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Vector Control of Permanent Magnet Synchronous Motor for Fan of New Energy Vehicle

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Abstract: In this paper, based on the analysis of the mathematical model of permanent magnet synchronous motor (PMSM) and the common control strategy, and the overall system architecture of the control system is analyzed based on the specific control algorithm.The control system uses NXP company's latest special motor control chip MC9S12ZVMC128 as the system controller and uses vector control (FOC) as the control algorithm.The design of controller software architecture is described in detail, using the state machine model to control the motor running in different stages, including start-up stage, motor open detection and treatment of closed loop phase and fault ring stage, etc...The experimental results show that ,with the NXP MC9S12ZVMC128 hardware platform, using vector control algorithm,permanent magnet synchronous motor can operate efficiently and stably, give full play to the role of MC9S12ZVMC128 in the electronic field of the advantages of new energy vehicles.

Key words: Permanent magnet synchronous motor; new energy vehicle; vector control; MC9S12ZVMC128

1. Introduction

In the environment and the energy demand increasingly higher today, energy consumption has become a serious problem, which resulted in the popularization and development of automobile energy consumption into explosive development, energy-saving and emission-reduction has become a major trend, new energy vehicles came into being [1].There are a large number of motors in the vehicle,which makes it the most energy consumption part in the vehicle.Such as automotive air conditioning, fans, pumps, oil pumps, wipers and other parts of the motor control [2].At present, this part of the motor is still a lot of traditional brush motor or low efficiency of DC motor. In the context of energy-saving emission reduction, require the use of power can achieve higher efficiency,increase the number of the development and use of more efficient speed control systems,permanent magnet synchronous motor (PMSM) control system has great potential in production and life because of its good control performance and operation performance[3].Permanent magnet synchronous motor (PMSM) has been widely used in this kind of background, and the brush motor on the vehicle is being replaced by brushless permanent magnet synchronous motor (PMSM) step by step. Because of the good performance, PMSM is widely used in many fields, and the control is also showing more efficient and stable trend, a variety of control theory and control algorithms have emerged [4-5].

Due to the many advantages of PMSM, many scholars and experts put the research direction to the PMSM, mainly divided into the following three directions[6]: one is the study of control strategy, that is, software and control algorithm. One is the design of the motor, including the use of higher performance motor design, improve its power density. Another is the design of the motor controller, the controller hardware circuit design.The most of them is that researching the controller and control algorithm, at present, it has become a hot research topic in major universities and enterprises.

Studying on the controller, uses MCU as the controller, three-phase bridge as the driving circuit, low voltage control high pressure and SVPWM technology, because the MOSFET turn-on voltage is a little high, The PWM generated by the MCU is not sufficient to drive the MOSFET or IGBT on, often on many occasions need to add additional driving circuit.Furthermore, using the FOC algorithm need to sample the two-phase current, and when the bus voltage is over voltage or under voltage, it is necessary to detect the fault and protect control system. In addition, the controller to deal with the FOC algorithm, must have a certain amount of computing power.Therefore, now there are more and more PWM driving circuit and operational amplifier integrated in a MCU,which makes hardware more simplified[7]. There are a lot of PMSM control system usually using the encoder as the position sensor, but more and more occasion need the hardware system more simplified, slowly,PMSM position sensorless control strategy gradually gets more and more wield [8].In the field of automotive electronics, PMSM has been widely used, the major semiconductor companies were launched its own dedicated motor control MCU, such as Infineon (Infineon), ELMOs En Zhipu (NXP), etc.. In this paper, NXP is used in the field of automotive electronic control of motor MCU.

The software, for the control algorithm of PMSM currently has the following three kinds[9]:vector control (Field Oriented Control, referred to as FOC), VVVF control (Variable Voltage Variable Frequency, referred to as VVVF or VF) and direct torque (Direct Torque Control, referred to as DTC). FOC has been widely used in many PMSM control systems because its good

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dynamic response and high stability [10].

The design in this paper mainly according to the related technical documents of NXP, based on a large number of domestic and international materials, designs a PMSM-FOC system based on MC9S12ZVMC128, after repeated experiments, the new energy automobile fan with PMSM-FOC system, the test run results up to the requirements of the project.

