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RENESAS

Application Note

Motor Control by μPD78F0714

Hall IC 180° Excitation Method

μPD78F0714

Document No. U18913EJ1V0AN00 (1st edition)
Date Published October 2008 N

[MEMO]

NOTES FOR CMOS DEVICES

① VOLTAGE APPLICATION WAVEFORM AT INPUT PIN

Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (MAX) and V_{IH} (MIN) due to noise, etc., the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (MAX) and V_{IH} (MIN).

② HANDLING OF UNUSED INPUT PINS

Unconnected CMOS device inputs can be cause of malfunction. If an input pin is unconnected, it is possible that an internal input level may be generated due to noise, etc., causing malfunction. CMOS devices behave differently than Bipolar or NMOS devices. Input levels of CMOS devices must be fixed high or low by using pull-up or pull-down circuitry. Each unused pin should be connected to V_{DD} or GND via a resistor if there is a possibility that it will be an output pin. All handling related to unused pins must be judged separately for each device and according to related specifications governing the device.

③ PRECAUTION AGAINST ESD

A strong electric field, when exposed to a MOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop generation of static electricity as much as possible, and quickly dissipate it when it has occurred. Environmental control must be adequate. When it is dry, a humidifier should be used. It is recommended to avoid using insulators that easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors should be grounded. The operator should be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions need to be taken for PW boards with mounted semiconductor devices.

④ STATUS BEFORE INITIALIZATION

Power-on does not necessarily define the initial status of a MOS device. Immediately after the power source is turned ON, devices with reset functions have not yet been initialized. Hence, power-on does not guarantee output pin levels, I/O settings or contents of registers. A device is not initialized until the reset signal is received. A reset operation must be executed immediately after power-on for devices with reset functions.

⑤ POWER ON/OFF SEQUENCE

In the case of a device that uses different power supplies for the internal operation and external interface, as a rule, switch on the external power supply after switching on the internal power supply. When switching the power supply off, as a rule, switch off the external power supply and then the internal power supply. Use of the reverse power on/off sequences may result in the application of an overvoltage to the internal elements of the device, causing malfunction and degradation of internal elements due to the passage of an abnormal current.

The correct power on/off sequence must be judged separately for each device and according to related specifications governing the device.

⑥ INPUT OF SIGNAL DURING POWER OFF STATE

Do not input signals or an I/O pull-up power supply while the device is not powered. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements.

Input of signals during the power off state must be judged separately for each device and according to related specifications governing the device.

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M8E 02. 11-1

INTRODUCTION

Target Readers

This application note is intended for users who understand the functions of the μPD78F0714, and who design application systems that use these functions. The applicable product is shown below.

- μPD78F0714

Purpose

The purpose of this application note is to help the user understand the system that drives a brushless DC motor (BLDCM) equipped with Hall ICs via the 180° excitation method, by using the μPD78F0714.

Organization

This application note is divided into the following sections.

- General information
- PMSM control principle
- System overview
- Control program

How to Read This Manual

It is assumed that the readers of this application note have general knowledge in the fields of electrical engineering, logic circuits, and microcontrollers.

For details of hardware functions (especially register functions, setting methods, etc.) and electrical specifications

→ See the **μPD78F0714 User's Manual (U16928E)**.

For details of instruction functions

→ See the **78K/0 Series Instructions User's Manual (U12326E)**.

Conventions

Data significance:	Higher digits on the left and lower digits on the right	
Active low representation:	$\overline{xxx}$ (overscore over pin or signal name)	
Memory map address:	Higher addresses on the top and lower addresses on the bottom	
Note:	Footnote for item marked with **Note** in the text	
Caution:	Information requiring particular attention	
Remark:	Supplementary information	
Numeric representation:	Binary ... xxxx or xxxxB	
	Decimal ... xxxx	
	Hexadecimal ... xxxxH	
Prefix indicating the power of 2 (address space, memory capacity):	K (kilo):	$2^{10} = 1,024$
	M (mega):	$2^{20} = 1,024^2$
	G (giga):	$2^{30} = 1,024^3$
Data type:	Word:	32 bits
	Halfword:	16 bits
	Byte:	8 bits

Related documents

The related documents indicated in this publication may include preliminary versions. However, preliminary versions are not marked as such.

Documents related to the device

Document Name	Document No.
μPD78F0714 User's Manual	U16928E
78K/0 Series Instructions User's Manual	U12326E
Inverter Control by μPD78F0714 120° Excitation Method Control by Zero-Cross Detection Application Note	U17297E
Single-Phase Induction Motor Control by μPD78F0714 Two-Phase Sine Wave Inverter Drive via V/f Control Application Note	U17481E
Motor Control by μPD78F0714 Hall IC 120° Excitation Method Application Note	U18774E
Motor Control by μPD78F0714 Sensorless (BEMF) 120° Excitation Method Application Note	U18051E
Motor Control by μPD78F0714 Hall IC 180° Excitation Method Application Note	This manual
Motor Control by μPD78F0714 Sensorless (A/D Conversion of BEMF) 120° Excitation Method Application Note	U18912E

Documents related to development software tools (user's manuals)

Document Name		Document No.
RA78K0 Ver. 3.80 Assembler Package	Operation	U17199E
	Language	U17198E
	Structured Assembly Language	U17197E
CC78K0 Ver. 3.70 C Compiler	Operation	U17201E
	Language	U17200E
ID78K0-QB Ver. 2.94 Integrated Debugger	Operation	U18330E
PM plus Ver. 5.20		U16934E

Documents related to development hardware tools (user's manuals)

Document Name	Document No.
QB-780714 In-Circuit Emulator	U17081E
QB-78K0MINI On-Chip Debug Emulator	U17029E
QB-MINI2 On-Chip Debug Emulator with Programming Function	U18371E

Documents related to flash memory writing

Document Name	Document No.
PG-FP4 Flash Memory Programmer User's Manual	U15260E

Caution The related documents listed above are subject to change without notice. Be sure to use the latest version of each document for designing.

Other related documents

Document Name	Document No.
SEMICONDUCTOR SELECTION GUIDE - Products and Packages -	X13769X
Semiconductor Device Mount Manual	**Note**
Quality Grades on NEC Semiconductor Devices	C11531E
NEC Semiconductor Device Reliability/Quality Control System	C10983E
Guide to Prevent Damage for Semiconductor Devices by Electrostatic Discharge (ESD)	C11892E

Note See the “Semiconductor Device Mount Manual” website (http://www.necel.com/pkg/en/mount/index.html)

Caution The related documents listed above are subject to change without notice. Be sure to use the latest version of each document for designing.

CONTENTS

CHAPTER 1 GENERAL INFORMATION

This system uses 180° excitation to drive a permanent magnet synchronous motor (hereinafter referred to as "PMSM") equipped with Hall ICs.

- This system (sample program) uses an NEC Electronics motor starter kit (μPD78F0714)[Note] and uses 180° excitation to drive a PMSM equipped with Hall ICs.
- The control gain is adjusted in accordance with the motor in the operating environment specified below. Operation when the motor or control period is to be changed is not guaranteed.

Note For the motor starter kit (μPD78F0714), contact an NEC Electronics sales representative.

1.1 Operating Environment

This system is created on the assumption that it will be used in the following environment.

- Motor starter kit (μPD78F0714) board set
- Low-voltage inverter set
  BLDCM PITTMAN (N2311A011)[Note]
  - Reference voltage [V]: 12
  - No-load rotation speed [r/min]: 7197
  - Continuous torque [Nm]: 0.11
  - Maximum torque [Nm]: 0.23
  - Drive coil: 3 phases (Y connection)
  - Magnetic pole rotor: 4 poles (2 sets of poles)
  - Stator: 6 throttles
  - Position sensor: Hall IC
- PM plus environment platform V5.20
- CC78K0 compiler W3.70
- RA78K0 assembler W3.80
- DF0714.78K device file V1.10

Note In this operating environment, a BLDCM is used instead of a PMSM.

1.2 Related Manuals

For the development environment and board, see the following manuals.

- Low-Voltage Motor Starter Kit Manual
- PM plus Ver. 5.20 User's Manual
- Each User's Manual of CC78K0 Ver. 3.70 C Compiler
- Each User's Manual of RA78K0 Ver. 3.80 Assembler Package

CHAPTER 2 PMSM CONTROL PRINCIPLE

A PMSM rotates by attraction caused between the permanent magnet rotor and the rotating magnetic field generated by the coils wound around the stators, at the same speed as the rotating magnetic field.

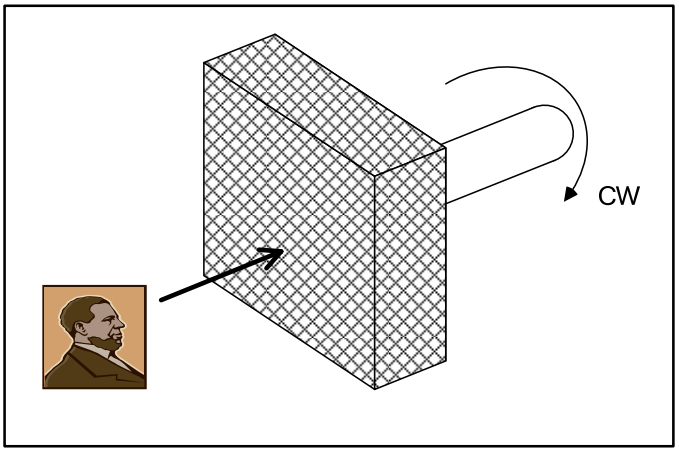
2.1 Rotation Direction Definition

First, the rotation direction of the motor is defined.

The rotation direction of the motor is either CW (clockwise) or CCW (counterclockwise).

CW or CCW is determined based on the direction in which the object to be rotated by the motor is rotated. As shown below, the rotation direction is based on when the surface on which the motor axis is located faces towards the object.

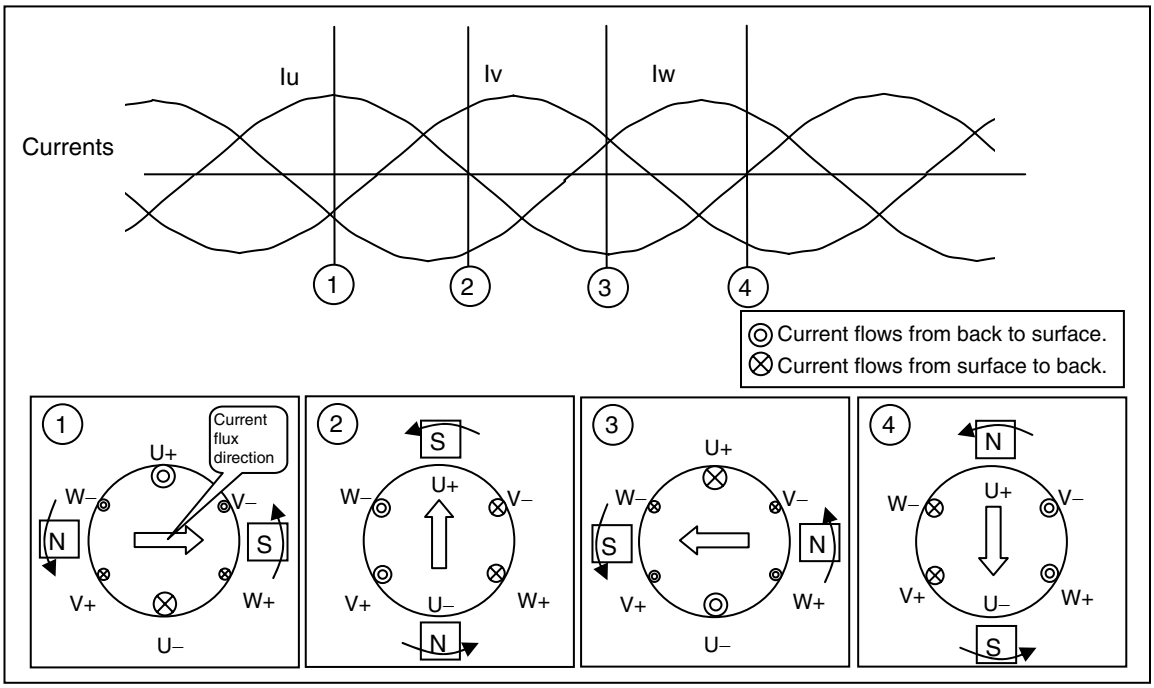
Figure 2-1. Motor Rotation Direction



2.2 Rotating Magnetic Field

With a PMSM, a rotating magnetic field is generated by passing an alternating current through the coils. The following figure illustrates the principle of using 3-phase windings to generate a rotating magnetic field. The 3-phase windings (phases u, v, and w) are placed at 120-degree intervals and 3-phase winding currents (Iu, Iv, and Iw) which have phase differences of 120 degrees each flow. The double-circles ("◎") in the figure are proportional to the current sizes.

Figure 2-2. 3-Phase Alternating Current and Principle of Generating Rotating Magnetic Field

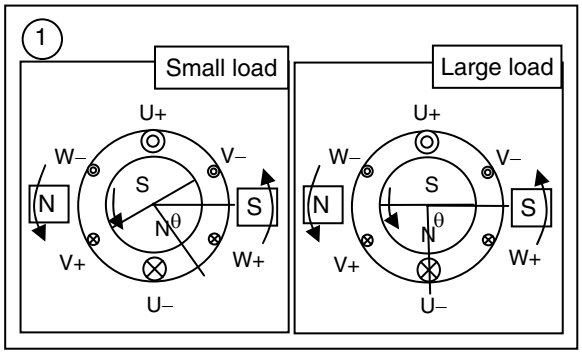


If the current flux direction is "*I*", the permanent-magnet flux "ϕ", and the gradients of the current flux and permanent-magnet flux "θ", the motor torque can be represented by the following expression.

$$T = I\varphi \sin\theta \quad (1)$$

As can be understood from expression (1), θ is 0° when there is no load, and synchronization is lost when the load exceeds the maximum occurring torque (the maximum torque occurs when θ = 90°).

Figure 2-3. Image During Rotation



If the current frequency is "f" and the number of pole pairs "P", speed "m" (rpm) can be represented by the following expression.

$$m = \frac{60f}{P} \quad (2)$$

For control that does not detect the rotor position (open-loop drive), the torque and current (voltage), as well as the speed and the current frequency must be controlled separately. If the load changes, θ in expression (1) also changes, resulting in inconsistent speed, occurrence of synchronization loss, and a large current flowing under a light load and a high voltage, making stable control difficult.

A highly efficient operation can be achieved by detecting the rotor position and always keeping θ at 90 degrees, because the occurring torque is always maximized. Also, the characteristics of the speed and torque will become identical to those of a DC motor by fixing the phases of the current and flux, and if the applied voltage is “V”, the coil resistance “R”, the induced voltage “E”, the current “I”, and the rotation speed of the rotor “N”, “E” becomes proportional to “N” and “T” becomes proportional to “I”. Consequently, if the proportionality constants are Ke and Kt, the following expressions can be derived.

$$V = RI + E \quad (3)$$

$$E = KeN \quad (4)$$

$$T = KtI \quad (5)$$

Expression (6) can be derived from the above-mentioned expressions.

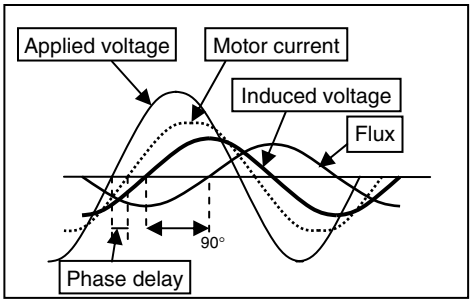
$$T = \left(Kt \middle/ R\right)(V - KeN) \quad (6)$$

If V is constant in expression (6), a decrease in rotation speed (N) leads to an increase in load (T) (synchronization is not lost). Consequently, a highly efficient operation by a current suited for the load can be performed by detecting the speed and adjusting the speed by using applied voltage V.

2.3 180° Excitation Method

Driving a motor by applying a sine wave voltage to windings is called 180° excitation method.
The following figure shows the instantaneous current waveform of phase U.

Figure 2-4. Instantaneous Voltage and Current Waveform



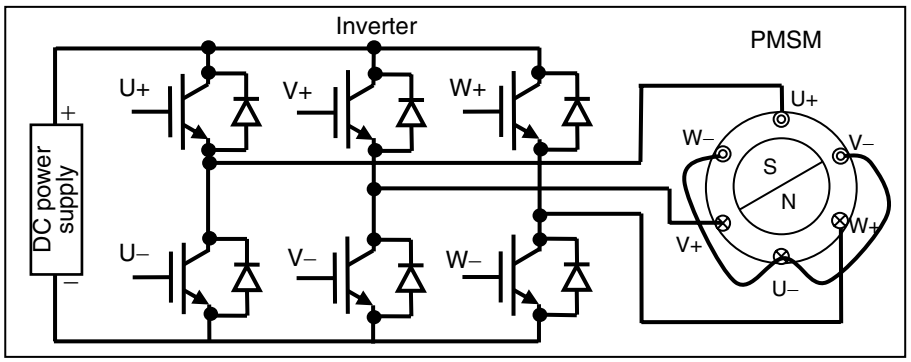
A difference voltage of the voltage applied to the motor and the induced voltage is applied to the motor coil, resulting in a motor current. The phase of the motor current is delayed from the applied voltage due to the coil inductance. Adjust this by the phase of the applied voltage, because the motor torque is maximized when the phase difference between the flux and current is 90 degrees.

2.4 Inverter

A PMSM generates a 3-phase alternating current from the DC power supply via variable-voltage, variable-frequency control (VVVF inverter control, or variable frequency drive) and performs variable control of the execution voltage and frequency in accordance with the load.

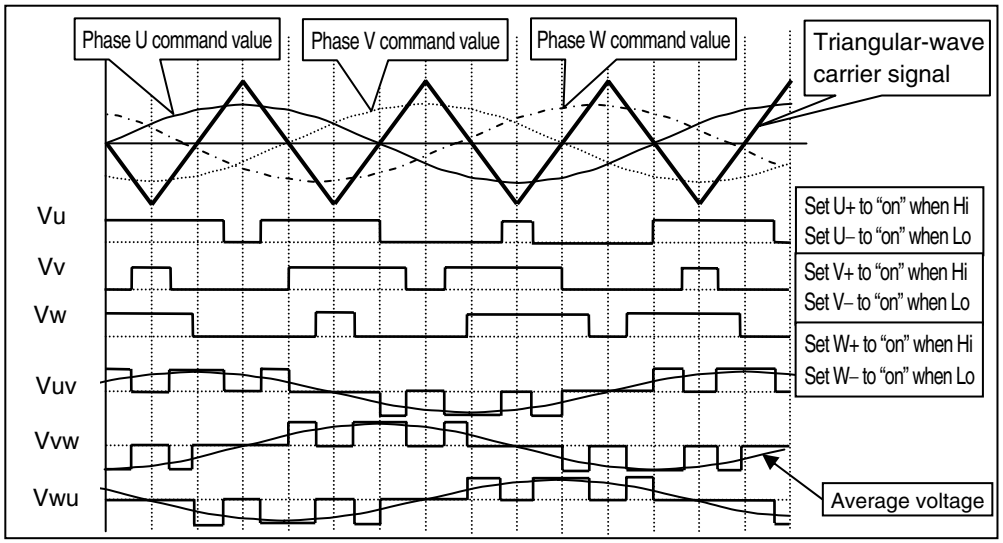
The following figure shows the connections between the PMSM and the 3-phase inverter.

Figure 2-5. 3-Phase Inverter and PMSM



The following figure shows an example where a 3-phase alternating current is passed through the coil by performing a chopper operation of the switching elements at the timing when the above-mentioned circuit was created via the triangular-wave comparison PWM method (phase modulation method).

Figure 2-6. 3-Phase Inverter Output Waveform (Triangular-Wave Comparison PWM Method)



The interphase voltage (Vuv, Vvw, Vwu) can be derived by toggling the switch of each phase to "on" or "off" in accordance with a command value (sine wave signal), which is identical to the operating inverter output frequency, and the size of the triangular-wave carrier signal. (The direction and intensity of the current changes according to the difference in the interphase voltage.)

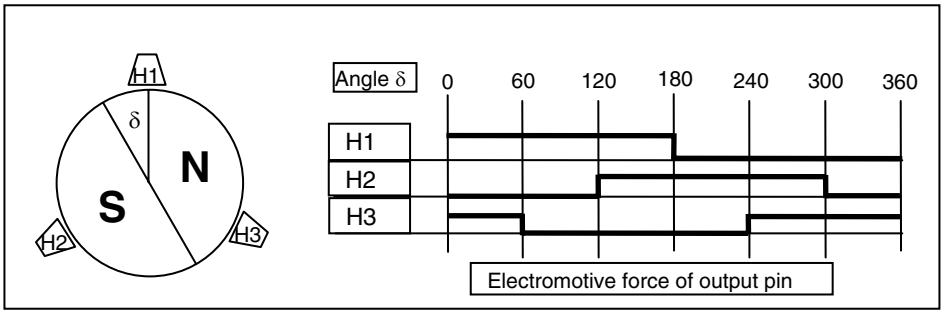
2.5 Position Detection

With the 180° excitation method, detailed position information is required to keep the angle between the current flux and the permanent-magnet flux at 90 degrees.

In this system, the positions of the Hall ICs are detected every 60 degrees from the changes of the Hall ICs (six pulses per cycle) that are placed at 120-degree intervals, and positions smaller than 60 degrees are inferred from the rotation speed.

The following figure illustrates an example of the output of the magnetic pole position sensors by using Hall ICs.

Figure 2-7. Hall IC Output



The positions of the Hall ICs can be detected every 60 degrees for the three phases, because the Hall IC output of each phase changes every 180 degrees.

When the rotor has four magnetic poles, the value of a Hall IC changes every 90 degrees and the excitation pattern is switched every 30 degrees.

Usually, one cycle (six excitation patterns) is defined as 360 degrees of electrical angle and one rotation of the motor axis is defined as 360 degrees of mechanical angle (all angles in this document are electrical angles unless otherwise specified).

Mechanical angle: Electrical angle/Number of pole pairs
Number of pole pairs: Number of poles/2

2.6 Starting Method

With the position information of the Hall ICs, the position of the rotor can be inferred from the change in Hall IC output and rotation speed. When the rotor is stopped, the position of the rotor may be erroneous up to 60 degrees, so the motor must be started by using a method that does not require detailed position information.

Representative starting methods are described below.

2.6.1 Synchronous start method

This method switches to 180-degree sine wave drive from a point where synchronous starting is performed by passing through 180-degree sine wave current and the rotor position can be inferred from the change in Hall IC output and rotation speed, after the rotor was forcibly positioned by exciting the coil.

When the resolution of the position information is low, adjusting the applied voltage and current frequency is difficult and rotation is unstable for 180-degree excitation drive from a stopped state.

2.6.2 120° excitation method

This method switches to 180-degree sine wave drive from a point where an excitation pattern of the 120° excitation method is used to pass through a current from Hall IC output and the rotor position can be inferred from the change in Hall IC output and rotation speed.

The 120° excitation method is mainly used, because torque pulsation occurs only when starting the motor and is therefore not a significant problem.

2.7 Speed Detection

The rotation speed of the motor is derived from calculating the period of time over which the values of the Hall ICs change.

2.8 Voltage Control

The voltage to be applied to the motor coil is controlled by PWM (Pulse Width Modulation) which adjusts the conduction rate (average voltage) through a chopper operation of the conduction period of the switching elements at a high frequency.

2.9 Speed Control

The speed is controlled by using the voltage applied to the coil, based on expression (6). Specifically, the rotor position is estimated from the Hall IC output and rotation speed, and the command value (comparison value with the triangular-wave carrier signal) of each phase to be applied to the triangular-wave comparison PWM method is calculated and set.

The command values are adjusted by PID control.

2.9.1 PID control

PID control changes the command values by calculations based on a deviation between the specified speed and detected rotation speed.

A PID control action consists of a proportional (P) action that produces an output in proportion to a deviation, an integral (I) action that produces an output in proportion to the integral of the deviation, and a derivative (D) action that produces an output in proportion to the derivative of the deviation.

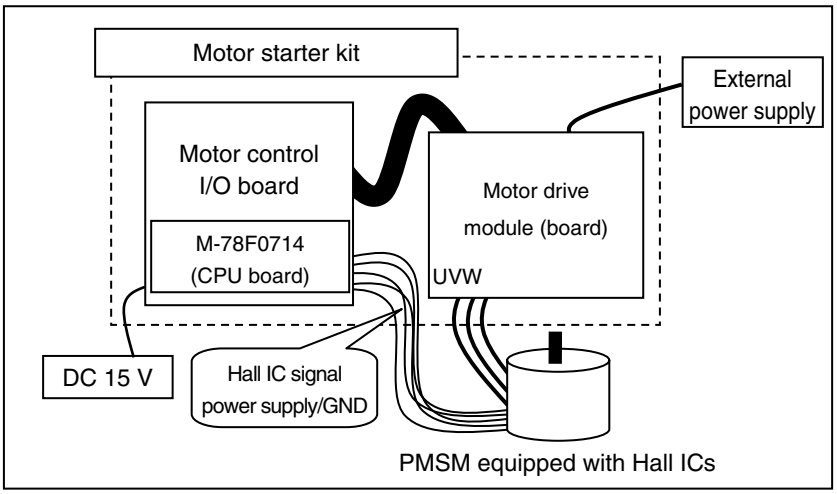
CHAPTER 3 SYSTEM OVERVIEW

This chapter presents an overview of the system.

3.1 Configuration

The following figure shows the configuration of this system.

