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FM4

PMSM Servo Motor Speed Control On FM4 MCU

32-bit ARM Cortex-M4F based Microcontroller MB9BF568x Series and S6E2HG Series

APPLICATION NOTE

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1. Introduction

1.1 Purpose

This document describes servo motor control on SPANSION FM4 series MCU, including whole system scope, hardware design, software design and results.

FM4 MB9BF568x series and S6E2HG series MCU are all supported.

1.2 Definitions, Acronyms and Abbreviations

GUI	Graphics User Interface
HW	Hardware, at this document it means Invertor platform hardware board
FW	Firmware

1.3 Document Overview

The rest of document is organized as the following:

Section 2 explains PMSM Control Theory.

Section 3 explains System Scope.

Section 4 explains Hardware Design.

Section 5 explains Software Design.

Section 6 explains Results.

2. PMSM Control Theory

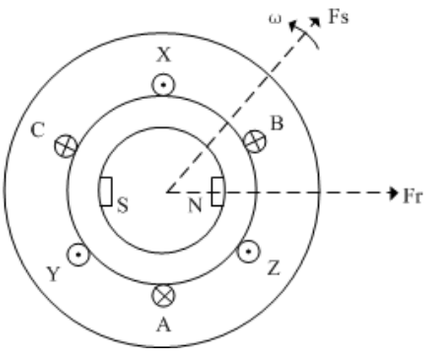
2.1 The Structure of a 3-Phase PMSM

A 3-phase PMSM is mainly composed of two parts: the stator and the rotor.

At stator side, the 3-phase windings are coiled on the stator core. The windings of 3 phases are separately placed by the rule of 120 degrees angle to generate a round rotating magnetic field (Fs) when a 3-phase AC current goes through the 3 phase windings. The separated 3-phase winding placed by the rule of 120 degrees angle is named as 3-phase symmetric winding.

At rotor side, one or more pairs of permanent magnetic poles are mounted to offer a constant rotor magnetic field (Fr).

Figure 2-1: Structure of a 3-phase PMSM

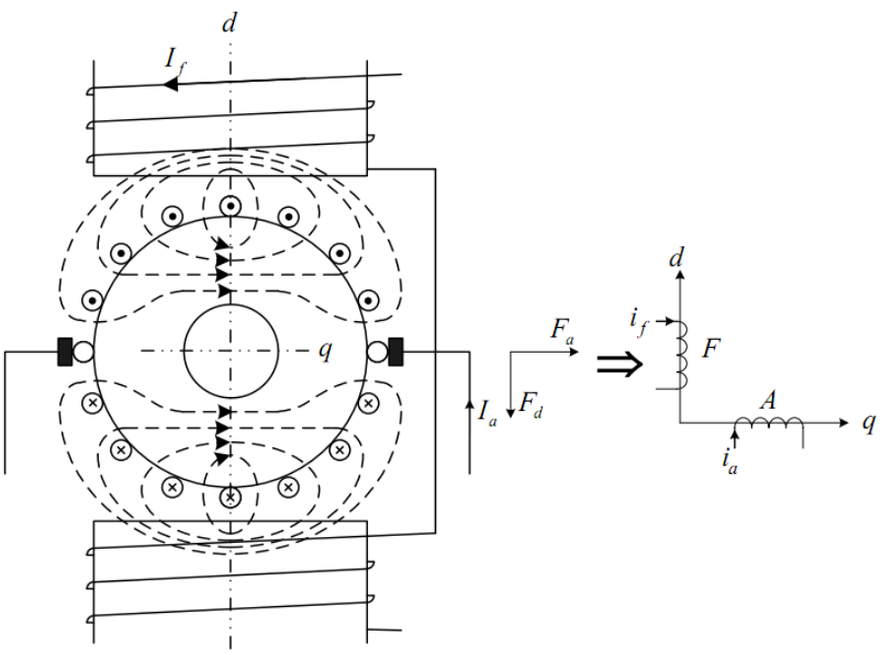


Because Fs is a rotating magnetic field, the Fr will be dragged and follow the Fs. If the Fr cannot catch up with Fs, the rotor will rotate continuously. If the 3-phase current in 3-phase windings disappears, the Fs will disappear at the same time, and the rotor will also stop.

2.2 FOC Principle

Brush DC motor is a conventional DC motor with a long history. A big advantage of the brush DC motor is that its torque control and magnetizing control are decoupled, which makes brush DC motor is easy to control. The brush DC motor de-coupled control is shown in below figure.

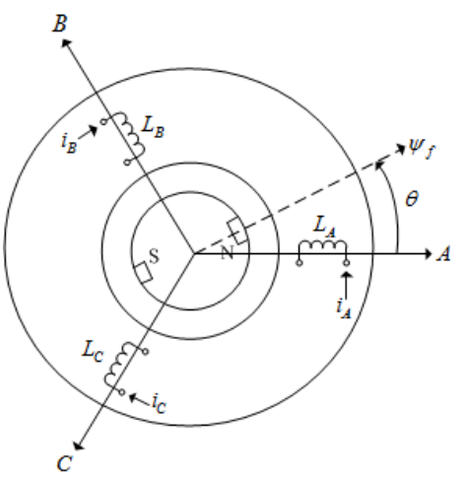
Figure 2-2: Brush DC Motor De-coupled Control



The magnetizing is controlled by magnetizing current (I_f), and the torque control is controlled by torque current (I_a). The direction of the magnetizing magnetic field is parallel with d-axis (vertical direction), and the direction of the torque magnetic field is parallel with q-axis (horizontal direction). So these two magnetic fields do not influence each other. That is to say, it is decoupled between the 2 magnetic fields and motor's magnetizing and torque can be adjusted individually. For example, the torque control formula is $T_e = C_m \emptyset I_a$, which means torque is only controlled by torque current I_a.

