國　立　交　通　大　學

機械工程學系

碩士論文

以微控制器 HD64F2612FA20 實現三相直流無刷馬達控制

Realization for Brushless DC Motor Control by Micro Controller HD64F2612FA20 chip

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中華民國九十九年七月

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摘要

直流無刷馬達因為具有高效率、高轉速以及高扭力等優點。不同的控制方式會使直流無刷馬達有不同的效能，若欲增進直流無刷馬達的控制效率，則需使用更複雜的控制策略。本文將使用瑞薩出產之 HD64F2612FA20 的 16 位元微控制器，其多達 15 相的 PWM 輸出且具備板上編程(on-board programming)能力，利於程式的撰寫與發展，並以此晶片實現三相直流無刷馬達控制。其中使用霍爾感測器訊號估算轉速並透過外部控制面板顯示轉速，透過比例積分控制器實現轉速閉迴路控制。本文發展 16 位元之高效能晶片完成直流無刷馬達控制，以利未來更複雜之控制策略的實現。

關鍵字：微控制器、直流無刷馬達、六步方波、脈衝寬度調變

Realization for Brushless DC Motor Control by Micro Controller HD64F2612FA20 chip

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Abstract

The BLDC motors are everywhere because of its advantages such as high efficiency, high speed and high torque. Different control method can cause different efficiency, if someone wants to improve the efficiency of BLDC motor, the more complex control strategy needs to be used. This paper will use the microcontroller HD64F2612FA20 which is produced by Renesas company because that it has at most 15-phase PWM output and the On-board programming function, these are helpful for programming and the development of program. In this paper, the 16-bit and high efficiency's microcontroller of brushless DC motor control will be implemented. The hall sensor's signal is used to estimate motor's speed which is displayed through digital operator. The speed closed-loop control is realized by Proportional-Integral controller. This paper will use 16-bit and high efficiency microcontroller to implement brushless DC motor control for more complex control strategy in the future.

Keywords: Microcontroller (MCU), BLDC motor, Six-step square waveform, PWM

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Chapter 1 Introduction

1.1 Motive and Objectives

Motor is around in our life, such as scanner, hardware, printer DVD players, compressors, etc. In order to improve the efficiency of motor control, we need some control strategy, for this purpose, the micro controller unit is applied, such as Application Specific Integrated Circuit (ASIC). The 8-bit micro controller unit is used popularly and extensively because of its low-cost, simplicity, and easy to development firmware. As the development of the micro controller unit, the efficiency of the micro controller unit is more powerful and variety of capabilities. For higher control efficiency, the more complex control strategy will be applied. The 8-bit micro controller unit will become inadequate for motor control, so to development of the 16-bit micro controller unit used to motor control is needed.

In this thesis, we will realize the brushless DC motor control by micro controller unit HD64F2612FA20 chip, which is published by the Renesas company.

1.2 Thesis Organization

At first, the motive and objective is presented in chapter 1. In chapter 2, we talk about basic theories and knowledge, such as the feature of BLDC motor, difference between outrunner and inrunner of the BLDC's structure, and explaining the Hall sensor's theory and application, commutation method's procedure. After that, the mathematical model of BLDC motor is induced. Finally, the speed control is concerned.

In chapter 3, the program flowchart will show that the process of program, including MCU's peripheral functions and interrupts. The method of speed estimation will be discussed and a PI controller will be applied.

In chapter 4, this chapter indicates the structure of system and the specification of MCU, digital operator and BLDC motor.

The experiment result is in chapter 5, and chapter 6 is my conclusion, some failure analysis is included in this chapter.

Chapter 2 Basic Theories and Knowledge

A brushless DC (BLDC) motor is a machine that convert power from electric energy to mechanical energy, its stator is a class three-phase stator like that of an induction motor and the rotor has surface-mounted permanent magnet. In section 2.1, we introduce the feature of BLDC motors. That is why we choose BLDC motors. Then the mathematical modeling of BLDC motors will be included in section 2.2. The BLDC motors need an inverter and a position sensor to replace the brushes and commutator, so the commutation can be executed, and the procedure will be illustrated in section 2.3. In section 2.4, the speed control analysis is performed.

2.1 The Feature of Brushless DC Motors

A BLDC motor is composed of a permanent magnet synchronous motor that transfers electrical power to mechanical energy. It uses the transistors’ on and off states to control the commutation according to the hall sensor. BLDC motors have many advantages, such as higher reliability, low electrical noise and low maintenance, long-life, and easy to control, etc. They have high power density, and lower inertia allowing for faster dynamic response to reference commands compared to induction motor. Unfortunately, the cost of BLDC’s driver is higher, so the application companies are not willing to take the place of the conventional motor drives due to their higher cost. Thus, it is needed to lower the cost by use of micro controller unit.

2.1.1 Structure of Brushless DC Motors

Fig2.1 shows the basic structure of BLDC motors, there are permanent magnets on the rotor and the armature is on the stator. In all BLDC motors, the stator-coils are stationary, BLDC motors have several physical configurations, typically separate to Outrunner or Inrunner. Outrunners have high torque at low PRMs and more poles which usually set up in triplets to keep the three groups of windings, Inrunners can spin fast and have better response to commands but have weak torque. They all rotate by magnetic force and change of magnetic field.

2.1.2 Hall Sensor

When a BLDC motor rotates around, we need to know the motor's position. In order to do this, the Hall sensor is applied. The Hall sensor replaces the traditional commutator and brushes because of its higher efficiency and low maintenance. The Hall sensor uses the Hall effect to output variable voltage in response to changes in magnetic field. As shown in Fig 2.2, a voltage called the Hall voltage, V_H, is applied to the rectangular metal, and the rectangular metal is placed in a perpendicular magnetic field, B. According to the Lorentz force, the electrons and holes in the metal are apart to different side, and accumulate on the surface of the metal. This leaves equal and opposite charges exposed on the other face and forms an electric field, the electric field is equal to the Lorentz force so that the other following electrons and holes will not be affected. This phenomenon is called the Hall effect.

$$V_H = -\frac{IB}{dne} = K\frac{I}{d}B \tag{2-1}$$

2.2 Commutation Method

In order to control BLDC motors, it also needs an inverter, Fig2.3 shows its schematic. The inverter consists of six transistors, controls the current which flows to motor so that we can change the outer stator's magnetic field according to the Hall sensor's signal, and then generates torque.

The six-step sequences is the typically and the must general commutation method for a BLDC motor, the six inverter's transistors switch according to the six-step sequences and Hall sensor's signal to produce the phase current waveforms, as shown in Fig 2.4. For simplicity, we assume that the currents are in rectangular shapes, and the stator's inductance voltage may be neglected. Thus, Table 2.1 indicates the sequence of the conducting phase, we call that "120° six-step square commutation table".

At the step 1, Q5、Q0 transistors switch on, so the current can flow Q5 → W → $\overline{U}$ → Q0, at step 2, Q3、Q0 transistors switch on, so the current can flow Q3 → V → $\overline{U}$ → Q0. At the switching moment, because that motor is inductive load, the current which passes the winding can't shut down as the switch is right off. Instead, the current will decrease gradually. For decreasing the current of inductance (ΔI_L) gradually in the motor, we need a circuit to let the current flow. So there is a free-wheeling diode accompanied a transistor. This can ease ΔI_L so that we can avoid the peak inductance's voltage (V_L) induced from rapid change of ΔI_L, the inductance's voltage can be expressed as

$$V_L = L\frac{\Delta I_L}{\Delta t} \tag{2-2}$$

Following the table's sequences, shown in table 2.1, the BLDC motor's rotor will rotate around, according to the poles of the rotor, there is a relationship between the electrical angle and mechanical angle, that is

$$Ellectric\_angle = Mechanical\_angle \times \frac{Pole\_number}{2}$$

Fig 2.5 shows an example of a BLDC motor with 2 poles of rotor, so when it travels an electrical angle cycles, the inner rotor rotates one revolution, and the higher of poles number, the higher resolution of the motor's rotation.

2.3 The Mathematical Model of BLDC Motors

In general, a BLDC motor has a permanent-magnet rotor and its stator windings are wound to generate the back electromotive force (Back-EMF). The dynamic equations of BLDC motors with Y-connected stator winding are shown in Fig 2.6

Using Kirchhoff's law and Newton's law, we can get 3-phase BLDC electromagnetic equation and dynamic equation, which express as follows:

Electromagnetic equation:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_p & -M & -M \\ -M & L_p & -M \\ -M & -M & L_p \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{2-3}$$

The back electromotive force (Back-EMF) express as

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = \frac{2\omega_r K_e}{P} \begin{bmatrix} \sin(\theta_e) \\ \sin(\theta_e - \frac{2\pi}{3}) \\ \sin(\theta_e + \frac{2\pi}{3}) \end{bmatrix} \tag{2-4}$$

Dynamic equation:

$$\begin{aligned} T_e &= K_t(i_a - \frac{i_b}{2} - \frac{i_c}{2})\sin(\theta_e) + \frac{\sqrt{3}}{2}(i_c - i_b)\cos(\theta) \\ &= \frac{2J}{p}\dot{\omega}_r + \frac{B_m}{p}\omega_r + T_L \end{aligned} \tag{2-5}$$

V_a, V_b, V_c : a, b, and c phase voltages

i_a, i_b, i_c : a, b, and c phase currents

e_a, e_b, e_c : a, b, and c phase back electromotive force

L_p : self-inductance of a, b and c phase

M : mutual inductance between any two phase

R : stator resistance

ω_r : rotor speed

θ_e : angle between stator phase A and rotor

K_e : Back-EMF constant

p : number of pole pairs

T_e : electric torque

K_t : torque constant

T_L : load torque

J : moment of inertia

B_m : damping constant

2.4 Speed Control Analysis

The BLDC motor's equivalent circuit is shown in Fig 2.7. the voltage equation can be derived from the circuits as follows:

$$V_s(PWM) = V_{CE(sat)} + IR_a + E$$

$$I = \frac{V_s(PWM) - V_{CE(sat)} - E}{R_a} \tag{2-6}$$

$V_s(PWM)$: Average effective voltage

$V_{CE(sat)}$: BJT's conduct voltages between collection and emitter

I : Equal total current

R_a : Equal total resistance

E : Back-EMF

The conduct voltage term V_{CE} can be neglected because that it is too small, and the equations become:

$$V_s(PWM) = IR_a + E$$
$$I = \frac{V_s(PWM) - E}{R_a} \quad (2\text{-}7)$$

Beside the voltage equation, the torque equation and back-EMF equation are also needed in order to analyze speed control. The torque equation and back-EMF equation are represented individually as follows:

$$T = K_t \cdot I \quad (2\text{-}8)$$

$$E = K_e \cdot \omega_r \quad (2\text{-}9)$$

Summarizing the equations of (2-7), (2-8), and (2-9), we can analyze situations when BLDC motors are in acceleration or deceleration. In the case of acceleration, PWM increases results in the average effective voltage increases, according to equation (2-7), the current I also increases, according equation

