RL78/G14

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Motor control by RL78/G14 micro controller

120 degrees conducting control of permanent magnetic synchronous motor with hall sensor

Summary

This application note aims at explaining the sample program for operating the 3-phase permanent magnetic synchronous motor with hall sensor by 120° conducting method, by using functions of RL78/G14.

The sample program is only to be used as reference and Renesas Electronics Corporation does not guarantee the operations. Before using this sample program, carry out a thorough evaluation in a suitable environment.

Operation checking device

Operations of the sample program are checked by using the following device.

- RL78/G14 (R5F104LEAFP)

Contents

1. Overview

This application note describes an example of speed control by permanent magnetic synchronous motor with hall sensor by using micro controller RL78/G14. The speed control is performed by 120° conducting method.

1.1 Usage of the system

This system (sample program) enables 120° conducting control by using RSSK (Note 1) for motor control (Low Voltage Motor Control Starter-Kit Evaluation System and permanent magnetic synchronous motor (FH6S20E-X81 (Note 2))).

For installation and technical support of 'RSSK for motor control', contact Sales representatives and dealers of Renesas Electronics Corporation.

Notes:

1. RSSK (Renesas Solution Starter Kit) is the product of Renesas Electronics Corporation.
2. FH6S20E-X81 is the product of NIDEC SERVO CORPORATION.

NIDEC SERVO CORPORATION. (http://www.nidec-servo.com/en/index.html)

1.2 Development environment

(1) Software development environment

Integrated development environment	CubeSuite+ (V1.03.00)

(2) Hardware environment

On-chip debug emulator	E1
Microcomputer used	RL78/G14 (R5F104LEAFP)
Inverter board for motor control	Low Voltage Motor Control Starter-Kit Evaluation System (P03401-D1-001)
Permanent magnetic synchronous motor	FH6S20E-X81

2. System overview

Overview of this system is explained below.

2.1 Hardware configuration

Hardware configuration is shown below.

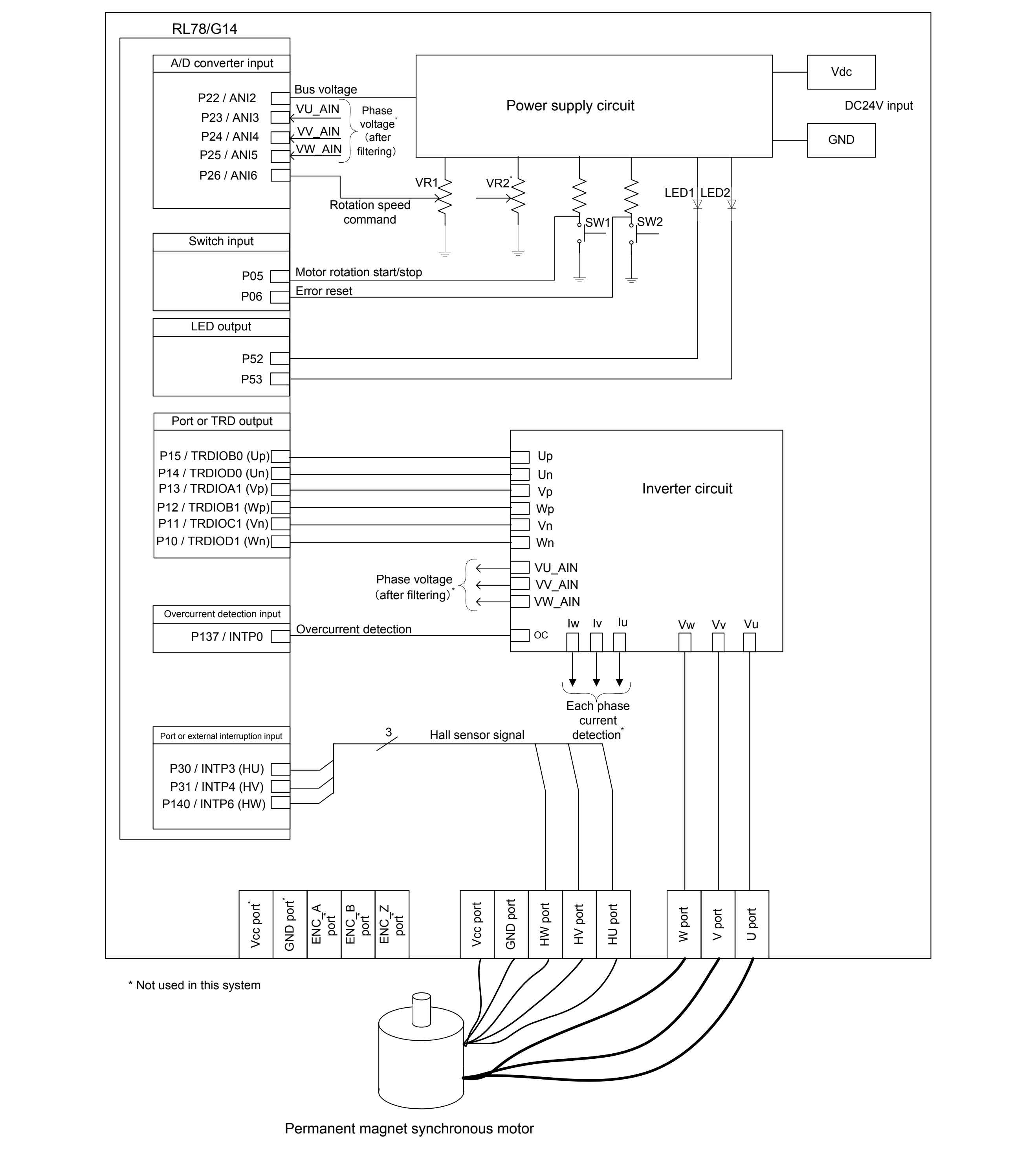


Figure 2-1 Hardware Configuration Diagram

2.2 Hardware specifications

2.2.1 User interface

List of user interfaces of this system is given in Table 2-1.

Table 2-1 User Interface

Item	Interface component	Function
Rotation speed	Variable resistance (VR1)	Rotation speed command value input (analog value)
START/STOP	Push switch (SW1)	Motor rotation start/stop command
ERROR RESET	Push switch (SW2)	Command of recovery from error status
LED1	Yellow Green LED	· At the time of Motor rotation: ON · At the time of stop: OFF
LED2	Yellow Green LED	· At the time of error detection: ON · At the time of normal operation: OFF
RESET	Push switch (RESET)	System reset

List of interfaces of RL78/G14 micro controller of this system is given in Table 2-2.

Table 2-2 Port Interface

Terminal name	Function
P22 / ANI2	Inverter bus voltage measurement
P26 / ANI6	For rotation speed command value input (analog value)
P05	START/STOP push switch
P06	ERROR RESET push switch
P52	LED1 ON/OFF control
P53	LED2 ON/OFF control
P30 / INTP3	Hall sensor input (HU)
P31 / INTP4	Hall sensor input (HV)
P140 / INTP6	Hall sensor input (HW)
P15 / TRDIOB0	Port or non-complimentary PWM output (Up)
P14 / TRDIOD0	Port or non-complimentary PWM output (Un)
P13 / TRDIOA1	Port or non-complimentary PWM output (Vp)
P12 / TRDIOB1	Port or non-complimentary PWM output (Wp)
P11 / TRDIOC1	Port or non-complimentary PWM output (Vn)
P10 / TRDIOD1	Port or non-complimentary PWM output (Wn)
P137 / INTP0	PWM emergency stop input at the time of overcurrent detection
RESET#	RESET

2.2.2 Peripheral functions

List of peripheral functions used in this system is given in Table 2-3.

Table 2-3 Peripheral Functions List

Peripheral function	Usage
A/D converter (ANI2, ANI6)	· Rotation speed command value input · Inverter bus voltage measurement
Port / external interruption (P30/INTP3, P31/INTP4, P140/INTP6)	· Hall sensor signal input (position detection) · Hall sensor read out and external interruption (both edges)
Timer RD (TRD)	Non-complimentary PWM output using reset synchronous PWM mode (six outputs)
INTP0 input	In the case of overcurrent detection, set ports executing PWM output to high impedance
Port (P10 – P15)	Motor control signal output by port output
Timer Array Unit (TAUS)	· 1 [ms] interval timer · Free run timer for rotation speed measurement

(1) A/D converter

The rotation speed command value input and inverter bus voltage (Vdc) are measured by using ‘A/D converter’.
For A/D conversion, set channel selection mode to ‘Select mode’ and conversion operation mode to ‘One shot conversion mode’ (use software trigger).
Conversion speed of the A/D converter is 2.375 [μs] per channel and the smallest unit of conversion input value is given in Table 2-4.