The condition of PMSM motor control is much more complex than a brush DC motor. The magnetic field of a 3-phase symmetry winding is a coupled magnetic field. We can discover the complex coupled relationship from the torque control formula.

Figure 2-3: The Coupled Magnetic Flux of a PMSM



$$T_e = \frac{1}{2} n_p [I_{ABC}]^T \frac{\partial [L_{ABC}]}{\partial \theta} [I_{ABC}] \ldots (3.1.1-1)$$

$$[L_{ABC}] = \begin{bmatrix} L_A & M_{AB} & M_{AC} \\ M_{BA} & L_B & M_{BC} \\ M_{CA} & M_{CB} & L_C \end{bmatrix} (M \text{ is mutual inductance}),\ [I_{ABC}] = \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$

From the expression of Te, it is easy to understand that the torque is determined by all 3-phase inductances (including self-inductance and mutual-inductance) and currents. Obviously, the torque control seems much more complex than a brush DC motor.

Coordinate transformation is just the way to simplify the PMSM torque control. By coordinate transformation, a PMSM control model is converted from A-B-C coordinate to d-q coordinate. The torque control formula is also converted into d-q coordinate, the formula is:

$$T_e = \frac{3}{2} n_p \psi_d I_q \ldots (3.1.1-2)$$

The simple formula in d-q coordinate makes the PMSM torque control as easy as a brush DC motor.

2.3 FOC Control Structure

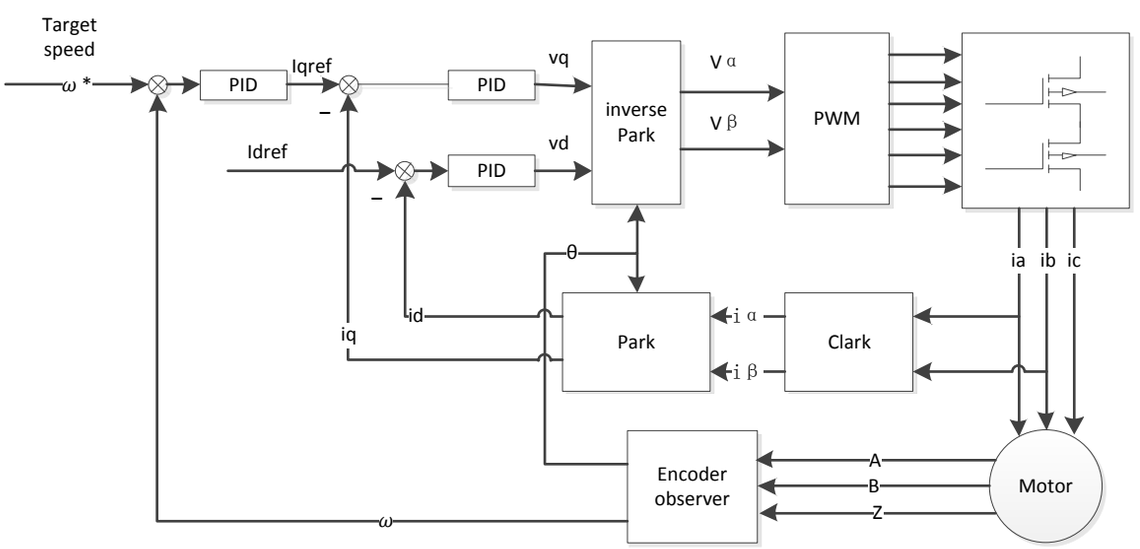
From the explanation above, key of FOC is to make the torque control of PMSM as easy as a DC brush motor through a motor rotor magnetic field orientation technology. In the technology, the coordinate transformation method turns the motor module from the u-v-w coordinate to the rotational d-q coordinate, and the d-q coordinate rotational speed is the same as the stator magnetic field rotational speed. Then the control of a PMSM is simplified and the control performance is almost the same a DC brush motor.

Some PID regulators are added to adjust the motor output according to the given input. By setting different PID parameters, system gets different dynamic and static performance.

SVPWM technology is applied to accept the driving voltage in α-β coordinate and output a set of switching instruction to control the 6 switches in full bridge inverter.

Position and speed estimator is used to observe the real time motor speed by the motor driving voltage and current. The estimated motor speed compares with the expected speed, and the compare result acts as the input of the speed PI regulator. The estimated rotor position angle is used by the coordinate transformation unit.

Figure 2-4: FOC Control Diagram



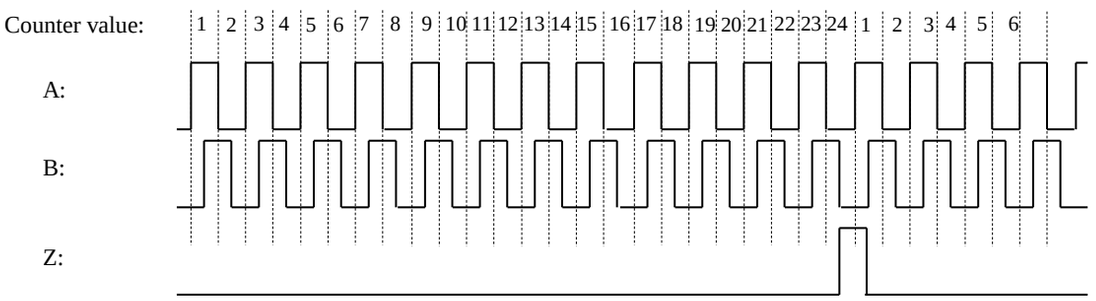
2.4 Incremental Encoder Introduction

Quadrature position encoder contains two types of signal: quadrature-phase signal A and B, and zero-match signal Z.

