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# HIGH INTEGRATION BRUSHLESS DC MOTOR CONTROL SCHEME FOR NEW ENERGY VEHICLES

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## Abstract:-

*With the factory to power consumption, efficiency, noise, electromagnetic compatibility requirements gradually increasing, brushless dc motor will be more and more widely applied in the new energy electric cars. The paper propose the improvement of the freescale to provide a high level of integration solutions - S12ZVM mixed-signal MCU series and introduce the detail sensorless brushless dc motor control scheme implementation. Based on the freescale semiconductor MC9S12ZVML128 dedicated to auto motor control chip, combining with the FreeMASTER monitoring software user interface, build high integration brushless dc motor control experimental platform. The experimental results show the applicability and advantage of S12ZVM series control scheme on the new energy automobile motor control.*

**Key words: -** *Brushless DC motor; S12ZVM; High integration control scheme*

**CLC number: TP217**

## 0 INTRODUCTION

Motor has been used in all walks of life, according to statistics, in 2013, a total of 10 billion motors were produced, of which 25% were used in the automotive field, with an average of 30 motors per vehicle. These motors constitute various applications in automobiles, such as window motors, wiper motors, skylights, air conditioning blowers, oil pumps, water pumps, engine cooling fans, and so on. They have various applications [1-2].

Traditional motor control uses discrete device scheme, which may be possible in other industrial occasions, but when applied to the field of new energy vehicles, control hardware will occupy extra space. For the control of brushless DC motor, it is hoped that the size of PCB is small, the cost of BOM is low, the hardware is simple and reliable, and the power consumption is low, etc.[3-4]. In response to this series of requirements, Freescale Semiconductor introduced a single chip control S12ZVM solution for three-phase brushless DC motor of new energy vehicles. This scheme greatly simplifies the hardware design because of its highly integrated characteristics.

In order to verify the reliability of this scheme, based on the MC9S12ZVML128 chip of Freescale Semiconductor dedicated to automotive motor control, combined with Codewarrior 10.3 development environment and FreeMASTER user interface, a highly integrated sensorless brushless DC motor control platform is simply built. The experimental results verify the reliability and practicability of S12ZVM series solutions.

## 1 S12ZVM Chip and Its Characteristics

Firstly, by comparing the discrete device scheme with the S12ZVM scheme, we can see that the discrete device scheme includes MCU, op-amp, LIN trigger, and precursor and so on. The scheme of S12ZVM is equivalent to integrating these analog parts and MCU parts into one chip, which greatly simplifies the hardware design. The size of the S12ZVM control board is very small. Only the S12ZVM and MOS tube can significantly reduce the PCB space, reduce the welding points and meet the specific design application [5].

Secondly, S12ZVM adopts SafeAssure project, and its hardware design is developed in accordance with ISO26262. There are many applications for safety, such as Voltage/clocks monitoring, Memories w/error and Windows Watchdog. The chip design is based on the Safety Process process. In addition, it also provides FIT rates, Dynamic FMEDA, Safety manual and Technical support as required. With regard to Safety Software, S12Z provides kernel detection and can be used as a self-test function [6].