2. Principles of PMSM vector control

2.1 mathematical model of PMSM

Permanent magnet synchronous motor (PMSM) is a kind of strongly coupled non-linear system. Its mathematical model is the theoretical basis of the analysis of motor performance and the realization of torque and speed control. The Clark transform and the Park transform are used to transform the motor from the three-phase static coordinate system to the two-phase rotating coordinate system to realize the decoupling of the torque and flux.

Voltage model in d-q coordinate system is：

$$\begin{cases} u_d = ri_d + L_d \dfrac{di_d}{dt} - w_e L_d i_q \\ u_q = ri_q + L_q \dfrac{di_q}{dt} + w_e (L_d i_d + \psi_f) \end{cases} \quad (1)$$

The expression of electromagnetic torque produced by stator winding is：

$$T_e = \frac{3}{2} N_p (L_d - L_q) i_d i_q + \frac{3}{2} N_p i_q \psi_f \quad (2)$$

Motor motion equation is：

$$T_e - T_L = \frac{3}{2} N_p (i_q \psi_d - i_d \psi_q) - T_L = J \frac{dw_m}{dt} \quad (3)$$

In the formula: u_d is straight shaft voltage, u_q is quadrature axis voltage; i_d is direct axis current, i_q is quadrature axis current; L_d is direct axis inductance, L_q is quadrature axis inductance; ψ_f is the rotor flux reference value; T_e is motor output electromagnetic torque ; T_L is load torque;

N_p is motor pole pairs; w_e and w_m respectively are electric angular velocity and angular velocity.

2.2 space vector pulse width modulation

The first step of space vector modulation (SVPWM) is to analyze the motor ideally，then establish the mathematical model of the motor in each state.And according to the coordinate transformation of the motor space vector combine with the model.According to the switching state of the inverter, an appropriate pulse width modulation is generated, so that the actual flux of the permanent magnet synchronous motor is infinitely close to the ideal flux circle. Space vector pulse width modulation (PWM) technology has a very obvious advantage, it can produce standard sine wave and can provide high voltage and decrease low current distortion. The inverter is composed of three half bridge,in total,six power tubes, we set "1" as turn on and "0" as turn off, six power tubes have eight kinds of combination state, namely 000, 001, 010, 011, 100, 101, 110, 111. Schematic as shown in figure (1).