Table 2-4 A/D Converter Correspondence Table

Item	Control value for A/D converter 1 bit	Channel
Rotation speed command	2048 [rpm]/512 = 4 [rpm] step (speed range is 600 [rpm] to 2000 [rpm] for both CW/CCW)	ANI6
Bus voltage	30 [V]/1024 = 0.0293 [V]	ANI2

(2) Timer Array Unit (TAUS)

(a) 1 [ms] interval timer

1 [ms] interval timer uses ‘Interval timer function’ of Timer Array Unit TAUS. In this system, channel 0 is used.

(b) Free-run timer for speed measurement

Free-run timer for speed measurement uses ‘Interval timer function’ of Timer Array Unit TAUS. However, it does not use the interruption. In this system, channel 1 is used.

Table 2-5 Timer Array Unit Usage Channel

No.	Usage
Channel 0	Interval timer for 1 [ms] generation
Channel 1	Free-run timer for rotation speed measurement
Channel 2	Not used in this system
Channel 3	Not used in this system

(3) Timer RD (TRD)

The 6-phase PWM output with saw-tooth wave modulation, without dead time, is performed by using the reset synchronous PWM mode. Combination of motor control signal output and timer output pins is given in Table 2-6.

Table 2-6 Combination of Motor Control Signal Output and Timer Output Pins

Motor control signal	Timer output pin
Up	TRDIOB0
Un	TRDIOD0
Vp	TRDIOA1
Vn	TRDIOC1
Wp	TRDIOB1
Wn	TRDIOD1

This system enables “High” active PWM output on a 50 [μs] cycle. Also, high impedance output is performed from the port executing the PWM output when an overcurrent is detected (at the time of input of “Low” to the INT0 port) by using the pulse output forced shut down function.

(4) General-purpose port

Magnetic position detection signals (hall sensor signal) of the motor are input to a general-purpose port. As edge detection of the position signal is also necessary, a port dual used with external interruption is used. Combination of hall sensor input and general-purpose ports in this system is given in Table 2-7.

Table 2-7 Combination of Hall Sensor Input and General-purpose Port

Position detection signal	General-purpose port
HU	P30/INTP3
HV	P31/INTP4
HW	P140/INTP6

Also, in this system, a motor control signal is created by using port output along with PWM output. Combination of motor control signal output and general-purpose ports is given in Table 2-8.

Table 2-8 Combination of Motor Control Signal Output and General-purpose Port

Motor control signal	General-purpose port
Up	P15
Un	P14
Vp	P13
Vn	P11
Wp	P12
Wn	P10

Note:
1. For the notes when switching the port from input mode to output mode, refer to RL78/G14 User’s Manual: Hardware.

(5) Interruption

List of interruptions in this system is given in Table 2-9.

Table 2-9 Usage Interruption List

Interruption name	Interruption source
INTP3	Detects a variation of hall sensor signal HU (both edges)
INTP4	Detects a variation of hall sensor signal HV (both edges)
INTP6	Detects a variation of hall sensor signal HW (both edges)
INTTRD0	PWM carrier interruption
INTP0	At the time of overcurrent detection (falling edge)
INTTM00	1 [ms] interval interruption

2.3 Software structure

2.3.1 Software file structure

Folders and files structure of the sample program is given below.

Table 2-10 Folder and Files Structure of Sample Program

RL78G14_RSSK_SSNS_HALL_120_ICS_CSP_V100	inc	ics.h	Header for ICS
		main.h	Main function, user interface control header
		mtr_common.h	Header for common definition
		mtr_ctrl_rssk.h	Board dependent processing part header
		mtr_ctrl_rl78g14.h	RL78/G14 dependent processing part header
		mtr_ssns_hall_120.h	Hall sensor used 120° conducting control dependent part header
		r_dsp.h	Header for operation library
		r_fixmath.h	Header for operation library
		r_stdint.h	Header for operation library
	lib	R_dsp_rl78.lib	Operation library
		ics_rl78g14.lib	ICS library
	src	main.c	Main function, user interface control
		mtr_ctrl_rssk.c	Board dependent processing part
		mtr_ctrl_rl78g14.c	RL78/G14 dependent processing part
		mtr_interrupt.c	Interruption handler
		mtr_ssns_hall_120.c	Hall sensor used 120° conducting control depending part

2.3.2 Module structure

Module structure of the sample program is described below.

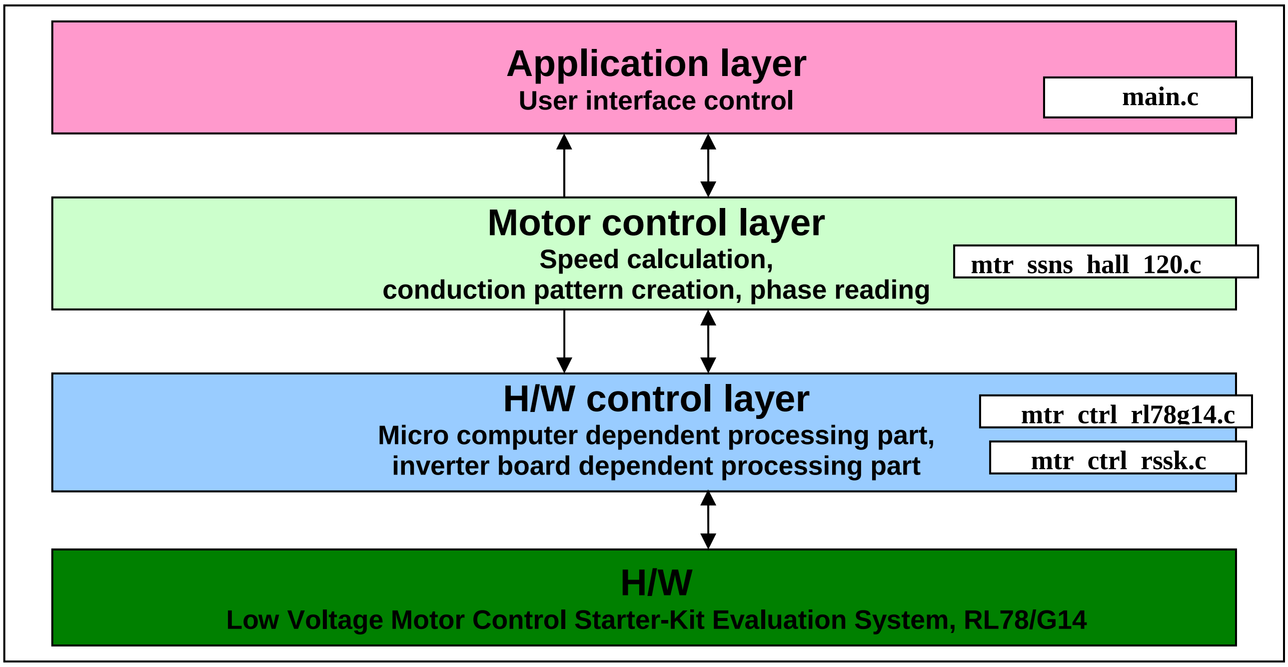


Figure 2-2 Module Structure of Sample Program

2.4 Software specifications

Basic specifications of software of this system are given in Table 2-11.

Table 2-11 Software Basic Specifications

Item	Content
Control method	120° conducting method
Motor rotation start/stop	Determined depending on the level of SW1 (P05) ("Low": Rotation start "High": stop) (If a speed command value from VR1 is less than 550 [rpm], determined as stop irrespective of level of SW1)
Position detection of rotor magnetic pole	Position detection by hall sensor (every 60°)
Carrier frequency (PWM)	20 [kHz]
Control cycle	• Position detection by hall sensor (every 60°) • Determination of PWM duty setting and conduction pattern
Rotation speed control range	600 [rpm] to 2000 [rpm] for both CW/CCW
Rotation speed operation	• Detects the edge of hall signal then calculates the rotation speed by timer counts for π [rad] every π/3 [rad] hall signal detection • Uses the interval timer for measurement of edge intervals
Speed control (speed PI control)	Obtains the speed command value from input voltage of VR1 and performs speed control by PI control (5 [ms] cycle)
Processing stop for protection	• Disables the motor control signal output (six outputs) under any of the following three conditions: 1. Inverter bus voltage exceeds 28 [V] (monitored for each 1 [ms]). 2. Rotation speed exceeds 16000 [rpm] (electrical angle) (monitored for each 1 [ms]). 3. No hall sensor interruption is generated for 20 [ms] while the motor is driving. • Changes the port executing the PWM output to high impedance when an overcurrent detection signal ("Low" is input to the INTP0 port) is detected from external

3. Motor control method

120° conducting control and speed control of the permanent magnetic synchronous motor with hall sensor, used in the sample program are explained here.