Figure 3-1. System Configuration

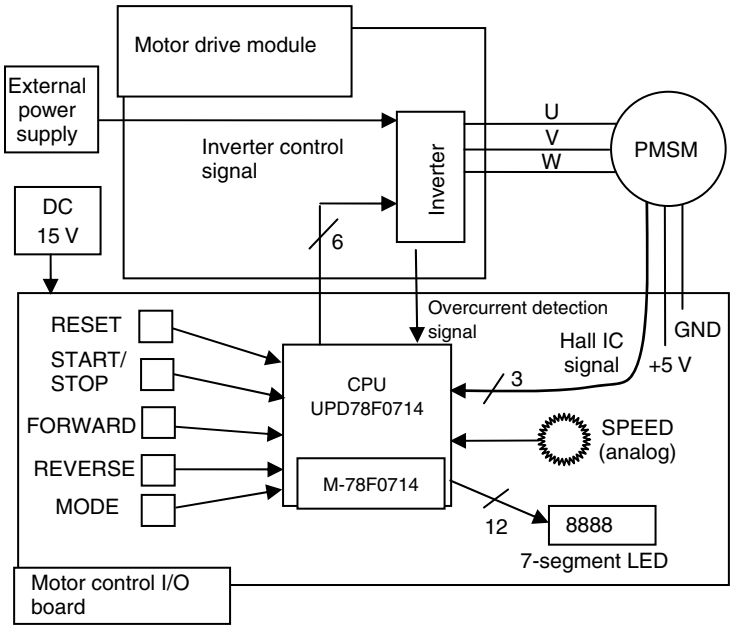


The system consists of a motor drive module that drives the motor, a motor control I/O board equipped with a switch that controls the motor, and M-78F0714 having a CPU.

A PMSM has three phases and four poles (two pairs of poles), and is equipped with Hall ICs.

The block configuration of the motor starter kit is shown below.

Figure 3-2. Block Configuration



The motor is controlled by the switch on the motor control I/O board.

3.2 Interface

Table 3-1 lists the user interface functions.

Table 3-1. User Interface

Function Name	Parts Number	Function
RESET	SW1	Reset
START/STOP	SW2	Start/stop
FORWARD	SW3	Rotation direction (Right rotation, clockwise, CW)
REVERSE	SW4	Rotation direction (Left rotation, counterclockwise, CCW)
MODE	SW5	Switching speed specification Switching speed display
SPEED	R52	Changing specified speed
8-segment LED	DISP1 DISP2 DISP3 DISP4	Displaying speed (rpm)[Note]

Note The specified speed is always displayed while the motor is stopped.
A dot (“.”) is displayed at the lower right while the specified speed is fixed.
The rotation speed is displayed while the motor is rotating.
The specified speed is displayed while the MODE switch is depressed when the motor rotates.
Reset continues while RESET is depressed and is released when it is released.
“SELF” is displayed for 2 seconds immediately after reset release.

Table 3-2 lists errors.

Table 3-2. Errors

Error	LED Indication	Situation
Hardware overcurrent	0.C.	Motor current is abnormal.
Software overcurrent	S.0.C	Motor current is abnormal.
Hall IC	HALL	Hall IC value is abnormal.
System failure	FAIL	Motor is not rotating.

Table 3-3 lists the interfaces of the μPD78F0714 pin.

Table 3-3. Interface of Pin

Pin Number	Pin Name	Function
8	$\overline{\text{RESET}}$	RESET (SW1)[Note]
27 to 32	TW0TO0/RTP10 to TW0TO5/RTP15	3-phase PWM inverter selection
11	P01/INTP1	Hall IC signal (HALL1)
10	P02/INTP2	Hall IC signal (HALL2)
9	P03/INTP3/ADTRG	Hall IC signal (HALL3)
49 to 52	P64 to P67	7-segment LED selection (LD_LED0 to LD_LED3)
56	P73	START/STOP (SW2)
55	P72	FORWARD (SW3)
54	P71	REVERSE (SW4)
53	P70	MODE (SW5)
41 to 48	P40/RTP00 to P47/RTP07	Output data to 8-segment LED
12	TW0TOFFP/INTP0/P00	Overcurrent detection (+5 V → 0 V)
60	P24/ANI4	Speed change (R52)
59	P25/ANI5	ISHUNT current
20	P53/TI000/INTP5	Timer capture trigger
21	P54/TI001/TO00	Motor drive module control

Note Shorts out 1-2 of 2JP7.

3.3 Functions

Table 3-4 lists the functions and operation overview of this system.

Table 3-4. System Functions and Operation Overview (1/2)

Function	Overview
Start (power supply)	• “SELF” is displayed with LEDs for 2 seconds. • Specified speed (rpm) of SPEED volume is displayed with LEDs.
RESET switch	• System is restarted regardless of the status of motor control.
START/STOP switch	While motor control is stopped: Motor control is started.
	• “0” is displayed with LEDs. • Motor starts rotating clockwise. • Motor revolution speed (rpm) is displayed with LEDs.
	While motor is controlled: Motor control is stopped.
	• Motor revolution speed (rpm) is displayed with LEDs until it reaches 0. • Specified speed (rpm) of SPEED volume is displayed with LEDs.
	START and STOP do not toggle even if this switch is depressed.
FORWARD switch	While motor control is stopped: Does not function.
	• Does not change.
	While motor is controlled: Rotation direction is changed.
	• If rotation direction is CCW, it is changed to CW after being stopped once. • If rotation direction is CW, it is not changed.
REVERSE switch	While motor control is stopped: Does not function.
	• Does not change.
	While motor is controlled: Rotation direction is changed.
	• If rotation direction is CCW, it is not changed. • If rotation direction is CW, it is changed to CCW after being stopped once.
MODE switch	While motor control is stopped: Speed specification is switched.
	• Change of specified speed by SPEED volume is enabled or disabled. • When disabled, a dot (“.”) is displayed to the lower right of the LED value.
	While motor is controlled: Changes display with LEDs.
	• Specified speed (rpm) of SPEED volume is displayed with LEDs while this switch is depressed.
SPEED volume	While motor control is stopped: Changes specified speed.
	• Speed (rpm) displayed with LEDs is displayed. • No change if disabled with MODE switch.
	While motor is controlled: Changes specified speed.
	• Motor rotates at specified speed (average).
Hardware overcurrent	• Occurs if permissible current of motor drive module is exceeded. • Motor control is stopped. • “0.C.” is displayed with LEDs. • Functions other than RESET switch are disabled.
Software overcurrent	Occurs if permissible current of motor is exceeded. Motor control is stopped. “S.0.C.” is displayed with LEDs. Functions other than RESET switch are disabled.

Caution The operation is not guaranteed if two or more switches are pressed at the same time.

Table 3-4. System Functions and Operation Overview (2/2)

Function	Overview
No rotation	• If motor does not rotate for 1.25 seconds from START and if motor has stopped for 0.5 seconds or longer during rotation. • Motor control is stopped. • “FAIL” is displayed with LEDs. • Functions other than RESET switch are disabled.
Hall IC abnormality	• Occurs if value from Hall IC is illegal. • Motor control is stopped. • “HALL” is displayed with LEDs. • Functions other than RESET switch are disabled.

Caution The operation is not guaranteed if two or more switches are pressed at the same time.

3.4 Peripheral I/Os

This system uses the following peripheral I/Os.

Table 3-5. Peripheral I/Os

Function	Peripheral I/O Function Name (μPD78F0714)
Inverter timer	• For PWM output • 10-bit inverter control timer (TW0UDC, etc.) • Carrier (modulation) frequency is 10 kHz (symmetrical triangular wave). • Carrier (modulation) synchronization interrupt is generated at intervals of 200 μs (interrupt frequency by carrier is set to once every two times). (Updated by calculating applied voltages of three phases by main PID control and calculating command values by carrier synchronization interrupt.)
Real-time output	• For changing excitation pattern • Real-time output port (RTBH01, RTBL01, etc.) • 16-bit timer capture/compare register 01 (CR01) (Used for excitation pattern output of 120° excitation method upon start.)
Timer for acquiring ISHUNT current value	• For timing adjustment • 8-bit timer/event counter 51 (TM51, CR51) • Interrupts are generated at 1.43 ms intervals and ISHUNT current measurement function is performed.
Wait processing	• For timing adjustment • 8-bit timer/event counter 50 (TM50, CR50) • Interrupt request flags are set at 1 ms intervals.
Reading specified speed	• Converts voltage on variable resistor value into specified speed. • A/D converter (ANI4)
Acquiring ISHUNT current value	• Acquires voltage value from pin (ANI5) by converting voltage of motor operating current.
Capture interrupt	• For speed calculation • Interrupt function (TI000/INTP5)
Hardware overcurrent interrupt	• Interrupt function (INTP0) • Occurrence of overcurrent in motor drive module (low-active)
Fail safe	• Watchdog timer

3.5 Interrupts

Table 3-6 shows the interrupts used in this system.

Table 3-6. Interrupts Used

Name	Function	Condition of Occurrence
INTP0	Detection of overcurrent occurrence	External pin
INTP5	Detection of change in HALL1 (speed calculation)	External pin
INTTW0UD	Occurrence of carrier synchronization interrupt	Underflow of inverter timer counter
INTTM51	Acquisition of ISHUNT current	Overflow of 8-bit timer counter
RESET	Occurrence of reset	$\overline{\text{RESET}}$ pin
WDT	Occurrence of internal reset	Watchdog timer overflow due to program runaway

Remark INTTM50 and INTAD are processed with polling of the interrupt request flag.

CHAPTER 4 CONTROL PROGRAM

This system uses a basic control program to actually control the speed of a motor.

4.1 Compiler Options

The two types of inverters that can be controlled by using this control program can be switched by using options when compiling[Note].

Table 4-1. Compiler Options

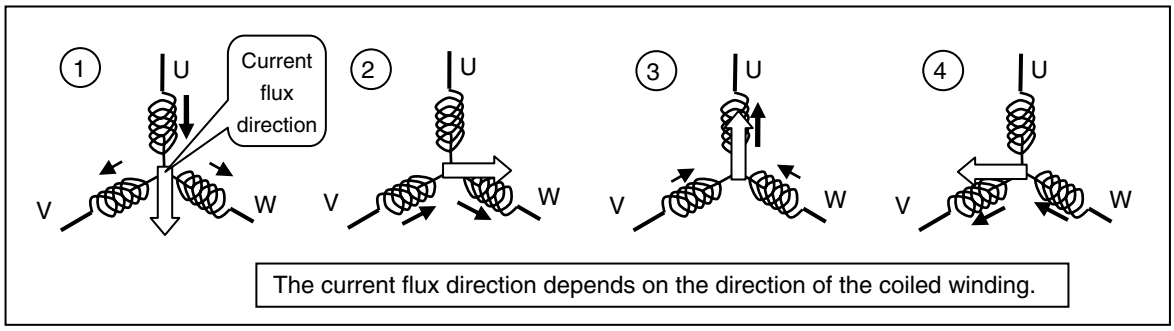
Option Name	Function
LOW	When using PITTMAN motor
None[Note]	When using another motor

Note LOW must be set, because a PITTMAN motor is used in this control program.

4.2 Rotating Magnetic Field

Figure 2-2 3-Phase Alternating Current and Principle of Generating Rotating Magnetic Field changes as follows, because this system uses a BLDCM (brushless DC motor) instead of a PMSM.

Figure 4-1. Rotating Magnetic Field with Concentrated Winding

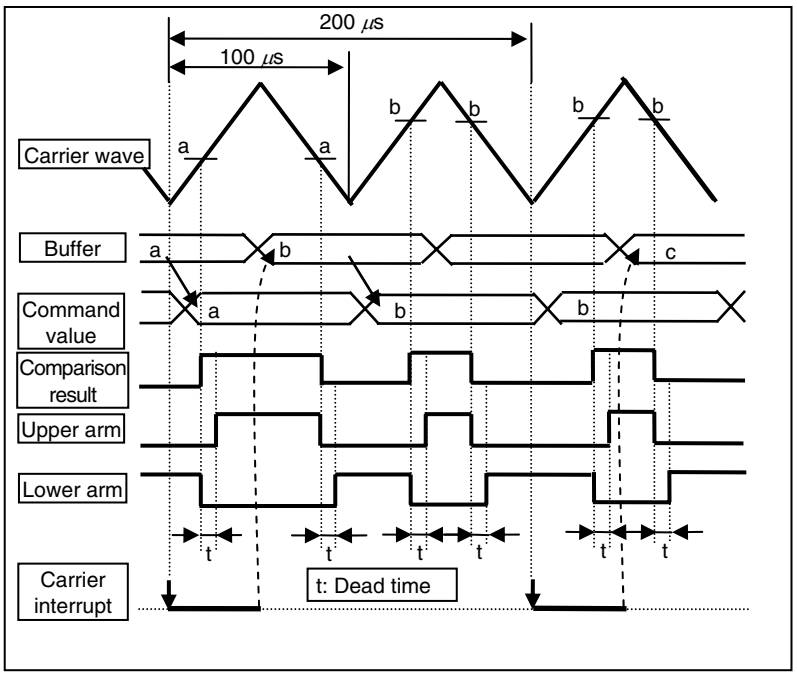


4.3 Inverter

The inverter timer function is used to switch the inverter.

A carrier synchronization interrupt occurs every time a counter underflow occurs, and the next inverter timer output pattern is set.

Figure 4-2. Timing of Carrier Synchronization Interrupt Occurrence

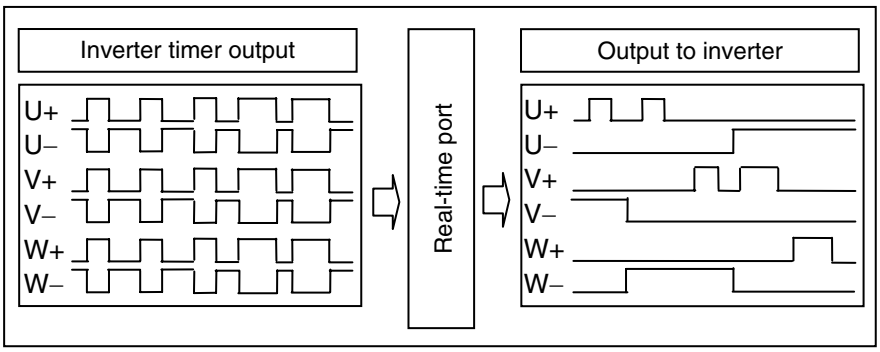


With the 180° excitation method, the real-time port function is stopped and the inverter timer output becomes the output to the inverter. The waveform of the inverter timer output is changed by carrier synchronization interrupts (every 200 μs), according to the result of a PID control operation that used position information calculated from the Hall IC value and the number of carrier synchronization interrupts.

For the case when the carrier wave was set to 5 kHz and a carrier synchronization interrupt was set to occur every time (200 μs), processing was performed by generating an interrupt for every two 10 kHz carrier waves, because the high-frequency sound has occurred in the motor used.

PWM control of a non-complementary operation for the entire upper arm area is performed with the 120° excitation method upon starting.

Figure 4-3. Image of PWM Output with 120° Excitation Method



The waveform of the inverter timer output will be changed according to the PID control operation result.

The mask processing (excitation pattern) by the real-time port is determined by the Hall IC value for each carrier synchronization interrupt (200 μs).

4.4 180° Excitation Method

The command values to be used with the triangular-wave comparison PWM method are derived as follows.

$$Vu = {E_d}/{2} \cdot M \cdot \cos(\delta + \alpha)$$
$$Vv = {E_d}/{2} \cdot M \cdot \cos(\delta + \alpha - {2\pi}/{3})$$
$$Vw = -(Vu + Vv)$$

Vu, Vv, Vw: Command values of the three phases
E_d: DC power supply voltage, δ: rotation angle, α: lead angle, M: voltage command value $0 < M \leq 1$

The voltage lead angle can be derived by representing the motor by using a voltage and current model expression.

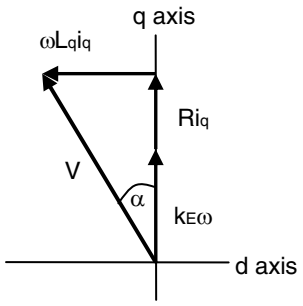
The voltage equation and torque expression when the permanent-magnet synchronous motor is stationary are as follows.

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R & -\omega L_q \\ \omega L_d & R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 \\ k_E\omega \end{bmatrix}$$

$T = P_n k_E i_q + P_n(L_d - L_q) i_d i_q$
id, iq: d and q axis elements of the armature current, v_d, v_q: d and q axis elements of the armature voltage,
k_E: induced-voltage constant, L_d, L_q: d and q axis inductance, ω: speed, P_n: number of pole pairs

The following figure shows the voltage vector locus when the d-axis current is controlled to be 0.

Figure 4-4. Vector Diagram



It can be understood from the torque expression that increase in load results in increase of the current, and from the vector diagram that increase in speed and current results in increase of lead angle α.

Processing was performed by setting a value corresponding to the conditions through tabulation as the lead angle, because this system (CPU) was not capable of performing these calculations as needed. (The lead angle can be changed within the program.)

4.5 Position Detection

The angles for every 60 degrees are detected from the Hall IC values and further detailed angles are reasoned by analogy from the time elapsed (number of carrier synchronization interrupts having occurred at 200 μs intervals) since the values of the motor rotation speed and Hall ICs changed.

The relations between the Hall IC values and the positions of the magnetic poles of the rotor are as follows, according to the excitation patterns of the 120° excitation method and the Hall IC values.

Figure 4-5. Excitation Patterns of 120° Excitation Method

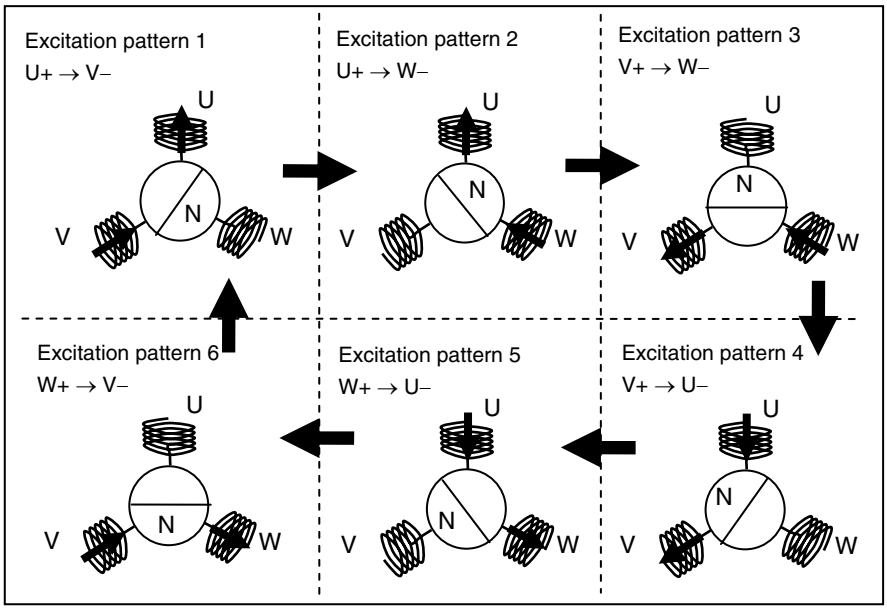


Table 4-2. Relations Between Excitation Patterns and Hall ICs (According to Motor Specification Table)

Excitation Pattern / Hall IC	1	2	3	4	5	6
S1 (HALL1)	L	L	H	H	H	L
S2 (HALL2)	H	L	L	L	H	H
S3 (HALL3)	H	H	H	L	L	L

The relations between changes in Hall IC output and angles are shown below.

The pin information, excitation patterns, and Hall IC values are described according to the BLDCM specifications.

4.5.1 Low-voltage inverter set

Table 4-3. BLDCM Pin Specifications

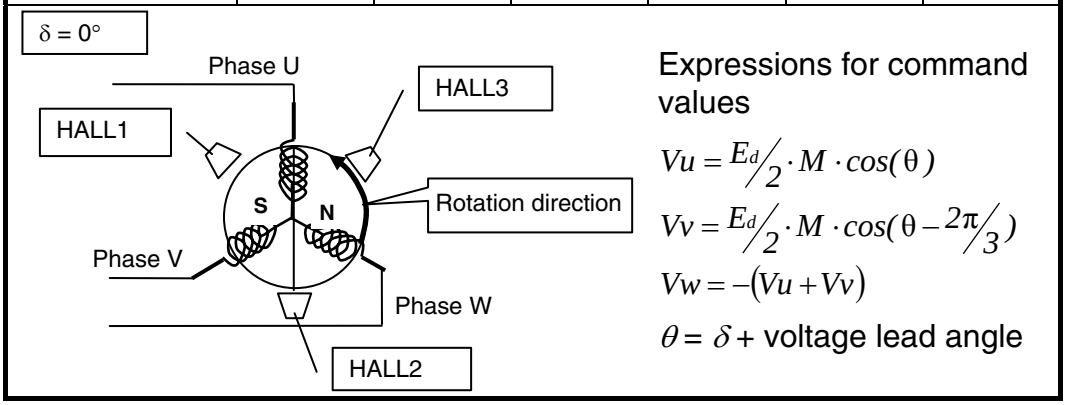
Color	Function	Remark
BROWN	MOTOR ϕA	Phase U
RED	MOTOR ϕB	Phase V
ORANGE	MOTOR ϕC	Phase W
GREY	SENSOR ϕ1	HALL1
BLUE	SENSOR ϕ2	HALL2
WHITE	SENSOR ϕ3	HALL3
VIOLET	SENSOR Vcc	
BLACK	SENSOR GND	

Table 4-4. Excitation Patterns and Hall IC Values in 120° Excitation Mode

Excitation (Positive Rotation)	+A −B	+A −C	+B −C	−B −A	+C −A	+C −B
SENSOR ϕ1	L	L	H	H	H	L
SENSOR ϕ2	H	L	L	L	H	H
SENSOR ϕ3	H	H	H	L	L	L
Excitation (reverse rotation)	+B −A	+C −A	+C −B	+A −B	+A −C	+B −C

Table 4-5. Angles in 180° Excitation Mode

Angle (δ) / Hall IC	0	60	120	180	240	300
HALL1	L	L → H	H	H	H → L	L
HALL2	H → L	L	L	L → H	H	H
HALL3	H	H	H → L	L	L	L → H



4.6 Starting Method

This system starts a motor by using the 120° excitation method. See **Motor Control System Specification Design Report Hall IC 120° Excitation Method** for details of the 120° excitation method.

4.7 Speed Detection

High-precision speed detection is performed with speed calculation that is not affected by delay which occurs when count values are saved in normal processing, by using the timer capture function to instantaneously save the timer count values at the point when the Hall IC values change.

In the case of the BLDCM of this system (three phases, four poles), a Hall IC changes four times with one rotation; however, only the change on the rising side is processed due to the specifications of the timer function to be used, so the speed is calculated from the timer value that has changed during half a rotation.

$$N = \frac{60}{s \times n \times 2} = \frac{2343750}{n}$$

N: Number of revolutions per minute (*rpm*)

s: Resolution of timer (12.8 μs)

n: Value of timer

2: Number of poles facing each other

This system supports a revolution speed range of 200 to 7,200 rpm for a PITTMAN motor.

4.8 Voltage Control

The voltage command values to be used with the triangular-wave comparison PWM method are used to control the interphase voltage of the three phases.

4.9 Speed Control

Speed is controlled by changing the voltage command values of the triangular-wave comparison PWM method. The voltage command values are adjusted by PID control.

4.9.1 PID control

The speed is adjusted by feeding back the difference between the rotation speed and the specified speed and performing a PID control operation on the DC power supply voltage command value. The manipulated variable of the voltage command value uses the following speed type PID algorithm suitable for the sampling method (discrete value).

$$MV_n = MV_{n-1} + \triangle MV_n$$
$$\triangle MV_n = Kp(e_n - e_{n-1}) + Ki \times e_n + Kd((e_n - e_{n-1}) - (e_{n-1} - e_{n-2}))$$

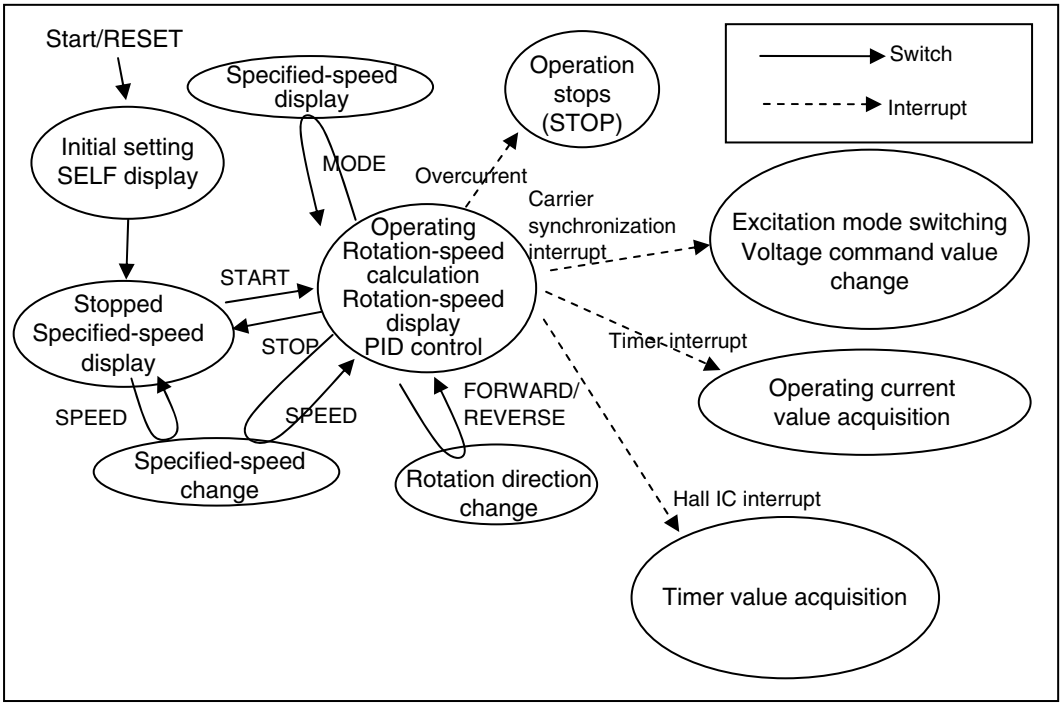
MV_n: Current manipulated variable
MV_{n-1}: Previous manipulated variable
$\triangle MV_n$: Difference between current and previous manipulated variables
e_n: Current deviation (difference between specified speed and actual speed)
e_{n-1}: Previous deviation
e_{n-2}: Deviation before previous deviation
Kp: Feedback gain (proportional element)
Ki: Feedback gain (integral element)
Kd: Feedback gain (derivative element)

The optimum values of the feedback gains change depending on the motor characteristics and on the presence or absence of a load.