(2-8), the induced torque of stator $T_{induced}$ increases follows the current I increases. When the $T_{induced}$ is larger than the loading torque, the motor's speed increases. According to the equation (2-9), the back-EMF increases when the motor's speed increases. The result makes the current I decreases. When the current I is down, the $T_{induced}$ decreases until $T_{induced}$ equals to T_{load}. Therefore, the speed is not only accelerated but also stable. In the other case of deceleration, the analysis is opposite, PWM decreases results in the average effective voltage decreases, according to equation (2-7), the current I also decreases, according equation (2-8), the induced torque of stator $T_{induced}$ decreases follow the current I decreases. When the $T_{induced}$ is smaller than the loading torque T_{load}, the back-EMF decreases when the motor's speed decreases. The result makes the current I increase. When the current I is up , the $T_{induced}$ increases until $T_{induced}$ equals to T_{load}. Base on the analysis, the speed control can easily implement.

Chapter 3 Software Setup

3.1 Main program

The flowchart of main program is shown in Fig 3.1. First, we do the initialization, which enables and initializes SCI (serial communication interface), TPU (timer pulse unit) and ADC (A/D converter). Setting I/O pin of MCU is also included. Second, we communicate with digital operator for check sequence and initialize the information that we want to show in LCD. After that, we catch the ASCII code of Menu key to enter the Menu selection mode.

3.2 Initialization

3.2.1 Serial communication interface (SCI)

In SCI initialization, we use the asynchronous mode and following protocol:

SCI2:

Baud Rate: 9600

Data Bit: 8

Stop Bit: 1

Parity Bit: none

SCI1:

Baud Rate: 9600

Data Bit: 8

Stop Bit: 1

Parity Bit: none

There are two SCI channels we used, SCI2 is used for PC and SCI1 is used for digital operator. We set TE and RE bits in SCR to open SCI and let RIE bit enable so that we can allow SCI interrupt.

3.2.2 Timer pulse unit (TPU)

We use TPU0 as our timer for checking hall signal's status in period, according to our BLDC motor's specification, the rated speed is 3000 rpm, the time in every step at rating speed is

$$\frac{1}{\frac{3000}{60}(rps)\times 24}(step/s)\cong 0.83(ms/step)$$

By setting TGRA_0, the period is decided, we let the period be 0.1ms. It is enough to avoid missing hall signal's step.

TPU1 is used for open-loop or close-loop control's feedback time, and TPU2 is chosen for calculating BLDC motor's speed, We use the MCU's PWM mode 2 by setting the MD bit in TMDR, the MCU has at most 15-phase PWM output in PWM mode 2, but we only use 6 phases of them, as the following shown:

PWM output pins:

TIOCC3 – U phase (pin 28)
TIOCD3 – X phase (pin 29)
TIOCA4 – V phase (pin 30)
TIOCB4 – Y phase (pin 31)
TIOCA5 – W phase (pin 32)
TIOCB5 – Z phase (pin 33)

We choose TPU3, TPU4 and TPU5 as our PWM timer, and setting the SYNC3, SYNC4 and SYNC5 bit in TSTR so that we can make TPU3, TPU4 and TPU5 to be synchronized. It is necessary to set clearing source in synchronous mode, so we let TPU3's TGRA as our clearing source by setting TPU3's CCLR in TCR , and it can decide the PWM's carrier frequency. In this thesis, we set the PWM's carrier frequency to be 10k Hz, it is in the range of IGBT's operation.

After setting up the PWM's carrier frequency, we will set the duty ratio on each phase as follows (see Table 3.1):

PWM output registers:

TGRC_3: U phase duty ratio

TGRD_3: X phase duty ratio

TGR4A_4: V phase duty ratio

TGR4B_4: Y phase duty ratio

TGRA_5: W phase duty ratio

TGRB_5: Z phase duty ratio

By changing the value in above registers, we can change PWM’s duty ratio as well as we want. With IOC bits in TIORL_3, IOD bits in TIORL_3, IOA bits in TIOR_4, IOB bits in TIOR_4, IOA bits in TIOR_5, IOB bits in TIOR_5, we can control the PWM’s duty ratio and On or Off.

3.2.3 A/D Converter

For knowing the current value, we need to read the shunt resistance voltage, and turn the analog signal into digital signal so that the MCU can handle it.

We set the SCAN bit in ADCSR register to enter scan mode and set CH bits to 0010 to choose AN0, AN1 and AN2 channel as our A/D input pins (pin 71 ~ 73). These channels are the shunt resistance voltage’s input.

3.2.4 I/O

P1 is used to be input pins for hall sensor’s signal, we feedback hall sensor’s signal H1, H2 and H3 into port 1.6, port 1.5 and port 1.4.

3.3 Interrupt routine

3.3.1 RXI interrupt

When MCU received character from digital operator or PC, it will trigger RXI interrupt to store the character.

3.3.2 TGIA0 interrupt

TGIA0 interrupt is produced by TGRA_0 compare match in TPU0, in this interrupt, we will check the hall signal. If hall signal changes, we do the commutation job to the next step according to the six-step square commutation table and calculating the BLDC motor's speed by analyzing the time between steps. For better accuracy and small variation, we filter the speed and show it on digital operator. The flowchart is shown in Fig 3.2.

3.3.3 TCIV1 interrupt

This routing is for close-loop control's feedback. When we set up the speed as our command, the TPU1 timer will be trigger. After the TCNT of TPU1 overflow, it will feedback speed and send it to PI controller to regulate speed.

3.3.4 TCIV2 interrupt

The TPU2 is used for calculating speed, it is needed to avoid the situation of stall, so we enable the TCIV2 interrupt to extend the time for calculation.

3.4 Speed estimation

According to the time between hall signal steps, speed estimation can be realized by as following formula:

$$\frac{1}{counter \times \frac{1}{timer\_freq} \times 24(rev/s)} \times 60 = Speed(rpm)$$

Because we use interrupt at every 0.1ms to check the hall signal, so the speed calculated must exist error and vary in a range.

In this thesis, we take 3 steps and 6 steps time to calculate speed separately in order to reduce the error, and filter the value that we calculated to decrease the variation, it makes the speed error to be within 1 rpm.

The formula becomes:

3 step:

$$\frac{1}{counter \times \frac{1}{timer\_freq} \times 8(rev/s)} \times 60 = Speed(rpm)$$

6 step:

$$\frac{1}{counter \times \dfrac{1}{timer\_freq} \times 4(rev/s)} \times 60 = Speed(rpm)$$

If we take too more step to calculate speed, the frequency of updating speed will decrease, it will affect the speed response.

3.5 PI controller

For close-loop control, we use PI controller to regulate motor's speed. The block diagram is shown in Fig 3.4. Current speed (ω_r) can be estimated from hall signal, and ω_r^* is speed command, it is decided by digital operator.

TGRA_1 register's compare match is used to trigger the interrupt of checking speed variation for motor speed's feedback. When speed changes, we feedback the new current speed value and compare to speed command to get speed error e(k). After that, the speed error e(k) will be input to PI controller regulator, so we get the duty ratio' value as our input $u(k)$. Then we renew the duty ratio's value in registers.

In MCU, if current speed is less than speed command, it will increase duty ratio to accelerate, if current speed excesses speed command, it will decrease duty ratio to decelerate.

Chapter 4 Hardware Setup

4.1 The structure of system

Fig 4.1 is the structure of system, after rectifier the AC, it provides DC voltage to inverter, and the MCU communicates with PC and digital operator by RS232, after downloading the program from PC, we command the BLDC motor through digital operator, and the MCU control the communication by switching the six IGBTs' in the inverter. With the hall sensor's feedback to MCU, we can calculate the BLDC motor's speed showed on digital operator. The shunt resistance voltage is feedback to MCU too, it is used to avoid over current.

4.2 Introduction of MCU

The MCU we used is H8S/2612 group produced by Renesas company, its type is HD64F2612FA20. It has 128K ROM, 4K RAM and the ROM type is flash memory. The minimum instruction execution time is 50ns (20M Hz), and it has 47 internal interrupt and 7 external interrupt.

Its main peripheral functions are as following:

- Various peripheral functions
  - PC break controller x 2ch
  - Data transfer controller x 85ch
  - 16-bit timer-pulse unit (TPU) x 6ch

- Motor management timer (MMT)
- Programmable pulse generator (PPG) x 8ch
- Watchdog timer x 1ch
- Asynchronous or clocked synchronous serial communication interface (SCI) x3ch
- Controller area network (HCAN) x 1ch
- 10-bit A/D converter x 12ch
- Clock pulse generator

- General I/O ports
  - I/O pins: 43
  - Input-only pins: 13

4.3 MCU circuit

The MCU's pin arrangement is shown in Fig 4.2. The function of on-board programming is the feature of the MCU, it can download program from PC by changing the pin state of MD2, MD1, MD0 and FWE (Flash Write Enable). See table 4.1, if MD2, MD1, MD0 is high and FEW is low, it is in advance mode, this is normal mode, if MD1, MD0, FEW is high and MD2 is low, it is in boot mode, this is programming mode.

Fig 4.3 is the layout of MCU circuit, the RS232 port is used to communicate with PC. A digital operator is added to indicate the information that we need, so the left ten pins are for digital operator, the five pins below is +5V, GND and the hall sensor's signal input. The dip switch is used to switch between programming mode (boot mode) and normal mode (advanced mode).