3.1 120° conducting control of the permanent magnetic synchronous motor with hall sensor

In this system, the hall sensor is used to detect the position of permanent magnet and signals from the hall IC (hall sensor signals) are input to the microcomputer as position information.

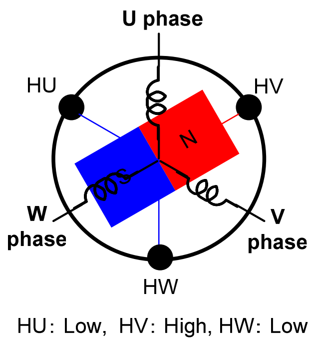


Figure 3-1 Example of Hall Sensor (HU, HV, HW) Position and Position Signal

As shown in Figure 3-1, a hall sensor is allocated every 120° and the respective hall sensor signals are switched depending on direction of rotating magnetic poles. Position information can be obtained every 60° (six patterns for one cycle) by combining these three hall sensor signals.

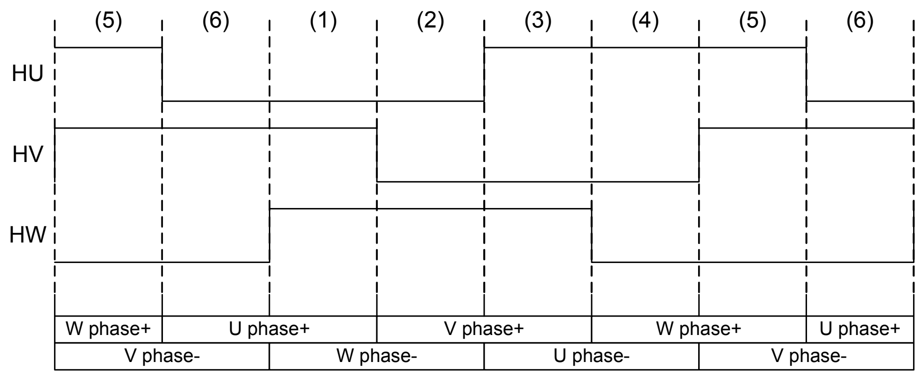


Figure 3-2 Relation between Hall Sensor Signals and Conduction Patterns (rotation direction: CW)

If the conduction patterns of each phase are changed in the switching timing of these hall sensor signals, as shown in Figure 3-2, rotating flux generated as shown in Figure 3-3. Then the rotor has the torque and rotates.

As conduction session of each switching element is 120°, this control method is referred to as 120° conducting control.

The relation between above-mentioned six conduction patterns and rotor position ranges is shown in Figure 3-3.

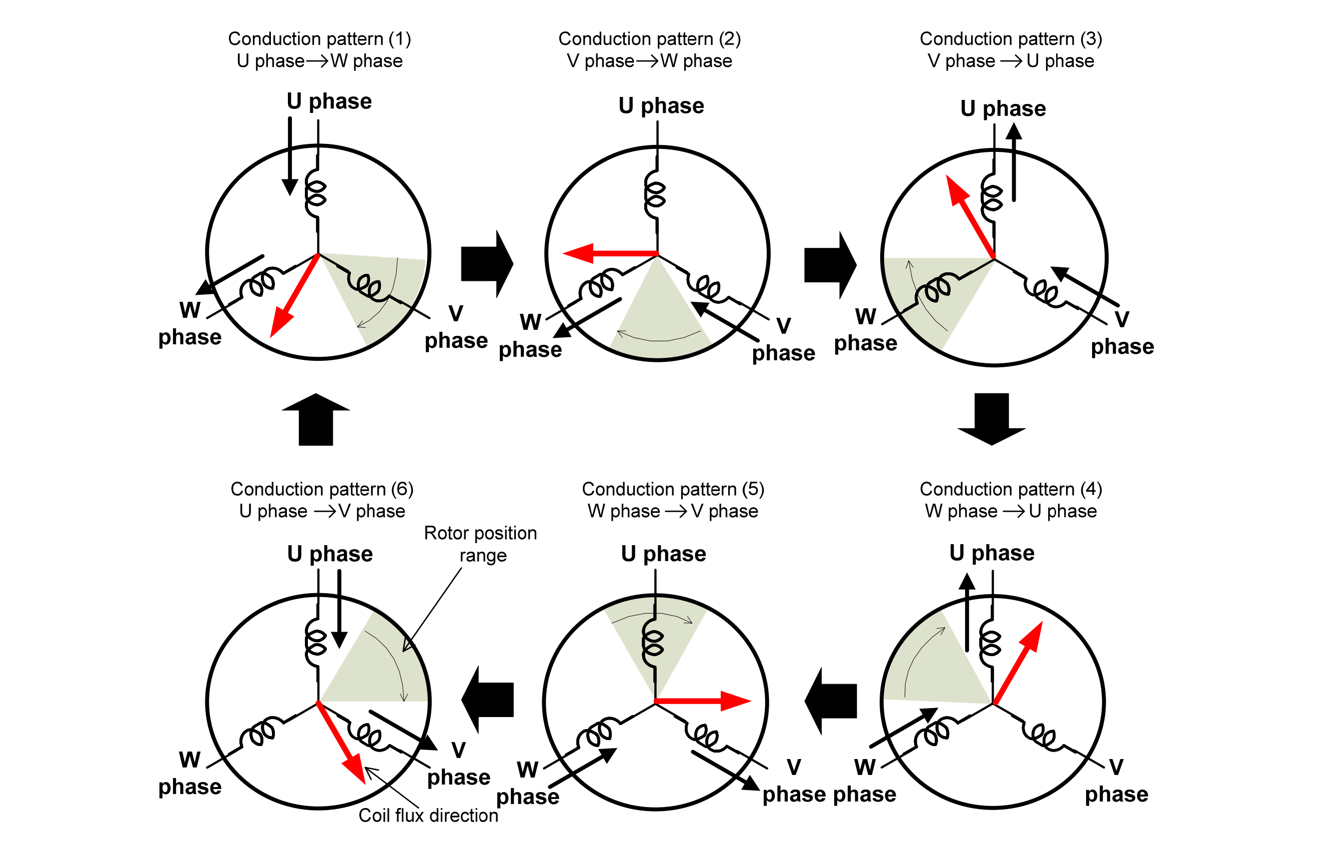


Figure 3-3 Six Conduction Patterns and Rotor Position Ranges

Supplements:

1. The relation between hall sensor signals and conduction patterns shown in Figure 3-3 is set to be suitable for this system. A different motor specification requires setting different conduction patterns appropriate to the system.
2. In the 120° conducting control, only six types of conduction patterns are generated for one cycle and hence in principle, a torque ripple occurs without fail.

3.2 Speed control

In this system, the motor rotation speed is calculated from a difference of the present timer value and the timer value π [rad] before. Timer values are obtained through the external interruption routine by hall sensor signals while having the timer of channel 1 of timer array unit performed free running. This method is applicable even if three hall sensors are not placed at equal spaces.