4.10 Module Configuration

A status transition diagram of the system is shown below.

Figure 4-6. Status Transition of System



A carrier synchronization interrupt occurs every 200 μs.

A Hall IC interrupt occurs twice every rotation.

4.11 Control Program Function List

The control program consists of many functions. The following tables list these functions and their features. For details of processing, see the flowcharts.

4.11.1 Functions usable by users

Table 4-6. Functions Usable by Users

Function Name	Function	Purpose
motor_init()	Initial settings	Performs initialization required for motor control, such as register setting for each function and interrupt setting.
motor_start()	Start instruction	Instructs start of motor rotation.
motor_stop()	Stop instruction	Instructs stopping of motor rotation.
motor_rotation()	Rotation direction instruction	Instructs the direction of motor rotation.
motor_pid()	PID operation	Instructs PID operation.
motor_pset()	Parameter setting	Sets the parameters required for motor control.

4.11.2 Motor library internal functions

Table 4-7. Motor Library Internal Functions

Function Name	Function	Purpose
system_restart()	Restart processing	Restarts after stopping reverse rotation.
system_stop()	Stop processing	Stops the system.
init_PORT()	Port setting processing	Sets the port to be used for motor control.
init_OSC()	Clock setting processing	Performs clock setting for CPU operating speed.
init_TW0()	Inverter setting processing	Sets the inverter timer.
start_TW0()	Inverter start processing	Starts the inverter timer.
stop_TW0()	Inverter stop processing	Stops the inverter timer.
set_TW0()	PWM setting processing	Sets PWM.
init_TM00()	TM00 setting processing	Sets the 16-bit timer.
start_TM00()	TM00 start processing	Starts the 16-bit timer.
stop_TM00()	TM00 stop processing	Stops the 16-bit timer.
init_RTPM01()	Real-time output port setting processing	Sets the real-time output port.
start_RTPM01()	Real-time output port start processing	Starts the real-time output port.
stop_RTPM01()	Real-time output port output stop processing	Stops the real-time output port.
end_RTPM01()	Real-time output port use stop processing	Shifts from real-time output port to PWM output.
set_RTPM01()	Excitation pattern switching processing	Sets the real-time output port output value and performs output switching processing.
init_AD()	A/D setting processing	Sets A/D conversion.
start_AD()	A/D start processing	Starts A/D conversion.
init_WDTM()	Watchdog timer setting processing	Sets the watchdog timer.
init_TM51()	TM51 setting processing	Sets the 8-bit timer.
start_TM51()	TM51 start processing	Starts the 8-bit timer.
read_Hall_IC()	Hall IC information acquisition	Acquires Hall IC information from port.
INTP0_on()	INTP0 enable processing	Enables overcurrent interrupts.
INTTW0UD_on()	INTTW0UD enable processing	Enables carrier synchronization interrupts.
INTTW0UD_off()	INTTW0UD disable processing	Disables carrier synchronization interrupts.
INTP5_on()	INTP5 enable processing	Enables speed information acquisition interrupts.
INTP5_off()	INTP5 disable processing	Disables speed information acquisition interrupts.
INTTM51_on()	INTTM51 enable processing	Enables timer interrupts for a current minor loop.
int_speed()	Interrupt servicing for speed information acquisition	Sets a flag urging updating of speed information.
int_fault()	Overcurrent interrupt servicing	Stops motor processing.
int_carrier()	Carrier interrupt (valley) servicing	Switches the excitation pattern, updates the duty factor, and diagnoses the motor operating state.
int_TM51()	Current acquisition interrupt servicing	Acquires current value.
get_coswt()	COS operation processing	Performs COS operation.
set_pwm()	PWM value acquisition processing	Performs acquisition operation for PWM value optimal for acquired Hall IC.

4.11.3 Reference program functions

Table 4-8. Reference Program Functions

Function Name	Function	Purpose
print_error()	Error display	Displays the error status with the LEDs.
get_sw()	Switch read instruction	Instructs reading of switch information on the MC-IO board and returns operation information corresponding to the switch read.
speed_print()	Speed display	Displays the speed with the LEDs.
led_print()	Data generation for display	Generates and passes data to the LEDs.
led_set()	LED display	Displays data with the LEDs.
wait()	Wait	Waits for a specified time.
startup_disp()	LED display during start	LED display during start
vol2speed()	Speed instruction	Acquires the speed.
get_vol()	Volume read instruction	Instructs reading of volume information on the MC-IO board.
init_PORT()	Port setting	Performs port setting on the MC-IO board.
init_TM50()	TM50 setting processing	Sets the 8-bit timer.
start_TM50()	TM50 start processing	Starts the 8-bit timer.
wait_TM50()	TM50 wait processing	Waits for a specified time.
clear_WDTM()	WDT clear processing	Clears the watchdog timer counter.

4.12 Flowcharts

The flowchart of each function is shown below.

- Motor library

Figure 4-7. Motor Initial Setting Processing (motor_init Function)

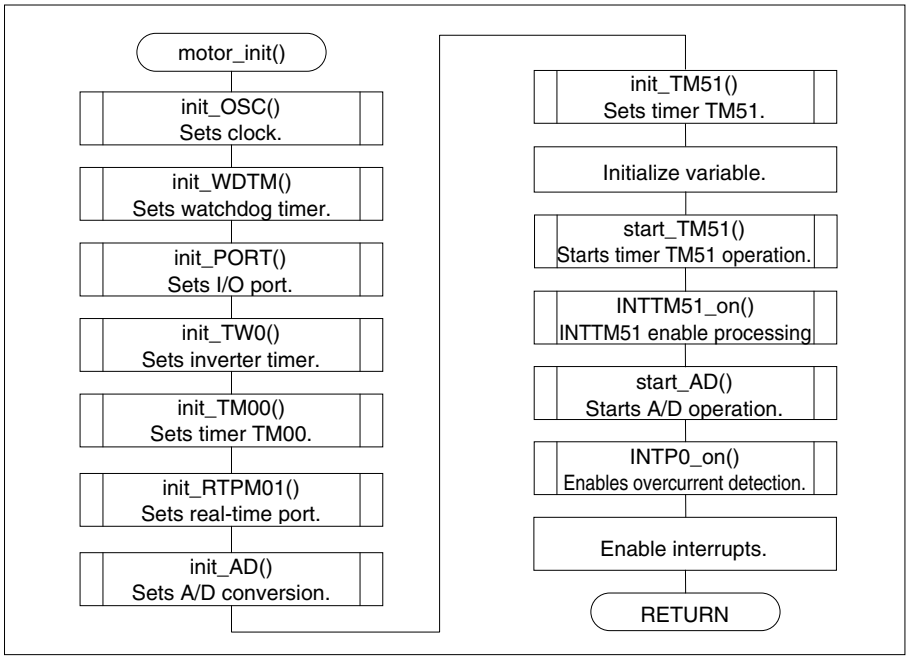


Figure 4-8. Motor Start Processing (motor_start Function)

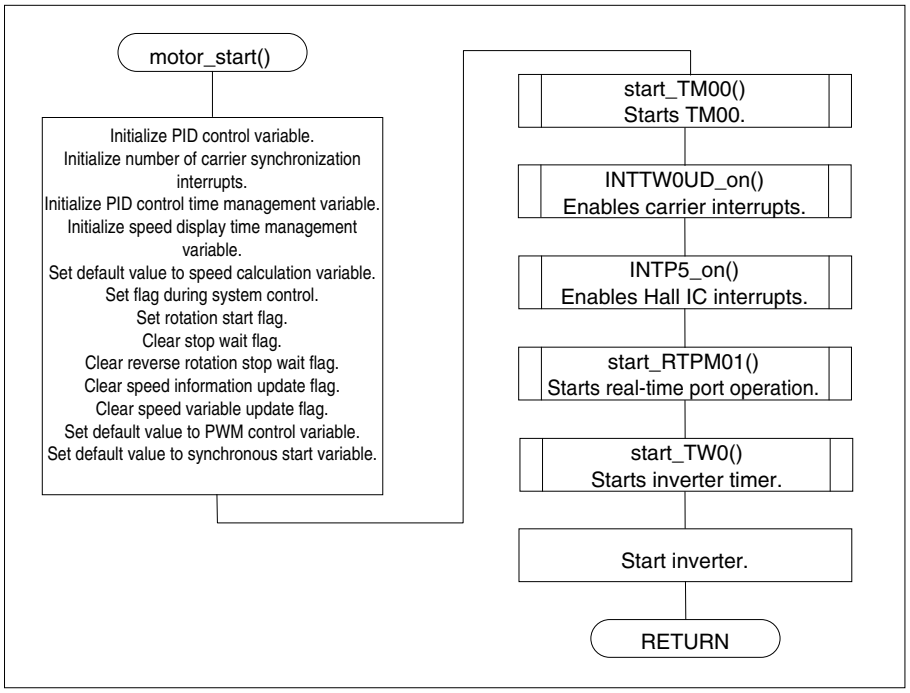


Figure 4-9. Motor Stop Processing (motor_stop Function)

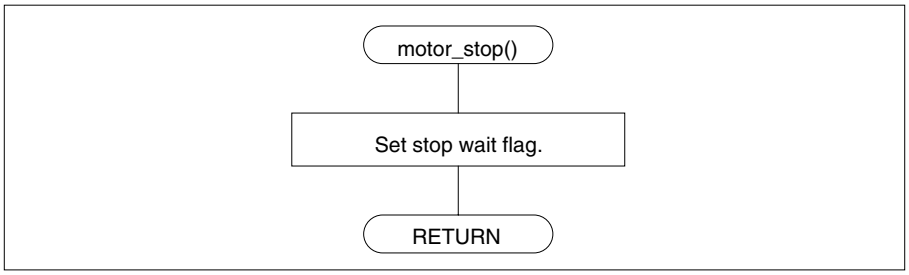


Figure 4-10. Motor Rotation Direction Change Processing (motor_rotation Function)

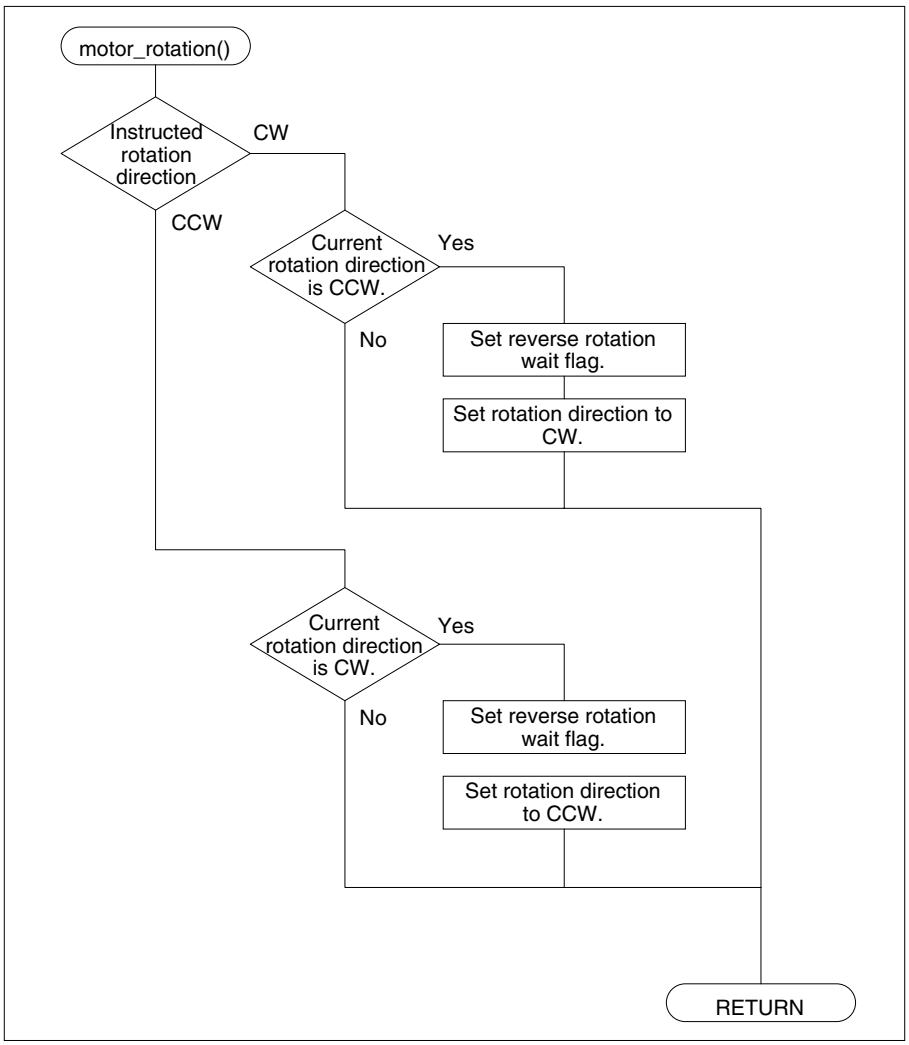


Figure 4-11. Speed PID Control Processing (motor_pid Function)

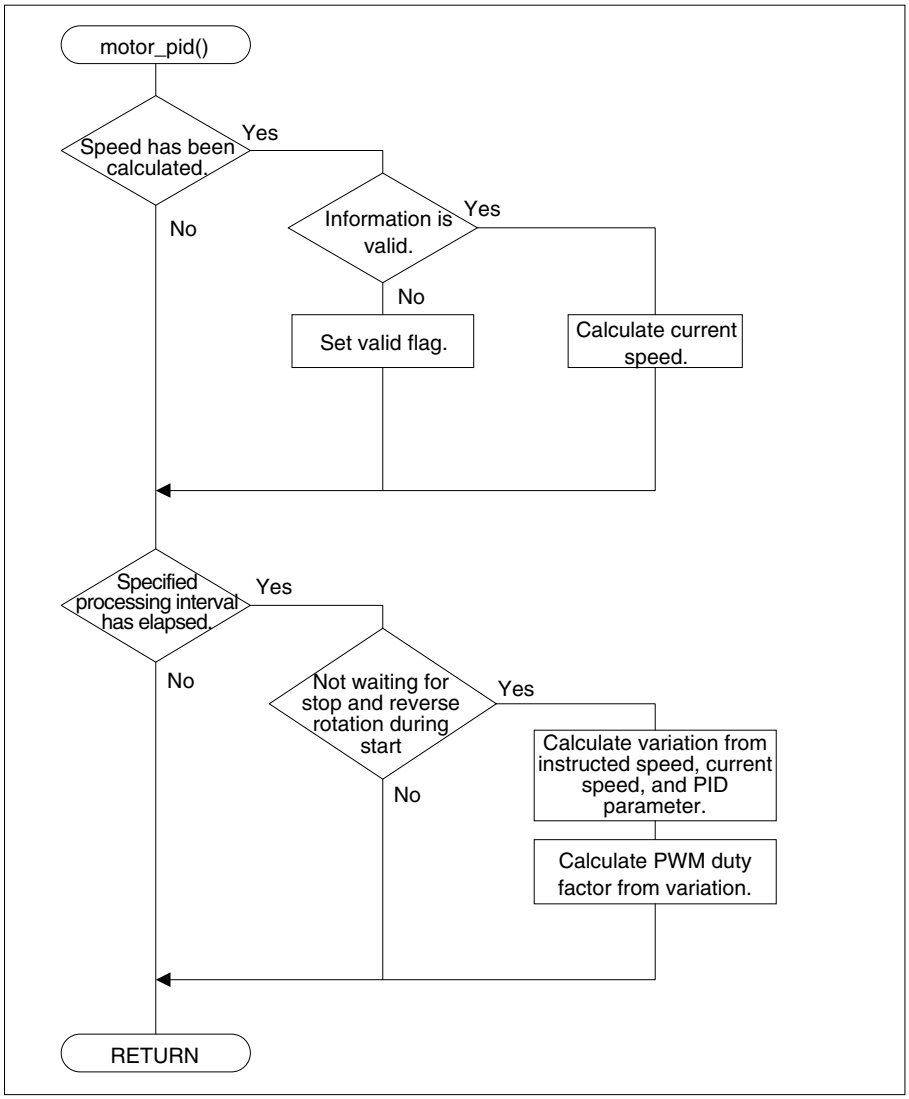


Figure 4-12. Motor Control Parameter Change Processing (motor_pset Function)

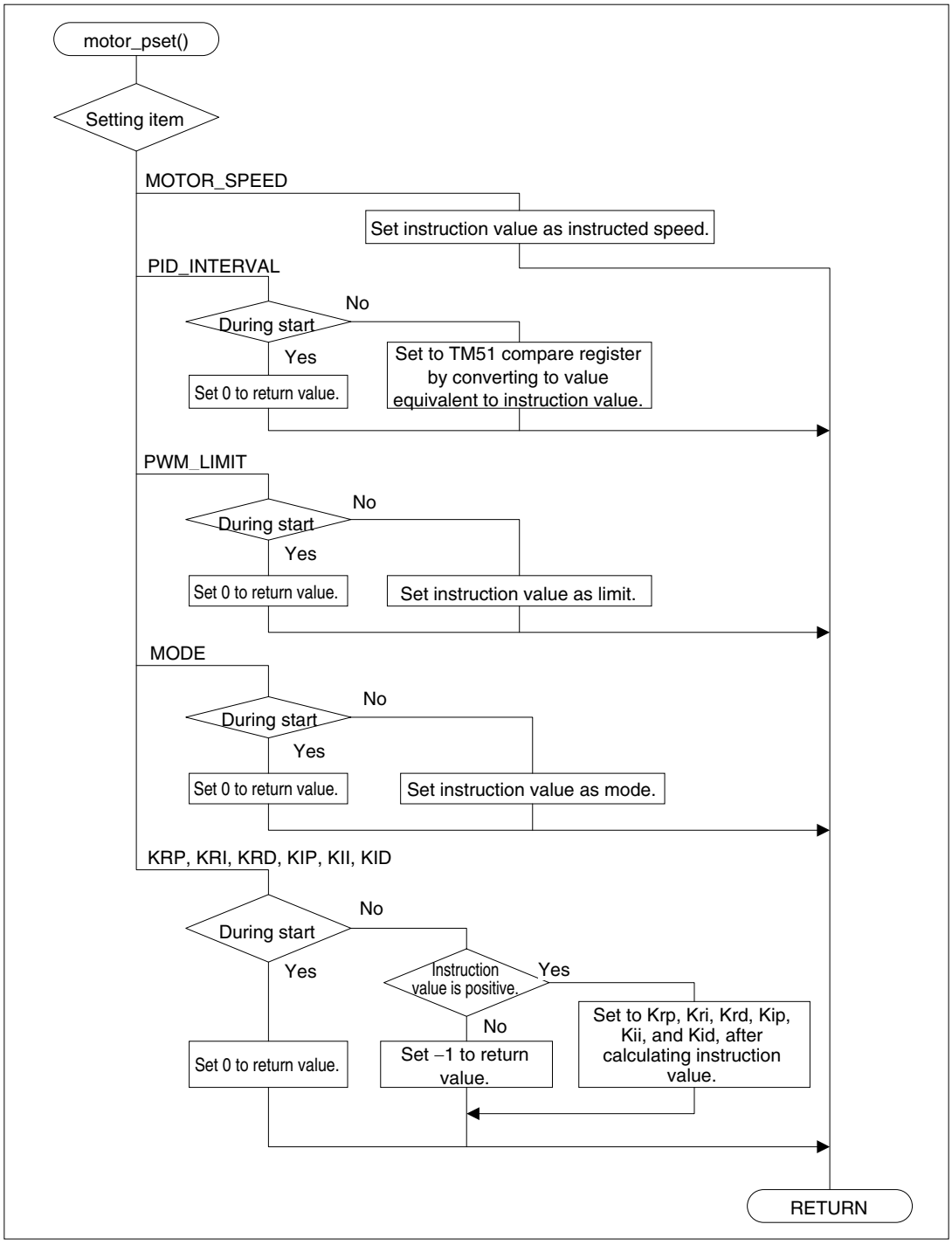


Figure 4-13. Processing of Restarting from Stop of Reverse Rotation (system_restart Function)

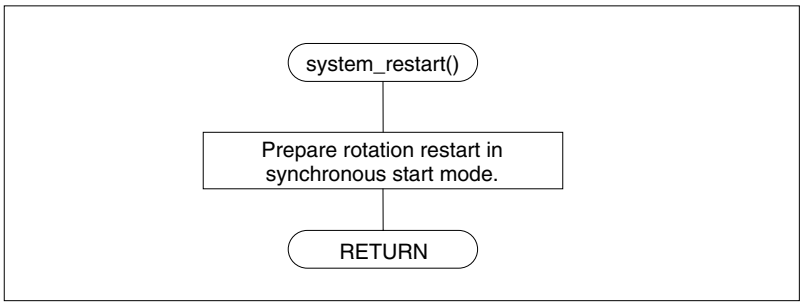


Figure 4-14. System Stop Processing (system_stop Function)

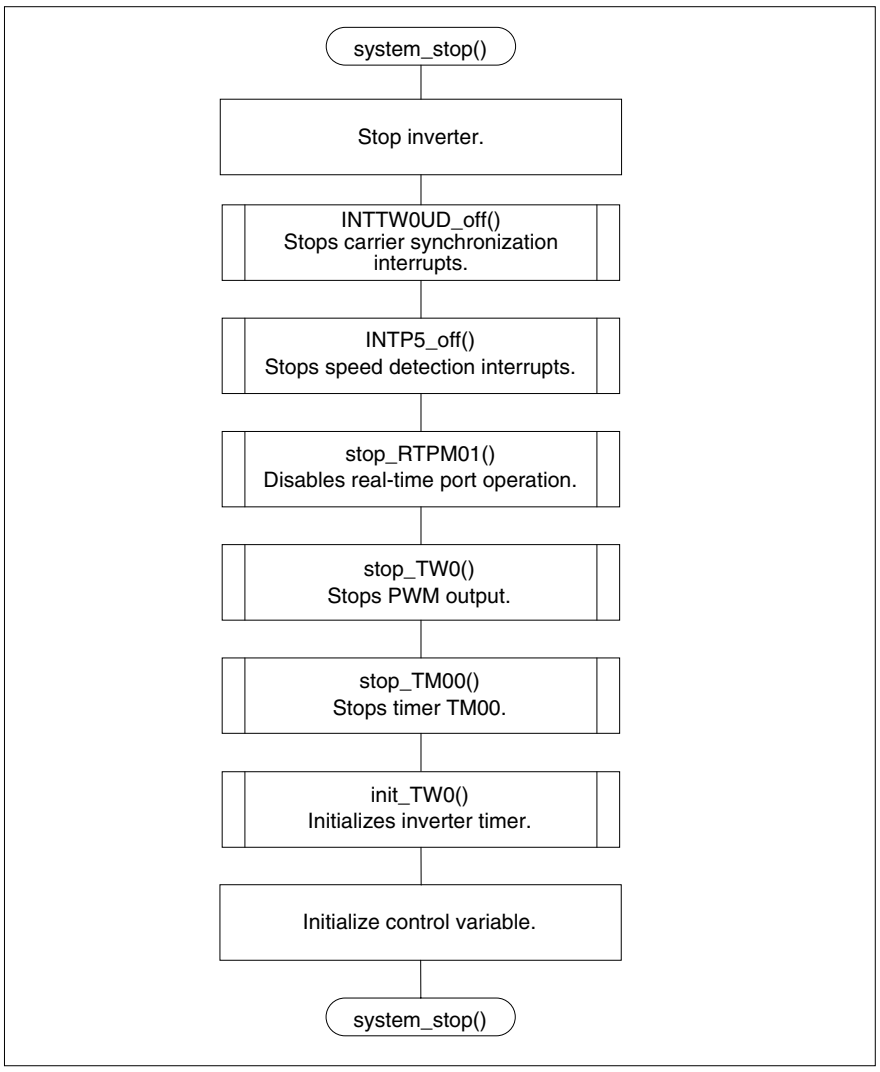


Figure 4-15. Port Setting Processing (init_PORT Function)

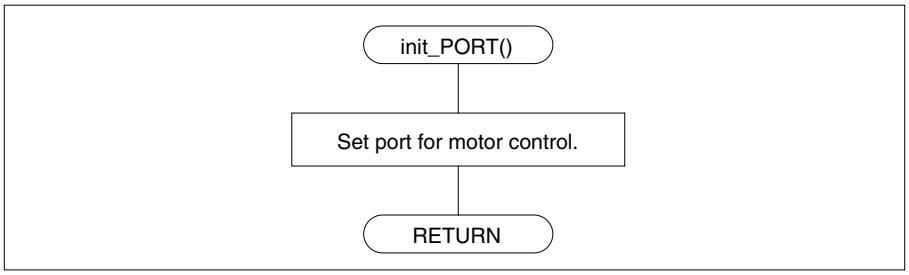


Figure 4-16. Clock Switching Processing (init_OSC Function)

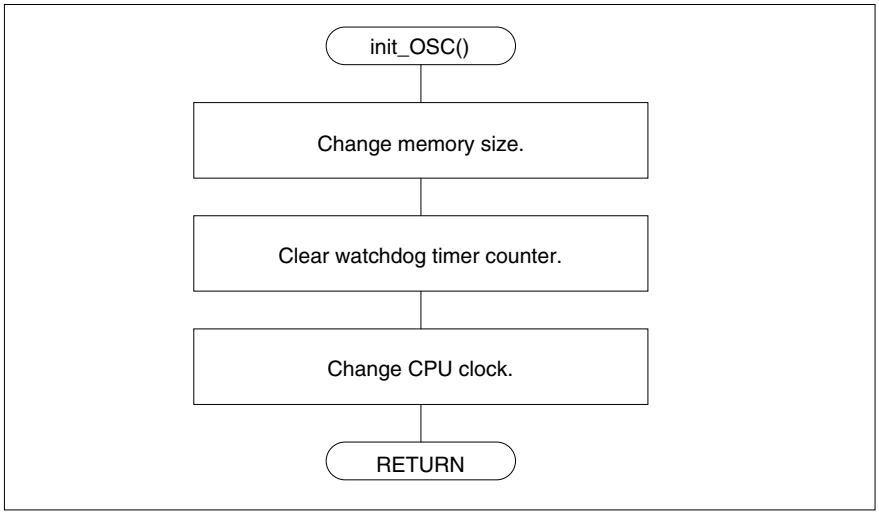


Figure 4-17. Inverter Timer Initial Setting Processing (init_TW0 Function)

