normally, the motor will rotate. If the oscilloscope is used to observe the signal output of the controller, you can see that the waveforms of the upper and lower arms of each phase are strictly complementary in the three-phase inverter, as shown in Figure 6.

![Figure 6. Control output waveform](image)

5. Conclusion
This paper designed a PMSM motor controller based on DSP. The controller is composed of DSP minimum system, switching power supply, stepped step-down circuit, three-phase inverse, Variable circuit and condition monitoring circuit. The software part is written by Code Composer Studio software, and the hardware part is designed and produced by Cadence software. Finally, by controlling a 36V, 14W PMSM, the output signal and feedback signal are detected to be normal. The motor control and speed control functions are realized, so that the motor runs normally and stably.

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