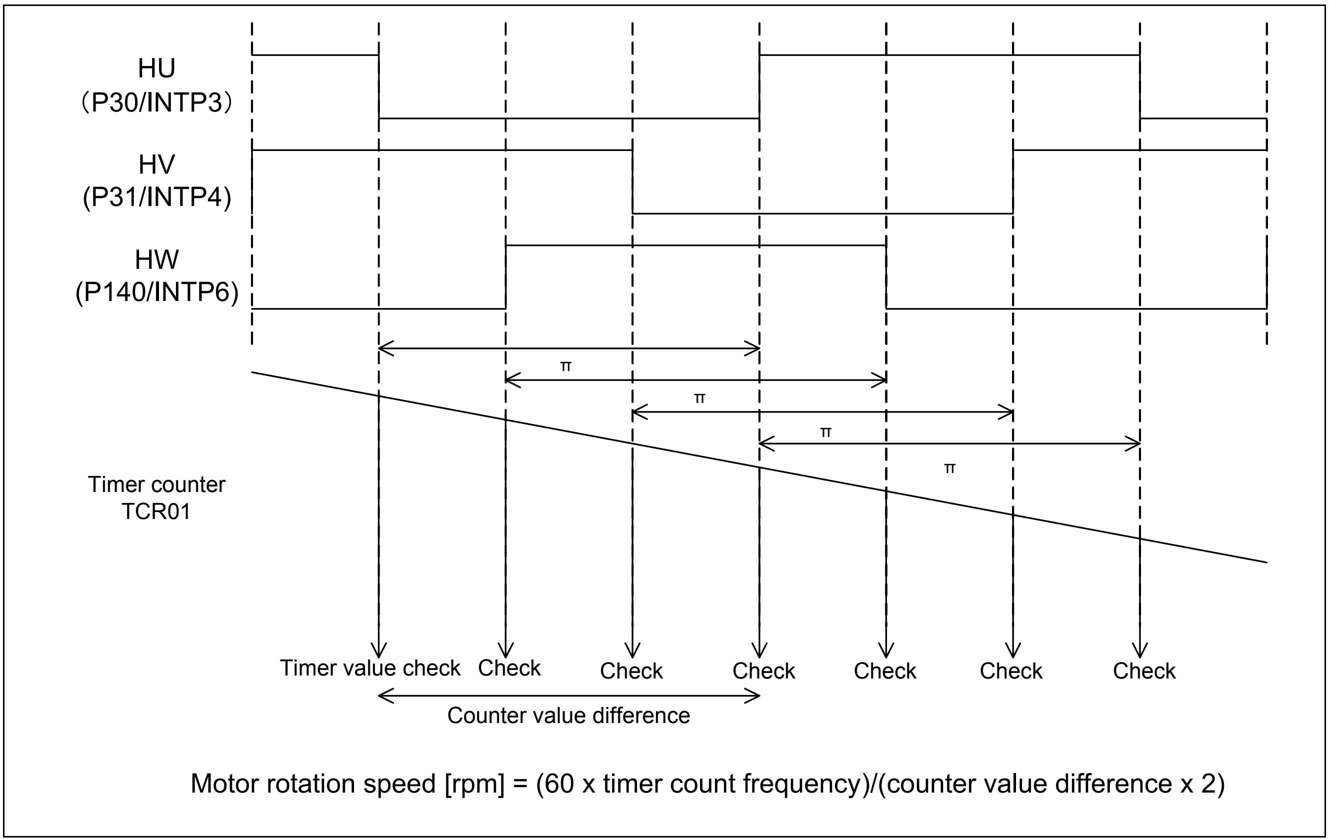


Figure 3-4 Method of Calculating Motor Rotation Speed

This system uses PI control for speed control. A voltage command value at any (discrete) time n is calculated by the following formula.

$$V[n] = V[n-1] + K_P \times (err[n] - err[n-1]) + K_I \times err[n]$$

V : Voltage err : Deviation of rotation speed command value and rotation speed calculation value
KP : Proportional gain KI : Integral gain

Also, PWM control is used for the output voltage control. The PWM control is a control method that continuously adjusts the average voltage by varying the duty of pulse, as shown in Figure 3-5.

$$\text{Duty} = \frac{T_{ON}}{T_{ON} + T_{OFF}} \times 100\ [\%]$$

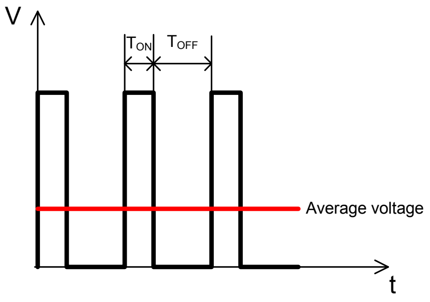


Figure 3-5 PWM Control

Here, modulation factor m is defined as follows.

$$m = \frac{V}{E}$$

M: Modulation factor V: Target voltage err: Inverter bus voltage

This modulation factor is reflected in the setting value of resistor that determines the PWM duty.

In this system, first 60° chopping is adopted and thus output voltage and speed are controlled. An example of motor control signal output waveforms at the time of first 60° chopping is given in Figure 3-6.

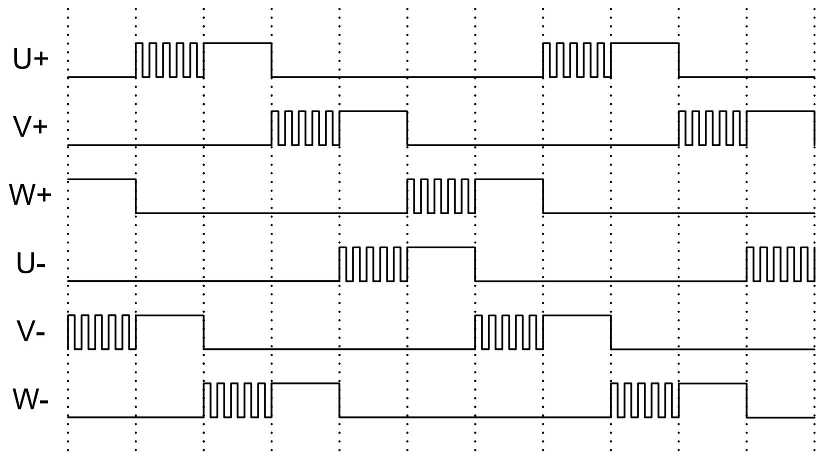


Figure 3-6 First 60° Chopping

4. Description of peripheral functions used

Peripheral functions used in this system are explained.
Following peripheral functions are explained in this chapter.

- External interruption function
- A/D converter function
- Timer Array Unit TAUS function
- Timer RD function

4.1 External interruption function

In this system, external interruptions are set as given in Table 4-1.

Table 4-1 External Interruption Setting Details

Interruption	Item	Content	Usage
INTP3, INTP4, INTP6	Valid edge	Both edges	Edge detection of hall sensor signal
	Interruption priority level	2	
INTP0	Valid edge	Falling edge	Overcurrent detection
	Interruption priority level	0	

4.2 A/D converter function

A/D converter converts the analog input to digital values. The target micro controller (RL78/G14) incorporates one circuit of 10-bit A/D converter. Analog input of 12 channels can be converted to digital values by controlling the conversion channel.

In this system, the A/D converter is set as given in Table 4-2.

Table 4-2 A/D Converter Setting Details

Channel	Item	Content	Conversion target
ANI6	Conversion time	2.375 [μs]	Rotation speed command value
	Channel selection mode	Select mode	
	Conversion operation mode	One-shot conversion mode	
	Conversion start condition	Software trigger	
ANI2	Conversion time	2.375 [μs]	Inverter bus voltage
	Channel selection mode	Select mode	
	Conversion operation mode	One-shot conversion mode	
	Conversion start condition	Software trigger	

4.3 Timer Array Unit TAUS function

The Timer Array Unit TAUS consists of four 16-bit timers. Each 16-bit timer is called ‘Channel’ and can be used as an independent timer as well as an advanced timer function by combining multiple channels.

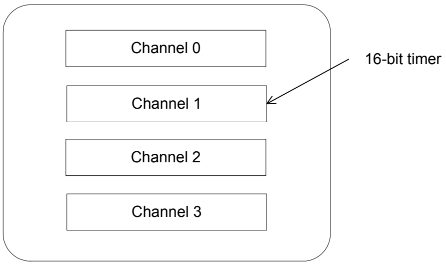


Figure 4-1 Timer Array Unit

In this system, the Timer Array Unit is set as given in Table 4-3.

Table 4-3 Timer Array Unit Setting Details

Channel	Item	Content	Usage
Channel 0	Operation mode of timer	Interval timer function	Timer for generating 1 [ms]
	Source clock	CK00	
	Count clock frequency	32 [MHz]	
	Interruption cycle	1 [ms]	
	Timer data resistor 0 (TDR00) setting value	31999 (1 [ms]/31.25 [ns] - 1)	
Channel 1	Operation mode of timer	Interval timer function	Timer for speed calculation
	Source clock	CK01	
	Count clock frequency	125 [kHz]	
	Interruption cycle	524 [ms] (unused)	
	Timer data resistor 1 (TDR01) setting value	65535	
Channel 2	Not used in this system		
Channel 3	Not used in this system		

Also, basic timings of the interval timer are shown in Figure 4-2.