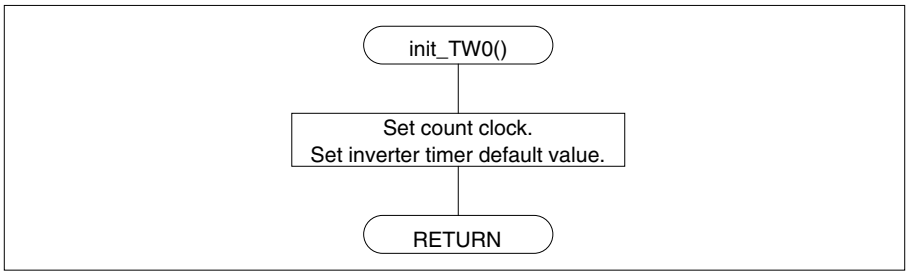


Figure 4-18. Inverter Timer Operation Start Processing (start_TW0 Function)

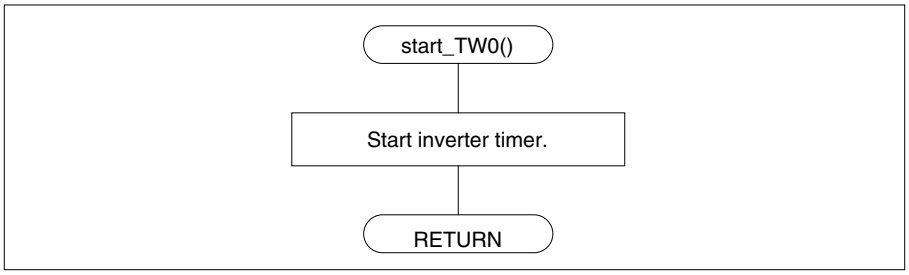


Figure 4-19. Inverter Timer Operation Stop Processing (stop_TW0 Function)

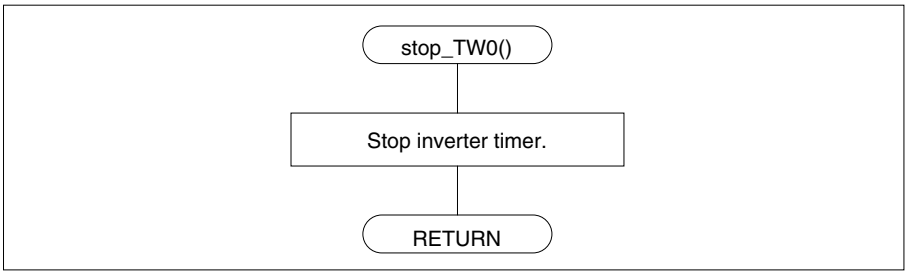


Figure 4-20. PWM Duty Factor Setting Processing (set_TW0 Function)

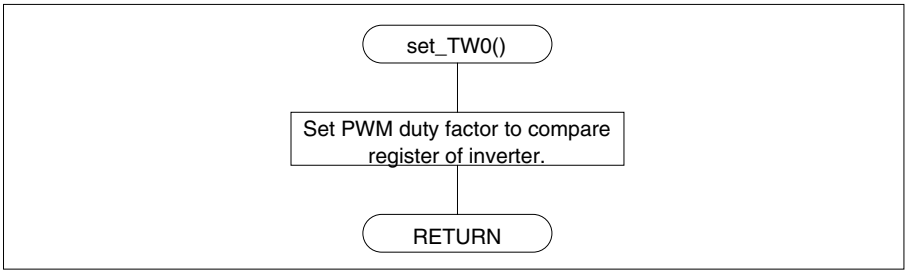


Figure 4-21. Timer Initial Setting Processing for Excitation Pattern Switching (init_TM00 Function)

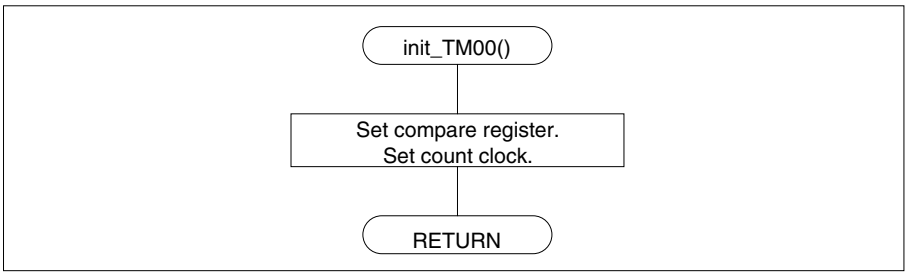


Figure 4-22. Timer Start Processing for Excitation Pattern Switching (start_TM00 Function)

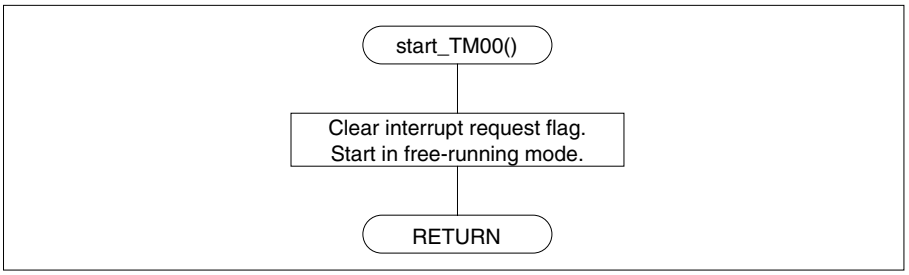


Figure 4-23. Timer Stop Processing for Excitation Pattern Switching (stop_TM00 Function)

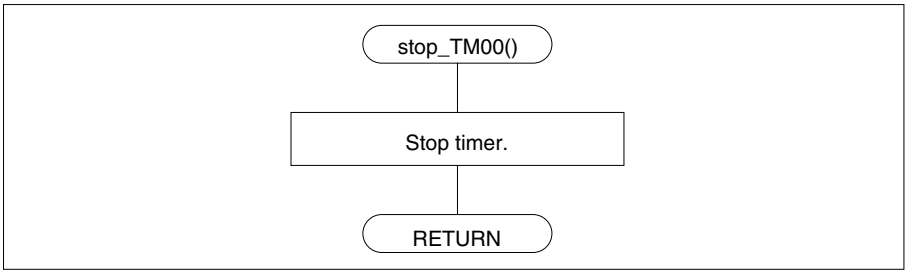


Figure 4-24. Port Initial Setting Processing for Excitation Pattern Switching (init_RTPM01 Function)

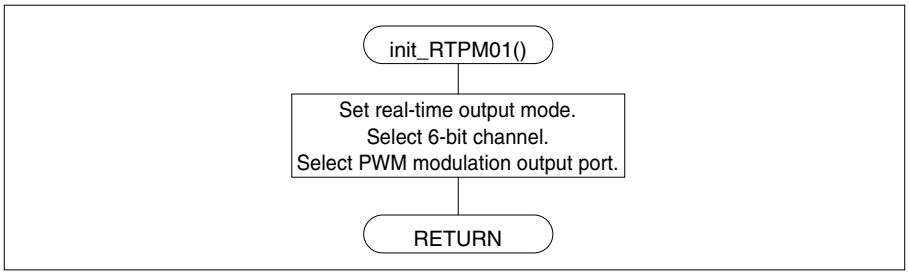


Figure 4-25. Port Output Enable Processing for Excitation Pattern Switching (start_RTPM01 Function)

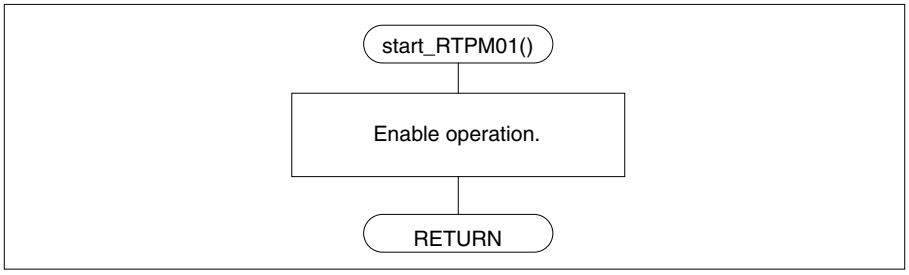


Figure 4-26. Port Output Disable Processing for Excitation Pattern Switching (stop_RTPM01 Function)

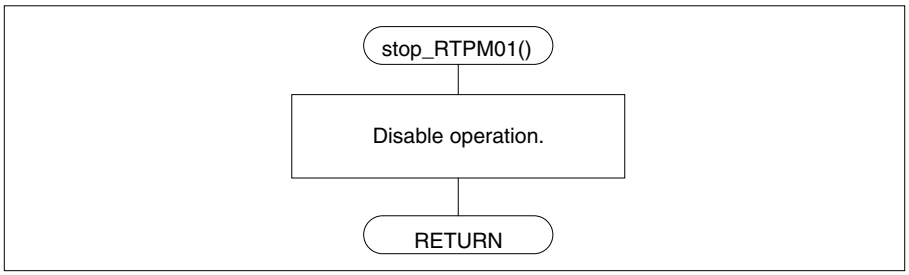


Figure 4-27. Port PWM Output Mode Switch Processing for Excitation Pattern Switching (end_RTPM01 Function)

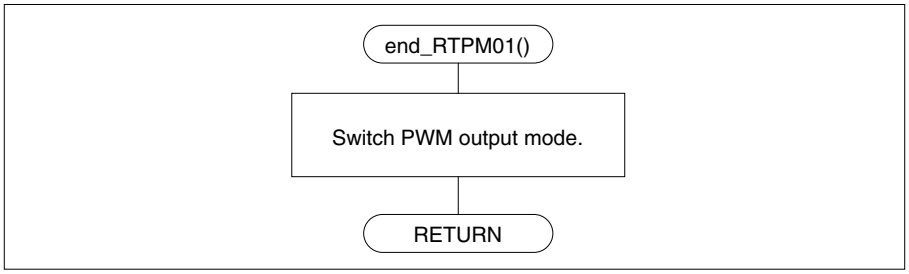


Figure 4-28. Excitation Pattern Setting (set_RTPM01 Function)

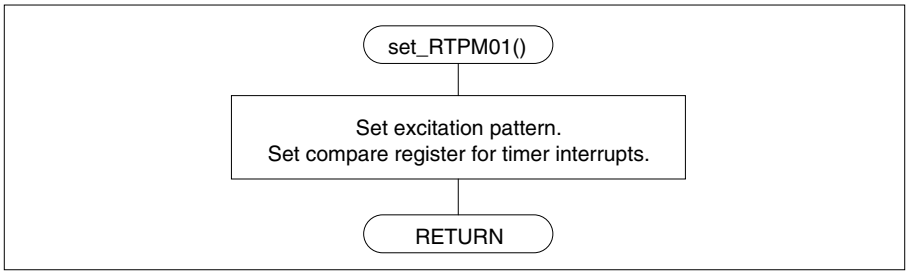


Figure 4-29. A/D Initial Setting Processing (init_AD Function)

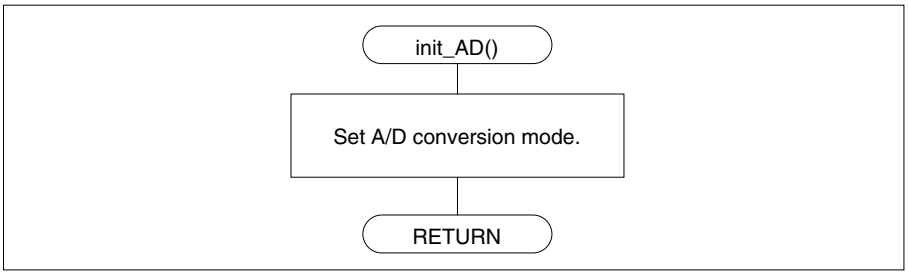


Figure 4-30. A/D Conversion Operation Start Processing (start_AD Function)

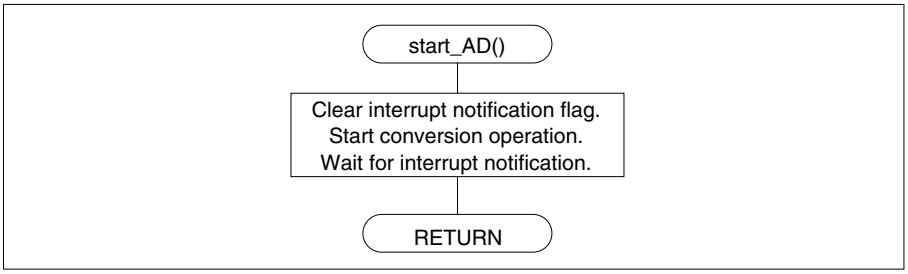


Figure 4-31. Watchdog Timer Initial Setting Processing (init_WDTM Function)

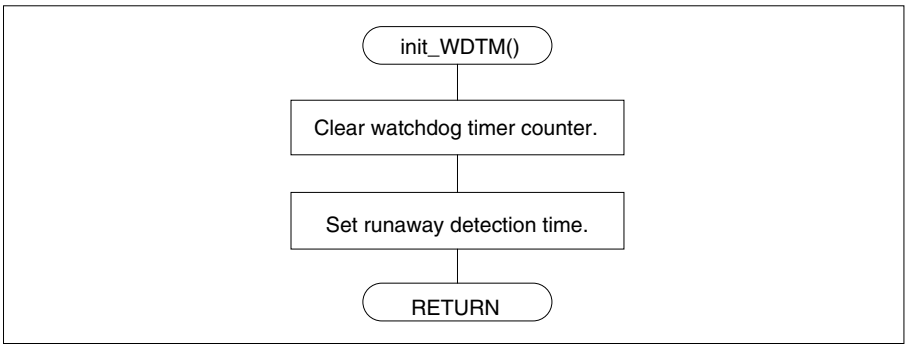


Figure 4-32. 8-bit Timer (TM51) Initial Setting Processing (init_TM51 Function)

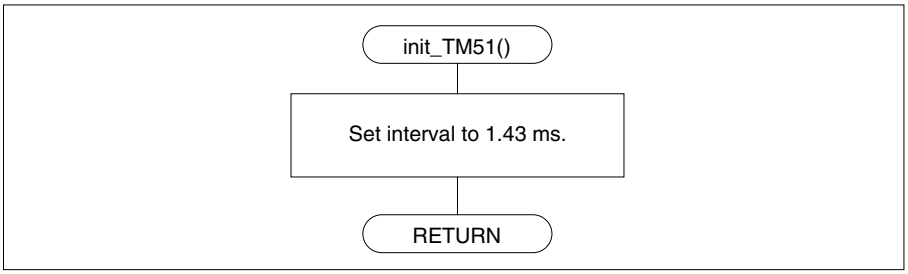


Figure 4-33. 8-bit Timer (TM51) Start Processing (start_TM51 Function)

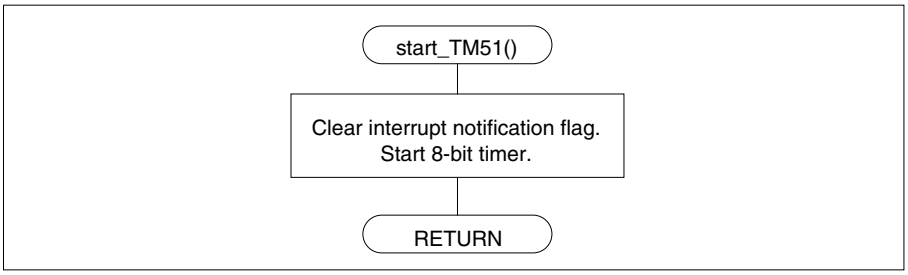


Figure 4-34. Hall IC Read Processing (read_Hall_IC Function)

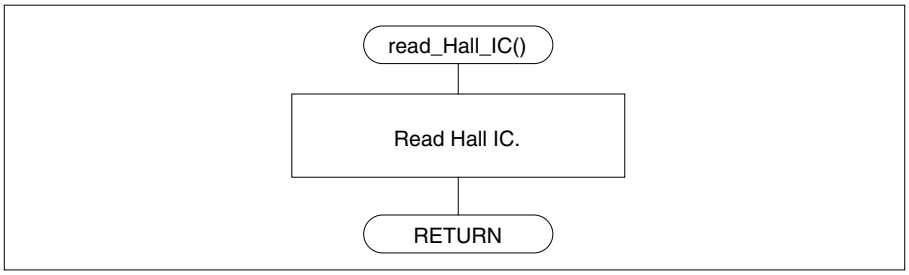


Figure 4-35. Overcurrent Interrupt Enable Processing (INTP0_on Function)

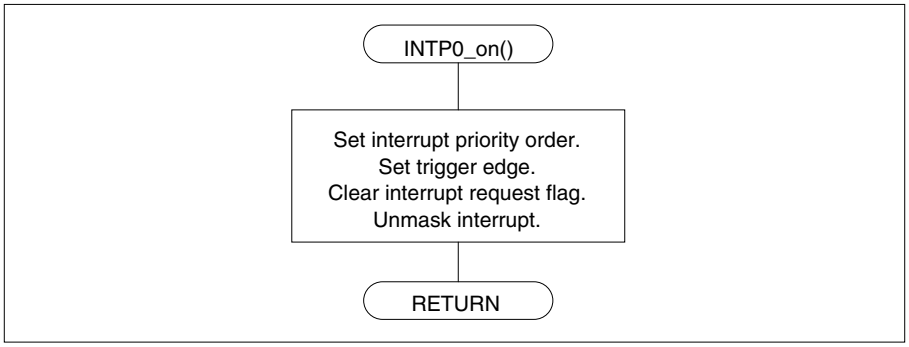


Figure 4-36. Carrier Synchronization Interrupt (Valley Processing) Enable Processing (INTTW0UD_on Function)

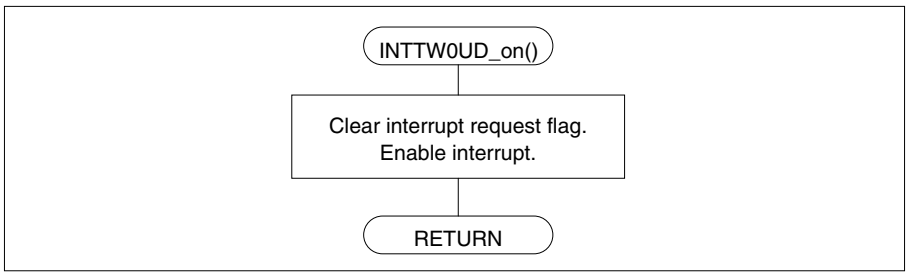


Figure 4-37. Carrier Synchronization Interrupt (Valley Processing) Disable Processing (INTTW0UD_off Function)

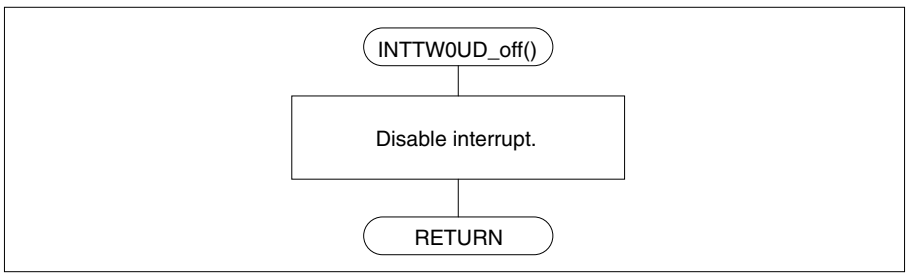


Figure 4-38. INTP5 Interrupt Enable Processing (INTP5_on Function)

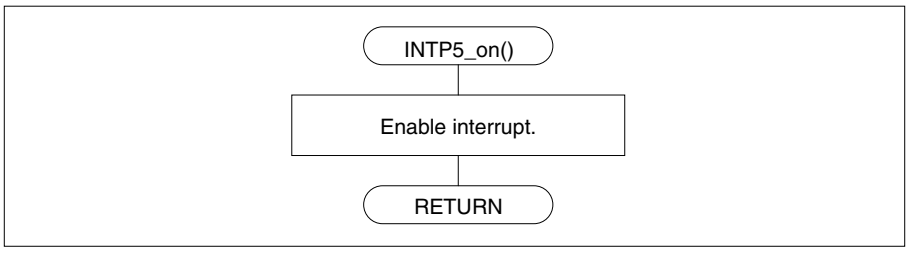


Figure 4-39. INTP5 Interrupt Disable Processing (INTP5_off Function)

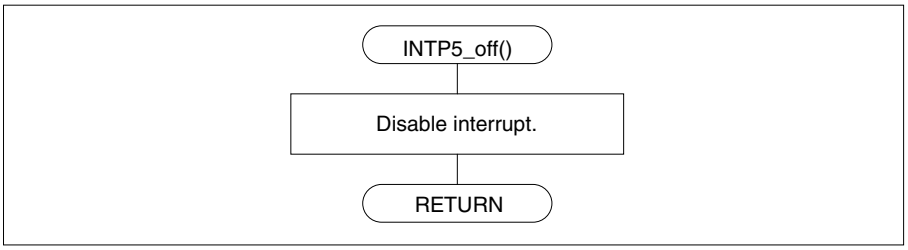


Figure 4-40. Current Value Acquisition Enable Processing (INTTM51_on Function)

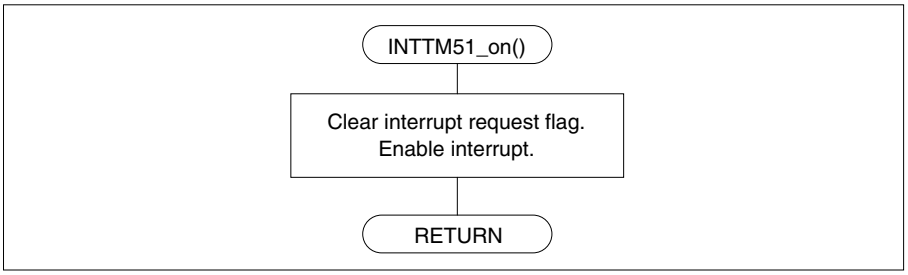


Figure 4-41. Overcurrent Interrupt Servicing (int_fault Function)

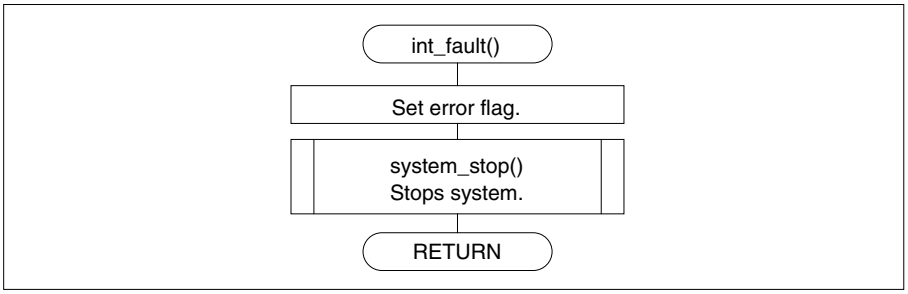


Figure 4-42. Speed Acquisition Interrupt Servicing (int_speed Function)

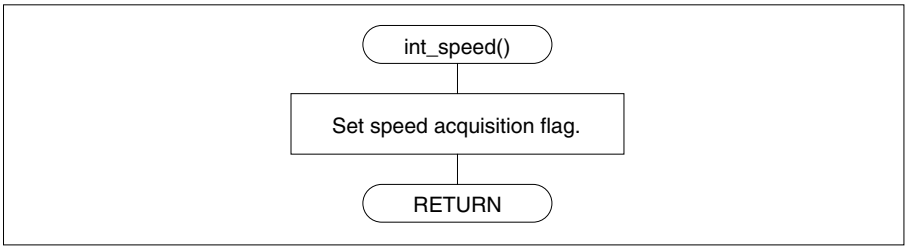


Figure 4-43. Current Acquisition Interrupt Servicing (int_TM51 Function)

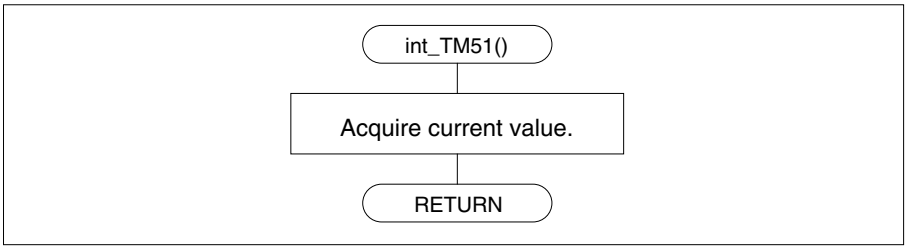


Figure 4-44. COS Operation Processing (get_coswt Function)

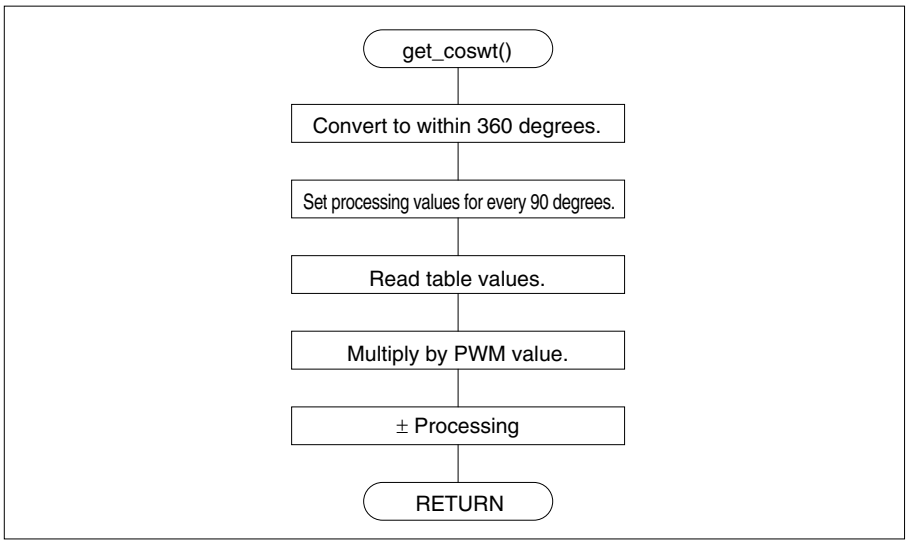


Figure 4-45. PWM Setting Processing (set_pwm Function)