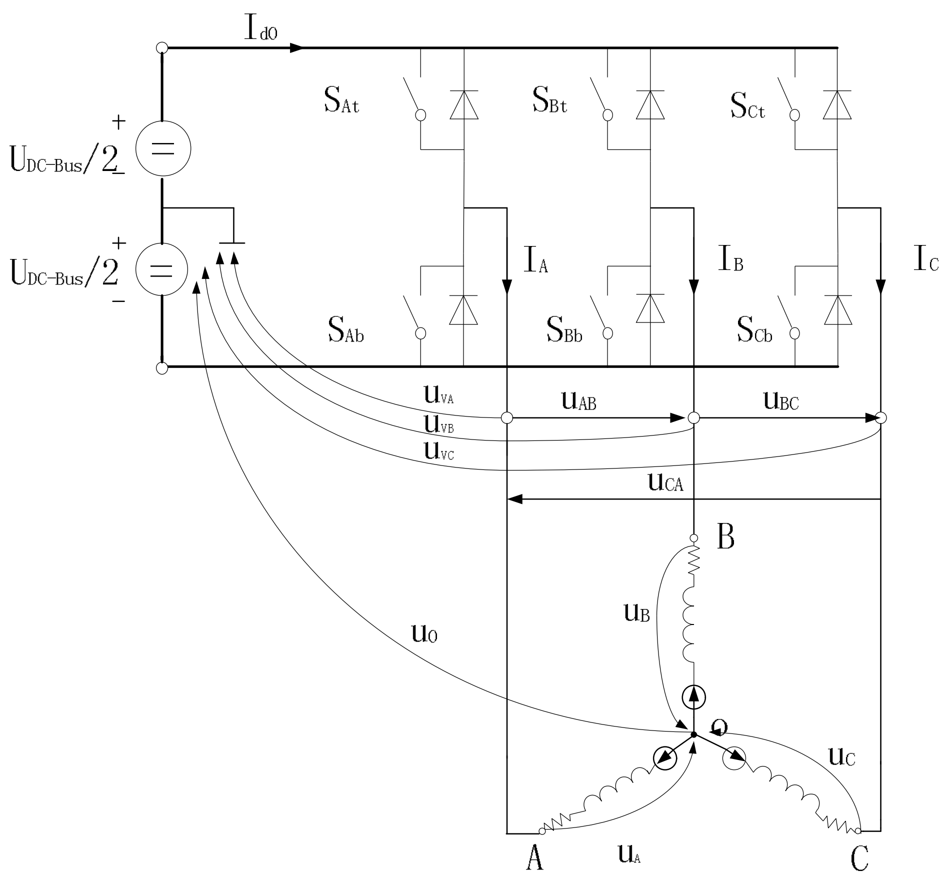

Fig. 1 principle of space vector pulse width modulation inverter

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The power tube of top and bottom work in a complementary mode, if the upper tube S_{At} is "1",the S_{Ab} corresponding is "0"; in the space vector pulse width modulation, eight voltage vector synthesize a resultant vector, of which there are two zero vector. As shown in Figure 2, a period can be divided into six sectors, each of the adjacent two sectors between the angle is 60^o, the middle point of sector,(000) and (111) represent the zero vector.

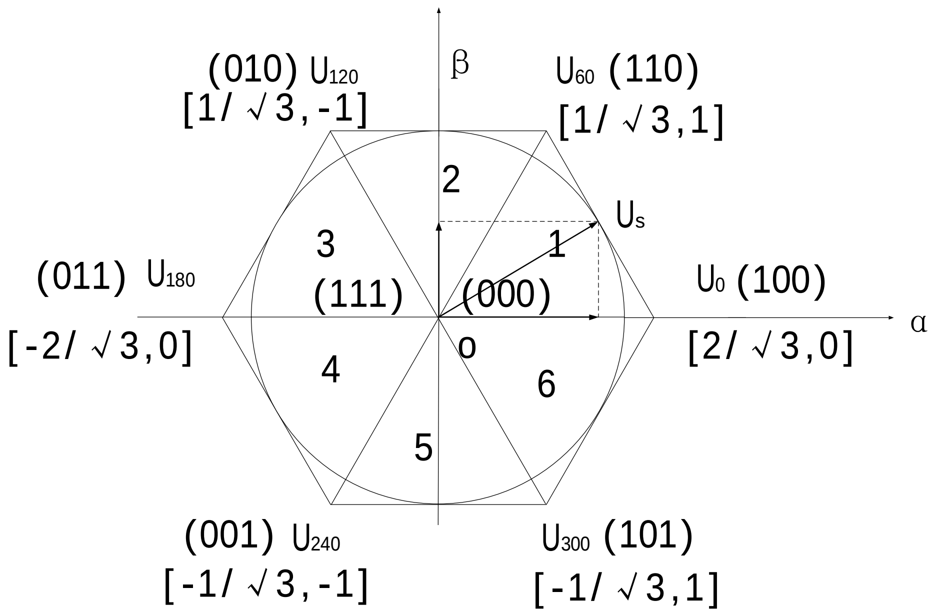

Fig. 2 Diagram of voltage vector

2.3 construction of vector control system for permanent magnet synchronous motor

The characteristic of the vector control algorithm is to control the stator current(i.e.,control i_d $i_q$and) to realize the torque control. The system control i_d and i_q by two PI controllers and the system structure is shown in figure 3.