## 2 Sensorless Control Scheme of Brushless DC Motor

### 2.1 Hardware Solution

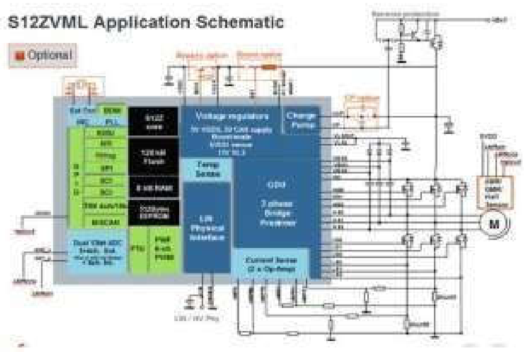


**Fig.1 Typical application schematic of S12ZVML**

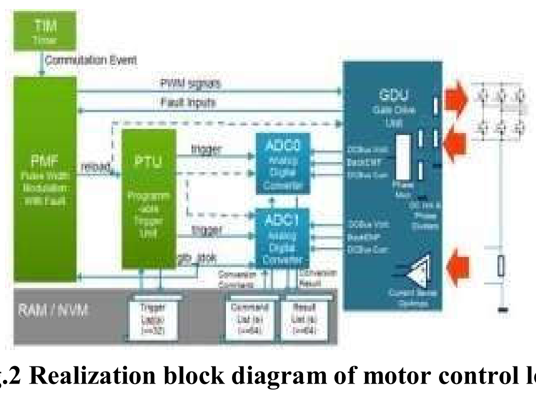


**Fig.2 Realization block diagram of motor control loop**

The typical application schematic diagram of S12ZVML is shown in Fig. 1, and the hardware implementation block diagram of motor control loop is shown in Fig. 2. CPU is involved and interrupted in the motor control cycle. PMF module, which is related to motor, is a fault protection module of pulse width modulator. It consists of six channels, based on three 15-bit counters, which can operate at the core clock frequency (up to 100MHz, maximum). The channel can be driven independently (up to 6) or in pairs (up to 3). Complementary operations include insertion dead time, independent top and bottom pulse width correction, and polarity control. The module can flexibly configure different edge or center alignment, refresh rate is 1 ~ 16PWM cycle, and has programmable fault protection function.

Other hardware peripherals include: three 15-bit counters based on the core clock (maximum 100MHz); separated top and bottom pulse width correction; asymmetric PWM output (phase shift) in central alignment mode; half-cycle overload capability; six-step BLDC support restart from the timer output; refresh overflow interrupt; PWM output polarity control; and PWM output polarity control. Sexual control. Both ADC converters and 2 sampling and holding units are integrated into the S12ZVM device, which improves the accurracy control algorithm. A total of nine external channels can be measured with two ADCs, and these channels share the output of the operational amplifier internally. In addition to these, there are several internal channels connected to two temperature sensors, a bandgap reference voltage measurement calibration, motor phase voltage, DC bus voltage or power supply voltage multiplexer. The conversion can be triggered manually or automatically by the trigger unit, 32 times per control cycle. The converted commands and results are stored in a double buffer list, which can have up to 64 commands or results, enabling the CPU to update the ADC buffer. This command can be stored in Flash or RAM and is an organized sequence. The core of ADC is a switched capacitor DAC based on a 12-bit successive approximation algorithm. 12-bit plus 480ns programmable sampling time with conversion time of 1.8 mus. The trigger unit can preset ADC conversion in a PWM control cycle, which is synchronized with the overload signal of the PWM module. It is a relatively simple 16 bit counter, which starts to count synchronously with the PWM cycle. Once the trigger value equals the trigger signal of the counter value, it executes to the linked ADC. The PWM control cycle is selected as the duration of two PWM cycles, which means that the overload signal of each two PWM cycles is output as a synchronous signal to other peripheral devices to be activated. The GDU part, Gate Driver Unit, deals with external MOS tubes. The 11V voltage regulator is used to provide a low-side driver. Meanwhile, the charging bootstrap capacitor will drive the high-side driver.

### 2.2 Software Solution

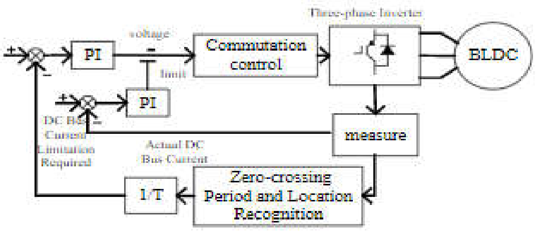


**Fig.3 Speed control block diagram with current limitation**

Figure 3 shows the structure of the sensorless brushless DC motor software control scheme, which includes BEMF acquisition and zero-crossing detection to control commutation. The motor speed is predicted according to the zero-crossing time period. The difference between the required speed and the expected speed will be fed to the speed PI controller. The output of speed PI controller is proportional to the voltage applied by BLDC motor. The motor current is measured and filtered during the BEMF zero-crossing event and transmitted to the current controller as feedback. The output of current PI controller limits the output of speed PI controller. The output of the speed PI controller can protect the motor from exceeding the allowable maximum motor current.

In this paper, MC9S12ZVM motor control peripherals are optimized to minimize the kernel's involvement in state variable acquisition and output operation applications. Motor control peripherals (PMF, PTU, ADC, TIM and GDU modules) work independently of the core, and realize the acquisition of time analog quantities and the accurate commutation of the stator magnetic field. The software part of the application includes different modules. The whole application behavior is controlled by a PC using FreeMASTER tools.