Z-signal comes out every mechanical cycle. It is used to calculate cycles of rotation or correct estimated motor position.

By integration of A or B pulses, motor position is estimated. Encoder peripheral is integrated in MCU MB9BF568R to count A or B signal. A and B indicate the position of rotor, and their frequency is related to the precision of position.

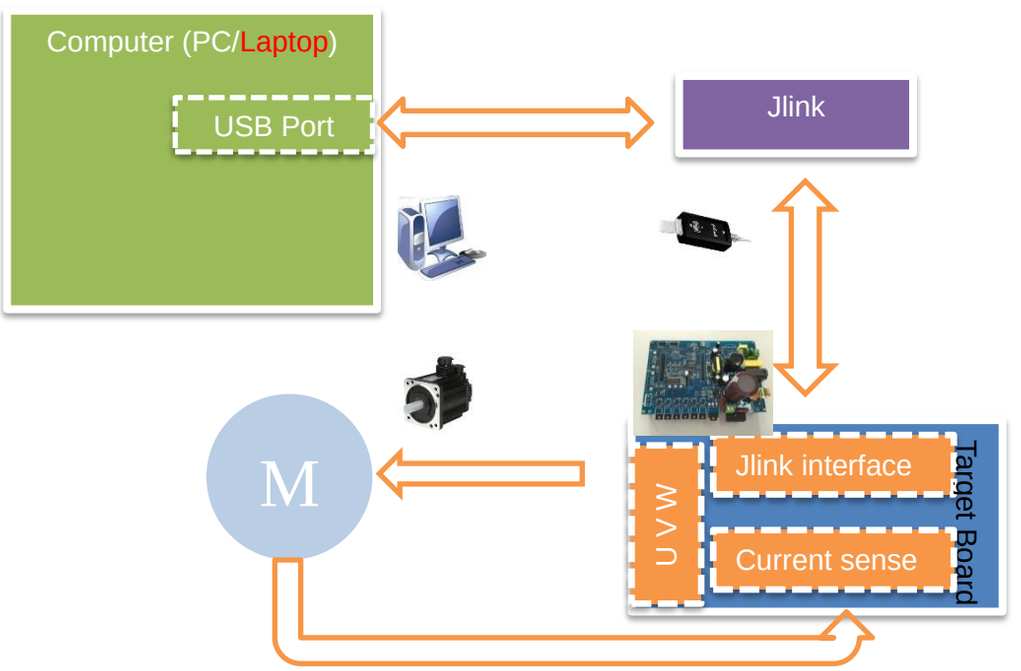
Figure 2-5: Encoder Signal



3. System Scope

This chapter describes the driving system of 3-phase permanent magnet synchronous motor. The system structure and driving performance is shown below

Figure 3-1: System Structure



- MB9BF568X and S6E2HG is the target controller with configured 160MHZ main clock and 80MHZ all bus clock.
- Motor combines incremental encoder with 360 pulses per cycle.
- The following is the whole system specification
  - Three-phase hall current sensor for sampling
  - Fully high and low voltage supplier separation.
  - Auto Z-signal position detection
  - Wide speed range: 100rpm ~ 3500rpm
  - Rapid speed acceleration within 200ms from 0rpm to 3500rpm.
  - Rapid speed deceleration with in 300ms from 3500rpm to 0.
  - Field-weaken do not implement in this system.
  - Accurate speed controlling with less than 1% target error.
  - Bi-directional rotating.
- Firmware development environment
  - Windows XP or above
  - IAR 7.3

4. Hardware Design

Hardware design for servo motor control is different from normal motor control hardware. Servo motor is applied to industrial control.

For documents about hardware, please refer to hardware design application note.

Here gives some specification about hardware.

- AC-DC power supply
- Three-shunt current sample
- Support J-LINK connection
- Combine hall sensor interface (HA , HB, HC, 5V, GND)
- Combine encoder interface(AIN, BIN,ZIN, 5V, GND)
- IPM for motor drive

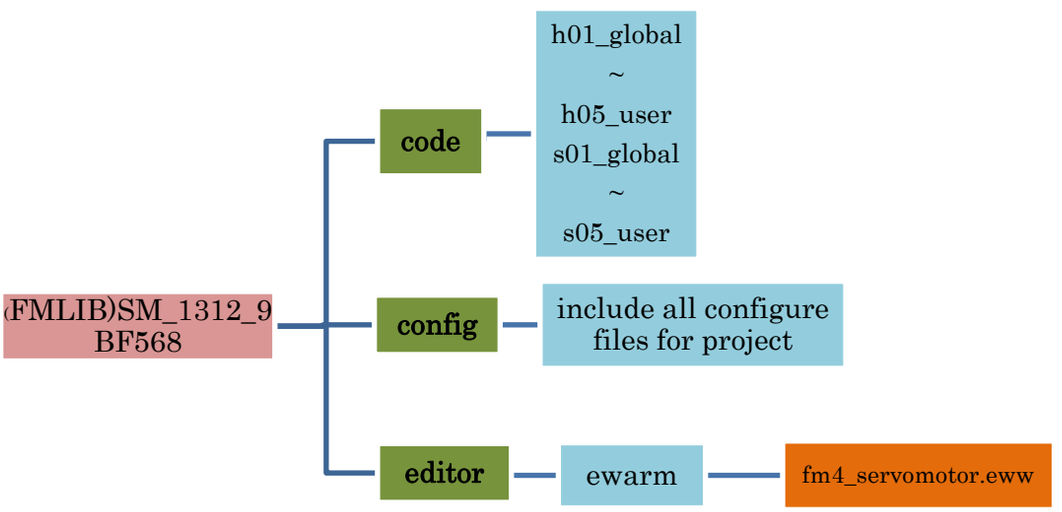
5. Software Design

This chapter describes servo motor speed control implementation. Firmware version, firmware structure and control process are explained respectively.