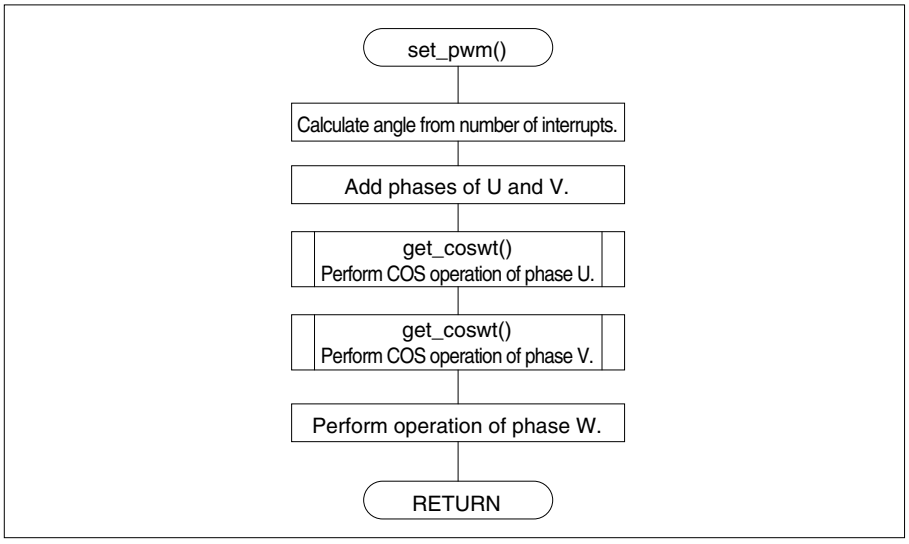


Figure 4-46. Carrier Synchronization Interrupt (Valley Processing) (1/2) (int_carrier Function)

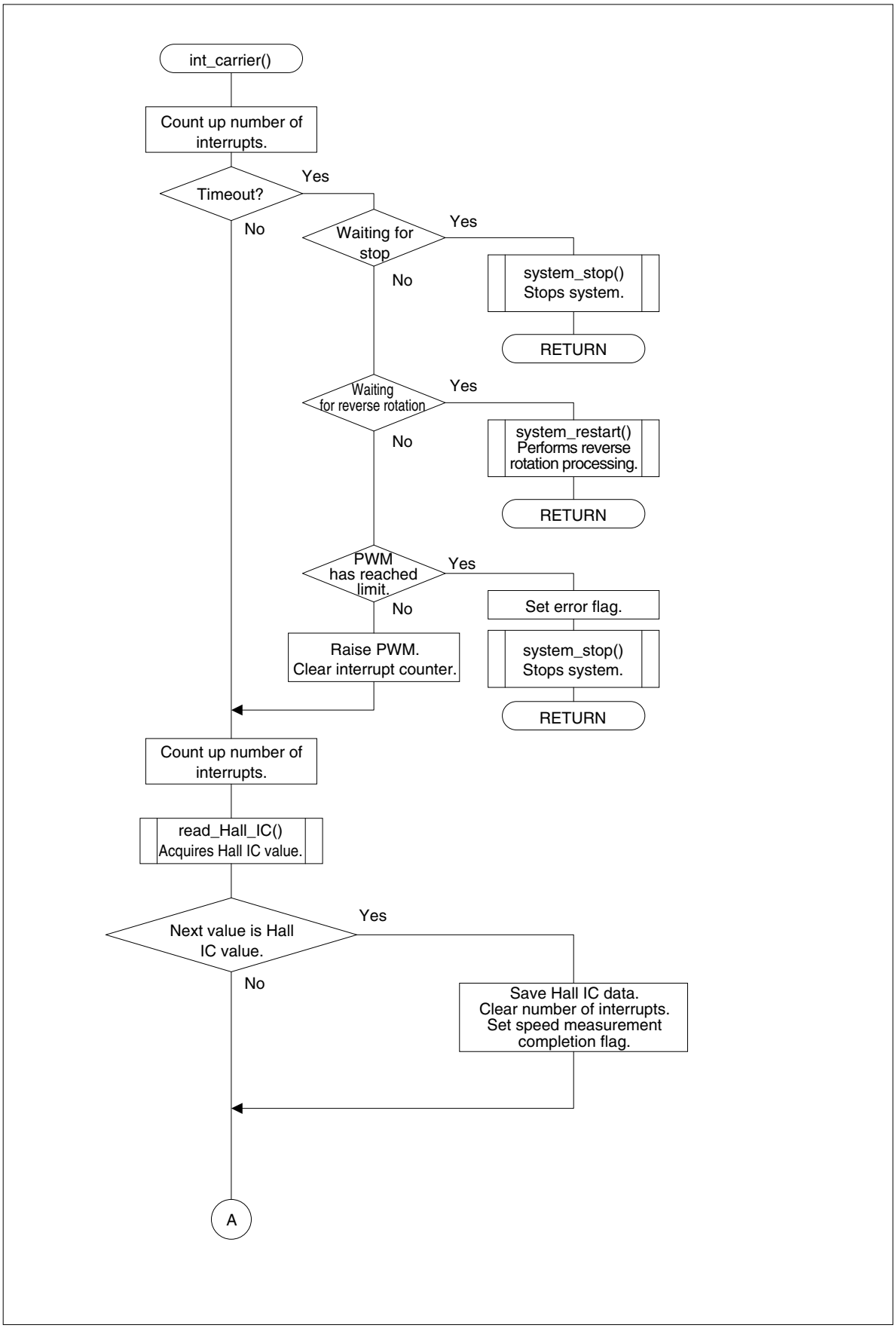
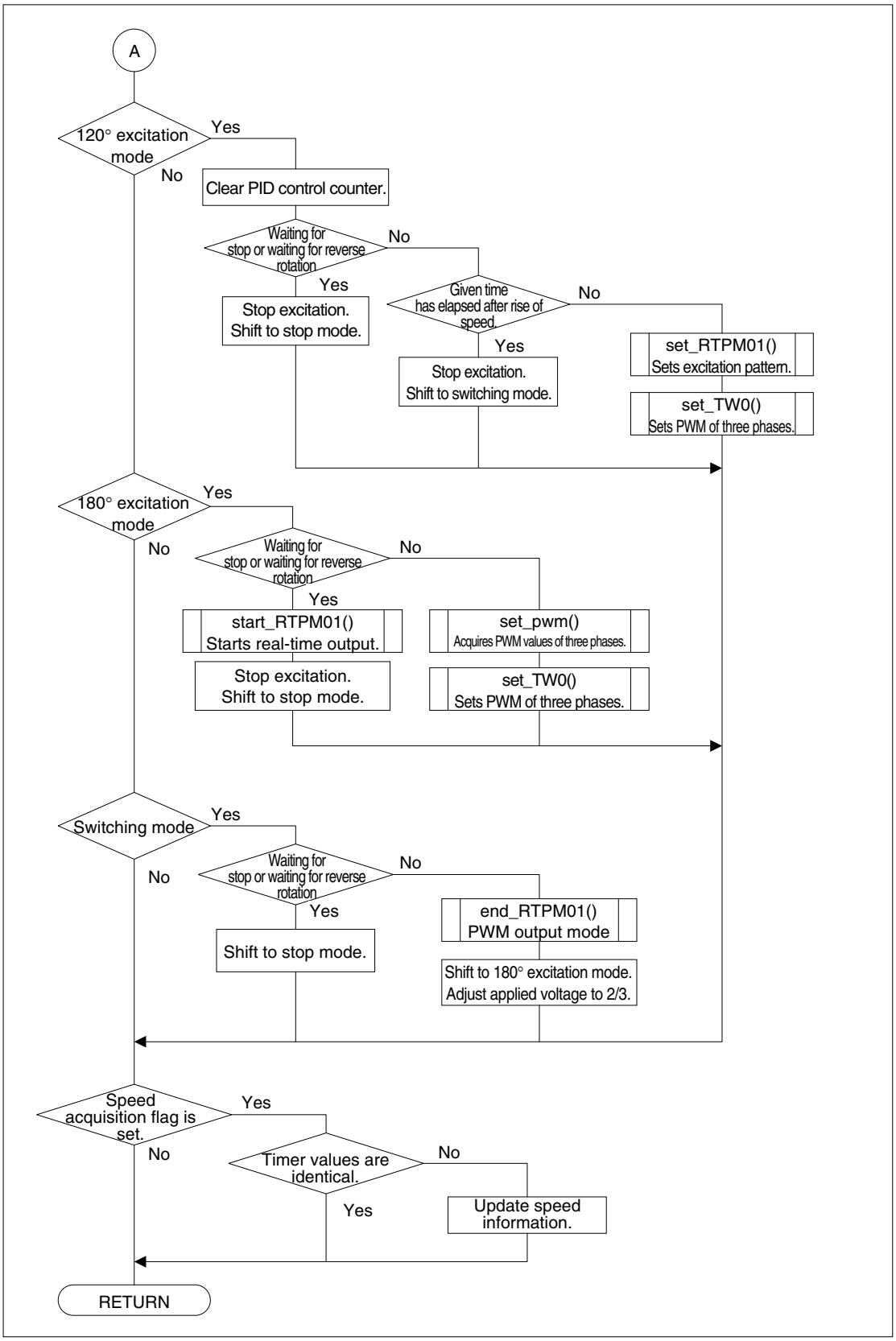


Figure 4-47. Carrier Synchronization Interrupt (Valley Processing) (2/2) (int_carrier Function)



4.13 Motor Library Constant List

4.13.1 Constants changeable by users

- Low-voltage inverter settings

Table 4-9. Motor Library Constants Changeable by Users (L/V)

Name	Meaning	Setting Value	Remark
PWM_F_MIN	Minimum value of duty factor	5	
PWM_F_MAX	Maximum value of duty factor	PWM_BASE_REF	
STARTUP_METHOD_REF	Initial starting method	PWM_START	Settings for initial start process for sensorless control. The setting is left because it is required for compatibility with the GUI. Only PWM2_REF is used.
T_KNEE_REF	Initial start switching time	0.75	
T_END_REF	Initial start end time	1.50	
RPM0_REF	Initial number of revolutions during initial start	60	
RPM1_REF	Number of revolutions during initial start switching	100	
RPM2_REF	Number of revolutions at end of initial start	200	
I_REF0_REF	Initial current value during initial start	140	
I_REF1_REF	Current value during initial start switching	160	
I_REF2_REF	Current value at end of initial start	160	
PWM0_REF	Initial PWM value during initial start	100	
PWM1_REF	PWM value during initial start switching	100	
PWM2_REF	PWM value at end of initial start	100	
PWM_F_START	PWM value at start	10	
ADGAIN_REF	Amplified variable of A/D conversion value	1.0	
ADOFFSET_REF	Offset variable of A/D conversion value	0	
MAXCURRENT_REF	Maximum current value	1024	
MINCURRENT_REF	Minimum current value	10	
MAXSPEED_REF	Maximum number of revolutions	5000	
MINSPEED_REF	Minimum number of revolutions	300	
I_RATE_MAX_REF	Rise rate for each current unit time	900	
RPM_RATE_MAX_REF	Rise rate for each unit time of number of revolutions	2000	
KRP_REF_REF	Kp value of number of revolutions	0.05	
KRI_REF_REF	Ki value of number of revolutions	0.02	
KRD_REF_REF	Kd value of number of revolutions	0.01	
KIP_REF_REF	Kp value of current	0.10	
KII_REF_REF	Ki value of current	0.04	
KID_REF_REF	Kd value of current	0.02	
CLIMIT	Current value for overcurrent detection	700	

4.13.2 Constants referenceable by users

Table 4-10. Motor Library Constants Referenceable by Users

Name	Meaning	Setting Value	Remark
FLG_ON	Flag value	1	Indicates whether flag is valid.
FLG_OFF	Flag value	0	
CW	Rotation direction	0	Indicates rotation direction of motor.
CCW	Rotation direction	1	
ERROR_NONE	Error flag bit	0x00	No error
ERROR_HALL	Error flag bit	0x01	Hall IC error
ERROR_OC	Error flag bit	0x02	Error due to overcurrent
ERROR_MOTOR	Error flag bit	0x04	Error of motor failure
ERROR_S_OC	Error flag bit	0x08	Error due to overcurrent
MOTOR_SPEED	Parameter set code	0x01	Sets number of revolutions of motor.
PID_INTERVAL	Parameter set code	0x10	Sets PID interval.
MODE	Parameter set code	0x12	Sets mode.
KRP	Parameter set code	0x20	Sets Kp of number of revolutions.
KRI	Parameter set code	0x21	Sets Ki of number of revolutions.
KRD	Parameter set code	0x22	Sets Kd of number of revolutions.
KIP	Parameter set code	0x23	Sets Kp of current.
KII	Parameter set code	0x24	Sets Ki of current.
KID	Parameter set code	0x25	Sets Kd of current.
WDTE_CLR	Watchdog timer value	0xac	WDT clear value
CURRENT_START	Initial start mode	0x01	
PWM_START	Initial start mode	0x02	
NOTABLE_START	Initial start mode	0x03	
SPEED_CMD	Operation mode	0x01	
I_CMD	Operation mode	0x02	
V_CMD	Operation mode	0x03	
AD_ISHUNT	Current detection channel	5	
UNIT_RPM	Constant for calculating number of revolutions	2343750	

4.13.3 Internal constants

Table 4-11. Motor Library Internal Constants

Name	Meaning	Setting Value	Remark
FLG_ON	Flag value	1	Indicates whether flag is valid.
FLG_OFF	Flag value	0	
FLG_WAIT	Flag value	2	Waits for stop.
FLG_SW	Flag value	3	Waits for switching.
FLG_120	Flag value	12	120° excitation method
FLG_180	Flag value	18	180° excitation method
PWM_BASE_REF	PWM base	1000	Used for PWM output
PWM_F_REF	PWM default value	0	
PWM_DTM_REF	Dead time	0	
IN	For port setting	1	Used to specify port function
OUT	For port setting	0	
CLEAR	For register bit setting	0	Used to access bits of registers
SET	For register bit setting	1	
INV_OFF	For inverter control	1/0	Low-voltage inverter
INV_ON	For inverter control	0/1	
INVERTER_SW	Inverter control port	P54	Inverter control port
INVERTER_SW_MODE	Inverter control register	PM54	Inverter control port
INTP0	Port control register	PM00	Overcurrent detection port
IMS_DATA	Memory size switching	0xc8	
WDTM_SET	WDT setting value	0x6f	
P_OFF	Excitation pattern	0x3f	Excitation of real-time port
P_STOP	Excitation pattern	0x15	
P_T1	Excitation pattern	0x36	
P_T2	Excitation pattern	0x1e	
P_T3	Excitation pattern	0x1b	
P_T4	Excitation pattern	0x39	
P_T5	Excitation pattern	0x2d	
P_T6	Excitation pattern	0x27	
INT_CNT_MAX	Limit value	500	For judging no rotation (time)
START_PWM_FF_MAX	Limit value	300	For judging no rotation (voltage)
DELTA_CW	Lead angle	0	Lead angle on CW side
DELTA_CCW	Lead angle	0	Lead angle on CCW side
CHANGE_SPEED	Limit value	100	Speed of switching from 120° excitation to 180° excitation
CR01_ADD	Counter value	3	Excitation pattern switching wait time
PWM_MIDDLE	PWM value	500	PWM_BASE_REF ÷ 2
PWM_x3	PWM value	1500	PWM_MIDDLE × 3
INTERVAL_BASE	Reference value	5	Reference for generating 1 [ms]
TIME_OUT	Reference value	5000	Reference for generating 1 [s]

4.14 Reference Program Constant List

4.14.1 Internal constants

Table 4-12. Reference Program Internal Constants (1/2)

Name	Meaning	Setting Value	Remark
AD_VOL	A/D channel	4	Volume on MCIO board
IN	For port setting	1	Used to specify port function
OUT	For port setting	0	
CLEAR	For register bit setting	0	Used to access bits of registers
SET	For register bit setting	1	
KEY_WAIT	Switch observation time	10	Used to eliminate chattering
SW	Switch	(P7&0xf)	Switch connection port
SW2	Port control register	PM73	Port for START/STOP
SW3	Port control register	PM72	Port for FORWARD
SW4	Port control register	PM71	Port for REVERSE
SW5	Port control register	PM70	Port for MODE
LD_LED0	Port control register	PM64	Port for LED selection
LD_LED1	Port control register	PM65	
LD_LED2	Port control register	PM66	
LD_LED3	Port control register	PM67	
LD_DATA	Port control register	PM4	Port that outputs data to LED
START_SW	Start	0x7	Switch status
STOP_SW	Stop	0x7	
FORWARD_SW	CW	0xb	
REVERSE_SW	CCW	0xd	
MODE_SW	Mode	0xe	
START_TR	For status setting	0x01	Starts control.
STOP_TR	For status setting	0x02	Stops control.
FORWARD_TR	For status setting	0x04	Changes rotation to CW.
REVERSE_TR	For status setting	0x08	Changes rotation to CCW.
MODE_TR	For status setting	0x10	State where MODE switch is pressed
LED_0	LED display data	0xc0	Displays “0”.
LED_1		0cf9	Displays “1”.
LED_2		0xa4	Displays “2”.
LED_3		0xb0	Displays “3”.
LED_4		0x99	Displays “4”.
LED_5		0x92	Displays “5”.
LED_6		0x82	Displays “6”.
LED_7		0xf8	Displays “7”.
LED_8		0x80	Displays “8”.
LED_9		0x98	Displays “9”.
LED_O		0xc0	Displays “0” instead of “O”.
LED_I		0xcf	Displays “I”.
LED_C		0xc6	Displays “C”.
LED_H		0x89	Displays “H”.

Table 4-12. Reference Program Internal Constants (2/2)

Name	Meaning	Setting Value	Remark
LED_A	LED display data	0x88	Displays “A”.
LED_L		0xc7	Displays “L”.
LED_		0xff	Displays “ ”.
LED_S		0x92	Displays “S”.
LED_E		0x86	Displays “E”.
LED_F		0x8e	Displays “F”.
LED_P		0x8c	Displays “P”.
LED_dot		0x7f	Displays “.”.

4.15 Motor Library Variable List

4.15.1 Externally disclosed variables

Table 4-13. External Disclosed Motor Library Variables (1/2)

Variable Name	Type	Meaning	Remark
sys_flag	char	Control flag	Control status
err_flag	char	Error flag	Error status
stop_wait	char	Stop command flag	Indicates whether stop command is issued.
cw_ccw_flag	char	Rotation direction command flag	Rotation direction status
cw_ccw_wait	char	Reverse stop command flag	Indicates whether command to stop by reversing is issued.
maxed_flags	unsigned char	Upper-limit flag	Flag set when upper limit of unit time has been exceeded
print_cnt	unsigned int	Speed display timing	Number of carrier synchronization interrupts
pwm_ff	int	Current PWM command value	Current PWM duty factor value
pwm_ff_o	int	PWM command value	PWM duty factor command value
m_speed	int	Actual speed	Revolution speed of motor (rpm)
krp_ref	float	Kp value of number of revolutions	Speed control
kri_ref	float	Ki value of number of revolutions	
krd_ref	float	Kd value of number of revolutions	
kip_ref	float	Kp value of current	Current minor loop control
kii_ref	float	Ki value of current	
kid_ref	float	Kd value of current	
startup_method	unsigned char	Synchronous start method	
I_ref	float	Current value of current command	
I_ref_o	float	Current command value	
I_measured	float	Operating current value	
speed_ref	int	Current speed command value	
speed_ref_o	int	Speed command value	
maxspeed	int	Maximum speed	
minspeed	int	Minimum speed	
dspeed_ref_max	int	Controlled variable of speed within unit time	
dI_ref_max	float	Controlled variable of current within unit time	
RPM_rate_max	float	Variation of speed within unit time	

Table 4-13. External Disclosed Motor Library Variables (2/2)

Variable Name	Type	Meaning	Remark
l_rate_max	float	Variation of current within unit time	
t_knee	float	Initial start switching time	
t_end	float	Initial start end time	
RPM0	float	Initial number of revolutions during initial start	
RPM1	float	Number of revolutions during initial start switching	
RPM2	float	Number of revolutions at end of initial start	
l_ref0	float	Initial current value during initial start	
l_ref1	float	Current value during initial start switching	
l_ref2	float	Current value at end of initial start	
PWM0	float	Initial PWM value during initial start	
PWM1	float	PWM value during initial start switching	
PWM2	float	PWM value at end of initial start	
adgain	float	Amplified variable of A/D conversion value	
adoffset	float	Offset variable of A/D conversion value	
maxcurrent	float	Maximum current value	
mincurrent	float	Minimum current value	

4.15.2 Internal variables

Table 4-14. Motor Library Internal Variables

Variable Name	Type	Meaning	Remark
old_hdata	char	Hall IC history	Value of previous Hall IC
speed_flag	char	Speed information flag	Indicates whether data required for calculating speed is present.
int_cnt	unsigned int	Interrupt counter	Number of carrier synchronization interrupts
pid_cnt	unsigned int	PID control timing	Number of carrier synchronization interrupts
pwm_base	int	PWM base clock value	PWM carrier width
old_ff	int	PWM command value history	Value of previous pwm_ff
up_flag	char	Actual-speed calculation status flag	For calculating rotation speed
capture_flag	char	Timer value acquisition flag	
clk_flag	char	Timer value calculation enable flag	
old_clk	unsigned int	Previous clock value	
new_clk	unsigned int	Newest clock value	
mvn_f	float	Previous amount operated	
startdelay	char	Current detection start delay value	
start_flag	char	Rotation start flag	
cy_time	int	PID control interval	
cmd_mode	char	Control mode	
dpwm_ff_max	int	Controlled variable of PWM within unit time	

4.16 Reference Program Variable List

4.16.1 Internal variables

Table 4-15. Reference Program Variables

ad_flag	char	Speed change flag	Limits specified-speed change function.
led_data[ ]	char	LED output data	Value displayed with LEDs