The programming mode is working through the RxD2 and TxD2 pins, and the normal mode is working through the RxD1 and TxD1 pins, besides, the output of the MCU's RxD2, TxD2, RxD1, TxD1 pins and digital operator's Rx, Tx pins are TTL signal. It is necessary to convert the TTL signal to RS232 signal so that we can communication from the MCU to PC or MCU to digital operator. Thus, we use the MX232CPE (Fig 4.4) IC to finish this job.

4.4 Digital operator

I/O is needed for a control system, we can command the motor by a digital operator shown in Fig 4.5. Table 4.2 is the digital operator's protocol. There are four checks in the beginning of communication, and the data format is shown in Table 4.3.

For Operator to MCU, the first two bytes are start code, and the third and forth bytes are data bytes which indicated the LED information of digital operator. The last two bytes are the CRC (Cyclic redundancy check) code. It is a short, fixed-length binary sequence.

For MCU to Operator, the first two bytes are also start code, and the LED_Ctrl control the blink of the LED, and the LED_Data control the LED's on or off. After the following four null characters, the LCD_Ctrl1 and LCD_Ctrl2 affect the blink of characters which is shown in line 1 and line 2, the LCD_Line1 and LCD_Line2 decide the content of line 1 and line 2, the last two bytes are CRC code.

4.5 BLDC motor's specification

Table 4.4 shows the specification of BLDC motor and Fig 4.5 shows the BLDC motor, it is produced by Adlee Powertronic company. Its model No. is AM750M, the number means the rated output is 750W, about 1 horse power. The last M means the rated speed is about 3000 rpm, it has U, V, W phase and the maximum input current is 11.4A.

According the motor's hall signal and Fig 2.4, when motor runs 1/4 revolution, the hall signal changes six times, there are 24 steps in one revolution, so it's position resolution is 15 degree.

Chapter 5 Experiment

5.1 Hardware setup

The inverter we used is shown in Fig 5.1, an IGBT module is inside and the current limit is 8A. We use tachometer to sensor the current speed in order to compare the speed calculated by microcontroller, the tachometer's type is RM-1000, and its specification is shown in Table 5.1.

Fig 5.2 shows the hardware setup, the experiment equipment is as following:

A. PC
B. Scope 1 (4 channel)
C. Scope 2 (2 channel)
D. Isolation transformer 1
E. Isolation transformer 2
F. Auto-transformer
G. Inverter
H. Digital operator
I. BLDC motor
J. Tachometer

The isolation transformer is needed to isolate MCU and computer from the power source for safety, and the auto transformer is used to boost 110V AC to

220V AC and provide to inverter.

5.2 Experiment result

Fig 5.3 shows the six-step waveform at 1000 rpm, and Fig 5.4 shows its hall signal's waveform, according to Fig 5.4, the each step time is about 2.5ms, so the speed can be calculated as follow:

$$\frac{1}{2.5ms \times 24(rev/s)} \times 60 = 1000(rpm)$$

So the experiment result is the same as theory.

At this experiment, we use 3 step and 6 step's time to calculate speed separately, and compare it to tachometer to get speed error. The speed error is shown in Fig 5.5. The result indicates that the 6 step is better and speed error is within 0.2 rpm,

The speed response without load at 1000 rpm and 3000 rpm is shown in Fig 5.6 and Fig 5.7, we record the process of experiment and take the every moment of speed and time when speed changed, after gathering these points, we can plot the waveform as shown.

The dash line is command and the plus mark is the response of parameter Kp = 0.03 and Ki = 0.1, the circle mark is the response of parameter Kp = 0.03 and Ki = 0.05. Both the response time are about 5 to 6 second.

The star mark is the response of Adlee driver, it is used to make comparison. The specification of Adlee driver is shown in Table 5.2.

Fig 5.8 shows the speed response with load at 500 rpm. So as figure shown, the response of parameter Kp = 0.03 and Ki = 0.05 is good than Adlee driver.

Chapter 6 Conclusion

According to the experiment result, we can find that the response is faster and the overshoot may exist when Ki become decrease.

In the experiment, we have some problems when we implement the BLDC motor control and make it failure. The failure analysis list as following:

1. Isolation

   Fig 5.2 shows the hardware setup. At first, we did not add the isolation transformer, so the computer's ground and the inverter's ground are the same. It will cause damage to computer and microcontroller. Besides, the primary and secondary's ground of flyback converter in the inverter are conncected, it will also ruin computer or microcontroller.

2. PWM output waveform

   When we set up the PWM output pin by TIOR (Timer input/output control register), the output pins state are right at beginning, but after four to five times of switching PWM output pins state, the output waveforms are error. This is caused by wrong setting so that we ruin many IGBT module in the inverter. So the pins state need to check carefully.

3. Priority

In the experiment, the interrupt of checking hall signal and doing commutation must be the highest priority in the interrupts we used, if this interrupt be affected, we have chance to break IGBT module. Table 6.1 shows the priority of internal interrupt, so TGIA_0 interrupt is used for checking hall signal.

The MCU we used is powerful, it can be used to develop more complex control method in BLDC motor such as direct torque control.

Reference

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Table

Step	Electrical angle	Phase current	Hall sensor	Switch on
1	0°~60°	$W \rightarrow \overline{U}$	100	Q5, Q0
2	60°~120°	$V \rightarrow \overline{U}$	101	Q3, Q0
3	120°~180°	$V \rightarrow \overline{W}$	001	Q3, Q4
4	180°~240°	$U \rightarrow \overline{W}$	011	Q1, Q4
5	240°~300°	$U \rightarrow \overline{V}$	010	Q1, Q2
6	300°~360°	$W \rightarrow \overline{V}$	110	Q5, Q2

Table 2.1 120 degree six-step square commutation table

		Output Pins	
Channel	Registers	PWM Mode 1	PWM Mode 2
0	TGRA_0	TIOCA0	TIOCA0
	TGRB_0		TIOCB0
	TGRC_0	TIOCC0	TIOCC0
	TGRD_0		TIOCD0
1	TGRA_1	TIOCA1	TIOCA1
	TGRB_1		TIOCB1
2	TGRA_2	TIOCA2	TIOCA2
	TGRB_2		TIOCB2
3	TGRA_3	TIOCA3	TIOCA3
	TGRB_3		TIOCB3
	TGRC_3	TIOCC3	TIOCC3
	TGRD_3		TIOCD3
4	TGR4A_4	TIOCA4	TIOCA4
	TGR4B_4		TIOCB4
5	TGRA_5	TIOCA5	TIOCA5
	TGRB_5		TIOCB5

Table 3.1 PWM output registers and output pins

MD2	MD1	MD0	FWE	LSI state after Reset end
1	1	1	0	Advance Mode
0	1	1	1	Boot Mode

Table 4.1 Two Mode correspond to their pins state respectively

1. check 1
Digital operator → MCU (8 bytes)
0x 07 03 50 3B 00 0A 05 D7
MCU → Digital operator (7 bytes)
0x 12 09 F2 33 01 A0 M0
2. check 2
Digital operator → MCU (8 bytes)
0x 04 23 10 3D 01 00 51 43
MCU → Digital operator (7 bytes)
0x 21 02 32 11 2E A9 9C
3. check 3
Digital operator → MCU (6 bytes)
0x 00 07 01 05 01 44
MCU → Digital operator (36 bytes)
0x 01 71 20 38 21 56 55 56 78 20 54 56 55 78 25 45 35 D 5 78 38 50 55 06 18 38 54 79 55 28 10 49 AA 4C E0 Q8 DF
4. check 4
Digital operator → MCU (6 bytes)
0x 04 78 51 10 C6 4F
MCU → Digital operator (46 bytes)
0x 22 25 38 44 44 7E 45 44 3C 40 42 43 3C 3C 40 42 21 6C 3C 41 40 43 AC 20 55 56 54 98 38 45 56 54 14 38 46 45 56 68 73 FD 20 01 03 A0 30 50

Table 4.2 Digital operator’s protocol

5. data
Digital operator → MCU (6 bytes)
0x 10 70 10 01 DC F 3
MCU → Digital operator (46 bytes)
0x 10 70 10 53 00 00 00 00 00 00 00 00 53 39 45 2D 30 35 34 33 20 20 20 20 20 20 20 20 55 31 2D 30 31 3D 20 20 30 2E 30 30 20 48 5A 20 D0 0F

Table 4.2 Digital operator's protocol (continue)

Operator to MCU

Start code 1	Start code 2	DATA 1	DATA 2	CRC16_LB	CRC16_HB

MCU to Operator

Start code 1	Start code 2	LED_Ctrl	LED_Data	0x00	0x00
0x00	0x00	LCD_Ctrl1	LCD_Ctrl2	LCD_Line1	LCD_Line2
CRC16_LB	CRC16_HB				

Table 4.3 Digital operator's data format

Motor Model No.	AM750M
Input voltage	220V±10%
Input frequency	50/60 Hz
Max. input current	11.4 A
Motor phase	3∅
Rated torque	70 kg-cm
Motor insulation/ Max. working TEMP	B Class (130°C/266°F)/Max. 100°C/212°F
Motor weight	8.0 kg

Table 4.4 The specification of BLDC motor

Type:	RM-1000
Range	10 rpm ~100,000 rpm
Basic Accuracy	+/- 0.01% +/- 1 dgt
Resolution	0.1 rpm
Sample rate	1 sec.
Measuring distance	50mm to 200m
Max distance	300mm
Recall	Max value, Min value
Data hold	Stop measurement and data hold
Time base	12.0MHz quartz crystal
Circuit	High speed microcomputer
Range selection	Automatic
Battery	Four 1.5V batteries (AA UM-3)
Low battery indicator	Red LED display
Operation temperature	0 to 50 degree C

Table 5.1 Specification of tachometer

ADLEEPOWEWR MATCHSERVO MTR DRIVES	
BL2 - 107M	
AC - INPUT	AC – OUTPUT
200~130V 50/60Hz 1ϕ Max 11.4A	0~230V 3ϕ 750W max 7A
ADLEE POWERTRONIC CO., LTD.	