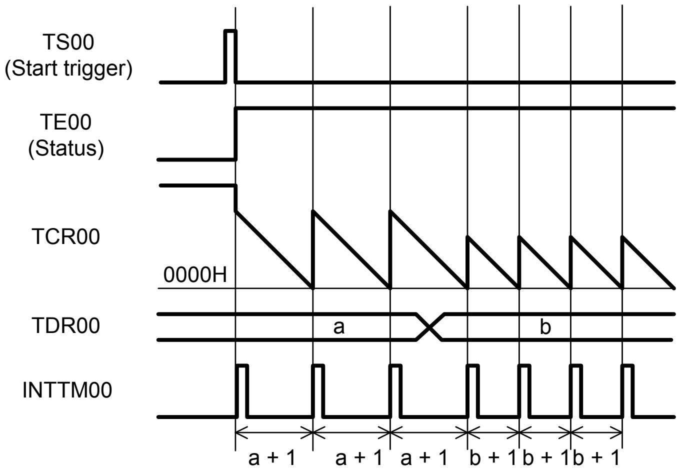


Figure 4-2 Example of Basic Timings of Interval Timer (Example of Channel 0)

4.4 Timer RD function

Timer RD has two 16-bit timers (timer RD0 and timer RD1).
Following four modes are provided in timer RD.

- Timer mode
- Reset synchronous PWM mode
- Complementary PWM mode
- PWM3 mode

In this system, the timer RD is set as given in Table 4-4.

Table 4-4 Timer RD Setting Details

Timer used	Item	Content	Usage
Timer RD	Mode used	Reset synchronous PWM mode	6 phase PWM output
	PWM cycle	50 [μs]	
	Count frequency	64 [MHz]	
	Output level	Initial output ”Low”, active level ”High”	
	Buffer operation	None	
	Pulse output forced shutdown control	Valid (Output value at the time of shutdown: high impedance output)	
	Output port	Refer to Figure 4-3	

Note:

1. In reset synchronous mode, the timer RD outputs a waveform by combining the counters and resistors of timer RD0 and timer RD1.

An example of PWM output waveform is shown in Figure 4-3.

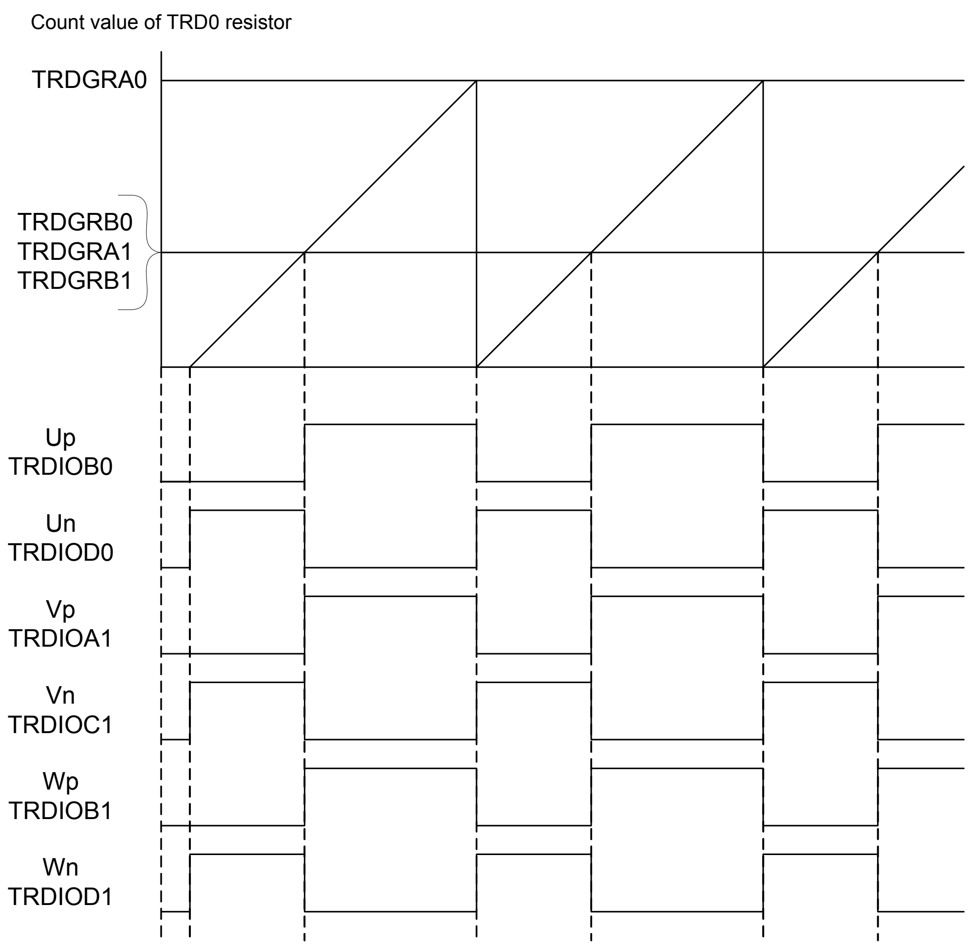


Figure 4-3 Example of PWM Output Waveform In Reset Synchronous PWM Mode

4.5 Calculation of PWM duty setting using modulation factor

This part summarizes how to set duty in reset synchronous PWM mode.
Set the PWM cycle in the TRDGRA0 resistor first. Accordingly, define a setting value of each compare resistor of TRDGRB0, TRDGRA1, and TRDGRB1. Each value set here determines duty of PWM of U phase, V phase, and W phase respectively. Note that the setting values of compare registers vary in positive phase and negative phase even in case of setting the same duty.
Setting values of TRDGRA0, TRDGRB0, TRDGRA1, and TRDGRB1 are calculated by the following formula.

TRDGRA0 = PWM cycle [s] × Count clock frequency [Hz] - 1

(Positive phase) TRDGRB0 = TRDGRA1 = TRDGRB1 = {(TRDGRA0 + 1) / 100} × (100 – duty [%])

(Negative phase) TRDGRB0 = TRDGRA1 = TRDGRB1 = {(TRDGRA0 + 1) / 100} × duty [%] - 1

From the modulation factor explained in section 3. 2, values to be set to TRDGRB0, TRDGRA1, and TRDGRB1 are calculated by the following formula.

(Positive phase) TRDGRB0 = TRDGRA1 = TRDGRB1 = (TRDGRA0 + 1) × (1 - modulation factor) - 1

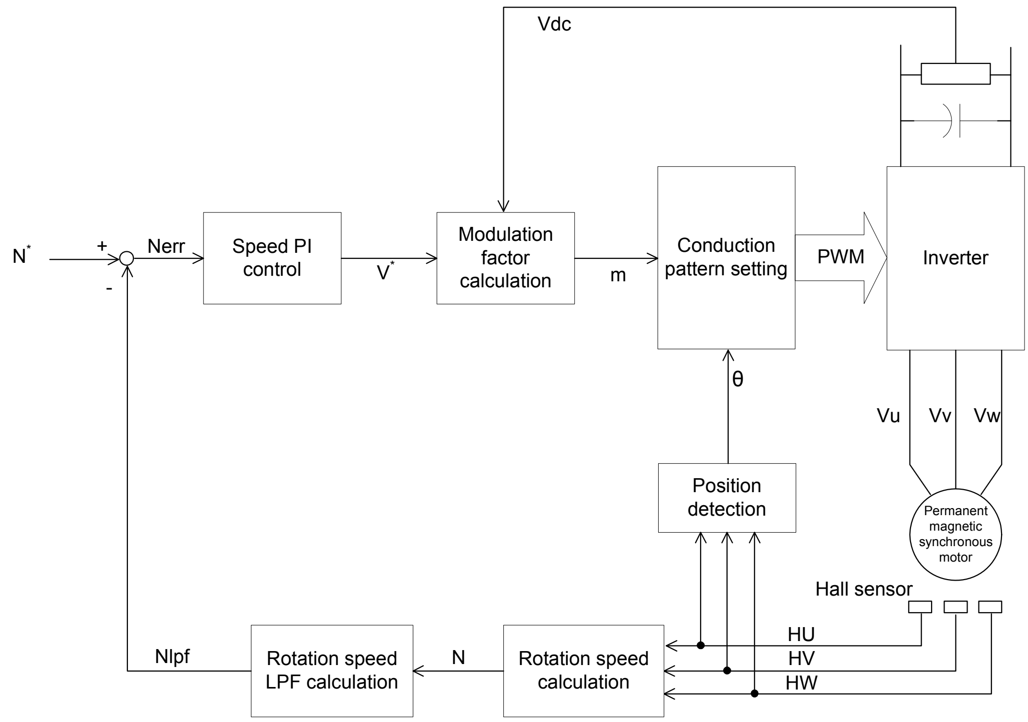
(Negative phase) TRDGRB0 = TRDGRA1 = TRDGRB1 = (TRDGRA0 + 1) × modulation factor - 1

5. Description of control program

Control program of this system (120° conducting control of permanent magnetic synchronous motor with hall sensor) is explained here.