4.17 Motor Library Source File

Memory size ROM: 23A8h
RAM: 420h

```
/*


    BLDCM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit


    date    : 2007/05/30
    filename: motor.h

    NEC Micro Systems,Ltd
*/

#ifdef LOW
/* ================================================ */
/* For Pittman motor */
#define PWM_F_MIN          5             /* Minimum value                              */
#define PWM_F_MAX          PWM_MIDDLE    /* Maximum value                              */

/* startup parameters */
#define STARTUP_METHOD_REF PWM_START     /* which method to use: PWM_START, CURRENT_START, or NOTABLE_START */
#define T_KNEE_REF         2.0           /* start of second startup segment */
#define T_END_REF          4.0           /* end of startup second segment */
#define RPM0_REF           100           /* initial startup RPM */
#define RPM1_REF           200           /* midpoint startup RPM */
#define RPM2_REF           300           /* final startup RPM */
#define I_REF0_REF         140           /* initial startup current command */
#define I_REF1_REF         160           /* midpoint  startup current command */
#define I_REF2_REF         160           /* final  startup current command */
#define PWM0_REF           140           /* initial startup voltage setting */
#define PWM1_REF           145           /* midpoint startup voltage setting */
#define PWM2_REF           150           /* final startup voltage setting */

/* original startup NOTABLE_START */
#define SYNC_DEF_REF       500
#define PWM_F_START        150            /* Default value at start                      */

/* a/d gain parameters (for GUI mostly) */
#define ADGAIN_REF         4.0           /* mA = Gain*(A/D - Offset) */
#define ADOFFSET_REF       0             /* */
#define MAXCURRENT_REF     1023          /* mA */
#define MINCURRENT_REF     10            /* mA */
#define MAXSPEED_REF       5000          /* RPM */
#define MINSPEED_REF       300           /* RPM */

/* Setpoint change maximum rates */
/* used for setpoint changes     */
#define I_RATE_MAX_REF     900           /* dI_int/sec maximum */
#define RPM_RATE_MAX_REF   2000          /* RPM/sec */

/* Feedback Gains: current measured in A/D units, voltage in PWM%*10 */
/*  RPM feedback to I command  #define */
#define KRP_DEF_REF        0.05          /* dI_ints/dRPM error */
#define KRI_DEF_REF        0.02          /* dI_ints/RPM error  */
#define KRD_DEF_REF        0.01          /* dI_ints/d(dRPM error) */

/*  Current feedback to PWM command */
#define KIP_DEF_REF        0.025         /* dPWM/dI_error */
#define KII_DEF_REF        0.010         /* dPWM/I_error  */
#define KID_DEF_REF        0.005         /* dPWM/d(derror) */

/* ================================================ */
#else
/* ================================================ */
/* For Oriental motor */
#define PWM_F_MIN          5             /* Minimum value                              */
#define PWM_F_MAX          PWM_BASE_REF  /* Maximum value                              */

/* startup parameters */
#define STARTUP_METHOD_REF PWM_START /* which method to use: PWM_START, CURRENT_START, or NOTABLE_START */
#define T_KNEE_REF         0.75          /* start of second startup segment */
#define T_END_REF          1.5           /* end of startup second segment */
#define RPM0_REF           300           /* initial startup RPM */
#define RPM1_REF           300           /* midpoint startup RPM */
#define RPM2_REF           300           /* final startup RPM */
#define I_REF0_REF         140           /* initial startup current command */
#define I_REF1_REF         160           /* midpoint  startup current command */
#define I_REF2_REF         160           /* final  startup current command */
#define PWM0_REF           195           /* initial startup voltage setting */
#define PWM1_REF           195           /* midpoint startup voltage setting */
#define PWM2_REF           195           /* final startup voltage setting */

/* original startup NOTABLE_START */
#define SYNC_DEF_REF       500
#define PWM_F_START        70            /* Default value at start                      */

/* a/d gain parameters (for GUI mostly) */
#define ADGAIN_REF         1.0           /* mA = Gain*(A/D - Offset) */
#define ADOFFSET_REF       100           /* */
#define MAXCURRENT_REF     1023          /* mA */
#define MINCURRENT_REF     10            /* mA */
#define MAXSPEED_REF       3000          /* RPM */
#define MINSPEED_REF       300           /* RPM */
```

```
/* Setpoint change maximum rates */
/* used for setpoint changes     */
#define I_RATE_MAX_REF     900           /* dI_int/sec maximum */
#define RPM_RATE_MAX_REF   3000          /* RPM/sec */

/* Feedback Gains: current measured in A/D units, voltage in PWM%*10 */
/*  RPM feedback to I command  #define */
#define KRP_DEF_REF        0.4           /* dI_ints/dRPM error */
#define KRI_DEF_REF        0.005         /* dI_ints/RPM error  */
#define KRD_DEF_REF        0.05          /* dI_ints/d(dRPM error) */

/*  Current feedback to PWM command */
#define KIP_DEF_REF        0.9           /* dPWM/dI_error */
#define KII_DEF_REF        0.9           /* dPWM/I_error  */
#define KID_DEF_REF        0             /* dPWM/d(derror) */

/* ============================================== */
#endif

#define CLIMIT          1024      /* 1024 */

#define AD_VOL          4        /* VOL pin    */
#define AD_ISHUNT       5

/* +++++++++++++++ The following cannot be changed. +++++++++++++++ */

#define CW              0               /* Clockwise                          */
#define CCW             1               /* Counterclockwise                   */

#define ERROR_NONE      0x00
#define ERROR_HALL      0x01     /* Hall IC failure                 */
#define ERROR_OC        0x02     /* Overcurrent                     */
#define ERROR_MOTOR     0x04     /* Motor failure                   */
#define ERROR_S_OC      0x08     /* Overcurrent (software detection) */

#define MOTOR_SPEED     0x01     /* Number of revolutions instructed */
#define PID_INTERVAL    0x10     /* PID control interval */
#define PWM_LIMIT       0x11     /* PWM variation limiter */
#define MODE            0x12
#define KRP             0x20     /* Kp value */
#define KRI             0x21     /* Ki value */
#define KRD             0x22     /* Kd value */
#define KIP             0x23     /* Kp value */
#define KII             0x24     /* Ki value */
#define KID             0x25     /* Kd value */

#define WDTE_CLR        0xac

#define CURRENT_START   0x01
#define PWM_START       0x02
#define NOTABLE_START   0x03

#define SPEED_CMD       0x01
#define I_CMD           0x02
#define V_CMD           0x03

  /*
    m_speed constant:  x[rpm] = ( 60[s] * 78.125[Krps] ) / 6
                                        ------          ---
                                          ↑              ↑Counter value acquisition
                                          ↑              ↑Timing
                                          ↑              ↑HallIC(6)
                                          ↑TM00 count clock
                                          ↑78.125[KHz]
  */
#define UNIT_RPM            2343750  /* 2count */
#define CARRIRE_DEF_CONST   50000
#define SPEED_CAL_CONST     100000

/* ------------------------------------- */

extern char             sys_flag;    /* System operation status          */
extern int              speed_ref;   /* Number of revolutions instructed */
extern int              speed_ref_o;
extern int              m_speed;     /* Current number of revolutions    */
extern char             stop_wait;   /* Stop wait flag                   */
extern char             cw_ccw_wait; /* Reversal wait flag               */
extern char             cw_ccw_flag; /* Rotation direction status        */
extern char             err_flag;    /* Error flag                       */
extern unsigned char    maxed_flags;
extern int              pwm_ff;
extern int              pwm_ff_o;
extern float            I_ref;
extern float            I_ref_o;
extern float            I_measured;
extern float            kip_ref, kii_ref, kid_ref;
extern float            krp_ref, kri_ref, krd_ref;
extern unsigned char    startup_method;
extern float            t_knee;
extern float            t_end;
extern float            RPM0, RPM1, RPM2;
extern float            I_ref0, I_ref1, I_ref2;
extern float            PWM0, PWM1, PWM2;
extern float            adgain;
extern int              adoffset;
extern float            maxcurrent, mincurrent;
extern float            I_rate_max, RPM_rate_max;
extern float            dI_ref_max;
extern int              dspeed_ref_max;
extern int              maxspeed, minspeed;
extern unsigned int     print_cnt;
extern unsigned int     ad_data_vol;

/* ------------------------------------- */
```

```
void motor_init(void);
void motor_start(void);
void motor_stop(void);
void motor_rotation(char);
void motor_pid(void);
char motor_pset(unsigned char, long);

/* ------------------------------ EOF ---- */
```

```
/*


    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit


    date    : 2007/06/26
    filename: motor.c

    NEC Micro Systems,Ltd
*/

#pragma sfr
#pragma ei
#pragma di

#pragma INTERRUPT INTP0     int_fault    rb1  /* Overcurrent occurrence */
#pragma INTERRUPT INTP5     int_speed    rb1
#pragma INTERRUPT INTTW0UD  int_carrier  rb2  /* Carrier synchronization interrupt */
#pragma INTERRUPT INTTM51   int_TM51     rb3

/* ------------------------------------------- */
#include "motor.h"

/* ------------------------------------------- */
#define IN              1       /* Input */
#define OUT             0       /* Output */

#define FLG_ON          1       /* Valid */
#define FLG_OFF         0       /* Invalid */
#define FLG_WAIT        2       /* Wait for switching */
#define FLG_SW          3
#define FLG_120         12      /* 120-degree excitation method */
#define FLG_180         18      /* 180-degree excitation method */

#define START_TR        0x01    /* Identifies pressed switches  */
#define STOP_TR         0x02
#define FORWARD_TR      0x04
#define REVERSE_TR      0x08
#define MODE_TR         0x10

#define IMS_DATA        0xc8

#define WDTM_SET        0x6f

#define P_OFF           0x3f    /* Real-time output port off */
#define P_STOP          0x15
#define P_T1            0x36    /* Excitation pattern 1      */
#define P_T2            0x1e    /* Excitation pattern 2      */
#define P_T3            0x1b    /* Excitation pattern 3      */
#define P_T4            0x39    /* Excitation pattern 4      */
#define P_T5            0x2d    /* Excitation pattern 5      */
#define P_T6            0x27    /* Excitation pattern 6      */

#define INT_CNT_MAX     500     /* Identification of no rotation: x200 us */
#define START_PWM_FF_MAX 300    /* Limit value during no rotation: 10%    */

#define DELTA_CW        0       /* Lead angle on CW side                  */
#define DELTA_CCW       0       /* Lead angle on CCW side                 */

#define CHANGE_SPEED    100     /* Speed of switching from 120-degree excitation to 180-degree excitation */
#define CHANGE_TIME     2500

#define CLEAR           0
#define SET             1

#define CR01_ADD        3       /* Switching wait time counter value */
                                /* Dependent on TM00 setting         */

#define PWM_BASE_REF    1000    /* Half of PWM period                */
#define PWM_F_REF       0       /* Default PWM waveform value        */
#define PWM_DTM_REF     200     /* Dead time                         */

#define PWM_MIDDLE      PWM_BASE_REF / 2
#define PWM_x3          PWM_MIDDLE * 3

#define INTERVAL_BASE   5       /* 1ms = 200[us] * INTERVAL_BASE       */
#define TIME_OUT        5000    /* 1s  = 200[us] * TIME_OUT            */
                                /* Dependent on inverter timer setting */

#define INV_OFF         1       /* For LowVoltage */
#define INV_ON          0

#define INTP0           PM00    /* Overcurrent detection port      */
#define INVERTER_SW     P54     /* Inverter operation control port */
#define INVERTER_SW_MODE PM54   /* Inverter operation control port */


/* ------------------------------------------- */
static const unsigned int sin_tbl[91] = {  /*  sin(theta) x (2^16 - 1) */
    0,  1143,  2287,  3429,  4571,  5711,  6850,  7986,
    9120, 10251, 11380, 12504, 13625, 14742, 15854, 16961,
```

```
    18063, 19160, 20251, 21336, 22414, 23485, 24549, 25606,
    26655, 27696, 28728, 29752, 30766, 31771, 32767, 33753,
    34728, 35692, 36646, 37589, 38520, 39439, 40347, 41242,
    42125, 42994, 43851, 44694, 45524, 46340, 47141, 47929,
    48701, 49459, 50202, 50930, 51642, 52338, 53018, 53683,
    54330, 54962, 55576, 56174, 56754, 57318, 57863, 58392,
    58902, 59394, 59869, 60325, 60762, 61182, 61582, 61964,
    62327, 62671, 62996, 63301, 63588, 63855, 64102, 64330,
    64539, 64728, 64897, 65046, 65175, 65285, 65375, 65445,
    65495, 65525, 65535
};


const unsigned char tr_sw[2][8] = {      /* Excitation pattern        */
#ifdef LOW
    /*
       PITTMAN N2311A011 12VDC  driveLayer U:brown , V:red,    W:orange
                                Hall-sensor U:grey  , V:blue,   W:white
                                             Hall-1    Hall-2    Hall-3
     */
    {P_OFF, P_T4, P_T6, P_T5, P_T2, P_T3, P_T1, P_OFF},   /* CW               */
    {P_OFF, P_T1, P_T3, P_T2, P_T5, P_T6, P_T4, P_OFF}    /* CCW              */
#else
    /*
       OrientalMOTOR FBLM575W-A driveLayer U:purple, V:blue,   W:gray
                                Hall-sensor U:beige , V:orange, W:pink
                                             Hall-1    Hall-2    Hall-3
     */
    {P_OFF, P_T3, P_T5, P_T4, P_T1, P_T2, P_T6, P_OFF},   /* CW         */
    {P_OFF, P_T6, P_T2, P_T1, P_T4, P_T5, P_T3, P_OFF}    /* CCW        */
#endif
};

const unsigned char next_type[2][8] = {  /* Next Hall IC value */
    {8, 3, 6, 2, 5, 1, 4, 8},
    {8, 5, 3, 1, 6, 4, 2, 8}
};

unsigned int        int_cnt;                /* Number of carrier synchronization interrupts */
unsigned int        pid_cnt;
unsigned int        start_cnt;
unsigned int        print_cnt;
unsigned int        cnt_data;
unsigned int        cnt_data1;
unsigned int        cnt_data2;
unsigned int        cnt_data3;

int                 m_speed   = 0;
int                 speed_ref = 0;          /* Specified speed                      */
int                 speed_ref_o = 0;
float               I_ref;
float               I_ref_o;
float               I_measured;

char                stop_wait;              /* Stop wait flag                       */
char                cw_ccw_wait;            /* Reversal wait flag                   */

char                cw_ccw_flag;            /* Rotation direction status            */
char                sys_flag;               /* System operation status              */
char                err_flag = FLG_OFF;     /* Error flag                           */
static char         start_flag;             /* Identification of rotation start     */
static char         speed_flag;             /* Presence/absence of speed information */
static char         hall_new;
static char         hall_old;

static char         clk_flag;
static char         capture_flag;
static unsigned int new_clk, old_clk;       /* Timer value for speed measurement     */

int                 sin_table_end = 90;
static unsigned int angle;                  /* Angle information                     */
int                 pwm_ff;                 /* Active width: 0 to 500                */
int                 pwm_ff_o;               /* Active width: 0 to 500                */
int                 old_ff;                 /* Active width: 0 to 500                */
int                 pwm_base = PWM_BASE_REF;/* Half period of PWM: Fixed to 1000     */

unsigned char        startup_method = STARTUP_METHOD_REF;
unsigned char        maxed_flags;           /* bits to specify if on limits: bits 7-6-5 are RPM-Current-Volts respectively */

int                  maxspeed = MAXSPEED_REF;
int                  minspeed = MINSPEED_REF;

/* Setpoint change maximum rates */
float                RPM_rate_max = RPM_RATE_MAX_REF; /* RPM/sec */
float                I_rate_max   = I_RATE_MAX_REF;   /* dI_int/sec maximum */

static int           dpwm_ff_max  = PWM_BASE_REF /10; /* max change in pwm per control cycle */
int                  dspeed_ref_max;                  /* max change in speed ref per control cycle */
float                dI_ref_max;

float                t_knee = T_KNEE_REF;
float                t_end = T_END_REF;
float                RPM0 = RPM0_REF;
float                RPM1 = RPM1_REF;
float                RPM2 = RPM2_REF;
float                I_ref0 = I_REF0_REF;
float                I_ref1 = I_REF1_REF;
float                I_ref2 = I_REF2_REF;
float                PWM0 = PWM0_REF;
float                PWM1 = PWM1_REF;
float                PWM2 = PWM2_REF;

/* RPM feedback to I command */
float                krp_ref = KRP_DEF_REF;  /* dI_ints/dRPM error    */
float                kri_ref = KRI_DEF_REF;  /* dI_ints/RPM error     */
float                krd_ref = KRD_DEF_REF;  /* dI_ints/d(dRPM error) */
```

```
/* Current feedback to PWM command */
float               kip_ref = KIP_DEF_REF;  /* dPWM/dI_error  */
float               kii_ref = KII_DEF_REF;  /* dPWM/I_error   */
float               kid_ref = KID_DEF_REF;  /* dPWM/d(derror) */

float               adgain = ADGAIN_REF;
int                 adoffset = ADOFFSET_REF;
float               maxcurrent = MAXCURRENT_REF;
float               mincurrent = MINCURRENT_REF;


/*
    Static variable
*/
static unsigned int  cy_time = 150 * INTERVAL_BASE;
static char          cmd_mode = SPEED_CMD;
static char          up_flag;               /* Speed update notification flag */
static unsigned int  pwm_ff_u, pwm_ff_v, pwm_ff_w;
static float         mvn;                   /* Manipulated variable           */
static float         en, en_1, en_2;        /* Deviation                      */

/* ---------------------------------------------- */
static void init_PORT(void);
static void init_OSC(void);
static void init_TW0(void);
static void init_TM00(void);
static void init_RTPM01(void);
static void init_AD(void);
static void init_TM51(void);
static void init_WDTM(void);

static void start_AD(void);
static void start_TW0(void);
static void start_TM00(void);
static void start_TM51(void);
static void start_RTPM01(void);

static void stop_TW0(void);
static void stop_TM00(void);
static void stop_RTPM01(void);

static void INTP0_on(void);
static void INTP5_on(void);
static void INTTM51_on(void);
static void INTTW0UD_on(void);

static void INTP5_off(void);
static void INTTW0UD_off(void);

static void set_TW0(unsigned int, unsigned int, unsigned int, unsigned int);
static void set_RTPM01(unsigned char);

static void wait(unsigned int);

static void system_restart(void);
static void system_stop(void);

static char read_Hall_IC(void);
static void filters(void);


/* ================================================== */
/* ------------------------------------------------------
    Motor control function section disclosed to users
   ------------------------------------------------------ */

/* ------------------------------------------------------
    Initial settings of functions related to motor control
   ------------------------------------------------------ */
void
motor_init(void)
{
    init_OSC();
    init_WDTM();
    init_PORT();
    init_TW0();
    init_TM00();
    init_RTPM01();
    init_AD();
    init_TM51();

    dspeed_ref_max = (int)(RPM_rate_max/10.0);
    dI_ref_max     = (float)(I_rate_max/10.0);

    start_TM51();
    INTTM51_on();

    start_AD();             /* Starts A/D conversion         */
    INTP0_on();             /* Unmasks overcurrent interrupt */
    EI();                   /* Enables interrupt             */
}

/* ------------------------------
    System start
   ------------------------------ */
void
motor_start(void)
{
    en_1        =
    en          =
    mvn         = 0.0;
    int_cnt     =
    pid_cnt     =
    print_cnt   =
    start_cnt   = 0;
    cnt_data1   =
    cnt_data2   =
```

```
    cnt_data3    = 500;
    cnt_data     = 1500;
    new_clk      =
    old_clk      =
    m_speed      = 0;
    sys_flag     = FLG_120;
    start_flag   = FLG_ON;
    stop_wait    = FLG_OFF;
    cw_ccw_wait  = FLG_OFF;
    speed_flag   = FLG_OFF;
    clk_flag     = FLG_OFF;
    up_flag      = FLG_OFF;
    capture_flag = FLG_OFF;
    err_flag     = ERROR_NONE;
    pwm_ff       = (int)PWM2;
    I_ref        = I_measured;
    speed_ref    = (int)RPM2;
    hall_old     = read_Hall_IC();

    start_TM00();
    INTTW0UD_on();        /* Unmasks carrier synchronization interrupt */
    INTP5_on();           /* Unmasks Hall IC interrupt                 */
    start_RTPM01();
    start_TW0();

    INVERTER_SW = INV_ON;    /* INVERTER enable  */
}

/* ------------------------------
    Motor stop processing
   ------------------------------ */
void
motor_stop(void) {
    stop_wait = FLG_ON;
}


/* -----------------------------------------
    Motor rotation direction change processing
   ----------------------------------------- */
void
motor_rotation(char dir) {
    switch(dir) {
    case CW:
        if(cw_ccw_flag == CCW) {
            cw_ccw_wait = FLG_ON;
            cw_ccw_flag = CW;
        };
        break;
    default:
        if(cw_ccw_flag == CW) {
            cw_ccw_wait = FLG_ON;
            cw_ccw_flag = CCW;
        };
    };
}

/* ------------------------------
    PID control
   ------------------------------ */
void
motor_pid(void)
{
    unsigned long tmp;
    unsigned long old_tmp, new_tmp;
    int pwm_tmp;

    if(speed_flag == FLG_ON){           /* Speed is already measured */
        speed_flag = FLG_OFF;
        if(start_flag == FLG_OFF){
            if(clk_flag == FLG_ON){
                clk_flag = FLG_OFF;
                up_flag = FLG_ON;       /* Speed is already updated */
                angle = cnt_data1;
                DI();
                new_tmp = new_clk;
                old_tmp = old_clk;
                EI();
                if(old_tmp > new_tmp){
                    tmp = (unsigned long)((65536 - (long)old_tmp) + (long)new_tmp);
                }else{
                    tmp = new_tmp - old_tmp;
                }
                m_speed = (int)(UNIT_RPM/tmp);
            };
        }else{
            start_flag = FLG_OFF;   /* First speed information is not used */
        }
    }
    if(pid_cnt >= cy_time){    /* cy_time (ms) has elapsed */
        pid_cnt = 0;
        if(up_flag == FLG_ON){
            up_flag = FLG_OFF;
            if((sys_flag    != FLG_OFF) &&  /* Being started                          */
               (stop_wait   != FLG_ON) &&   /* Not waiting for stop                   */
               (cw_ccw_wait != FLG_ON)){    /* Not waiting for stop of reverse rotation */
                maxed_flags = 0;    /* reset all flags here */
                switch(cmd_mode) {
                case V_CMD:         /* voltage control: pwm set by GUI */
                    /* no loop on speed */
                    speed_ref = m_speed;
                    /* no loop on current */
                    I_ref = I_measured;
                    /* adjust setpoint (acceleration limits) */
                    if((pwm_ff_o - pwm_ff) > dpwm_ff_max) {
                        pwm_ff += dpwm_ff_max;
                        maxed_flags |= 0x20;  /* on limit, set bit 5 */
```

```
                    } else if((pwm_ff_o - pwm_ff) < -dpwm_ff_max) {
                        pwm_ff -= dpwm_ff_max;
                        maxed_flags |= 0x20;  /* on limit, set bit 5 */
                    } else {
                        pwm_ff = pwm_ff_o;
                    };
                    break;

                case I_CMD:        /* current control (no use) */
                case SPEED_CMD:    /* speed control            */
                    /* no loop on current */
                    I_ref = I_measured;
                    /* adjust setpoint (acceleration limits) */
                    if((speed_ref_o - speed_ref) > dspeed_ref_max) {
                        speed_ref += dspeed_ref_max;
                        maxed_flags |= 0x80;  /* on limit, set bit 7 */
                    } else if((speed_ref_o - speed_ref) < -dspeed_ref_max) {
                        speed_ref -= dspeed_ref_max;
                        maxed_flags |= 0x80;  /* on limit, set bit 7 */
                    } else {
                        speed_ref = speed_ref_o;
                    };
                    en_2 = en_1;  /* last last error */
                    en_1 = en;    /* last error */
                    en   = (float)(speed_ref - m_speed); /* up-to-date error */

                    mvn = mvn
                        + krp_ref*(en - en_1)
                        + kri_ref*en
                        + krd_ref*((en - en_1) - (en_1 - en_2));

                    pwm_tmp = (int)(mvn);

                    if(pwm_tmp > dpwm_ff_max) {
                        pwm_tmp += dpwm_ff_max;
                        maxed_flags |= 0x20;  /* on limit, set bit 5 */
                    } else if(pwm_tmp < -dpwm_ff_max) {
                        pwm_tmp -= dpwm_ff_max;
                        maxed_flags |= 0x20;  /* on limit, set bit 5 */
                    };

                    pwm_ff += pwm_tmp;

                    if(pwm_ff > PWM_F_MAX) {
                        pwm_ff = PWM_F_MAX;
                        mvn = 0.0;
                    } else if(pwm_ff < PWM_F_MIN) {
                        pwm_ff = PWM_F_MIN;
                        mvn = 0.0;
                    };
                    break;
                };
                MDB0 = (unsigned int)pwm_ff;
            };
        };
    };
}

/* -------------------------------
    Motor parameter setting
   ------------------------------- */
char
motor_pset(unsigned char com, long data) {
    char status = 1;

    switch(com) {
    case MOTOR_SPEED:
        speed_ref_o = (int)data;
        break;
    case PID_INTERVAL:
        if(sys_flag == FLG_OFF) {
            cy_time = (unsigned int)((int)data*INTERVAL_BASE);
        } else {
            status = 0;
        };
        break;
    case PWM_LIMIT:
        if(sys_flag == FLG_OFF) {
            if(data < 0) {
                status = -1;
            } else {
                dpwm_ff_max = (int)data;
            };
        } else {
            status = 0;
        };
        break;
    case MODE:
        if(sys_flag == FLG_OFF) {
            cmd_mode = (char)data;
        } else {
            status = 0;
        };
        break;
    case KRP:
        if(sys_flag == FLG_OFF) {
            if(data < 0) {
                status = -1;
            } else {
                krp_ref = (float)data / 1000;
            };
        } else {
            status = 0;
        };
        break;
    case KRI:
        if(sys_flag == FLG_OFF) {
```

```
            if(data < 0) {
                status = -1;
            } else {
                kri_ref = (float)data / 1000;
            };
        } else {
            status = 0;
        };
        break;
    case KRD:
        if(sys_flag == FLG_OFF) {
            if(data < 0) {
                status = -1;
            } else {
                krd_ref = (float)data / 1000;
            };
        } else {
            status = 0;
        };
        break;
    case KIP:
        if(sys_flag == FLG_OFF) {
            if(data < 0) {
                status = -1;
            } else {
                kip_ref = (float)data / 1000;
            };
        } else {
            status = 0;
        };
        break;
    case KII:
        if(sys_flag == FLG_OFF) {
            if(data < 0) {
                status = -1;
            } else {
                kii_ref = (float)data / 1000;
            };
        } else {
            status = 0;
        };
        break;
    case KID:
        if(sys_flag == FLG_OFF) {
            if(data < 0) {
                status = -1;
            } else {
                kid_ref = (float)data / 1000;
            };
        } else {
            status = 0;
        };
        break;
    default:
        status = -1;
    };

    return(status);
}


/* ======================================================= */
/* ------------------------------------------------------
    Motor control function section not disclosed to users
   ------------------------------------------------------ */
/*
    Restart from reverse rotation stop
*/
void
system_restart(void)
{
    init_TW0();

    en_1         =
    en           =
    mvn          = 0.0;
    int_cnt      =
    pid_cnt      =
    print_cnt    =
    start_cnt    = 0;
    cnt_data1    =
    cnt_data2    =
    cnt_data3    = 500;
    cnt_data     = 1500;
    new_clk      =
    old_clk      =
    m_speed      = 0;
    sys_flag     = FLG_120;
    start_flag   = FLG_ON;
    cw_ccw_wait  = FLG_OFF;
    speed_flag   = FLG_OFF;
    clk_flag     = FLG_OFF;
    up_flag      = FLG_OFF;
    capture_flag = FLG_OFF;
    pwm_ff       = (int)PWM2;
    I_ref        = I_measured;
    speed_ref    = (int)RPM2;

    hall_old     = read_Hall_IC();
}

/*
    System stop
*/
void
system_stop(void)
{
```

```
    pwm_ff = 0;
    INVERTER_SW = INV_OFF;  /* INVERTER disable                        */

    INTTW0UD_off();         /* Stops synchronization carrier interrupt */
    INTP5_off();
    stop_RTPM01();          /* Stops real-time port                    */
    stop_TW0();             /* Stops inverter timer                    */
    stop_TM00();            /* Stops 16-bit timer                      */

    init_TW0();

    sys_flag     = FLG_OFF;
    stop_wait    = FLG_OFF;
    cw_ccw_flag  = CW;
    m_speed      = 0;       /* Speed 0                                 */
}

/*
    Port settings
*/
static void
init_PORT(void)
{
    INTP0 = IN;                         /* Interrupt of overcurrent notification */

    INVERTER_SW_MODE = OUT;             /* INVERTER enable/disable               */
    INVERTER_SW      = INV_OFF;         /* INVERTER disable                      */

    EGP5 = SET;                         /* Rising edge is valid                  */
    EGN5 = CLEAR;
}


/*
    Clock switching
*/
static void
init_OSC(void)
{
    IMS = IMS_DATA;                     /* Switches memory size                */
    WDTE = WDTE_CLR;
    while(OSTC != 0x1f);                /* Waits for oscillation stabilization */
    PCC   = 0x00;                       /* Sets division ratio                 */
    MCM.0 = 1;                          /* X1 input clock                      */
    VSWC.1 = 1;
}

/*
    Inverter timer
*/
static void
init_TW0(void)
{
    TCL02    = 0;       /* Count clock: 20 MHz                    */
    TCL01    = 0;
    TCL00    = 0;
    IDEV02   = 0;       /* Generates one interrupt every two times */
    IDEV01   = 0;
    IDEV00   = 1;
    TW0M     = 0;
    TW0TRGS  = 0;
    TW0OC    = 0;
    TW0CM3   = PWM_BASE_REF;
    TW0CM0   = PWM_BASE_REF - PWM_F_REF;
    TW0CM1   = PWM_BASE_REF - PWM_F_REF;
    TW0CM2   = PWM_BASE_REF - PWM_F_REF;
    TW0DTIME = PWM_DTM_REF;                 /* Dead time                   */
    TW0BFCM3 = PWM_BASE_REF;
    TW0BFCM0 = PWM_BASE_REF - PWM_F_REF;
    TW0BFCM1 = PWM_BASE_REF - PWM_F_REF;
    TW0BFCM2 = PWM_BASE_REF - PWM_F_REF;
}

static void
start_TW0(void)
{
    TW0C.7 = SET;                       /* Starts timer   */
}

static void
stop_TW0(void)
{
    TW0C.7 = CLEAR;                     /* Stops timer    */
}

void
set_TW0(unsigned int u, unsigned int v, unsigned int w, unsigned int base)
{
    TW0BFCM3 = base;
    TW0BFCM0 = base - u;
    TW0BFCM1 = base - v;
    TW0BFCM2 = base - w;
}

/*
    16-bit timer

    CR01    Real-time output port trigger
*/
static void
init_TM00(void)
{
    ES000  = 0;
    ES001  = 0;                         /* Valid edge of TI000 pin: falling edge                */
    CRC000 = 1;                         /* CR00 capture register                                */
    CRC001 = 1;                         /* Capture with reverse phase of valid edge of TI000 pin */
    CRC002 = 0;                         /* CR01 compare register                                */
```

```
    PRM001 = SET;
    PRM000 = CLEAR;                     /* Count clock: 78.125 kHz */
}

static void
start_TM00(void)
{
    TMIF00 = CLEAR;
    TMC00  = 0x04;                      /* Free-running mode       */
}

static void
stop_TM00(void)
{
    TMC00 = CLEAR;                      /* Stops timer             */
}


/*
    Real-time port
*/
static void
init_RTPM01(void)
{
    RTPM01  = 0x3f;                     /* Real-time output mode   */
    RTPC01  = 0x20;                     /* 6 bits x 1 channel      */
    DCCTL01 = 0xc0;                     /* PWM modulation output   */
    RTBL01  = 0x3f;                     /* Output buffer           */
}

void
start_RTPM01(void)
{
    DCCTL01.7 = SET;                    /* Real-time output        */
    RTPC01.7  = SET;                    /* Enables operation       */
}

static void
stop_RTPM01(void)
{
    RTPC01.7 = CLEAR;                   /* Disables operation      */
}

void
end_RTPM01(void)
{
    DCCTL01.7 = CLEAR;                  /* Outputs inverter timer  */
}

void
set_RTPM01(unsigned char data)
{
    RTBL01 = data;                      /* Sets excitation pattern */
    CR01   = TM00 + CR01_ADD;
}


/*
    AD
*/
static void
init_AD(void)
{
    ADCS2 = SET;                        /* Enables circuit operation */
    ADS   = AD_ISHUNT;                  /* SHUNT */
    ADM   = 0x04;                       /* 3.6us */
}

static void
start_AD(void)
{
    ADIF = CLEAR;                       /* Clears interrupt notification flag */
    ADCS = SET;                         /* Enables conversion operation       */
    while(ADIF != SET);                 /* Waits for interrupt notification   */
}


/*
    Watchdog timer
*/
static void
init_WDTM(void)
{
    WDTE = WDTE_CLR;
    WDTM = WDTM_SET;
}


/* --------------------------------
    8-bit timer 51
   -------------------------------- */
static void
init_TM51(void) {
    TMC51 = 0x00;                       /* no PWM, TIMER out disabled */
    TCL51 = 0x05;                       /* 19.53KHz */
    CR51  = 28;                         /* 1.43 ms */
}

static void
start_TM51(void) {
    TMIF51 = CLEAR;                     /* Clears interrupt notification flag */
    TCE51  = SET;                       /* Starts timer                       */
}


/*
    Reading Hall IC
```

```
*/
char
read_Hall_IC(void)
{
    return((char)((P0>>1)&0x7));
}


/* ======================================================= */
/*
    Interrupt enable/disable processing
 */
/*
    Overcurrent interrupt enable
*/
void
INTP0_on(void)
{
    PR0L.1 = 0;                         /* Priority     */
    EGN.0  = 1;                         /* Falling edge */
    IF0L.1 = CLEAR;                     /* Clears flag  */
    MK0L.1 = CLEAR;                     /* Unmasks      */
}

/*
    Carrier synchronization interrupt enable
*/
static void
INTTW0UD_on(void)
{
    IF0H.1 = CLEAR;                     /* Clears request flag */
    MK0H.1 = CLEAR;                     /* Enables interrupt   */
}

/*
    Carrier synchronization interrupt disable
*/
static void
INTTW0UD_off(void)
{
    MK0H.1 = SET;                       /* Disables interrupt */
}

/* -------------------------------
    INTP5 interrupt enable
   ------------------------------- */
static void
INTP5_on(void) {
    PIF5 = CLEAR;
    PMK5 = CLEAR;
}

/* -------------------------------
    INTP5 interrupt disable
   ------------------------------- */
static void
INTP5_off(void) {
    PMK5 = SET;
}

/* -------------------------------
    Current minor interrupt enable
   ------------------------------- */
static void
INTTM51_on(void) {
    IF1H.0 = CLEAR;
    MK1H.0 = CLEAR;
}


/* ======================================================= */
/*
    Interrupt servicing
*/
/* ------------------------------------------- */
__interrupt void
int_fault(void)
{
    err_flag = ERROR_OC;
    system_stop();              /* Stops system */
}


/*
    INTP5
*/
__interrupt void
int_speed(void)
{
    capture_flag = FLG_ON;
}

/*
    Carrier synchronization interrupt
*/
static unsigned int
get_coswt(unsigned int wt)
{
    unsigned int   n;
    unsigned int   answer;
    unsigned char  dir, pm;


    n = wt / 90;
    if(n > 3){
        wt -= 360;
        n -= 4;
```

```
    };

    switch(n) {
    case 0:
        dir = 0xff;
        pm  = 0x00;
        break;
    case 1:
        wt -= 90;
        dir = 0x00;
        pm  = 0xff;
        break;
    case 2:
        wt -= 180;
        dir = 0xff;
        pm  = 0xff;
        break;
    default:
        wt -= 270;
        dir = 0x00;
        pm  = 0x00;
    };

    if(dir == 0) { MDA0L = sin_tbl[wt]; }
    else         { MDA0L = sin_tbl[sin_table_end - wt]; };

    DMUC0 = 0x81;
    while(DMUE == 1);

    if(pm == 0) { answer = PWM_MIDDLE + MDA0H;}
    else        { answer = PWM_MIDDLE - MDA0H;};

    return(answer);
}

static void
set_pwm(void)
{
    unsigned int    p, p_u, p_v;

#ifdef LOW
    if(cw_ccw_flag == CW) {
        p = ((60 * int_cnt)/angle) + DELTA_CW; /* Angle detail: Lead angle is fixed */
        switch(hall_new) {
        case 4: /* 0 - 59 */
            p_u = p;
            p_v = p_u + 240;
            break;

        case 5: /* 60 - 119 */
            p_u = p + 60;
            p_v = p_u + 240;
            break;

        case 1: /* 120 - 179 */
            p_u = p + 120;
            p_v = p_u + 240;
            break;

        case 3: /* 180 - 239 */
            p_u = p + 180;
            p_v = p_u + 240;
            break;

        case 2: /* 240 - 299 */
            p_u = p + 240;
            p_v = p_u + 240;
            break;

        case 6: /* 300 - 359 */
            p_u = p + 300;
            p_v = p_u + 240;
            break;

        default:
            p_u = 90;
            p_v = 90;
        };
    }else{
        p = ((60 * int_cnt)/angle) + DELTA_CCW; /* Angle detail: Lead angle is fixed */
        switch(hall_new){
        case 1: /* 0 - 59 */
            p_u = p;
            p_v = p_u + 240;
            break;

        case 5: /* 60 - 119 */
            p_u = p + 60;
            p_v = p_u + 240;
            break;

        case 4: /* 120 - 179 */
            p_u = p + 120;
            p_v = p_u + 240;
            break;

        case 6: /* 180 - 239 */
            p_u = p + 180;
            p_v = p_u + 240;
            break;

        case 2: /* 240 - 299 */
            p_u = p + 240;
            p_v = p_u + 240;
            break;

        case 3: /* 300 - 359 */
```

```
            p_u = p + 300;
            p_v = p_u + 240;
            break;

        default:
            p_u = 90;
            p_v = 90;
        };
    };
#else
    if(cw_ccw_flag == CW) {
        p = ((60 * int_cnt)/angle) + DELTA_CW; /* Angle detail: Lead angle is fixed */
        switch(hall_new) {
        case 5: /* 0 - 59 */
            p_u = p;
            p_v = p_u + 240;
            break;

        case 1: /* 60 - 119 */
            p_u = p + 60;
            p_v = p_u + 240;
            break;

        case 3: /* 120 - 179 */
            p_u = p + 120;
            p_v = p_u + 240;
            break;

        case 2: /* 180 - 239 */
            p_u = p + 180;
            p_v = p_u + 240;
            break;

        case 6: /* 240 - 299 */
            p_u = p + 240;
            p_v = p_u + 240;
            break;

        case 4: /* 300 - 359 */
            p_u = p + 300;
            p_v = p_u + 240;
            break;

        default:
            p_u = 90;
            p_v = 90;
        };
    }else{
        p = ((60 * int_cnt)/angle) + DELTA_CCW; /* Angle detail: Lead angle is fixed */
        switch(hall_new){
        case 3: /* 0 - 59 */
            p_u = p;
            p_v = p_u + 240;
            break;

        case 1: /* 60 - 119 */
            p_u = p + 60;
            p_v = p_u + 240;
            break;

        case 5: /* 120 - 179 */
            p_u = p + 120;
            p_v = p_u + 240;
            break;

        case 4: /* 180 - 239 */
            p_u = p + 180;
            p_v = p_u + 240;
            break;

        case 6: /* 240 - 299 */
            p_u = p + 240;
            p_v = p_u + 240;
            break;

        case 2: /* 300 - 359 */
            p_u = p + 300;
            p_v = p_u + 240;
            break;

        default:
            p_u = 90;
            p_v = 90;
        };
    };
#endif
    pwm_ff_u = get_coswt(p_u);
    pwm_ff_v = get_coswt(p_v);
    pwm_ff_w = PWM_x3 - (pwm_ff_u + pwm_ff_v);

    WDTE = WDTE_CLR;
}

__interrupt void
int_carrier(void)
{
    unsigned int     tmp_pwm;

    int_cnt++;
    print_cnt++;
    if(int_cnt > INT_CNT_MAX){                      /* Overflow                          */
        if(stop_wait != FLG_OFF){                   /* Waits for stop                    */
            system_stop();                          /* Stops system                      */
            return;
        }else if(cw_ccw_wait != FLG_OFF){           /* Waits for stop of reverse rotation */
            system_restart();                       /* Restart                           */
            return;
```

```
        }else if(pwm_ff > START_PWM_FF_MAX){            /* Motor does not rotate             */
            system_stop();                              /* Stops system                      */
            err_flag = (ERROR_HALL | ERROR_MOTOR);
            return;
        }else{
            pwm_ff++;                                   /* Raises voltage                    */
            int_cnt = 0;
            start_cnt = 0;
            MDB0 = (unsigned int)pwm_ff;
        }
    }
    pid_cnt++;
    start_cnt++;
    hall_new = read_Hall_IC();
    if(hall_new == next_type[cw_ccw_flag][hall_old]){  /* Hall IC value is next value */
        hall_old  = hall_new;
        cnt_data1 = int_cnt;
        int_cnt   = 0;
        speed_flag = FLG_ON;
    }
    if(sys_flag == FLG_120){                            /* 120-degree excitation method */
        pid_cnt = 0;                                    /* Does not perform PID control */
        if((stop_wait != FLG_OFF) || (cw_ccw_wait != FLG_OFF)){
            set_RTPM01(P_OFF);                          /* Stops excitation             */
            sys_flag = FLG_WAIT;
        }else if((m_speed != 0) && (start_cnt > CHANGE_TIME)){
            set_RTPM01(P_OFF);                          /* Stops excitation             */
            sys_flag = FLG_SW;
        }else{
            set_RTPM01(tr_sw[cw_ccw_flag][hall_new]);  /* Sets excitation pattern      */
            if(pwm_ff != old_ff) {
                set_TW0((unsigned int)pwm_ff,
                        (unsigned int)pwm_ff,
                        (unsigned int)pwm_ff,
                        (unsigned int)pwm_base);       /* Changes duty                 */
                old_ff = pwm_ff;
            }
        }
    }else if(sys_flag == FLG_180){                      /* 180-degree excitation method */
        if((stop_wait != FLG_OFF) || (cw_ccw_wait != FLG_OFF)){
            start_RTPM01();
            set_RTPM01(P_OFF);                          /* Stops excitation             */
            sys_flag = FLG_WAIT;
        }else{
            set_pwm();
            set_TW0(pwm_ff_u,
                    pwm_ff_v,
                    pwm_ff_w,
                    (unsigned int)(pwm_base));
        }
    }else if(sys_flag == FLG_SW){ /* Immediately after switching from 120-degree to 180-degree */
        if((stop_wait != FLG_OFF) || (cw_ccw_wait != FLG_OFF)){
            sys_flag = FLG_WAIT;
        }else{
            end_RTPM01();                               /* Ends real-time port output */
            tmp_pwm = (unsigned int)(pwm_base >> 1);
            set_TW0(tmp_pwm, tmp_pwm, tmp_pwm, pwm_base);
            sys_flag = FLG_180;
            pwm_ff = (pwm_ff/3)*2;                      /* Adjusts applied voltage to 2/3 */
            MDB0 = (unsigned int)pwm_ff;
        }
    };

    if(capture_flag == FLG_ON){
        if(CR00 != new_clk){
            old_clk      = new_clk;
            new_clk      = CR00;
            clk_flag     = FLG_ON;
            capture_flag = FLG_OFF;
        };
    }

    return;
}


/* ------------------------------
    Interrupt for TM51 overflow
  ------------------------------ */
__interrupt void
int_TM51(void) {
    unsigned int x_filt, reg;

    reg = ADCR;              /* 10 bit A/D reading */
    x_filt = reg>>6;
    I_measured = (float)x_filt;
}
```