Table 5.2 Specification of Adlee driver

Interrupt source	Original of interrupt source	IPR	Priority
TPU0 channel 0	TGIA_0	IPRF6 to IPRF4	High
	TGIB_0		
	TGIC_0		
	TGID_0		
	TCIV_0		
TPU channel 1	TGIA_1	IPRF2 to IPRF0	
	TGIB_1		
	TCIV_1		
	TCIU_1		
TPU Channel 2	TGIA_2	IPRG6 to IPRG4	
	TGIB_2		
	TCIV_2		
	TCIU_2		
TPU channel 3	TGIA_3	IPRF6 to IPRF4	
	TGIB_3		
	TGIC_3		
	TGID_3		
	TCIV_3		Low

Table 6.1 Internal priority of MCU

TPU channel 4	TGIA_4	IPRH6 to IPRH4	High
	TGIB_4		↑
	TCIV_4		
	TCIU_4		
TPU channel 5	TGIA_5	IPRH2 to IPRH0	
	TGIB_5		
	TCIV_5		
	TCIU_5		
SCI channel 0	ERI_0	IPRJ2 to IPRJ0	
	RXI_0		
	TXI_0		
	TEI_0		
SCI channel 1	ERI_1	IPRK6 to IPRK4	
	RXI_1		
	TXI_1		
	TEI_1		
SCI channel 2	ERI_2	IPRK2 to IPRK0	
	RXI_2		
	TXI_2		↓
	TEI_2		Low

Table 6.1 Internal priority of MCU (continue)

Figure

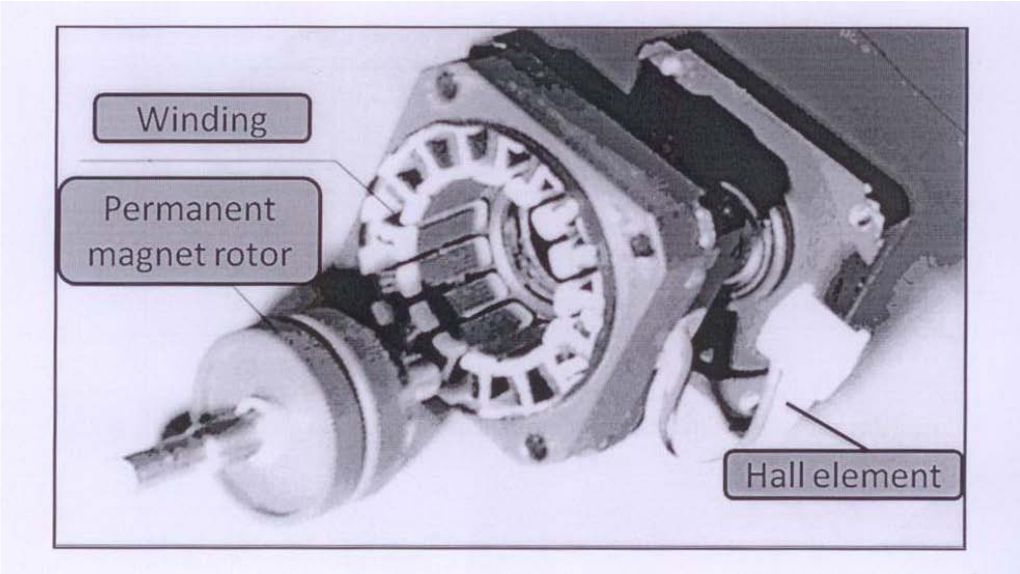


Fig 2.1 The structure of BLDC motors

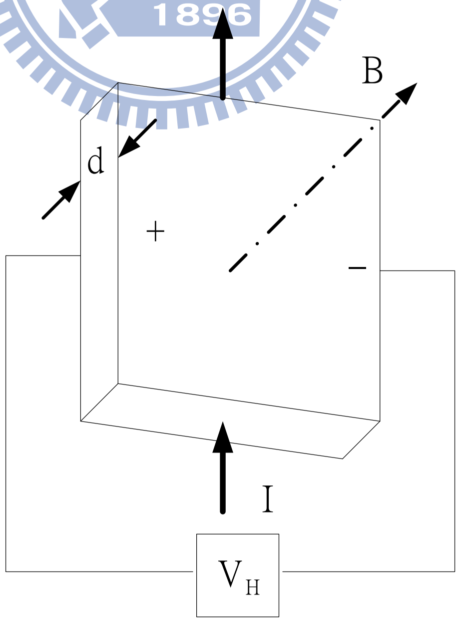


Fig 2.2 The Hall effect

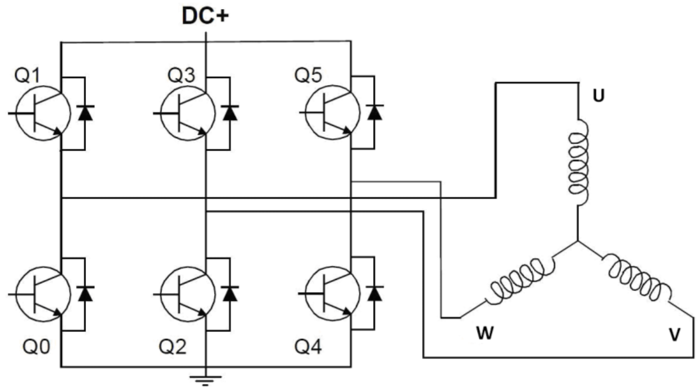


Fig 2.3 Schematic of the inverter and motor

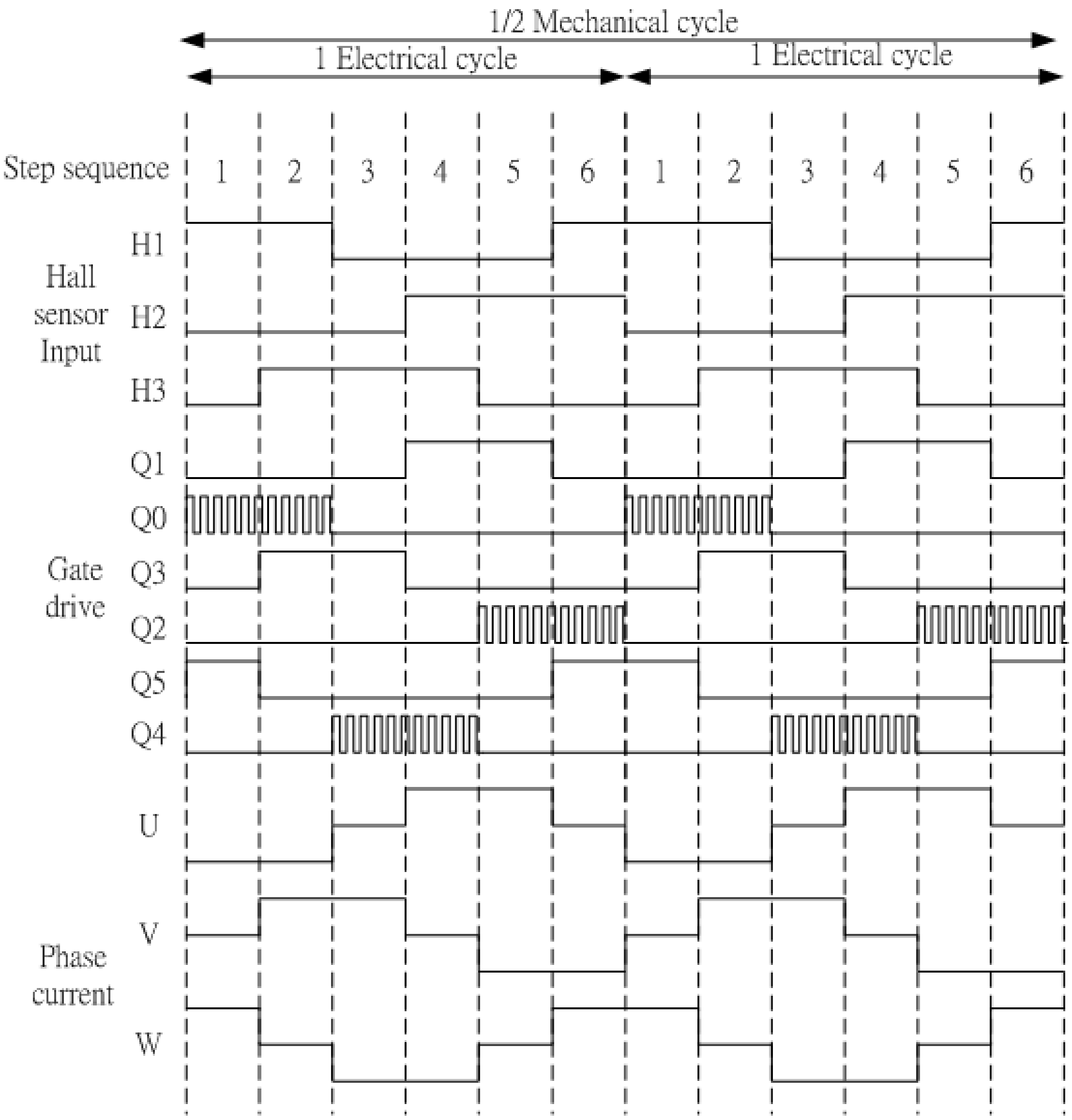
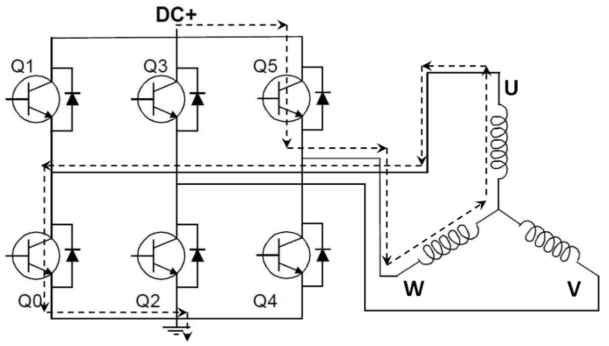
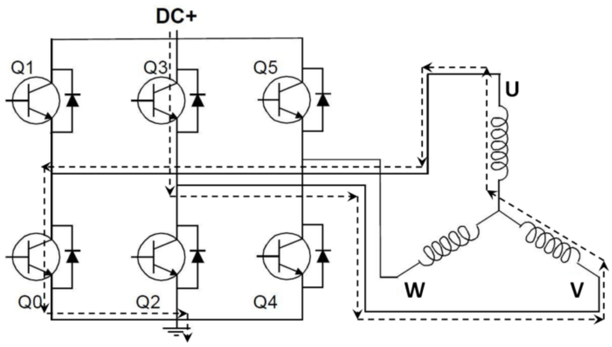