5.1 Firmware File Structure

The following figure shows firmware file structure.

Figure 5-1: Firmware File Structure



Firmware contains three sub-folders: folder code, folder config and folder editor.

All source codes are stored in folder code including head-files and c-source files.

Configuration files and MCU description files are stored in folder config.

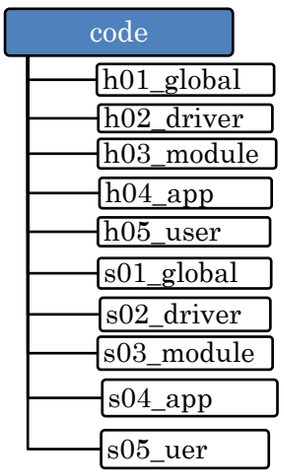
Double click on file “FM4_ServoMotor.eww” to open project.

- **Code Folder Introduction**

Source codes are divided into five different types by function and stored in five different folders.

Five layers are named “global”, “driver”,” module”, “app” and “user” respectively.

Figure 5-2：Structure in Code Folder



Global layer is empty.

Driver layer stores MCU header file and macro definition files.

Module layer stores independent functions.

App layer is related to actual project. Function in this folder is changeable depending on different system.

User layer is open to customer for configuration and debugging.

5.2 Control Implementation

This chapter explains peripherals and interrupts used in firmware firstly, and then control process flow.

5.2.1 Peripherals in Firmware

All peripherals used in firmware are configured in “init_mcu.c” stored in folder “s05_user”.

Details on peripheral initialization can refer to MCU datasheets.

Table 5-1:Peripherals Used in Firmware

Peripherals	Function in firmware
Clock	Configure system main clock and bus clock
NVIC	Enable or disable interrupts, configure priorities
QPRC	Count encoder signal pulses to detect motor position
Base timer	Measure the width of encoder signal to calculate motor current speed
Adc	Be used to sample phase current, ADC unit 0 is being used.
Multi-function timer(MFT)	Generate PWM signals to control 3 half-bridge to drive motor running. MFT unit 0 is being used.
Watch dog	Reset MCU when program goes wrong

- Clock setting

  SCM_CTL: System clock mode control.

  BSC_PSR: Base clock mode control.

  APBC0_PSR: APB0 prescale register.

  APBC1_PSR: APB1 prescaler register.

  APBC2_PSR: APB2 prescaler register.

- NVIC setting

  NVIC_SetPriority(IRQn, x): priority setting

  NVIC_EnableIRQ(IRQn): enable priority.

IRQn: irq number.

X: indicate priority number

- QPRC setting

  PC_Mode2 and RC_Mode0 is selected.

  QCR: QPCR control register

  QICRL: QPCR interrupt control register

- Base timer setting

  PWC function is selected in this firmware.

  TMCR: Timer control register.

  STC: Status control register.

  DTBF: Data Buffer control

- Adc setting

  Scan interrupt is enabled is this firmware, priority mode interrupt is not used.

  ADCR: AD control register.

  ADSR: AD status register.

  SCCR: Scan conversion control.

- MFT setting

  FRT, OCU, WFG and ADCMP is used in this firmware.

  Configuration details can refer to MCU datasheet.

  FRT selects up and down count mode. Complementary output of WFG with dead-time is selected.

- Watch dog setting

  WdogControl: Software watchdog timer control register.

  WDG_CTL: Hardware watchdog timer control register.

5.2.2 Interrupts in Firmware

The following table shows interrupts being used in system. Function “InitMcu_Nvic()” in “init_mcu.c” is for interrupt control.

More details about interrupt control can refer to document “Cotex-M4 Technical Reference Manual”

Table 5-2:Interrupts in Firmware

Interrupt type	Function in firmware
Multi-function timer zero match interrupt	FOC algorithm is executing in this interrupt.
ADC scan interrupt	It is for DC voltage and three-phase current sampling. Triggered by MFT zero matching.
Multi-function timer DTIF interrupt	It is for hardware over-current protection.
Software watch dog interrupt	When software watch overflow, motor stops running.

❖ For priority setting, the less the digit is, the higher the priority is.