4.18 Reference Program Source File

```
/*


    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit


    date    : 2007/05/21
    filename: main_mcio.c

    NEC Micro Systems,Ltd
*/

#pragma sfr

#include    "motor.h"
#include    "sub_mcio.h"

/*
    Main function
*/
void
main(void) {
    unsigned char  sw = 0;
    unsigned char  tmp_sw = 0;

    /* Initial system settings */
    motor_init();
    init_PORT();
    init_TM50();

    /* Motor parameter settings */
    motor_pset(PID_INTERVAL, 150);  /* PID control interval: 150 ms */

    motor_pset(KRP,  50);           /* RPM-Kp setting. Sets value multiplied by 1000            */
    motor_pset(KRI,  20);           /* RPM-Ki setting. Sets value multiplied by 1000            */
    motor_pset(KRD,  10);           /* RPM-Kd setting. Sets value multiplied by 1000            */

    startup_disp();
    while(1){
        clear_WDTM();
        vol2speed();
        speed_print(200);
        sw = get_sw();
        if(sys_flag != FLG_OFF){
            if((cw_ccw_wait == FLG_OFF) &&
               (stop_wait   == FLG_OFF)) {
                if(sw != tmp_sw) {
                    switch(sw){
                    case STOP_TR:    motor_stop();        break;
                    case FORWARD_TR: motor_rotation(CW);  break;
                    case REVERSE_TR: motor_rotation(CCW); break;
                    default: ;
                    };
                };
            };
            motor_pid();
        } else {                                /* Being stopped     */
            if(sw != tmp_sw) {
                switch(sw){
                case START_TR: motor_start(); break;
                case MODE_TR:
                    if(ad_flag == FLG_ON){      /* Function being stopped  */
                        ad_flag = FLG_OFF;      /* Restores function       */
                    }else{                      /* Function being operated */
                        ad_flag = FLG_ON;       /* Stops function          */
                    };
                    break;
                default: ;
                };
            };
        };
        tmp_sw = sw;
    };
    return;
}
```

```
/*


    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit


    date    : 2007/05/22
    filename: sub_mcio.h

    NEC Micro Systems,Ltd
*/

#define  CLEAR       0
#define  SET         1

#define  IN          1    /* Input */
```

```
#define  OUT         0    /* Output */

#define  FLG_ON      1    /* Valid */
#define  FLG_OFF     0    /* Invalid */

#define  KEY_WAIT    10
#define  SW          (P7&0x0f)
#define  SW2         PM73
#define  SW3         PM72
#define  SW4         PM71
#define  SW5         PM70

#define  LD_LED0     PM64
#define  LD_LED1     PM65
#define  LD_LED2     PM66
#define  LD_LED3     PM67

#define  LD_DATA     PM4

#define  START_SW    0x7
#define  STOP_SW     0x7
#define  FORWARD_SW  0xb
#define  REVERSE_SW  0xd
#define  MODE_SW     0xe

#define  START_TR    0x01   /* Identifies pressed switches  */
#define  STOP_TR     0x02
#define  FORWARD_TR  0x04
#define  REVERSE_TR  0x08
#define  MODE_TR     0x10

#define  LED_0       0xc0   /* LED display data  */
#define  LED_1       0xf9
#define  LED_2       0xa4
#define  LED_3       0xb0
#define  LED_4       0x99
#define  LED_5       0x92
#define  LED_6       0x82
#define  LED_7       0xf8
#define  LED_8       0x80
#define  LED_9       0x98
#define  LED_O       0xc0   /* O.C.             */
#define  LED_C       0xc6
#define  LED_I       0xcf   /* I                */
#define  LED_H       0x89   /* HALL             */
#define  LED_A       0x88
#define  LED_L       0xc7
#define  LED_        0xff   /* " "              */
#define  LED_S       0x92   /* SELF             */
#define  LED_E       0x86
#define  LED_F       0x8e
#define  LED_P       0x8c   /* PC               */
#define  LED_dot     0x7f   /* .                */

/* ------------------------------------------------------------ */
extern unsigned char ad_flag;

/* ------------------------------------------------------------ */
extern unsigned char get_sw(void);
extern void          speed_print(unsigned int);

extern void          init_PORT(void);
extern void          init_TM50(void);
extern void          vol2speed(void);
extern void          startup_disp(void);

extern void          clear_WDTM(void);
/* ------------------------------------------------------- EOF -- */
```

```
/*


    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit


    date    : 2007/05/22
    filename: sub_mcio.c

    NEC Micro Systems,Ltd
*/

#pragma sfr
#pragma stop
#pragma ei
#pragma di

#include "sub_mcio.h"
#include "motor.h"


#define  PRINT_INTERVAL  10     /* 100[us] * 10 = 1[ms] */

/*
    Static variable
*/
static const unsigned char led_data[10] = {          /* For displaying numerical values   */
    LED_0, LED_1, LED_2, LED_3, LED_4,
    LED_5, LED_6, LED_7, LED_8, LED_9
};

static void          led_set(unsigned char, unsigned char);
```

```
static void          led_print(int, char);
static void          wait(int);
static void          start_TM50(void);
static void          wait_TM50(void);
static void          print_error(char);
static unsigned int  get_vol(char);

unsigned char        ad_flag;

/* ============================================================ */
/*
    Error display
*/
static void
print_error(char eno) {
    switch(eno){
    case ERROR_HALL:
        led_set(0, LED_H);
        led_set(1, LED_A);
        led_set(2, LED_L);
        led_set(3, LED_L);
        break;

    case ERROR_OC:
        led_set(0, LED_);
        led_set(1, LED_O & LED_dot);
        led_set(2, LED_C & LED_dot);
        led_set(3, LED_);
        break;

    case ERROR_MOTOR:
        led_set(0, LED_F);
        led_set(1, LED_A);
        led_set(2, LED_I);
        led_set(3, LED_L);
        break;

    case ERROR_S_OC:
        led_set(0, LED_S & LED_dot);
        led_set(1, LED_);
        led_set(2, LED_O & LED_dot);
        led_set(3, LED_C & LED_dot);
        break;

    default:
        led_set(0, LED_F);
        led_set(1, LED_A);
        led_set(2, LED_I);
        led_set(3, LED_L);
    };

    STOP();
}


/*
   Reading switches in MC-IO
*/
unsigned char
get_sw(void)
{
    unsigned char data;

    int  i;
    unsigned char tmp;
    static unsigned char start_stop_flag = FLG_OFF;

    if(err_flag != ERROR_NONE){
        print_error(err_flag);
    };

    data = SW;                          /* Reads switch                              */
    if(data != 0xf){
        for(i=0;i<KEY_WAIT;){           /* Eliminates chattering.  Must be adjusted. */
            tmp = SW;                   /* Re-reads switch                           */
            if(data == tmp){
                i++;
            }else{
                i = 0;
                data = tmp;
            }
            wait(2);
        }
        if(sys_flag != FLG_OFF){
            switch(data){
            case STOP_SW:
                if(start_stop_flag == FLG_OFF){
                    data = STOP_TR;
                    start_stop_flag = FLG_ON;
                }
                break;

            case FORWARD_SW: data = FORWARD_TR; break;
            case REVERSE_SW: data = REVERSE_TR; break;
            case MODE_SW:    data = MODE_TR;    break;
            default:
                ;
            }
        }else{
            if((data == START_SW) && (start_stop_flag == FLG_OFF)){
                data = START_TR;
                start_stop_flag = FLG_ON;
            }else if(data == MODE_SW){
                data = MODE_TR;
            };
        };
    };
```

```
    if(data == 0xf){    /* No switch is pressed */
        start_stop_flag = FLG_OFF; /* Prevents toggling between START and STOP */
    };

    return(data);
}


/*
    Speed display
*/
void
speed_print(unsigned int ms)
{
    if((MODE_SW == SW) || (sys_flag == FLG_OFF)){
        led_print(speed_ref_o, ad_flag);
    }else{
        if(print_cnt > (ms*PRINT_INTERVAL)){
            led_print(m_speed, FLG_OFF);
            print_cnt = 0;
        };
    };
}


/*
    Displaying value on 7-segment LED
*/
static void
led_print(int data, char flag)
{
    unsigned int tmp;
    int flg = FLG_OFF;

    tmp = (unsigned int)(data / 1000);
    if(tmp != 0){                       /* Most significant digit is not 0 */
        flg = FLG_ON;                   /* Numerical value is displayed on most significant digit */
        led_set(0, led_data[tmp]);
    }else{
        led_set(0, LED_);
    };
    data %= 1000;
    tmp = (unsigned int)(data / 100);
    if((tmp != 0) || (flg == FLG_ON)){      /* Value is not 0 or number has already been displayed */
        flg = FLG_ON;
        led_set(1, led_data[tmp]);
    }else{
        led_set(1, LED_);
    };
    data %= 100;
    tmp = (unsigned int)(data / 10);
    if((tmp != 0) || (flg == FLG_ON)){      /* Value is not 0 or number has already been displayed */
        led_set(2, led_data[tmp]);
    }else{
        led_set(2, LED_);
    };
    data %= 10;
    if(flag == FLG_OFF){
        led_set(3, led_data[data]);
    }else{
        led_set(3, (unsigned char)(led_data[data])&LED_dot);
    };
}

/*
    Displaying data on 7-segment LED
    no:   Location of LED to be displayed
    data: Data to be output
*/
static void
led_set(unsigned char no, unsigned char data)
{
    unsigned char p;

    P6 = 0x00;
    P4 = data;

    switch(no){                         /* Location to be displayed */
    case 0:  p = 0x80; break;           /* Left edge                */
    case 1:  p = 0x40; break;
    case 2:  p = 0x20; break;
    default: p = 0x10; break;           /* Right edge               */
    };
    P6 = p;
}

/*
    Time adjustment   ms
*/
static void
wait(int cnt)
{
    int i;

    for(i=0;i<cnt;i++){
        start_TM50();               /* Starts timer                           */
        wait_TM50();                /* Waits for interrupt request generation */
        clear_WDTM();               /* Clears watchdog timer                  */
    };
    return;
}

/*
  Startup display
*/
void
startup_disp(void) {
```

```
    led_set(0, LED_S);
    led_set(1, LED_E);
    led_set(2, LED_L);
    led_set(3, LED_F);
    wait(2000);
}


/*
    Reading voltage of speed specification variable resistor
    Converting into specified speed
*/
#define SHIFT_BIT   2
void
vol2speed(void)
{
    unsigned int  data;
    unsigned long tmp;

    if(ad_flag == FLG_OFF){
        data = get_vol(SHIFT_BIT);
        data = ((data - 3) * 12) + MINSPEED_REF;
        if(data > MAXSPEED_REF){
            data = MAXSPEED_REF;
        }else if(data < MINSPEED_REF) {
            data = MINSPEED_REF;
        };
        tmp = (UNIT_RPM / (unsigned long)data);
        speed_ref_o = (int)(UNIT_RPM / tmp);
    }
}

static unsigned int
get_vol(char s_bit)
{
    unsigned int  data;
    unsigned char ads_backup;

    DI();
    ads_backup = ADS;
    ADS = AD_VOL;
    ADIF = CLEAR;
    while(ADIF != SET);
    data = ADCR;
    EI();
    ADS = ads_backup;
    ADIF = CLEAR;

    return((data>>(s_bit+6))&0x3ff);
}


/* ---------------------------------------------------- */
/*
    Port settings
*/
void
init_PORT(void) {
    SW2 = IN;                   /* START/STOP             */
    SW3 = IN;                   /* FORWARD                */
    SW4 = IN;                   /* REVERSE                */
    SW5 = IN;                   /* MODE                   */

    LD_LED0 = OUT;              /* LED selection: output  */
    LD_LED1 = OUT;
    LD_LED2 = OUT;
    LD_LED3 = OUT;

    LD_DATA = OUT;              /* LED display data: output */
}

/*
    8-bit timer 50
*/
void
init_TM50(void)
{
    TCL50 = 0x06;
    CR50  = 78;                         /* 1ms */
}

static void
start_TM50(void)
{
    TMIF50 = CLEAR;                     /* Clears interrupt notification flag */
    TCE50  = SET;                       /* Starts timer                       */
}

static void
wait_TM50(void)
{
    while(TMIF50 != SET);               /* Waits for interrupt notification   */
    TCE50  = CLEAR;                     /* Stops timer                        */
}

void
clear_WDTM(void)
{
    WDTE = WDTE_CLR;
}
```

APPENDIX A PROGRAM EXAMPLE

A program example when controlling this system by connecting the separately provided motor operation panel (GUI program) and the RS-232C pin located on the motor control I/O board is included.