Fig 2.4 Six-step sequences waveforms

Step 1



Step 2



Step 3

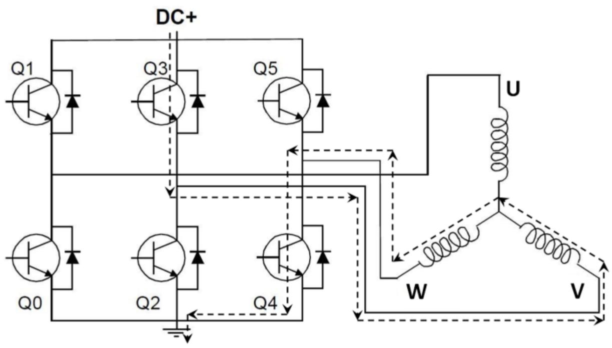
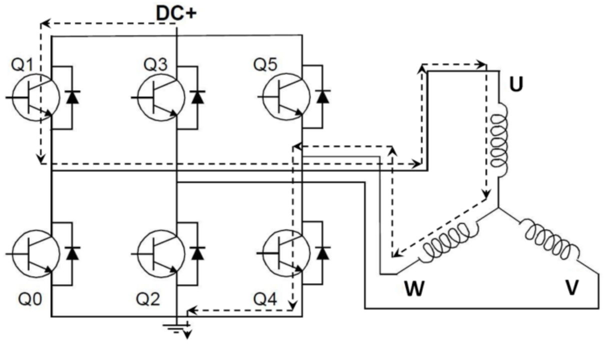
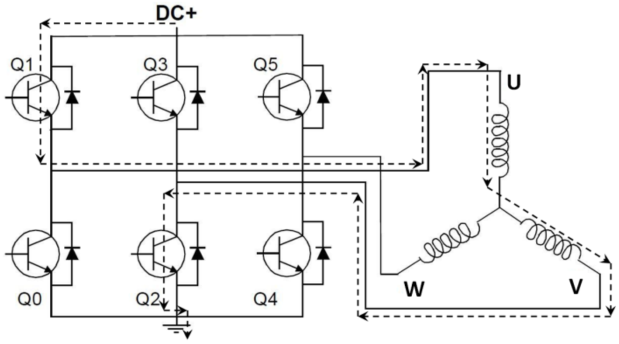


Fig 2.5 The procedure of the commutation

Step 4



Step 5



Step 6

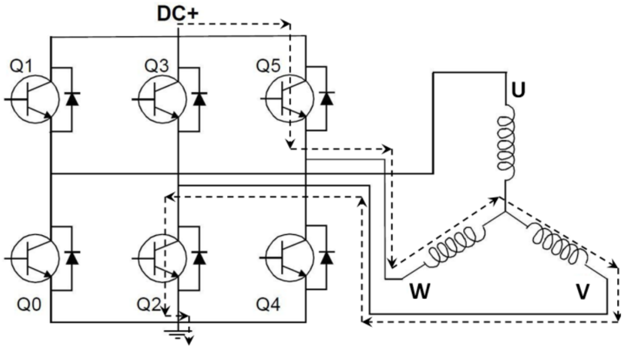


Fig 2.5 The procedure of the commutation (continue)