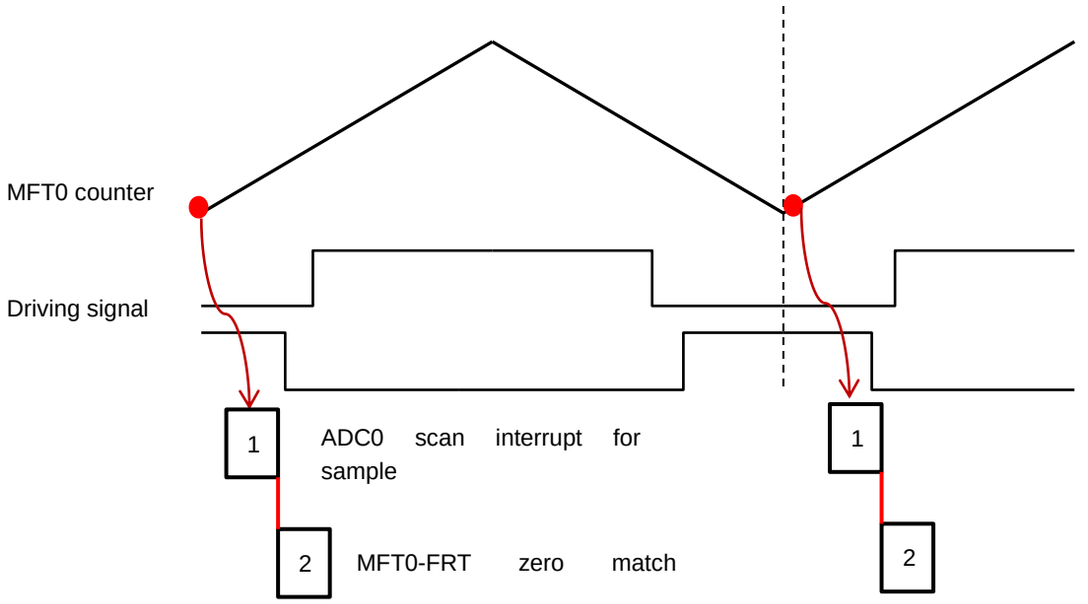
```
NVIC_SetPriority(ADC0_IRQn,1)
NVIC_SetPriority(FRT0_ZERO_IRQn,2)
```

ADC0_IRQn priority is higher than FRT_ZERO_IRQn through above setting.

MFT and ADC interrupt execution illustration is shown below, MFT and ADC interrupt includes all functions about motor controlling.

MFT and ADC interrupts is triggered every PWM cycle.

Figure 5-3: Interrupts Call Relation in Firmware

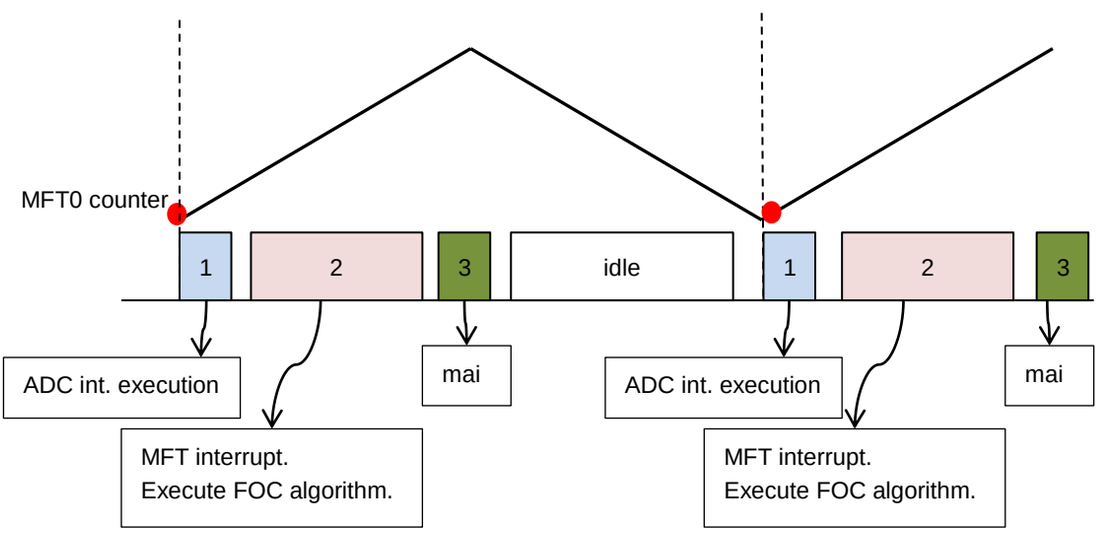


5.2.3 Control Process Flow

Because of higher priority the ADC interrupt is than MFT zero-match, basic control theory is shown below.

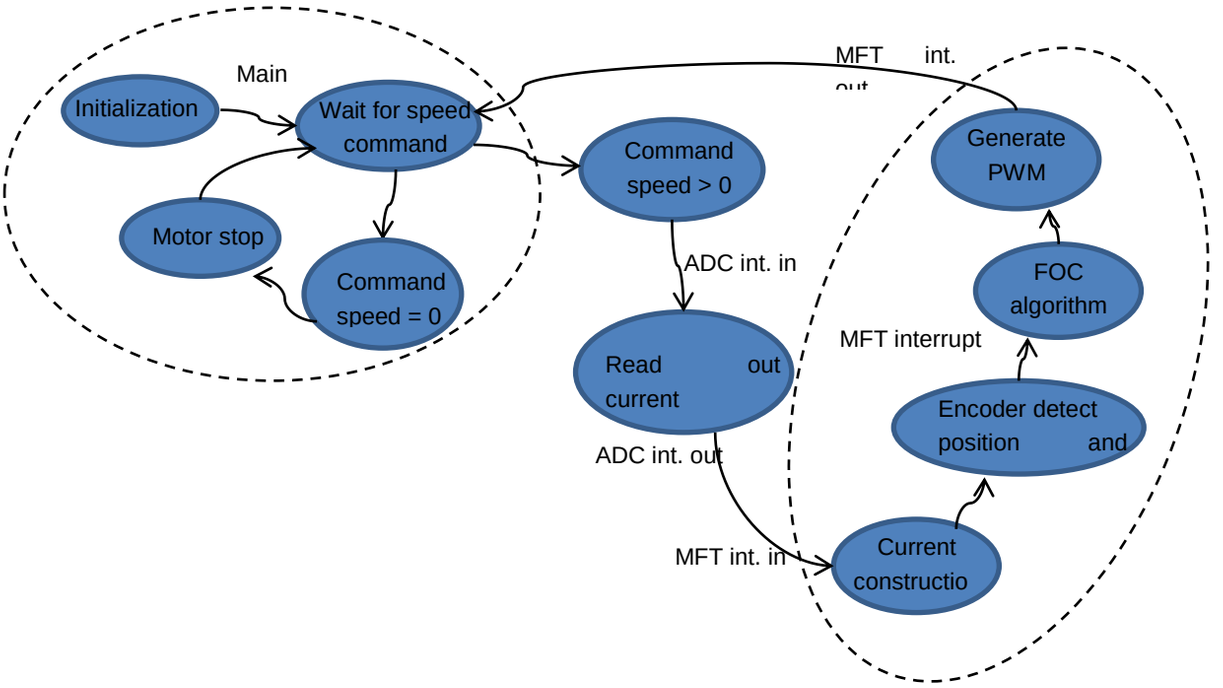
The main flow about control process contains three primary parts: ADC interrupt, MFT interrupt and main function.