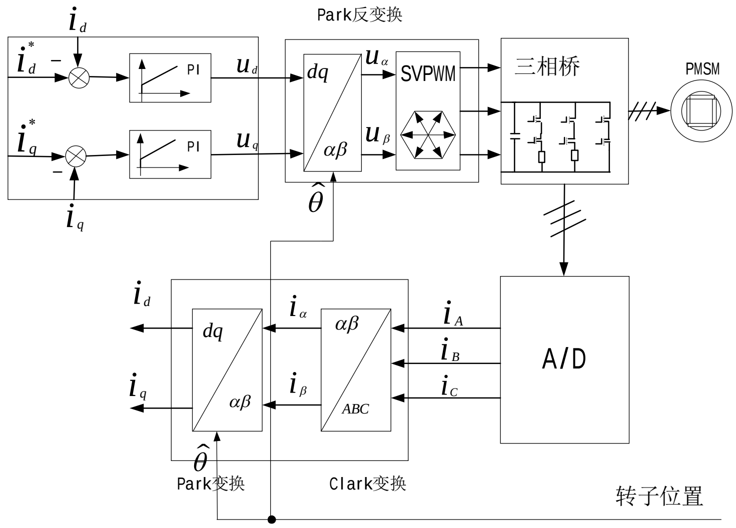

Fig. 3 FOC control's structure

It can be seen from Figure 3, to achieve permanent magnet synchronous motor vector control need the AD sampling to obtain two-phase current, and through the back electromotive force to estimate the rotor position and speed, then according to the location of the rotor determine i_d and i_q ,and through the two PI regulator to adjust.

3. Design of motor control state machine

The whole process that the motor from starting to the open loop,then to the closed-loop is all based on the state machine to achieve, the state machine uses a two-dimensional array function pointer state_table[][] (). The first parameter describes the current event, and the second parameter describes the program state. Figure 4 shows the principle of the state machine.

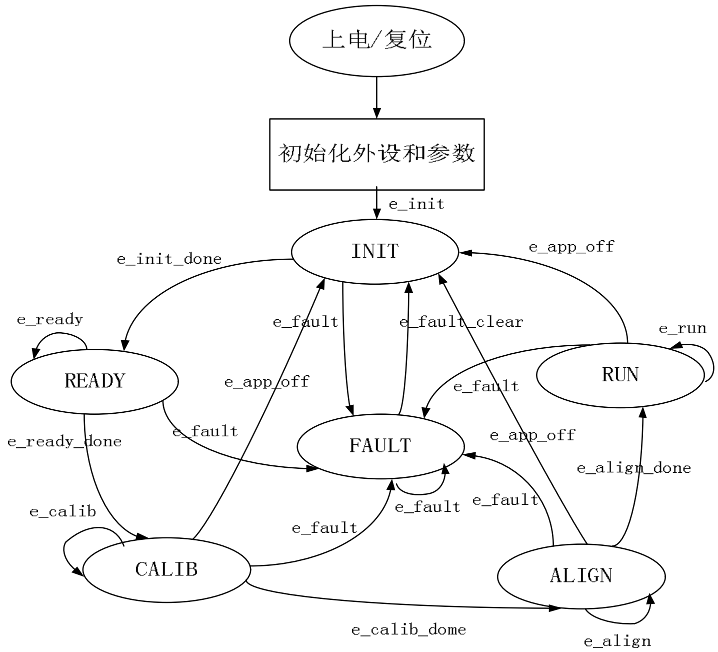

Fig. 4 principle of the state machine

As shown in Figure 4, the FAULT state can be entered from any other state, and when the program detects an error, it will jump to the FAULT and shutdown PWM. When the program detects over voltage, under voltage, over current or over temperature, it will enter this state.

In INIT state, it will initialize the state machine and some parameters of vector control algorithm , including the parameters of the PI regulator. After the completion of INIT,READY will be executed as the next state.

After entering the READY state, through the detection of the PWM's duty cycle, to determine whether the motor is started, if the start is effective， then set the corresponding speed. It will set to the corresponding flag after the end of READY's execution, and enter the next state ,namely CALIB. In the CALIB state, the PWM is output according to 50% duty cycle, ADC0 and ADC1 started to work, it can calibrate the sampling of ADC in this state, after the calibration will enter a state of ALIGN and set the corresponding flag.Since the permanent magnet synchronous motor in use is without position sensor, don't know the specific position of the motor at first. In the ALIGN state, the voltage is applied directly to the A phase for a period of time, the rotor will rotate until the rotor flux and the stator flux are aligned.When the alignment status is completed, the corresponding flag is set and enter the running status.