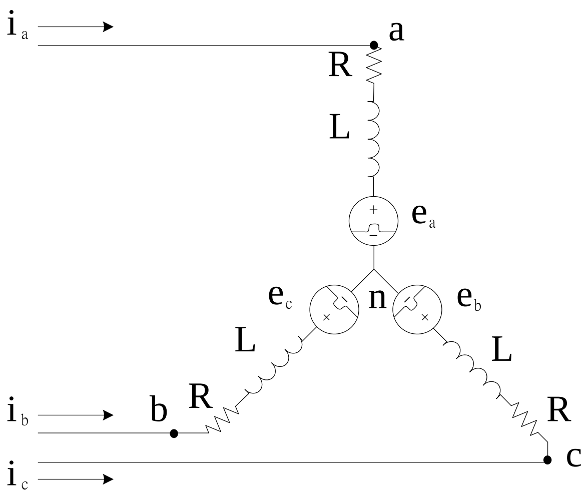


Fig 2.6 The equivalent model of a BLDC motor

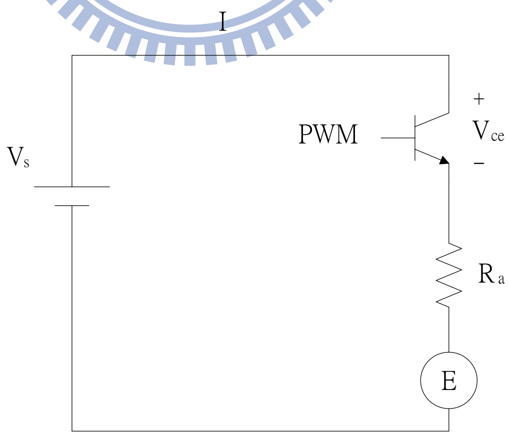


Fig 2.7 A BLDC motor equal circuit

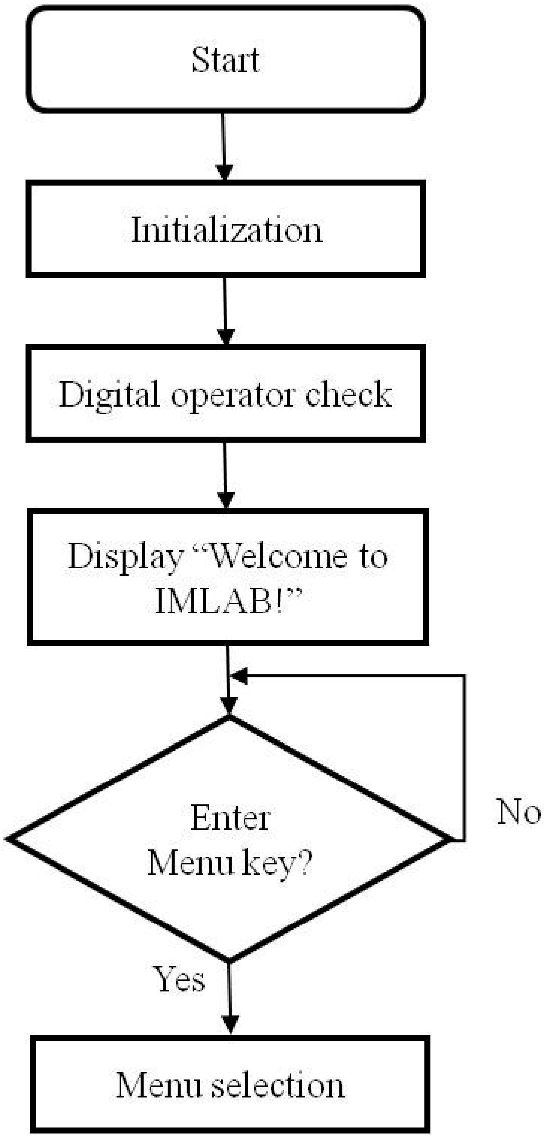


Fig 3.1 Main program flowchart

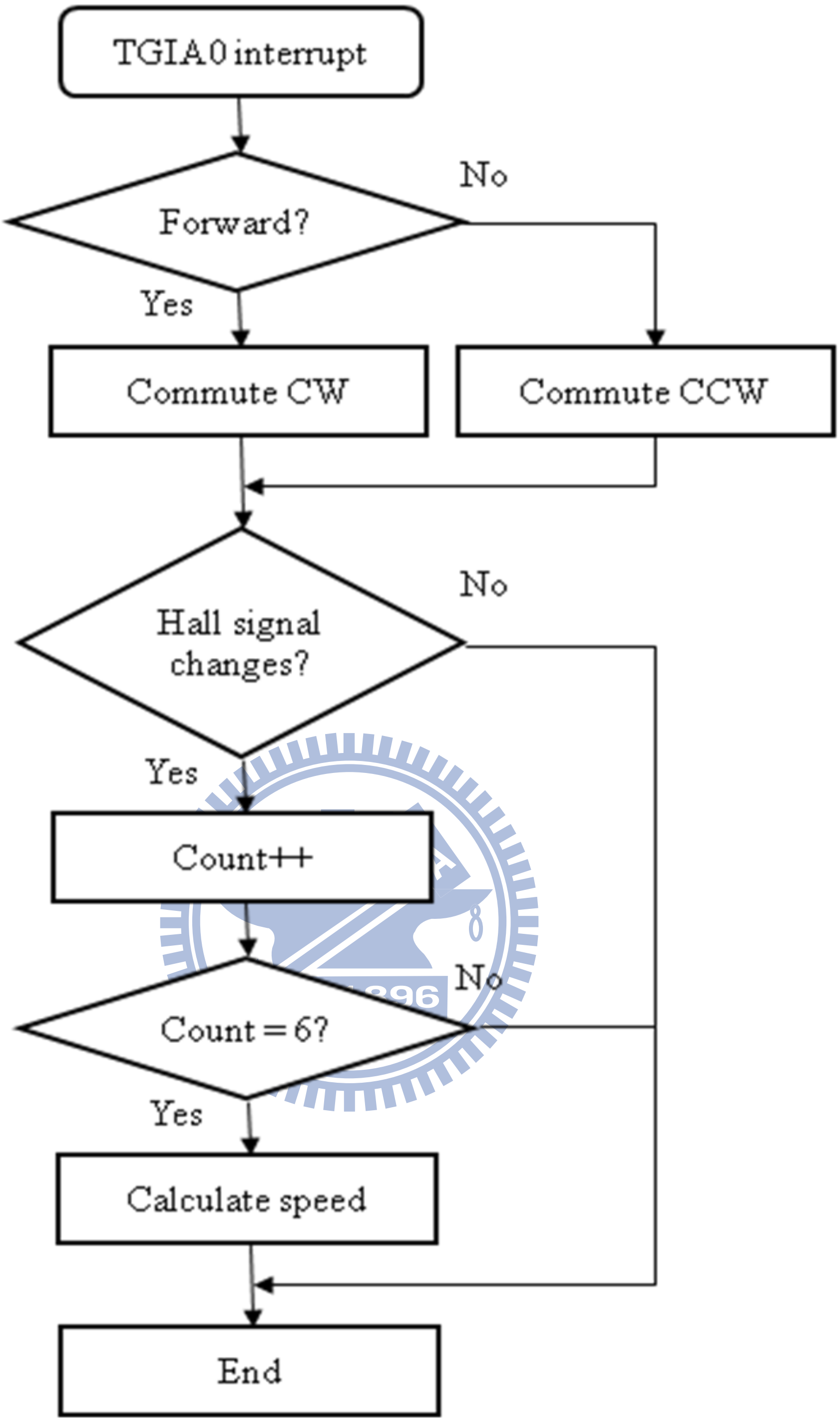


Fig 3.2 TGIA0 interrupt flowchart

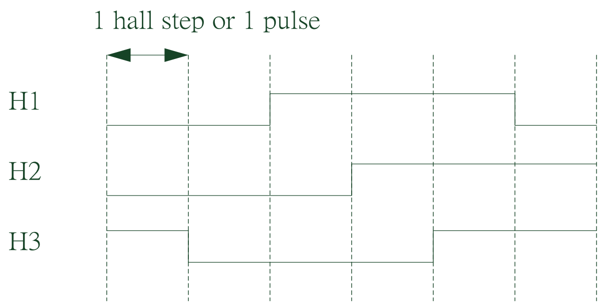


Fig 3.3 Hall signal

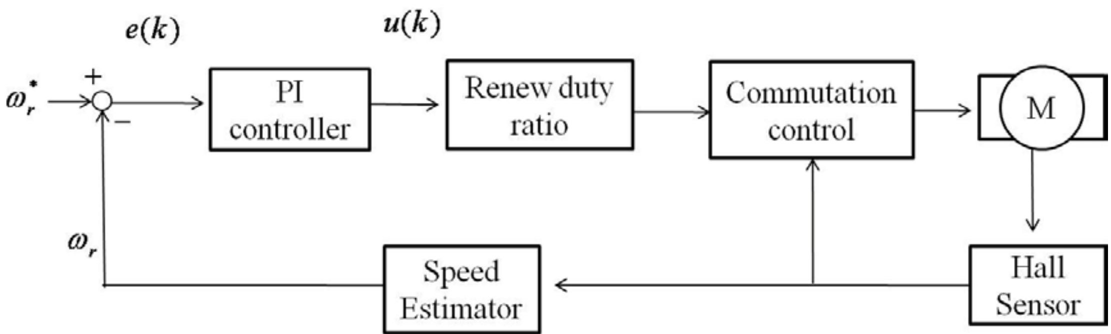


Fig 3.4 Close-loop control block diagram

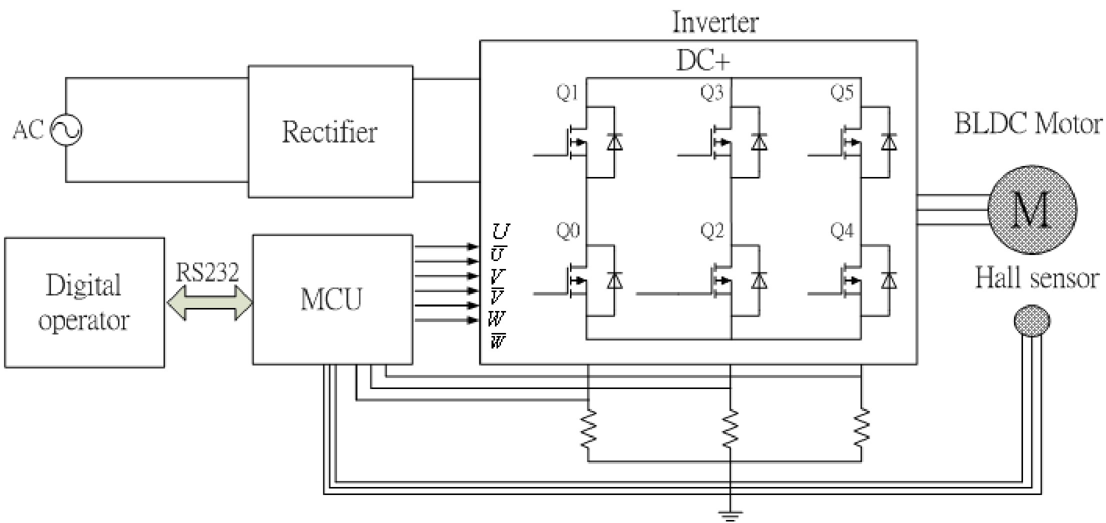