Figure 5-4: Control Flow Diagram



Control process state diagram is shown below.

Figure 5-5: Firmware State Diagram



6. Results

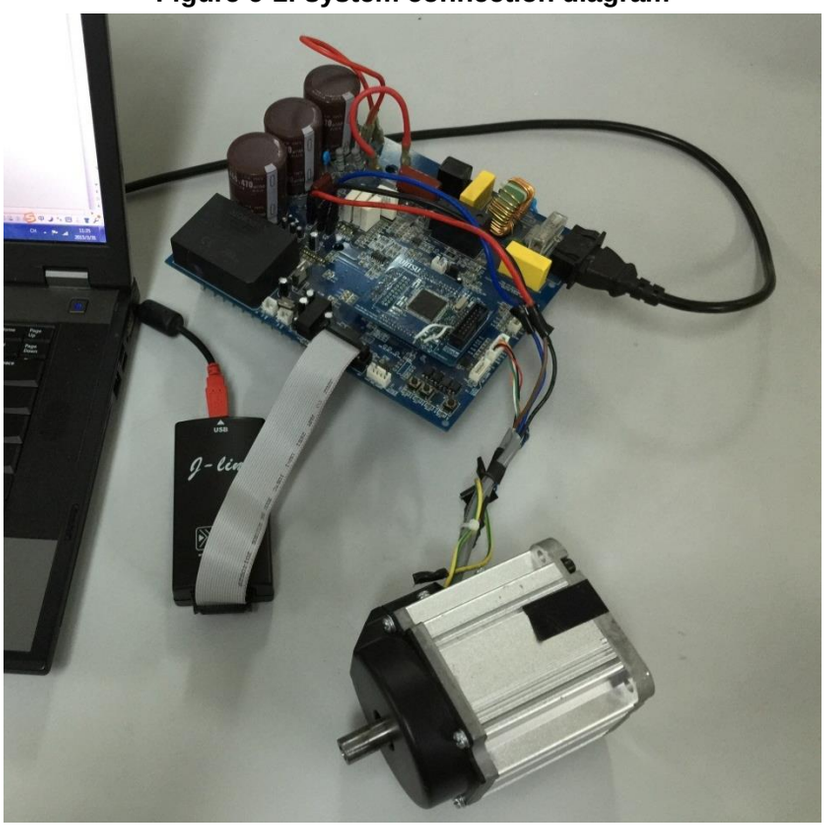
All results are based on a motor with 360 encoder pulses. Motor parameters are listed on table below

Table 6-1:Test Parameters

Motor parameters	Max	Unit
Phase current(peak)	15	A
Speed range	100~5000	rpm

The whole system connection is shown below

Figure 6-1: system connection diagram



6.1 Current Waveform

100rpm, 1800rpm and 3500rpm current waveform is shown below. Peak value of phase current is less than 300mA.