Figure 5 shows the flow chart of the running state of the permanent magnet synchronous motor, the corresponding flag is reset when the program is in the RUN state, just enter the RUN state rate is too low, can not produce enough the back EMF to recognize, so the motor will enter into an open loop mode, its location in this mode is not known, only use the corresponding acceleration formulas to make motor reaches a certain speed to identify the information of specific position, when it is enough to identify the information of specific location,the motor convert from open-loop to close-loop,then start to execute the FOC algorithm processing and back EMF observation Device in the close-loop mode.

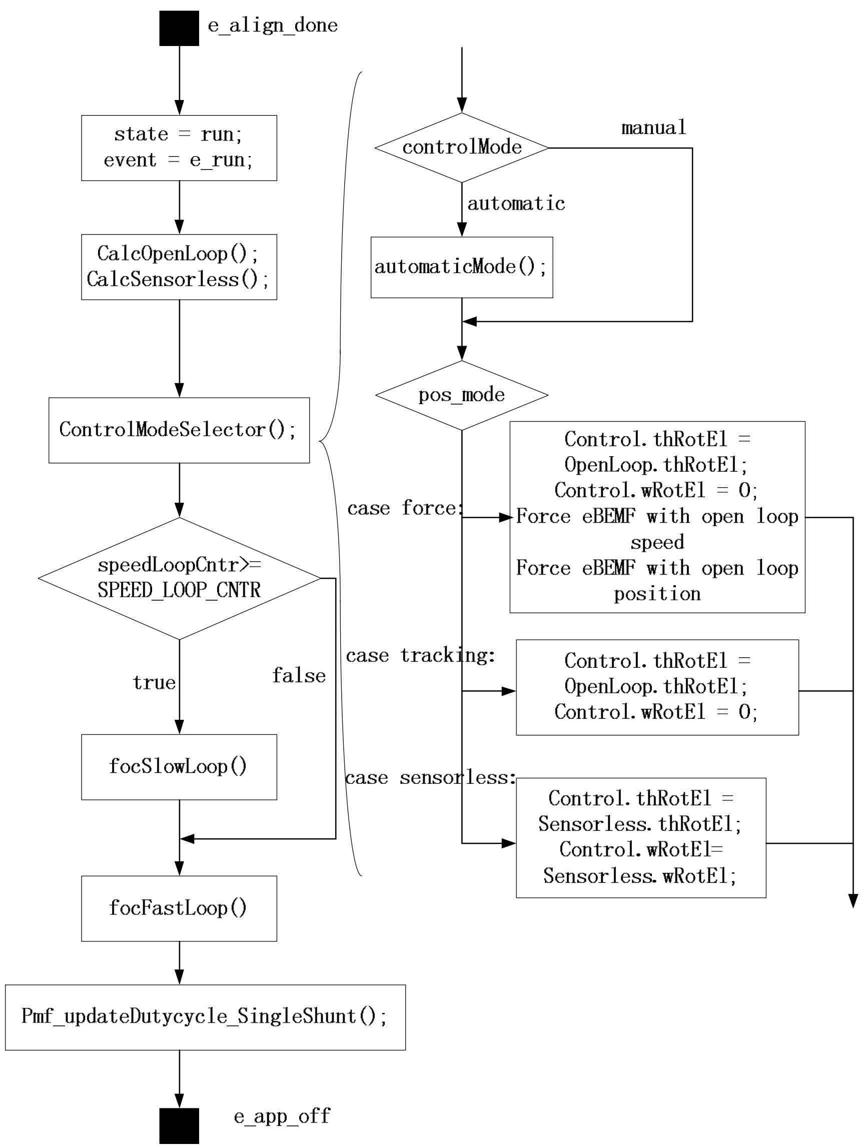

Fig. 5 flow chart in RUN state

In Figure 5, you can choose a different way of working,when choosing manual mode,the each process of motor's starting can use FreeMASTER to send commands to achieve the control of closed-loop,if select the automatic mode,it will control the whole process automatically by software, so choose the automatic mode in practical application.

4. Position detection based on back EMF

When the rotor rises to a certain speed, it can detect the back EMF,the rotor position information of permanent magnet synchronous motor is contained in the motor's stator voltage and current signals, so by accurately detecting the stator voltage and current signal and using the mathematical model and vector transform, can get the rotor position information, and then obtain the information of speed estimation. In this paper, the position and velocity of the rotor are estimated by referring to the Luenberger observer. The estimation of back EMF as shown in Figure 6, Luenberger stator current observer is the back EMF (BEMF) filter.