Fig 4.1 The structure of system

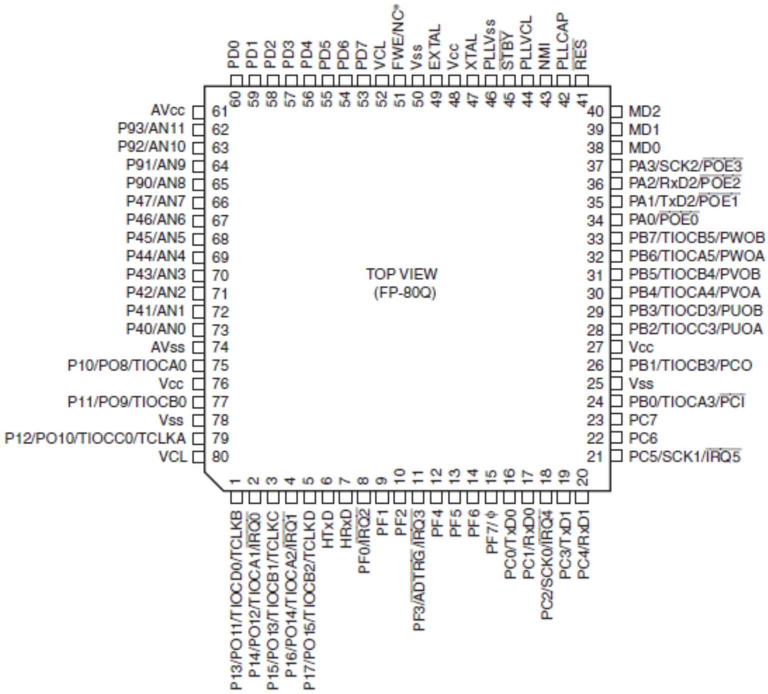


Fig 4.2 The HD64F2612F340 chip’s pin arrangement

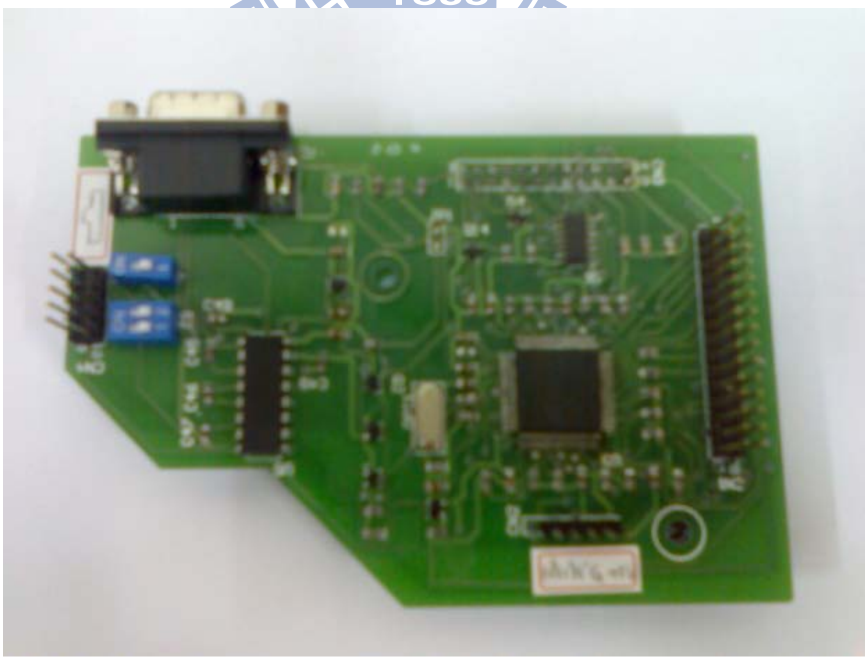


Fig 4.3 The layout of MCU circuit

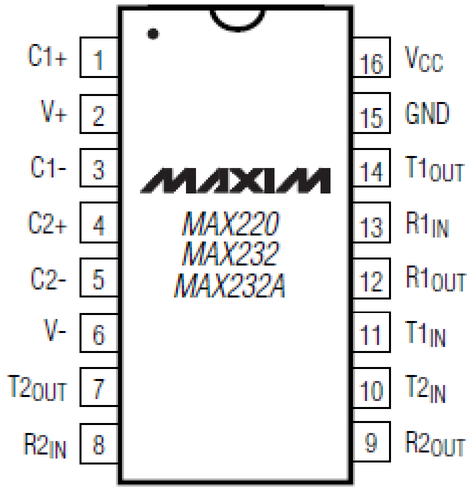


Fig 4.4 MAX232CPE

Fig 4.5 BLDC motor

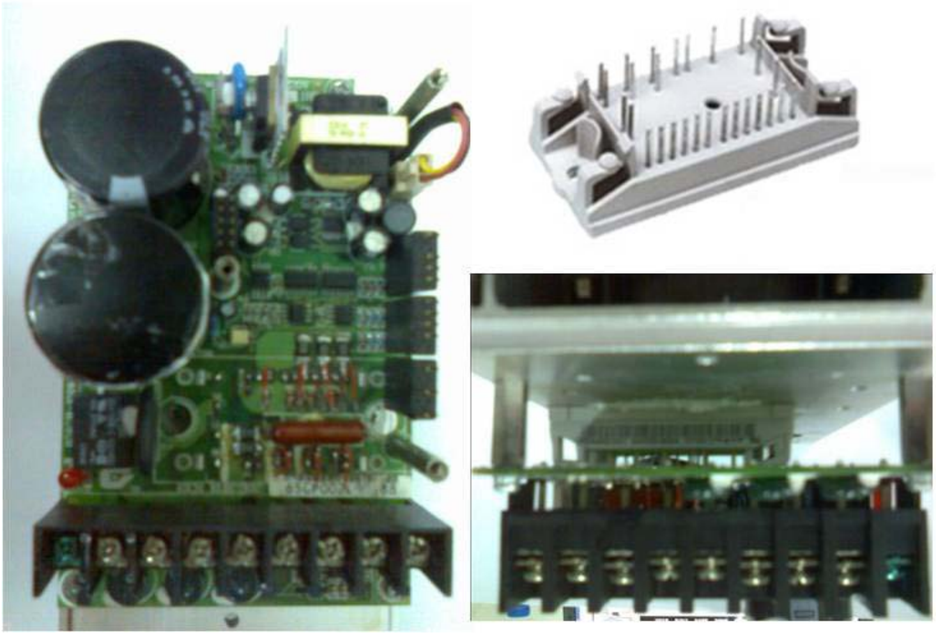


Fig 5.1 Inverter

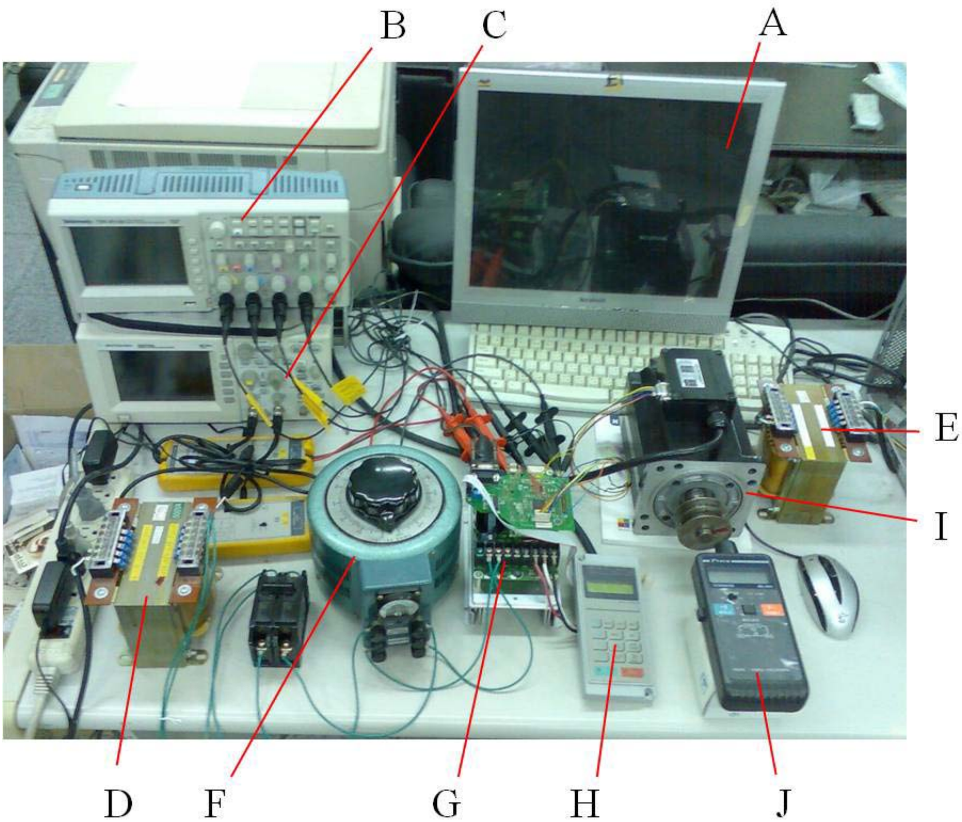


Fig 5.2 Hardware setup

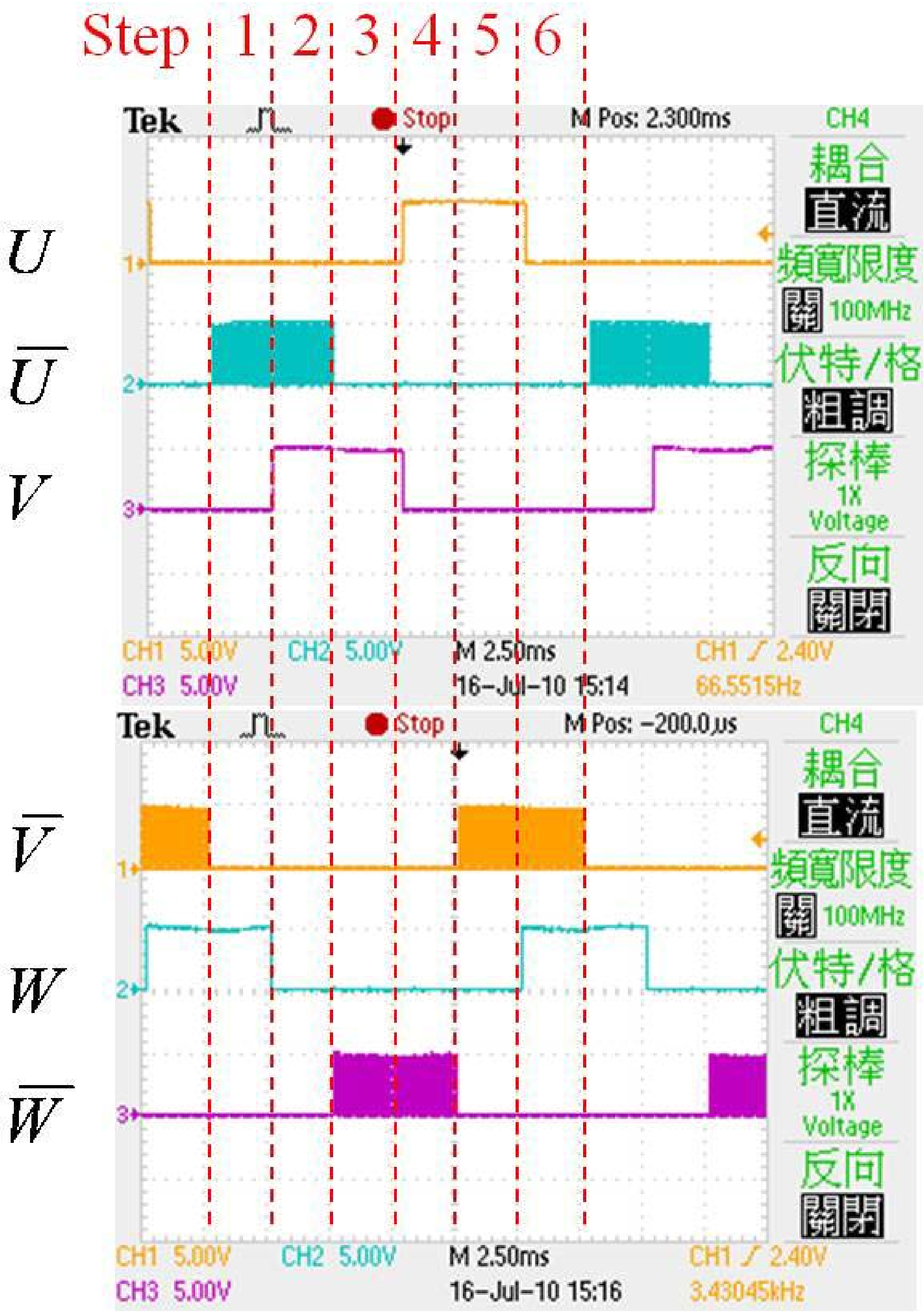


Fig 5.3 Six-step waveform