Figure 6-2: Motor phase current in 100rpm

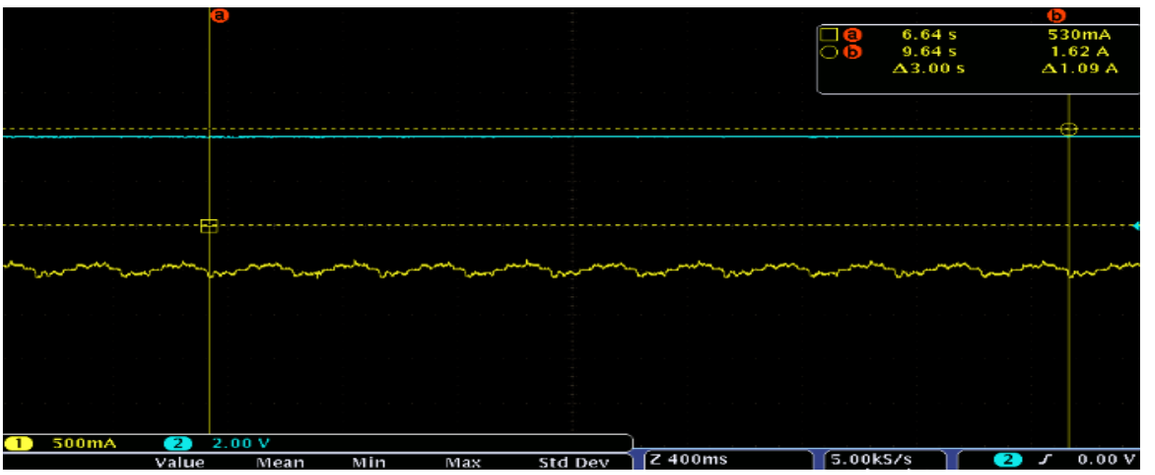


Figure 6-3: Motor phase current in 1800rpm

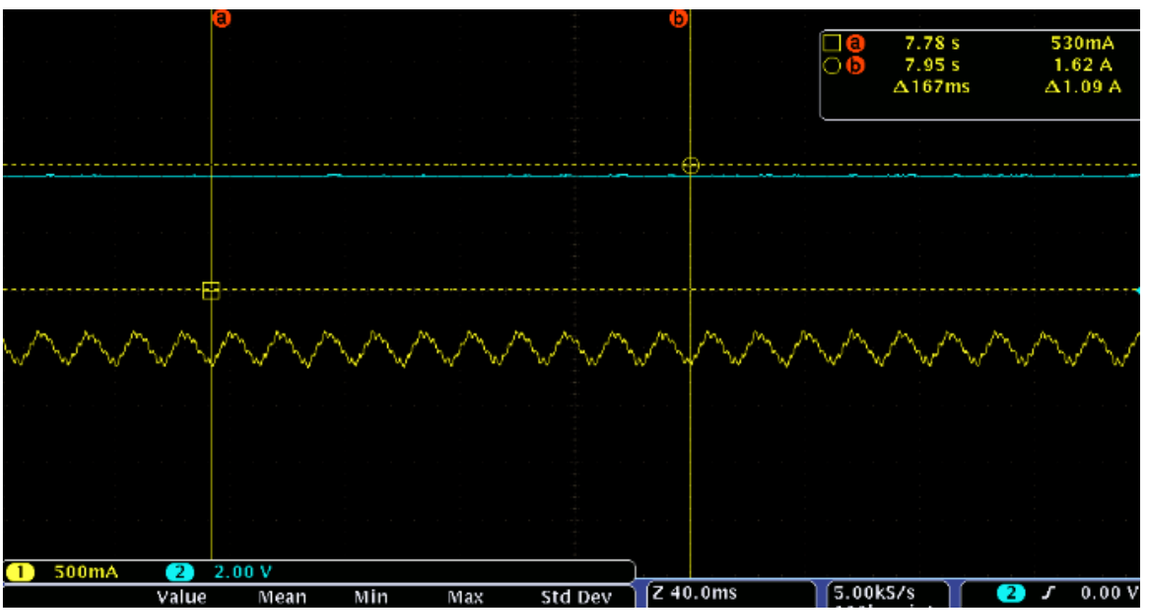
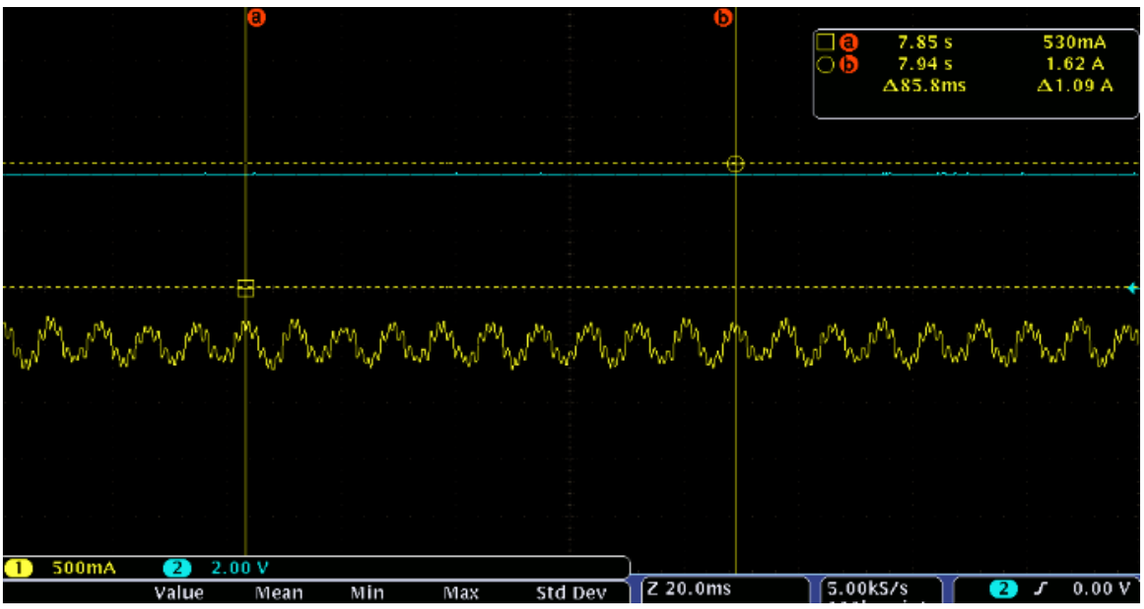
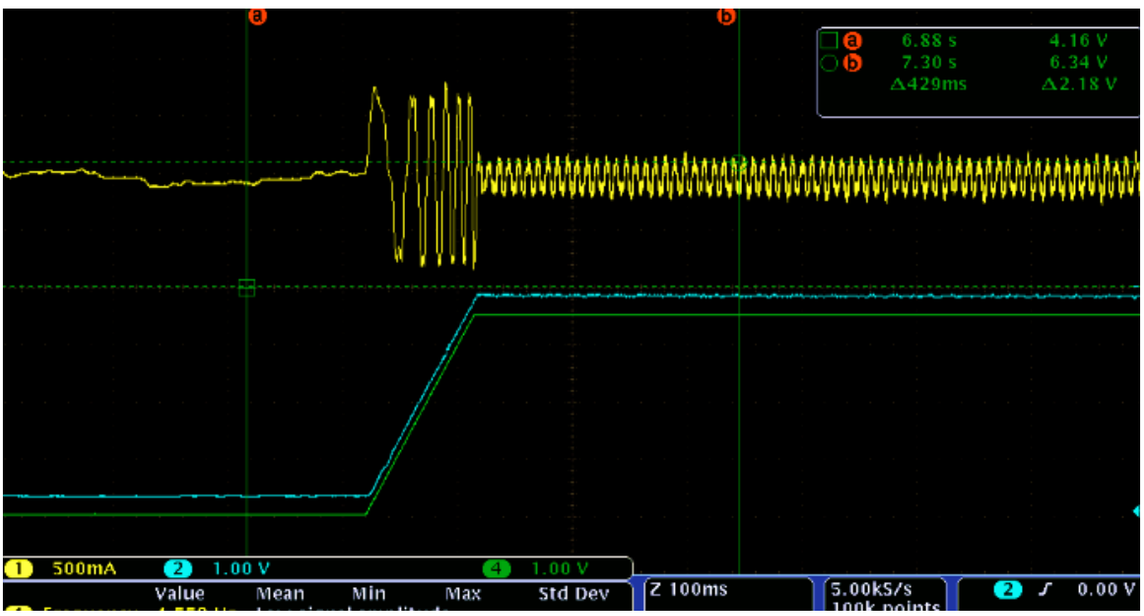