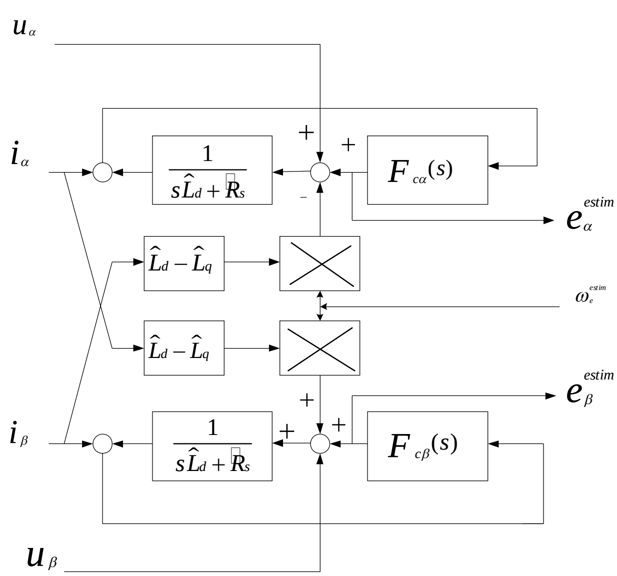

Fig. 6 Luenberger current observer

5. Achievement of FreeMASTER through the calibration of CAN bus

The calibration is through the PC software to modify the controller parameters online to confirm the optimal parameters, in automotive electronics, commonly use CAN bus as the communication mode of the calibration, used in this study is CAN communication and FreeMASTER 2.0 as the calibration software on the PC side, in addition, the FreeMASTERr bottom-driven need integrating with the software. So that you can read and write any variables in the microcontroller, including the value of the register, etc..

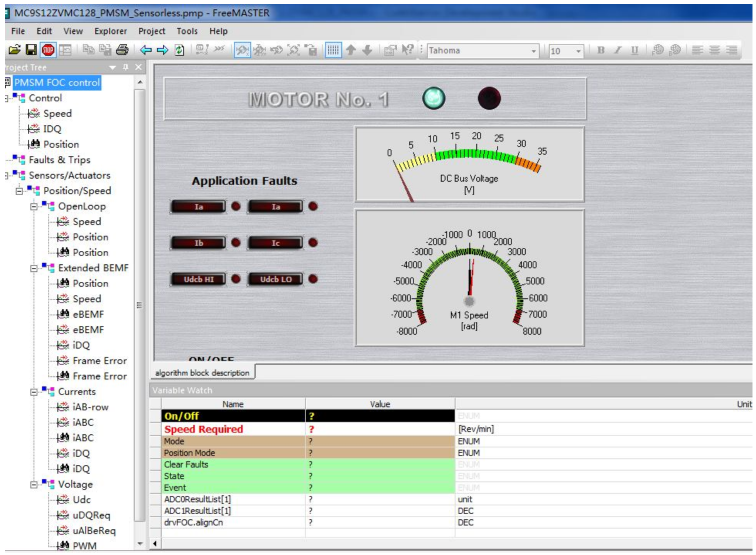

Fig. 7 FreeMASTER 2.0 PC debugging interface

Figure 7 is a FreeMASTER 2 PC debugging interface,in order to achieve online calibration not only need the software, but also need to integrate the underlying code of FreeMASTER into the project, the underlying code of FreeMASTER support SCI, CAN, BDM communication, by configuring the corresponding interface function and initializing parameter function can achieve online calibration through CAN bus.

6. experimental results and analysis

As shown in Figure 8 is FreeMASTER2.0 debugging interface, through the set, it can display all the data variables used in motor debugging, can also put specific variables according to the proportion into the curve tool to view the variables' change so that make it convenient that observing PI adjustment and other variables change. The interface shows whether the motor break down when it is running, as well as the change of the bus voltage, the analog dial display speed, you can see the bus voltage is 12V, the speed as the same as the set 944 RPM.