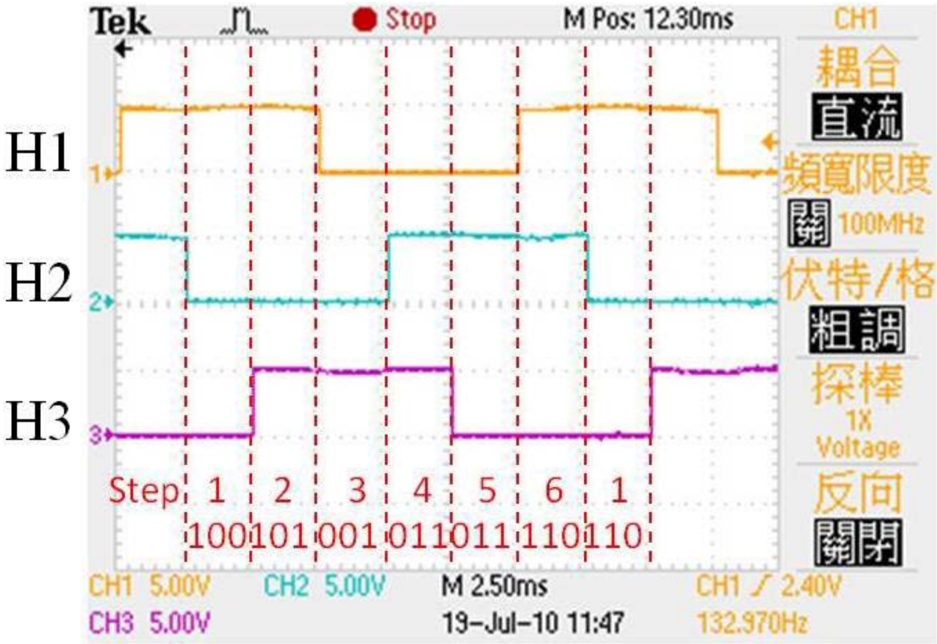


Fig 5.4 Hall signal's waveform

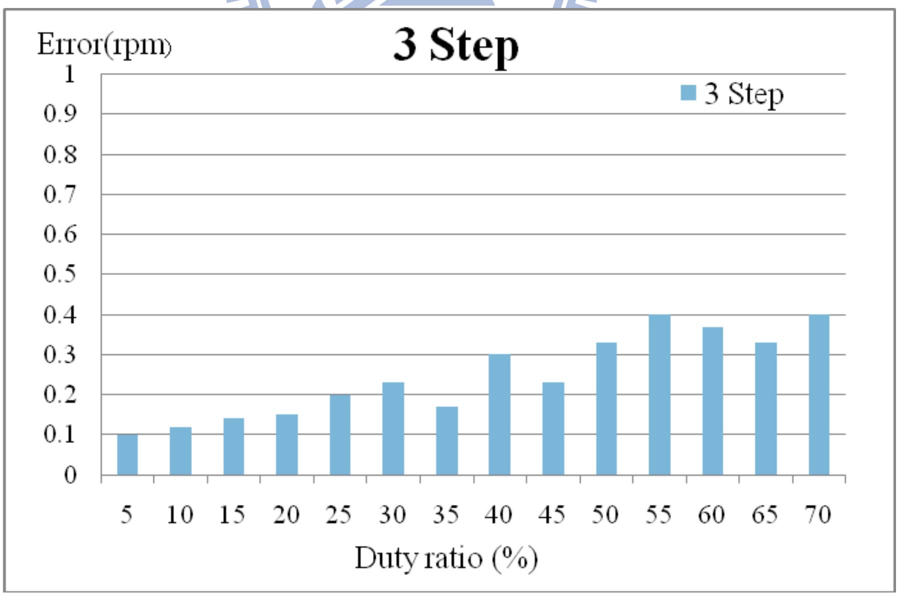


Fig 5.5 Speed error

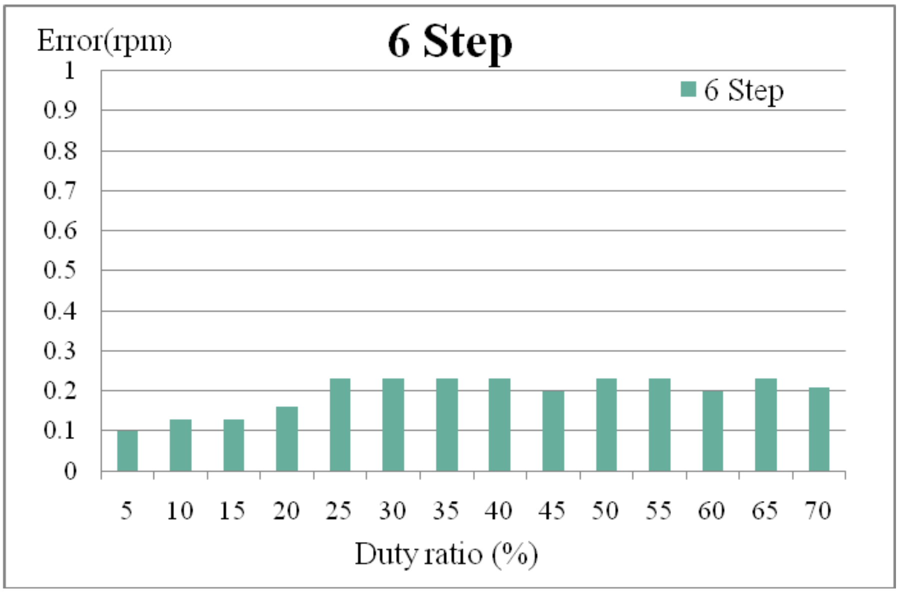


Fig 5.5 Speed error (continue)

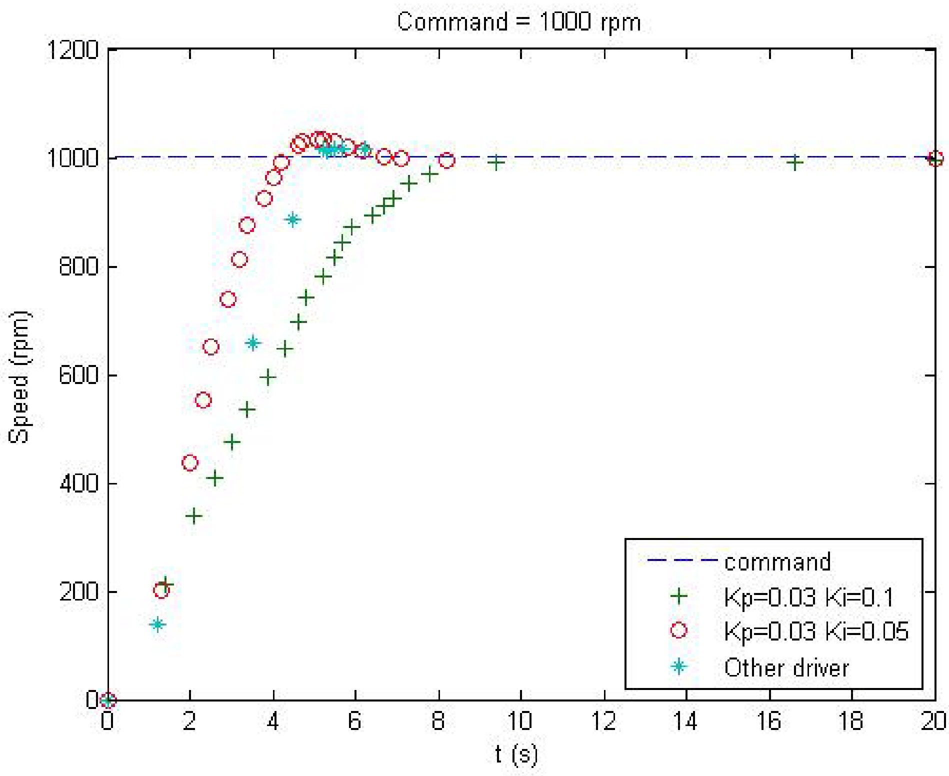


Fig 5.6 Speed response without load at 1000 rpm

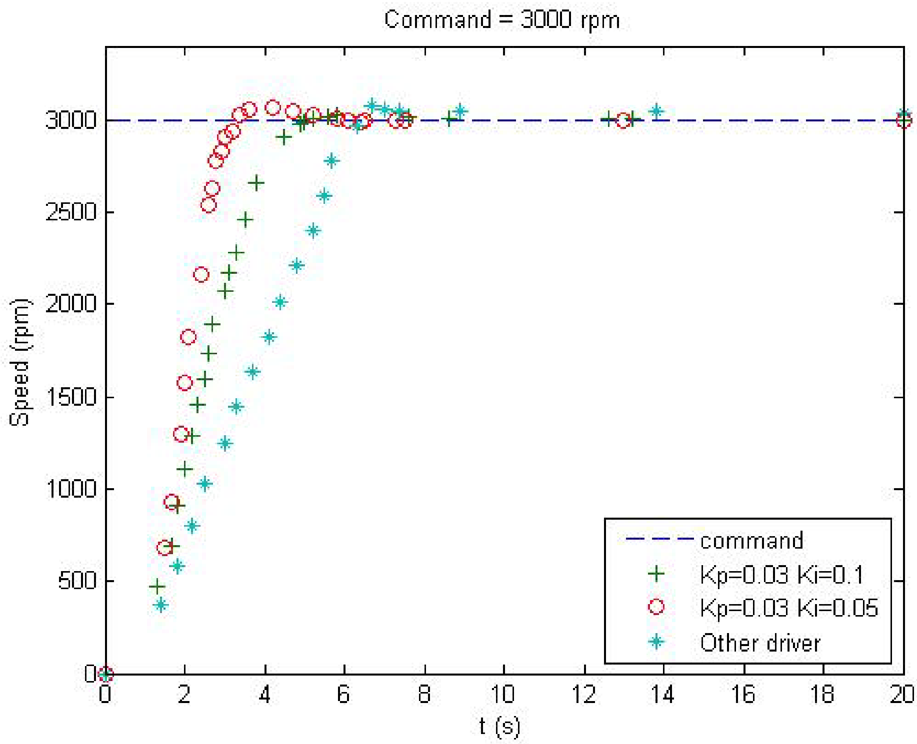


Fig 5.7 Speed response without load at 3000 rpm

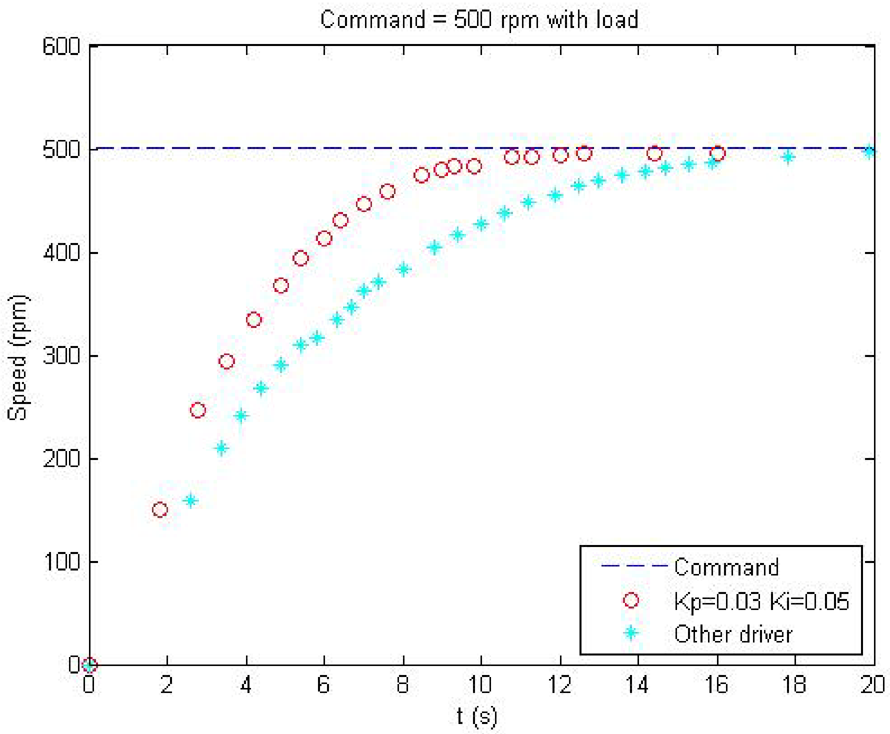


Fig 5.8 Speed response with load at 500 rpm