5.1 Control block diagram

In the sample program, a motor is driven by open loop control for the 100 [ms] after activation (operation mode during this period is called as BOOT mode). After that, control is performed according to the following block diagram.



Name	Meaning	Remarks
N	Rotation speed	
Nlpf	Rotation speed after LPF	
N*	Rotation speed command value	Set in VR1
Nerr	Rotation speed deviation	
V*	Voltage command value	Output from speed PI control
Vdc	Inverter bus voltage	
m	Modulation factor	Common to each phase
PWM	PWM output signal	
Vu, Vv, Vw	Phase voltage	
HU, HV, HW	Hall sensor signal	
θ	Rotor position	Detected for each 60°

Figure 5-1 Control Block Diagram

Function is given below:

(1) Position detection of permanent magnet
Permanent magnetic position is detected by reading the port values within the hall sensor interruption function.

(2) Rotation speed calculation
Rotation speed is calculated from the timer counter (TCR01) within the hall sensor interruption function. The rotation speed calculation value is used in speed control.

(3) Speed control
Speed control is using PI control. The output value of speed PI control is set as a voltage command value.

(4) Processing stop for protection
Processing stop for protection prevents the motor or inverter from breakage due to overcurrent or overvoltage.

5.2 Contents of control

5.2.1 Motor start/stop

Starting and stopping the motor are controlled by input from SW1 and VR1.

A general-purpose port (P05) is assigned to SW1. The sample program reads the P05 port within the main loop. When P05 is at "low" level, it is judged that the start switch is being pressed. On the other hand, when the level is switched to "high", the program determines to stop the motor.

Also, an analog input port (AN16) is assigned to VR1. Input to AN16 is A/D converted within the main loop, and a rotation speed command value is generated. (As for creation of the rotation speed command value, refer to 5.2.2) When the rotation speed command value is less than 550 [rpm], the program determines to stop the motor.

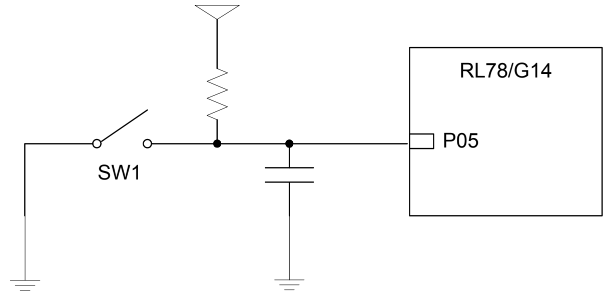


Figure 5-2 Conceptual Diagram of Start Switch External Circuit

5.2.2 Motor rotation speed command value, inverter bus voltage

(1) Motor rotation speed command value

The motor rotation speed command value N* can be set by A/D converting the output value (analog value) of VR1. The A/D converted VR1 values are used as rotation speed command value, as shown in Table 5-1.

Table 5-1 Conversion Ratio of Speed Command Value

Item	Conversion ratio (Command value N*: A/D conversion value)		Channel
Rotation speed command value	CW	0 [rpm] to 2048 [rpm] : 01FFH to 03FFH	ANI6
	CCW	0 [rpm] to 2048 [rpm] : 0000H to 01FFH	

(2) Inverter bus voltage

Inverter bus voltage is measured as given in Table 5-2.
It is used for modulation factor calculation and overvoltage detection. (When an overvoltage is detected, PWM is stopped.)

Table 5-2 Inverter Voltage Conversion Ratio

Item	Conversion ratio (Inverter voltage Vdc: A/D conversion value)	Channel
Inverter bus voltage	0 [V] to 30 [V] : 0000H to 03FFH	ANI2

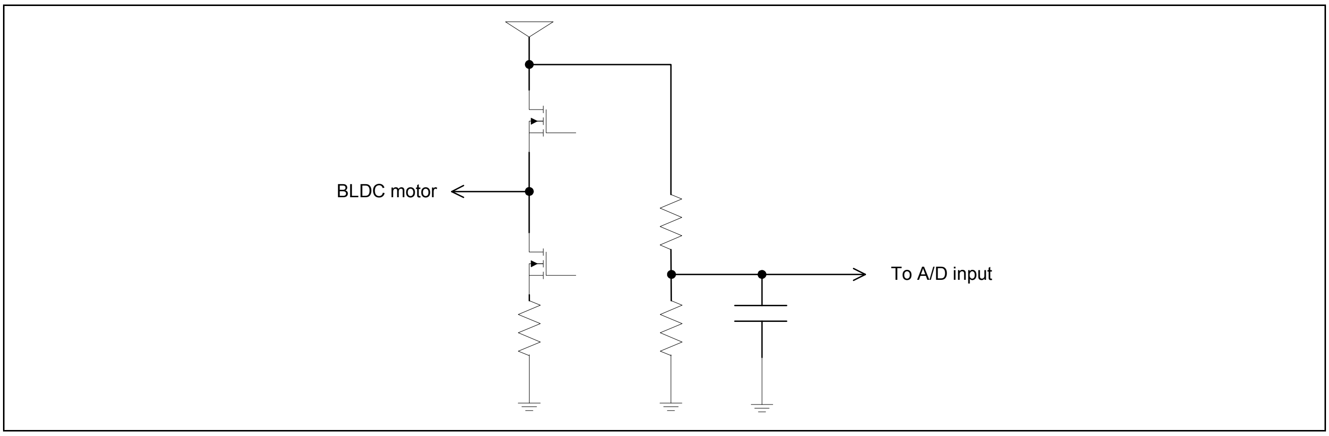


Figure 5-3 Conceptual Diagram of Inverter Voltage Measurement External Circuit

5.2.3 Rotation speed operations

The rotation speed is calculated by using the external interruption by hall sensor signal and free-run timer (TAUS channel 01). A counter value of free-run timer is obtained through hall sensor interruption routine, and a difference of the present timer value and the timer value π [rad] before is calculated. Based on the difference, speed is calculated by the following formula.

Rotation speed (N) = (60 × 125 [kHz]) / {(counter value π [rad] before – current counter value) × 2}

Notes:
1. 125 [kHz] = (count clock frequency of free-run timer)
2. (× 2) is done as the period for obtaining the counter value is π [rad].

In this sample program, LPF (migration average) processing is performed for the speed calculation result before speed PI control.

5.2.4 Speed PI control

In this sample program, speed PI control is performed on a 5 [ms] cycle, to avoid the multiple executions of PI control during hall sensor interruption. The voltage command value (V*) is created as given below.

Proportional (P) term: K_P × (current rotation speed deviation – last rotation speed deviation)
Integral (I) term: K_I × (current rotation speed deviation)
Voltage command value (V*) = previous voltage command value + proportional term + integral term

Notes:
1. Proportional gain (K_P): 0.0001
2. Integral gain (K_I): 0.00001

Values of K_P and K_I depend on the used system.

For details of PI control, refer to specialized books.

5.2.5 System protection function

This control program has the following five types of error status and enables emergency stop functions in case of occurrence of respective error.

- Overcurrent error
  An emergency stop signal (overcurrent detection) from hardware forces the program to execute high impedance output to the PWM output port (emergency stop without involving CPU). The INTP0 port is used.
- Overvoltage error
  The inverter bus voltage is monitored with 1 [ms] interval. When an overvoltage is detected (when the voltage exceeds 28 [V]), CPU performs emergency stop. The threshold of the overvoltage error is set in consideration of the error of resistance and the supply voltage.
- Rotation speed abnormality error
  The rotation speed calculation value is monitored with 1 [ms] interval. When an error value is detected in rotation speed values (in a case of value over 16000 [rpm] (electrical angle)), CPU performs emergency stop.
- Timeout error
  When no hall sensor interruption occurs for a certain period (20 [ms]), CPU performs emergency stop.
- Hall sensor signal pattern error
  Hall sensor signal patterns for each hall sensor interruption processing are monitored. When an error pattern is detected, CPU performs emergency stop.

5.3 System resource

5.3.1 Interruption

List of interruptions used in this control program is given below.