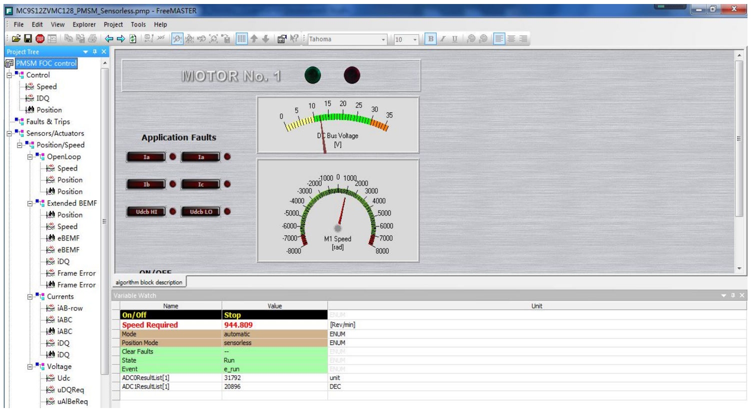

Fig. 8 FreeMASTER2.0 debugging interface of permanent magnet synchronous motor

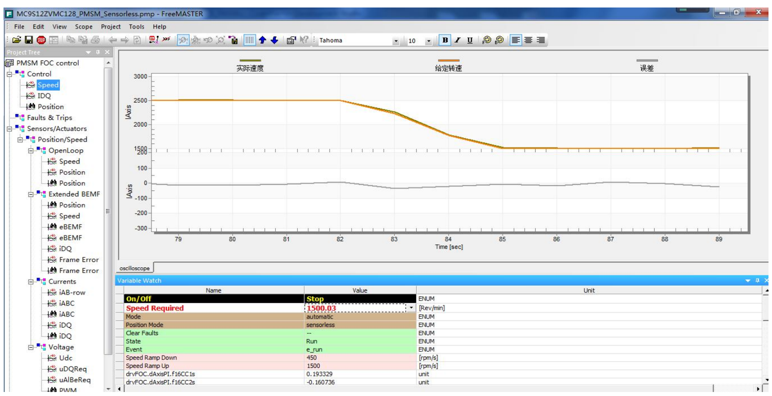

Fig. 9 curve of reaction time

In Figure 9, the orange curve is a given speed, the brown is the actual speed, the gray is the speed error, it can be seen from the figure, the error of the speed is relatively small, the given speed and the actual speed is basically synchronized. Figure 10, 11 are respectively experimental fan PMSM and controller, the controller eliminates the traditional gate drive, simple structure, volume is shrunk.

Fig. 10 fan used in experiment

Fig. 11 the controller of the fan

As can be seen from the figure, MC9S12ZVMC128 in the automotive electronic PMSM control system, making the entire system circuit is more simple. In addition, the system can not only realize the vector control of non-position sensor PMSM, can also use BLDC six step square wave control method to control non-position sensor Brushless DC motor, with the hands of the resources,successfully achieve the control of oil pump, water pump, fan brushless motor (PMSM or BLDC).

7. Conclusion

According to the relevant technical documents of NXP, based on a large number of domestic and foreign related data, design a vector control system of permanent magnet synchronous motor based on MC9S12ZVMC128, after repeated failures and try, achieve vector control system of new energy automobile fan with permanent magnet synchronous motor, the test run results achieved the requirements of the subject. The content completed in the design process as the following:

(1) come to know the development of permanent magnet synchronous motor (PMSM) and the application of permanent magnet synchronous motor (PMSM) in the field of automotive electronics at the present stage by some domestic and foreign references. By studying the basic principle and mathematical model of permanent magnet synchronous motor, the control strategy of permanent magnet synchronous motor (PMSM) is more deeply understood.

(2) The design of controller software architecture is described in detail, using the state machine model to control the motor running in different stages, including start-up stage, motor open detection and treatment of closed loop phase and fault ring stage, etc...The experimental results show that, with the NXP MC9S12ZVMC128 hardware platform, using vector control algorithm, permanent magnet synchronous motor can operate efficiently and stably, give full play to the role of MC9S12ZVMC128 in the electronic field of the advantages of new energy vehicles.

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