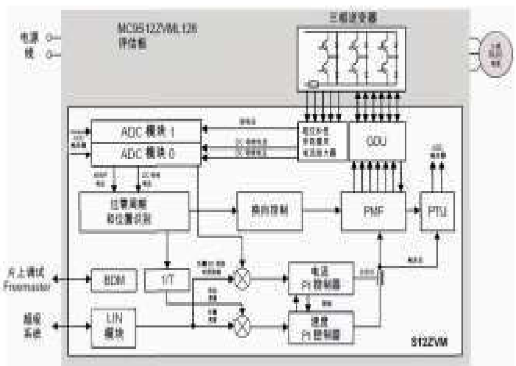


**Fig.4 System block diagram**

The block diagram shown in Figure 4 is an overview of the software control module. The top box shows the power part; the bottom half of the picture shows the functions implemented in the S12ZVM software. In the power part, the phase current is measured by a system based on single resistance. The module is implemented by software and the motor control library (MCLib) is used.

In the control view, the structure block diagram is divided into two logical parts: commutation control, phase voltage and DC bus voltage used to calculate the actual position of the axis. According to the position obtained, the next commutation event can be prepared; speed/torque control, the required axle speed will be compared with the actual measured speed, and adjusted by PI controller. The output of speed PI controller is duty cycle. The duty cycle is limited by current PI controller and applied to PWM. The application is controlled by a real-time debugging tool, FreeMASTER. FreeMASTER communicates with S12ZVM devices through BDM or SCI peripherals.

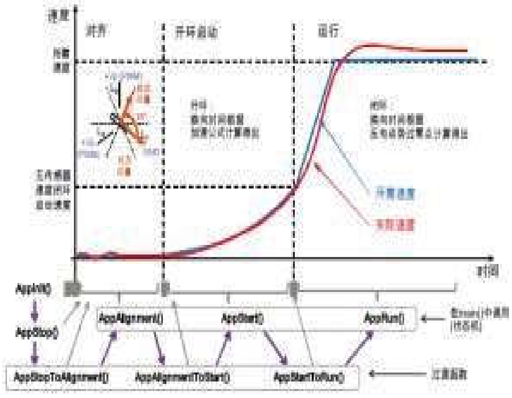


**Fig.5 Application state flow**

Fig. 5 is the application state flow, which corresponds to three main states of the application software: alignment state, open-loop start-up state and operation state [7-9]. In the operation state, the BLDCM is completely controlled in the closed-loop sensorless mode.

After initialization of peripheral module is completed, the software will enter alignment state. During alignment, the rotor position is stabilized to a known position to create the same starting torque in two rotating directions. This is achieved by using PWM to phase A and phase B. Duty cycle is calculated by alignment PI controller. In addition, the duty cycle of phase C equals zero; that is to say, phase C is connected to the negative pole of the DC bus. The duty cycle of phase A and phase B depends on the inertia of the motor and the load applied to the shaft. This technique will align the axis with C, and the two flux vectors generated by the C phase and the stator winding are orthogonal, so that the same starting torque can be ensured in both rotating directions. The duration of alignment depends on the electrical and mechanical constants of the motor, the applied current (duty cycle) and the mechanical load.

When the alignment timeout arrives, the application will switch to open-loop startup. At very low axle speed, BEMF voltage is too low to reliably detect zero-crossing points. Therefore, the motor must be controlled in open-loop mode, and maintain a certain period of time. The first vector generated by the stator winding needs to be set at 90 degrees with the flux vector generated by the magnet installed on the rotor. The alignment and the first startup vector are shown in Figure 5. The duration of open-loop start-up state is determined by the number of open-loop commutations. The number of open-loop commutation depends on the mechanical time constant (including load) of the motor and the applied motor current. After the open-loop start-up, the shaft speed is about 5% of the rated speed. At a speed of about 5% of the rated speed, the BEMF voltage is high enough to reliably detect zero-crossing points.

After a fixed number of commutation cycles, the state changes from open-loop start-up state to operation state. Thereafter, the commutation process based on BEMF zero-crossing measurement will occur, and the control will enter the closed-loop mode.