Table 5-3 Interruption Resource

Interruption	Interruption handler	Interruption occurrence condition	Main function
Carrier synchronous interruption (INTTRD0)	void mtr_carrier_interrupt(void)	50 [μs] (20 [kHz])	No processing
Interval timer interruption (INTTM00)	void mtr_tau0_interrupt(void)	1 [ms] (1 [kHz])	• Speed PI control • Error monitoring • Control start time measurement
Hall sensor interruption (INTP3, 4, 6)	void mtr_hall_interrupt(void)	Hall sensor signal edge detection	• Rotation speed calculation • Clearing motor stop determination counter value • Conduction pattern setting
Overcurrent detection interruption (INTP0)	void mtr_over_current_interrupt(void)	Overcurrent detection	Overcurrent protection

5.3.2 A/D converter input signal and used channels

List of used channels of A/D converter used in this control program is given below.

Table 5-4 A/D Converter Setting

Channel	Measurement signal	Range of setting value		Remark
ANI2	Inverter bus voltage	0 to 30 [V]: 0000H to 03FFH		Used in modulation factor calculation, excess voltage protection
ANI6	Rotation speed command value	CW	0 to 2048 [rpm] : 01FFH to 03FFH	Determined as limit in 2000 [rpm] and as stop in case of less than 550 [rpm]
		CCW	0 to 2048 [rpm] : 0000H to 01FFH	

5.3.3 Port function

List of port functions used in this control program is given below.

Table 5-5 Port Functions

Input/ output	Port number	Function	Remark
Input	INTP3/P30	Hall sensor signal interruption input (HU)	Performs both edge detection
	INTP4/P31	Hall sensor signal interruption input (HV)	
	INTP6/P140	Hall sensor signal interruption input (HW)	
	P05	START/STOP switch input	
	P06	ERROR RESET switch input	
Output	P52	LED display during operation	
	P53	Error LED display	
	P15	U phase upper arm motor control signal Port output (Up)	Logic setting is ”High” active
	P14	U phase lower arm motor control signal Port output (Un)	
	P13	V phase upper arm motor control signal Port output (Vp)	
	P11	V phase lower arm motor control signal Port output (Vn)	
	P12	W phase upper arm motor control signal Port output (Wp)	
	P10	W phase lower arm motor control signal Port output (Wn)	

5.3.4 PWM output part

List of PWM output parts used in this control program is given below.

Table 5-6 PWM Signals

Input/ output	Output port	Function	Remark
Output	TRDIOB0	U phase upper arm motor control signal PWM output (Up)	Logical setting is "High" active.
	TRDIOD0	U phase lower arm motor control signal PWM output (Un)	
	TRDIOA1	V phase upper arm motor control signal PWM output (Vp)	
	TRDIOC1	V phase lower arm motor control signal PWM output (Vn)	
	TRDIOB1	W phase upper arm motor control signal PWM output (Wp)	
	TRDIOD1	W phase lower arm motor control signal PWM output (Wn)	

5.4 Function specifications

Multiple control functions are used in this control program. Lists of control functions are given below.
For detailed processing, refer to flowcharts or source files.

Table 5-7 Control Functions List (1/3)

File name	Function overview	Processing overview
main.c	main() Input: None Output: None	・Hardware initialization function call ・User interface initialization function call ・Main processing used variable initialization function call ・Status transition and event execution function call ・Main processing ⇒ Main processing execution function call ⇒ Watchdog timer clear function call
	ctrl_ui() Input: None Output: None	・Motor status change ・Determination of rotation speed command value and rotation direction
	software_init() Input: None Output: None	Initialization of variables used in the main processing
mtr_ctrl_rssk.c	get_vr1() Input: None Output: (int16) ad_data / A/D conversion result	A/D conversion execution function call
	get_sw1() Input: None Output: (uint8) tmp_port /level of SW1	Obtaining the status of SW1
	get_sw2() Input: None Output: (uint8) tmp_port /level of SW2	Obtaining the status of SW2
	led1_on() Input: None Output: None	Turning LED1 ON
	led2_on() Input: None Output: None	Turning LED2 ON
	led1_off() Input: None Output: None	Turning LED1 OFF
	led2_off() Input: None Output: None	Turning LED2 OFF

Table 5-7 Control Functions List (2/3)

File name	Function name	Processing overview
mtr_ssns_hall_120.c	R_MTR_InitSequence() Input: None Output: None	Initialization of variables to use for sequence control
	R_MTR_ExecEvent() Input: (uint8)u1_event / occurred event Output: None	• Changing the status • Calling an appropriate processing execution function for the occurred event
	mtr_act_run () Input: (uint8)u1_state / Motor status Output: (uint8)u1_state /Motor status	• Variable initialization function call upon motor startup • Motor control startup function call • Output pattern determination function call
	mtr_act_stop () Input: (uint8)u1_state /Motor status Output: (uint8)u1_state /Motor status	Motor control stop function call
	mtr_act_none () Input: (uint8)u1_state /Motor status Output: (uint8)u1_state /Motor status	No processing is performed.
	mtr_act_reset () Input: (uint8)u1_state /Motor status Output: (uint8)u1_state /Motor status	Global variable initialization
	mtr_act_error() Input: (uint8)u1_state /Motor status Output: (uint8)u1_state /Motor status	Motor control stop function call
	mtr_pattern_set() Input: (uint8)u1_state /Motor status Output: (uint8)u1_state /Motor status	• Speed measurement function call • Obtaining hall sensor patterns • Conduction pattern determination • Motor control signal creation function call
	mtr_speed_calc () Input: None Output: None	Speed measurement calculation processing
	mtr_start_init () Input: None Output: None	Initializing only the variables required for motor startup
	mtr_pi_ctrl_speed () Input: None Output: None	Speed PI control
	R_MTR_SetSpeed () Input: (int16)ref_speed / Rotation speed command value Output: None	Rotation speed command value setting
	R_MTR_SetDir() Input: (uint8)dir / Rotation direction command value Output: None	Rotation direction setting
	R_MTR_GetSpeed () Input: None Output: (int16)g_s2_rpm / Rotation speed calculation value	Obtaining the rotation speed calculation value (electrical angle)
	R_MTR_GetStatus () Input: None Output: (uint8)g_u1_mode_system / Motor status	Obtaining the motor status
	mtr_error_check() Input: None Output: None	Error monitoring and detection

Table 5-7 Control Functions List (3/3)

File name	Function name	Processing overview
mtr_interrupt.c	mtr_hall_interrupt () Input: None Output: None	Output pattern determination function call
	mtr_over_current_interrupt () Input: None Output: None	• Changing the motor status • Event processing selection function call • Pulse output forced shutdown flag clear function call
	mtr_tau0_interrupt () Input: None Output: None	• Error check function call • BOOT mode time measurement • Calling speed PI control function every 5 [ms]
	mtr_carrier_interrupt () Input: None Output: None	Compare match flag (IMFA) clear function call
mtr_ctrl_rl78g14.c	R_MTR_InitHardware () Input: None Output: None	Initializing clock and peripheral functions
	init_ui() Input: None Output: None	Initializing user-usage peripheral functions
	mtr_ctrl_start () Input: None Output: None	Enabling hall sensor interruption (INTP3, INTP4, INTP6)
	mtr_ctrl_stop() Input: None Output: None	• Disabling hall sensor interruption (INTP3, INTP4, INTP6) • Stopping timer RD output • Setting motor control output port to inactive status • Waiting for motor rotation stop
	mtr_change_pattern() Input: (uint8)pattern / conduction pattern Output: None	• Output pattern setting • Changing the motor status when output pattern error occurs • Event processing selection function call
	mtr_get_adc() Input: (uint8)ad_ch / conversion channel Output: (int16)s2_temp / A/D conversion result	Executes A/D conversion
	clear_wdt() Input: None Output: None	Clearing the watchdog timer
	mtr_clear_oc_flag () Input: None Output: None	Clearing the pulse output forced shutdown flag
	mtr_clear_trd0_imfa() Input: None Output: None	Clearing the compare match flag (IMFA)

5.5 Variables list

Lists of variables used in this control program are given below. Note that local variables are not described.