Figure 6-4: Motor phase current in 3500rpm


a
b
7.85 s
7.94 s
Δ85.8ms
530mA
1.62 A
Δ1.09 A
1 500mA
2 2.00 V
Value
Mean
Min
Max
Std Dev
Z 20.0ms
5.00kS/s
2 0.00 V

6.2 Speed Acceleration and Deceleration

Figure 6-5: Motor phase current when 100rpm accelerate to 3500rpm within 200ms



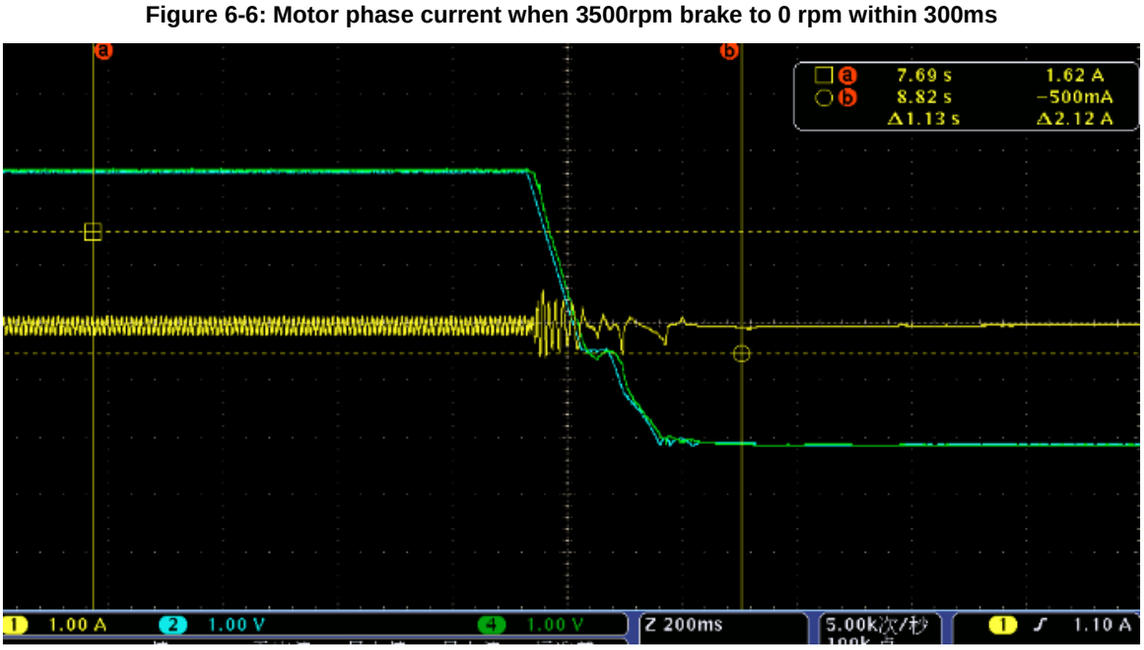
- Green curve indicates motor target speed.
- Blue curve represents motor speed estimated by encoder signal.

Motor speed acceleration from 100rpm to 3500rpm is controlled within 200ms. And speed overshoot is not obvious.

Maximum phase current peak value is controlled under 1.5A.

6.3 Braking

Figure 6-6: Motor phase current when 3500rpm brake to 0 rpm within 300ms



- Green curve indicates motor target speed.
- Blue curve represents motor speed estimated by encoder signal.

This picture shows an overview of motor braking from 3500rpm to 0, and stop at certain position, within 300ms.

7. Additional Information

For more Information on Spansion semiconductor products, visit the following websites:
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Chinese version address:
http://www.spansion.com/CN/Products/microcontrollers/

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China: mcu-ticket-cn@spansion.com
Europe: mcu-ticket-de@spansion.com
Japan: mcu-ticket-jp@spansion.com
Other: http://www.spansion.com/Support/SES/Pages/Ask-Spansion.aspx

8. Reference Documents

AN709-00012-1v0-E

Spansion • Application Note

FM4 Family
32-BIT MICROCONTROLLER
PMSM Servo Motor Speed Control On MB9BF568R

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