**3 High Integration Experimental Platform**

Fig. 6 gives the physical diagram of the sensorless brushless DC motor control experimental platform based on MC9S12ZVML128 chip. The physical diagram shows that the system platform is particularly simple. It consists of three parts: brushless DC motor, three-phase inverters composed of six MOS transistors and S12ZVM control board. The three-phase inverters are directly integrated with the main control board, which simplifies the control platform. The brushless DC motor is replaced by a small sensorless pump provided by the company.

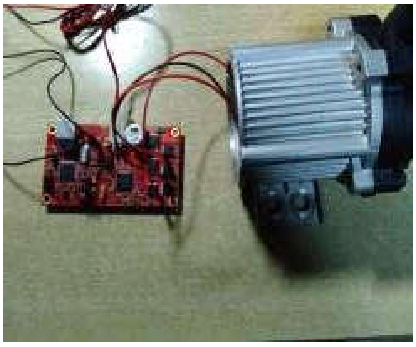

**Fig.6 High Integration Sensorless Brushless DC Motor Experimental Platform**

## 4 Experimental results and analysis

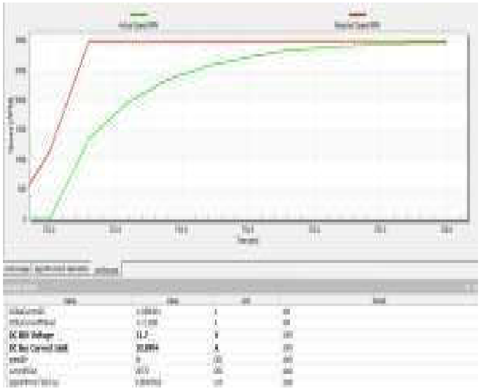

**Fig.7 Given and Actual Speed Curves**

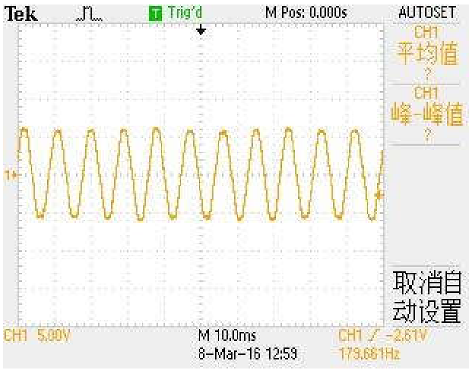


**Fig.8 Back EMF Curve without Electricity**


**Fig.9 Back EMF Curve at Power-on**

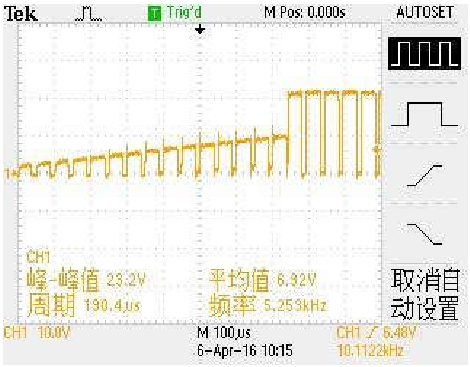


**Figure 10: Back EMF Local Amplification Curve at Power-on**

Figure 7 shows the contrast curve between real-time speed and given speed of brushless DC motor shown by FreeMASTER, which shows that there is no overshoot and no steady error of speed; Figure 8 shows the back EMF curve of manual rotating rotor when the brushless DC motor is not powered on, approximating trapezoidal wave; Figure 9 and Figure 10 show the back EMF curve when the brushless DC motor is running on, and the waveform can be divided into commutation phase and normal on by the local amplification diagram. In the electrical stage, the actual waveform accords with the theoretical analysis.

## 5 Conclusion

This paper introduces in detail the application advantages of Freescale S12ZVM hybrid integrated chip in brushless DC motor control of new energy vehicles. Based on the MC9S12ZVML128 chip of Freescale Semiconductor dedicated to automotive motor control, combined with FreeMASTER user interface monitoring software, a high integration control experimental platform for sensorless brushless DC motor is built. The sensorless control experiment of brushless DC motor is completed and the experimental results are analyzed. The experimental results prove that the highly integrated control scheme is applied to new energy vehicles. Superiority.

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