A.1 GUI Reference Program Function List

Table A-1. GUI Reference Program Functions

Function Name	Function	Purpose
uart_set()	UART setting	Sets UART function.
get_uart()	Command read instruction	Instructs reading of communication data in UART communication and returns operation information corresponding to read data.
uart_read()	Reading UART data	Instructs reading of UART receive data.
uart_wait()	Reading (provided with receive wait function) of UART data	Function used for successive reception of commands configured of multiple bytes in UART communication
uart_send()	UART data transmission	Instructs transmission in UART communication.
int_uart()	UART reception	Interrupt function performing reception in UART communication
set_error()	Storing error status	Stores error status in UART communication data.
led_set()	LED display	Displays data with LEDs.
startup_disp()	LED display at start	LED display at start
init_PORT()	Port setting	Performs port setting on the MC-IO board.

A.2 GUI Reference Program Constant List

A.2.1 Internal constants

Table A-2. GUI Reference Program Internal Constants (1/2)

Name	Meaning	Setting Value	Remark
IN	For port setting	1	Used to specify port function
OUT	For port setting	0	
CLEAR	For register bit setting	0	Used to access bits of registers
SET	For register bit setting	1	
LED_0	LED display data	0xc0	Displays “0”.
LED_1		0cf9	Displays “1”.
LED_2		0xa4	Displays “2”.
LED_3		0xb0	Displays “3”.
LED_4		0x99	Displays “4”.
LED_5		0x92	Displays “5”.
LED_6		0x82	Displays “6”.
LED_7		0xf8	Displays “7”.
LED_8		0x80	Displays “8”.
LED_9		0x98	Displays “9”.
LED_O		0xc0	Displays “0” instead of “O”.
LED_I		0xcf	Displays “I”.
LED_C		0xc6	Displays “C”.
LED_H		0x89	Displays “H”.
LED_A		0x88	Displays “A”.
LED_L		0xc7	Displays “L”.
LED_		0xff	Displays “ ”.
LED_S		0x92	Displays “S”.
LED_E		0x86	Displays “E”.
LED_F		0x8e	Displays “F”.
LED_P		0x8c	Displays “P”.
LED_dot		0x7f	Displays “.”.
LD_LED0	Port control register	PM64	Port for LED selection
LD_LED1		PM65	Port that outputs data to LED
LD_LED2		PM66	
LD_LED3		PM67	
LD_DATA		PM4	
START_TR	For status setting	0x01	Starts control.
STOP_TR		0x02	Stops control.
FORWARD_TR		0x04	Changes rotation to CW.
REVERSE_TR		0x08	Changes rotation to CCW.
MODE_TR		0x10	State where MODE switch is pressed
RTS	Communication ports	P11	
CTS		P10	
RX_BUFF_SIZE	Communication buffer size	6	
MD_ERROR_HALL	Communication information	0xF0	

Table A-2. GUI Reference Program Internal Constants (2/2)

Name	Meaning	Setting Value	Remark
MD_ERROR_OC	Communication information	0xF1	
MD_ERROR_MOTOR		0xF2	
MD_CMD_START	Communication commands	0x20	
MD_CMD_STOP		0x21	
MD_CMD_RESET		0x2f	
MD_CMD_GETID		0x10	
MD_CMD_GETVER		0x11	
MD_CMD_SETSSPEED		0x30	
MD_CMD_GETSSPEED		0x31	
MD_CMD_SETPIDPARAM		0x40	
MD_CMD_GETPIDPARAM		0x41	
MD_CMD_GETPIDI		0x42	
MD_CMD_GETPIDV		0x43	
MD_CMD_SETPIDI		0x44	
MD_CMD_SETPIDV		0x45	
MD_CMD_GETSPEED		0x50	
MD_CMD_GET_I_SHNT		0x60	
MD_CMD_GET_PWM		0x61	
MD_CMD_GET_I_CMD		0x62	
MD_CMD_SETICMD		0x70	
MD_CMD_SETVCMD		0x71	
MD_CMD_SETSTART		0x72	
MD_CMD_GETSTART		0x73	
MD_CMD_SETLIMIT		0x74	
MD_CMD_GETLIMIT		0x75	
MY_ID		0x02	
VER_MAJOR		0x01	
VER_MINOR		0x00	
VER_SEQ		0x01	

A.3 GUI Reference Program Variable List

A.3.1 Internal variables

Table A-3. GUI Reference Program Internal Variables

ad_flag	char	Speed change flag	Limits specified-speed change function.
led_data[ ]	char	LED output data	Value displayed with LEDs

A.4 GUI Reference Program Source Program

```
/*

    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit
              Compiler option GUI: GUI is used
    date    : 2007/05/22
    filename: main_gui.c

    NEC Micro Systems,Ltd
*/

#pragma sfr

#include    "motor.h"
#include    "sub_gui.h"

/*
    Main function
*/
void
main(void) {
    unsigned char  sw = 0;
    unsigned char  tmp_sw = 0;

    /* Initial system settings */
    motor_init();
    init_PORT();
    uart_set();
    startup_disp();

    /* Motor parameter settings */
    motor_pset(PID_INTERVAL, 150);  /* PID control interval: 150 ms */

    while(1){
        clear_WDTM();
        sw = get_uart();
        if(sys_flag != FLG_OFF) {
            if((cw_ccw_wait == FLG_OFF) &&
               (stop_wait   == FLG_OFF)){
                if(sw != tmp_sw) {
                    switch(sw){
                    case STOP_TR:    motor_stop();        break;
                    case FORWARD_TR: motor_rotation(CW);  break;
                    case REVERSE_TR: motor_rotation(CCW); break;
                    default: ;
                    };
                };
            };
            motor_pid();
        } else {
            if(sw != tmp_sw) {
                switch(sw){
                case START_TR: motor_start(); break;
                default: ;
                };
            };
        };
        tmp_sw = sw;
    };
    return;
}
```

```
/*

    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit
              Compiler option GUI: GUI is used

    date    : 2007/05/22
    filename: sub_gui.h

    NEC Micro Systems,Ltd
*/
```

```
#define IN                  1               /* Input  */
#define OUT                 0               /* Output */

#define CLEAR               0
#define SET                 1

#define START_TR    0x01
#define STOP_TR     0x02
#define FORWARD_TR  0x04
#define REVERSE_TR  0x08
#define MODE_TR     0x10

#define FLG_ON          1               /* Valid   */
#define FLG_OFF         0               /* Invalid */

#define MD_ERROR_HALL       0xF0            /* Hall IC failure     */
#define MD_ERROR_OC         0xF1            /* Overcurrent         */
#define MD_ERROR_MOTOR      0xF2            /* Motor failure       */

#define RTS                 P11
#define CTS                 P10
#define RX_BUFF_SIZE        6               /* UART00 receive buffer size */

#define MD_CMD_START        0x20            /* START                  */
#define MD_CMD_STOP         0x21            /* STOP                   */
#define MD_CMD_RESET        0x2f            /* RESET                  */
#define MD_CMD_GETID        0x10            /* ID request             */
#define MD_CMD_GETVER       0x11            /* Version request        */
#define MD_CMD_SETSSPEED    0x30            /* Specified-speed change */
#define MD_CMD_GETSSPEED    0x31            /* Specified-speed read   */
#define MD_CMD_SETPIDPARAM  0x40            /* PID change             */
#define MD_CMD_GETPIDPARAM  0x41            /* PID read               */
#define MD_CMD_GETPIDI      0x42
#define MD_CMD_GETPIDV      0x43
#define MD_CMD_SETPIDI      0x44
#define MD_CMD_SETPIDV      0x45
#define MD_CMD_GETSPEED     0x50            /* Actual-speed read      */

#define MD_CMD_GET_I_SHNT   0x60
#define MD_CMD_GET_PWM      0x61
#define MD_CMD_GET_I_CMD    0x62
#define MD_CMD_SETICMD      0x70
#define MD_CMD_SETVCMD      0x71

#define MD_CMD_SETSTART     0x72
#define   MD_CMD_GETSTART   0x73
#define MD_CMD_SETLIMIT     0x74
#define MD_CMD_GETLIMIT     0x75

#define MY_ID               0x02            /* Firmware identification ID */
#define VER_MAJOR           0x01            /* Version information        */
#define VER_MINOR           0x00
#define VER_SEQ             0x01

#define LD_LED0             PM64
#define LD_LED1             PM65
#define LD_LED2             PM66
#define LD_LED3             PM67

#define LD_DATA             PM4

#define LED_0               0xc0            /* LED display data                    */
#define LED_1               0xf9
#define LED_2               0xa4
#define LED_3               0xb0
#define LED_4               0x99
#define LED_5               0x92
#define LED_6               0x82
#define LED_7               0xf8
#define LED_8               0x80
#define LED_9               0x98
#define LED_O               0xc0            /* O-C                                 */
#define LED_I               0xcf
#define LED_C               0xc6
#define LED_H               0x89            /* HALL                                */
#define LED_A               0x88
#define LED_L               0xc7
#define LED_                0xff
#define LED_S               0x92            /* SELF                                */
#define LED_E               0x86
#define LED_F               0x8e
#define LED_P               0x8c            /* PC                                  */
#define LED_dot             0x7f


/* ------------------------------------------------------------ */
extern unsigned char get_uart(void);

extern void          clear_WDTM(void);
extern void          uart_set(void);
extern void          init_PORT(void);
extern void          startup_disp(void);

/* ------------------------------------------------------ EOF -- */
```

```
/*


    PMSM 180-degree excitation method with position sensor (Hall IC)

    Version with improved speed estimation accuracy (timer value capture method)
    Module conversion supported

    target  : uPD78F0714 motor starter kit
              Compiler option GUI: GUI is used
```

```
    date    : 2007/05/22
    filename: sub_gui.c

    NEC Micro Systems,Ltd
*/

#pragma sfr


#pragma INTERRUPT INTSR00       int_uart  rb1   /* For UART00 command reception         */


#include "sub_gui.h"
#include "motor.h"


/*
    Static variable
*/
static const unsigned char led_data[10] = {          /* For displaying numerical values */
    LED_0, LED_1, LED_2, LED_3, LED_4,
    LED_5, LED_6, LED_7, LED_8, LED_9
};

static unsigned char uart00_data[RX_BUFF_SIZE];      /* UART00 receive buffer           */
static unsigned char read_p, write_p;                /* Buffer pointer                  */
static char          uart_err_flag;

static unsigned char uart_read(void);
static unsigned char uart_wait(void);
static void          uart_send(unsigned char);
static void          led_set(unsigned char, unsigned char);
static void          set_error(char);

#define WDTE_RESET      0x00

/* ============================================================ */
/* ------------------------------------------------------ */
/*
    UART00 settings
*/
void
uart_set(void) {
    PM10    = IN;
    PM11    = OUT;
    PM13    = IN;
    PM14    = OUT;
    RTS     = 1;
    P14     = 1;
    BRGC00  = 0x56;                 /* 115200 */
    PS001   = CLEAR;
    PS000   = CLEAR;
    CL00    = SET;                  /* 8bit */
    SL00    = CLEAR;
    POWER00 = SET;
    TXE00   = SET;
    RXE00   = SET;
    STIF00  = SET;
    SRIF00  = CLEAR;
    SRMK00  = CLEAR;                /* Enables receive interrupt */
    RTS     = 0;
    read_p  = 0;
    write_p = 0;
}

/*
    Acquiring operation instructions via UART communication
 */
unsigned char
get_uart(void) {
    unsigned char data;
    int           ss, ref;
    unsigned char hi, lo;
    float         shunt_volt;
    float         shunt_command;
    float         tmp_float;
    int           tmp_int;

    /* convenient macros */
#define GET16to(thevar)            \
        lo = uart_wait();           \
        hi = uart_wait();           \
        thevar = (((int)(hi))<<8) + lo;

#define SETUART(thevar)                                 \
        uart_send((char)(((int)(thevar))&0xff));       \
        uart_send((char)((((int)(thevar))>>8)&0xff));

    if(err_flag != ERROR_NONE) {
        set_error(err_flag);
    };

    data = uart_read();
    switch(data){
    case MD_CMD_GETID:                  /* Get ID */
        uart_send(data);
        uart_send(MY_ID);
        break;

    case MD_CMD_GETVER:                 /* Get Version */
        uart_send(data);
        uart_send(VER_MAJOR);
        uart_send(VER_MINOR);
        uart_send(VER_SEQ);
        break;

    case MD_CMD_START:                  /* Start */
```

```
        uart_send(data);
        data = START_TR;
        break;

    case MD_CMD_STOP:                   /* Stop */
        uart_send(data);
        data = STOP_TR;
        break;

    case MD_CMD_RESET:                  /* Reset */
        uart_send(data);
        while(STIF00 != SET);
        WDTM = WDTE_RESET;
        break;

    case MD_CMD_SETSSPEED:              /* Set Setting Speed */
#if 1
        lo = uart_wait();
        hi = uart_wait();
        ss = ((int)hi<<8) + lo;
#else
        GET16to(ss);
#endif
        uart_send(data);
        if(hi > 0x80){                  /* CCW */
            ss = ~ss + 1;
            data = REVERSE_TR;
            if(sys_flag == FLG_OFF){
                cw_ccw_flag = CCW;
            }
        }else{
            data = FORWARD_TR;
            if(sys_flag == FLG_OFF){
                cw_ccw_flag = CW;
            }
        }
        speed_ref_o = ss;
        motor_pset(MODE, SPEED_CMD);   /* speed control mode */
        break;

    case MD_CMD_SETICMD:
#if 1
        lo = uart_wait();
        hi = uart_wait();
        ss = ((int)hi<<8) + lo;
#else
        GET16to(ss);
#endif
        uart_send(data);
        if(hi > 0x80){                  /* CCW */
            ss = ~ss + 1;
            data = REVERSE_TR;
            if(sys_flag == FLG_OFF){
                cw_ccw_flag = CCW;
            }
        }else{
            data = FORWARD_TR;
            if(sys_flag == FLG_OFF){
                cw_ccw_flag = CW;
            }
        }
        I_ref_o = (float)ss;
        speed_ref = m_speed;            /* open loop on speed */
        motor_pset(MODE, I_CMD);        /* current control mode */
          break;

    case MD_CMD_SETVCMD:
#if 1
        lo = uart_wait();
        hi = uart_wait();
        ss = ((int)hi<<8) + lo;
#else
        GET16to(ss);
#endif
        uart_send(data);
        if(hi > 0x80){                  /* CCW */
            ss = ~ss + 1;
            data = REVERSE_TR;
            if(sys_flag == FLG_OFF){
                cw_ccw_flag = CCW;
            }
        }else{
            data = FORWARD_TR;
            if(sys_flag == FLG_OFF){
                cw_ccw_flag = CW;
            }
        }
        pwm_ff_o = ss;
        I_ref = I_measured;
        speed_ref = m_speed;            /* open loop on speed */
        motor_pset(MODE, V_CMD);        /* voltage control mode */
          break;

    case MD_CMD_GETSSPEED:              /* Get Setting Speed */
        uart_send(data);
        ss = speed_ref;
        if(cw_ccw_flag == CCW){
            ss = ~ss + 1;
        }
#if 1
        lo = (unsigned char)((unsigned int)(ss)&0xff);
        hi = (unsigned char)(((unsigned int)(ss)>>8)&0xff);
        uart_send(lo);
        uart_send(hi);
#else
        SETUART(ss);
#endif
```

```
        break;

    case MD_CMD_GET_I_SHNT:             /* Get shunt a/d (current) */
        shunt_volt = I_measured*10.0;   /* 10 bits */
        uart_send(data);
#if 1
        ss = (int)shunt_volt;
        lo = (unsigned char)(ss&0xff);
        hi = (unsigned char)(ss>>8)&0xff;
        uart_send(lo);
        uart_send(hi);
#else
        SETUART(shunt_volt);
#endif
        break;

    case MD_CMD_GET_I_CMD:              /* Get shunt a/d (current) */
        uart_send(data);
        shunt_command = I_ref*10.0;
#if 1
        ss = (int)shunt_command;        /* 10 bits (TEMPORARY)     */
        lo = (unsigned char)(ss&0xff);
        hi = (unsigned char)(ss>>8)&0xff;
        uart_send(lo);
        uart_send(hi);
#else
        SETUART(shunt_command);
#endif
        break;

    case MD_CMD_GET_PWM:                /* Get PWM value */
        uart_send(data);
        ss = pwm_ff;
        if (ss > 1000) ss=1000;         /* overflow prevention for flag space */
        if (ss < 0) ss=0;               /* overflow prevention for flag space */
        lo = (unsigned char)((unsigned int)(ss)&0xff);
        hi = (unsigned char)(((unsigned int)(ss)>>8)&0xff);
        /*
              note: this is a 10 bit variable, so the upper bits are used
                    to transmit the maxed_flags variable.
        */
        hi |= maxed_flags;              /* use bits 7,6,5 for flags  */
        uart_send(lo);
        uart_send(hi);
        break;

    case MD_CMD_SETPIDI:
        GET16to(ref);
        kip_ref = (float)ref/1000.0;
        GET16to(ref);
        kii_ref = (float)ref/1000.0;
        GET16to(ref);
        kid_ref = (float)ref/1000.0;
        uart_send(data);
        break;

    case MD_CMD_SETPIDV:
        GET16to(ref);
        krp_ref = (float)ref/1000.0;
        GET16to(ref);
        kri_ref = (float)ref/1000.0;
        GET16to(ref);
        krd_ref = (float)ref/1000.0;
        uart_send(data);
        break;

    case MD_CMD_GETPIDI:            /* PID for current control */
        uart_send(data);
        uart_send((char)(((int)(kip_ref*1000))&0xff));
        uart_send((char)(((int)(kip_ref*1000))>>8)&0xff));
        uart_send((char)(((int)(kii_ref*1000))&0xff));
        uart_send((char)(((int)(kii_ref*1000))>>8)&0xff));
        uart_send((char)(((int)(kid_ref*1000))&0xff));
        uart_send((char)(((int)(kid_ref*1000))>>8)&0xff));
        break;

    case MD_CMD_GETPIDV:            /* PID for current control */
        uart_send(data);
        uart_send((char)(((int)(krp_ref*1000))&0xff));
        uart_send((char)(((int)(krp_ref*1000))>>8)&0xff));
        uart_send((char)(((int)(kri_ref*1000))&0xff));
        uart_send((char)(((int)(kri_ref*1000))>>8)&0xff));
        uart_send((char)(((int)(krd_ref*1000))&0xff));
        uart_send((char)(((int)(krd_ref*1000))>>8)&0xff));
        break;

    case MD_CMD_GETSPEED:               /* Reads rotation speed */
        if(uart_err_flag != ERROR_NONE){
            uart_send(uart_err_flag);
            err_flag = ERROR_NONE;
            uart_err_flag = ERROR_NONE;
        }else{
            uart_send(data);
            if(m_speed == 0){
                uart_send(0);
                uart_send(0);
            }else{
                ss = m_speed;
                if(cw_ccw_wait == FLG_OFF){
                    if(cw_ccw_flag == CCW){
                        ss = ~ss + 1;
                    }
                }else{  /* Waits for stop of reverse rotation */
                    if(cw_ccw_flag == CW){
                        ss = ~ss + 1;
                    }
                }
```

```
#if 1
                uart_send((unsigned char)((unsigned int)(ss)&0xff));
                uart_send((unsigned char)(((unsigned int)(ss)>>8)&0xff));
#else
                SETUART(ss);
#endif
            }
        }
        break;

    case MD_CMD_SETSTART:             /* open-loop startup parameters defined by gui*/
        GET16to(ref);
        startup_method = (unsigned char)(ref);
        GET16to(ref);
        t_knee = (float)ref/1000.0;
        GET16to(ref);
        t_end = (float)ref/1000.0;
        GET16to(RPM0);
        GET16to(RPM1);
        GET16to(RPM2);
        GET16to(I_ref0);
        GET16to(I_ref1);
        GET16to(I_ref2);
        GET16to(PWM0);
        GET16to(PWM1);
        GET16to(PWM2);
        uart_send(data);
        break;

    case MD_CMD_GETSTART:            /* send startup parameters to gui*/
        uart_send(data);
        uart_send(startup_method);
        uart_send(0x00);             /* char sent as int for convenience in gui */
        SETUART(t_knee*1000);
        SETUART(t_end*1000);
        SETUART(RPM0);
        SETUART(RPM1);
        SETUART(RPM2);
        SETUART(I_ref0);
        SETUART(I_ref1);
        SETUART(I_ref2);
        SETUART(PWM0);
        SETUART(PWM1);
        SETUART(PWM2);
        break;

    case MD_CMD_SETLIMIT:             /* A/D gains and rate limits */
        GET16to(ref);
        adgain = (float)ref/100.0;
        GET16to(adoffset);
        GET16to(ref);
        maxcurrent = (float)ref;
        GET16to(ref);
        mincurrent = (float)ref;
        GET16to(ref);
        I_rate_max = (float)ref/10.;
        GET16to(maxspeed);
        GET16to(minspeed);
        GET16to(ref);
        RPM_rate_max = (float)ref;

        dI_ref_max = I_rate_max*0.1;       /* dt of 0.1 sec, this is the max change per cycle */
        dspeed_ref_max = (int)(RPM_rate_max*0.1); /* dt of 0.1 sec, this is the max change per cycle */
        uart_send(data);
        break;

    case MD_CMD_GETLIMIT:            /* A/D gains and rate limits */
        uart_send(data);
        SETUART(adgain*100);
        SETUART(adoffset);
        SETUART(maxcurrent);
        SETUART(mincurrent);
        SETUART(I_rate_max*10.);
        SETUART(maxspeed);
        SETUART(minspeed);
        SETUART(RPM_rate_max);
        break;

    default:
        ;
    };

    return(data);
}

/*
    Returning UART00 receive buffer data
*/
static unsigned char
uart_read(void) {
    unsigned char data = 0;

    if(read_p != write_p){             /* Receive data is present */
        data = uart00_data[read_p++];  /* Extracts data           */
        read_p %= 6;                   /* Updates read pointer    */
    }
    return(data);
}

/*
    Waiting for UART00 reception
*/
static unsigned char
uart_wait(void) {
    unsigned char data;

    while(read_p == write_p);          /* Waits until data is input to buffer */
```

```
    data = uart00_data[read_p++];       /* Extracts data                        */
    read_p %= 6;                        /* Updates read pointer                 */
    return(data);
}

/*
    Transmission from UART00
*/
static void
uart_send(unsigned char data) {
    while(STIF00 != SET);               /* Waits for transmission completion   */
    STIF00 = CLEAR;
    TXS00 = data;                       /* Transmits                            */
}

/*
    For UART00 command reception
*/
__interrupt void
int_uart(void) {
    unsigned char tmp;

    tmp = ASIS00;                       /* Reads error status                   */
    uart00_data[write_p++] = RXB00;     /* Stores status in receive buffer     */
    write_p %= RX_BUFF_SIZE;            /* Updates write pointer                */
}


/* ---------------------------------------------------- */
/*
    Error display
*/
static void
set_error(char eno) {

    switch(eno){
    case ERROR_HALL:
        uart_err_flag = MD_ERROR_HALL;
        led_set(0, LED_H);
        led_set(1, LED_A);
        led_set(2, LED_L);
        led_set(3, LED_L);
        break;

    case ERROR_OC:
        uart_err_flag = MD_ERROR_OC;
        led_set(0, LED_);
        led_set(1, LED_O & LED_dot);
        led_set(2, LED_C & LED_dot);
        led_set(3, LED_);
        break;

    case ERROR_MOTOR:
        uart_err_flag = MD_ERROR_MOTOR;
        led_set(0, LED_F);
        led_set(1, LED_A);
        led_set(2, LED_I);
        led_set(3, LED_L);
        break;

    case ERROR_S_OC:
        uart_err_flag = MD_ERROR_OC;
        led_set(0, LED_S & LED_dot);
        led_set(1, LED_);
        led_set(2, LED_O & LED_dot);
        led_set(3, LED_C & LED_dot);
        break;

    default:
        uart_err_flag = MD_ERROR_MOTOR;
        led_set(0, LED_F);
        led_set(1, LED_A);
        led_set(2, LED_I);
        led_set(3, LED_L);
    };
}

/*
    Displaying data on 8-segment LED
    no:   Location of LED to be displayed
    data: Data to be output
*/
static void
led_set(unsigned char no, unsigned char data) {
    unsigned char p;

    P6 = 0x00;
    P4 = data;

    switch(no){                         /* Location to be displayed */
    case 0:  p = 0x80; break;           /* Left edge                */
    case 1:  p = 0x40; break;
    case 2:  p = 0x20; break;
    default: p = 0x10; break;           /* Right edge               */
    };
    P6 = p;
}

/*
  Startup display
*/
void
startup_disp(void) {
    led_set(0, LED_P);
    led_set(1, LED_C);
    led_set(2, LED_);
    led_set(3, LED_);
```

```
}

/*
    Watchdog timer
*/
void
clear_WDTM(void) {
    WDTE = WDTE_CLR;
}

/* ---------------------------------------------------- */
/*
    Port settings
*/
void
init_PORT(void) {
    LD_LED0 = OUT;                      /* LED selection: output */
    LD_LED1 = OUT;
    LD_LED2 = OUT;
    LD_LED3 = OUT;

    LD_DATA = OUT;                      /* LED display data: output */
}
```

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