Table 5-8 Variables List (1/2)

Variable name	Type	Content	Remark
g_s2_max_speed	int16	Rotation speed command maximum value	Mechanical angle [rpm]
g_s2_min_speed	int16	Rotation speed command minimum value	Mechanical angle [rpm]
g_s2_margin_min_speed	int16	Rotation speed command minimum value for motor stop	Mechanical angle [rpm]
g_s2_ref_speed	int16	User setting rotation speed	Electrical angle [rpm]
g_u1_rot_dir	uint8	User setting rotation direction	0: CW 1: CCW
g_u1_motor_status	uint8	User motor status management	0: Stop 1: Rotating 2: Error
g_u1_reset_req	uint8	Reset request flag	0: SW2 ON at the time of error status 1: SW2 OFF at the time of error status
g_u1_sw1_cnt	uint8	SW1 determination counter	Chattering removal
g_u1_sw2_cnt	uint8	SW2 determination counter	Chattering removal
g_u1_stop_req	uint8	VR1 stop command flag	Stop is determined when rotation speed command value is less than 550 [rpm].
g_u1_cnt_speed_pi	uint8	Speed PI control decimation counter	Speed PI control cycle 5 [ms] is counted.
g_s2_pwm_duty	int16	Timer RD compare register setting value	-
g_u2_cnt_boot_mode	uint16	BOOT mode time measurement counter	20 [ms] after motor startup is counted.
g_u2_cnt_wait_stop	uint16	Motor rotation stop waiting counter	10 [ms] after motor stop processing is counted. (Note that the count is reset when a hall sensor interrupt is detected.)
g_u1_flg_wait_stop	uint8	Motor rotation stop waiting flag	The flag set upon motor stop command. When no hall sensor interrupt is detected for 10 [ms] after motor stop processing, the flag is cleared.
g_u2_run_mode	uint16	Operation mode management	0: BOOT mode 3: Normal operation mode
g_u1_error_status	uint8	Error status management	1: Overcurrent error 2: Overvoltage error 3: Rotation speed abnormality error 4: Timeout error 5: Hall sensor pattern error (0xff: Non-definition error)
g_u1_mode_system	uint8	State management	0: Stop mode 1: Run mode 2: Error mode

Table 5-8 Variables List (2/2)

Variable name	Type	Content	Remark
g_u1_hall_signal	uint8	Three-phase hall sensor input value	-
g_u1_v_pattern	uint8	Conducting pattern	-
g_u1_direction	uint8	Rotation direction management	0: CW 1: CCW
g_s2_rpm	int16	Rotation speed calculation value	Electrical angle [rpm]
g_u2_hall_timer[3]	uint16	Free-run timer count value	TCR01
g_u1_hall_timer_num	uint8	Array element number π [rad] before	-
g_u2_180deg_cnt	uint16	Free-run timer count for π [rad]	-
g_f4_rpm_err	float32	Rotation speed deviation	Electrical angle [rpm]
g_f4_rpm_err_old	float32	Last rotation speed deviation	Electrical angle [rpm]
g_s2_rpm_ref	int16	Rotation speed command value	Electrical angle [rpm]
g_f4_rpm_ave	float32	Rotation speed calculation value after LPF	Electrical angle [rpm]
g_f4_rpm_ave_old	float32	Rotation speed calculation value after last LPF	Electrical angle [rpm]
g_f4_speed_pi_p	float32	Speed PI control proportional term	-
g_f4_speed_pi_i	float32	Speed PI control integral term	-
g_f4_speed_pi_kp	float32	Speed PI control proportional gain	-
g_f4_speed_pi_ki	float32	Speed PI control integral gain	-
g_f4_v_ref	float32	Voltage command value	Speed PI control output value [V]
g_s2_vdc	int16	Inverter bus voltage A/D value	[V]
g_u2_cnt_timeout	uint16	Stop determination time measurement counter	Cleared after every hall sensor interruption
g_u1_def_state	uint8	Motor status definition	Array members ・Stop mode ・Run mode ・Error mode
gp_u1_def_action	uint8	Action definition	Array members ・Stop action ・Run action ・Error action ・Reset action ・No action

5.6 Macro definitions

Lists of macro definitions used in this control program are given below.

Table 5-9 Macro Definitions List (1/5)

File name	Macro name	Definition value	Remark
main.h	M_CW	0	User setting rotation direction : CW
	M_CCW	1	User setting rotation direction : CCW
	MAX_SPEED	2000	Rotation speed command maximum value (Mechanical angle) [rpm]
	MIN_SPEED	600	Rotation speed command minimum value (Mechanical angle) [rpm]
	MARGIN_SPEED	50	Rotation speed command minimum value creation constant for stop (Mechanical angle) [rpm]
	MARGIN_MIN_SPEED	MIN_SPEED - MARGIN_SPEED	Rotation speed command minimum value for motor stop (Mechanical angle) [rpm]
	SW_ON	0	Active in case of “Low”
	SW_OFF	1	Active in case of “Low”
	CHATTERING_CNT	10	Chattering removal
	VR1_SCALING	4	Speed command value creation constant
	POLE_PAIR	7	Number of pole pairs
	REQ_CLR	0	VR1 stop command flag clearing
	REQ_SET	1	VR1 stop command flag setting
	ADJUST_OFFSET	0x1FF	Speed command value offset adjustment constant

Table 5-9 Macro Definitions List (2/5)

File name	Macro name	Definition value	Remark
mtr_ctrl_rl78g14.h	MTR_PWM_TIMER_FREQ	64	Timer RD count frequency [MHz]
	MTR_TAU1_FREQ	125000	Timer Array Unit channel 1 count frequency [Hz]
	MTR_PORT_HALL_U	P3.0	U phase hall sensor input port
	MTR_PORT_HALL_V	P3.1	V phase hall sensor input port
	MTR_PORT_HALL_W	P14.0	W phase hall sensor input port
	MTR_PORT_UP	P1.5	U phase (positive phase) output port
	MTR_PORT_UN	P1.4	U phase (negative phase) output port
	MTR_PORT_VP	P1.3	V phase (positive phase) output port
	MTR_PORT_VN	P1.1	V phase (negative phase) output port
	MTR_PORT_WP	P1.2	W phase (positive phase) output port
	MTR_PORT_WN	P1.0	W phase (negative phase) output port
	MTR_TAU1_CNT	TCR01	Timer count register for speed measurement
	MTR_ADCCH_VR1	6	VR1 A/D conversion channel
	MTR_ADCCH_VDC	2	Inverter bus voltage A/D conversion channel
	MTR_MAX_VDC	24	Limit of the voltage command value [V]
	MTR_VDC_RESOLUTION	30 / 1023	Inverter bus voltage resolution
	MTR_PORT_SW1	P0.5	SW1 input port
	MTR_PORT_SW2	P0.6	SW2 input port
	MTR_PORT_LED1	P5.2	LED1 output port
	MTR_PORT_LED2	P5.3	LED2 output port
	MTR_LED_ON	0	Active in case of “Low”
	MTR_LED_OFF	1	

Table 5-9 Macro Definitions List (3/5)

File name	Macro name	Definition value	Remark
mtr_ssns_hall_120.h	MTR_CARRIER_FREQ	20	PWM carrier frequency [kHz]
	MTR_START_DUTY	17	PWM duty initial value [%]
	MTR_PATTERN_CW_U_V	2	CW hall sensor value
	MTR_PATTERN_CW_U_W	3	
	MTR_PATTERN_CW_V_W	1	
	MTR_PATTERN_CW_V_U	5	
	MTR_PATTERN_CW_W_U	4	
	MTR_PATTERN_CW_W_V	6	
	MTR_PATTERN_CCW_U_V	5	CCW hall sensor value
	MTR_PATTERN_CCW_W_V	1	
	MTR_PATTERN_CCW_W_U	3	
	MTR_PATTERN_CCW_V_U	2	
	MTR_PATTERN_CCW_V_W	6	
	MTR_PATTERN_CCW_U_W	4	
	MTR_SPEED_PI_DECIMATION	4	Speed PI control decimation count
	MTR_SPEED_PI_KP	0.0001	Proportional term gain
	MTR_SPEED_PI_KI	0.00001	Integral term gain
	MTR_AVG_OLD	0.3	LPF previous value filter coefficient
	MTR_MAX_PWM_DUTY	1800	PWM duty setting register maximum value
	MTR_MIN_PWM_DUTY	544	PWM duty setting register minimum value
	MTR_SPEED_LIMIT	16000	Speed abnormality error determination value (electrical angle) [rpm]
	MTR_OVERVOLTAGE_LIMIT	28	Overvoltage error determination value [V]
	MTR_TIMEOUT_CNT	20	Stop determination time [ms]
	MTR_START_CNT	100	Control start time after startup [ms]

Table 5-9 Macro Definitions List (4/5)

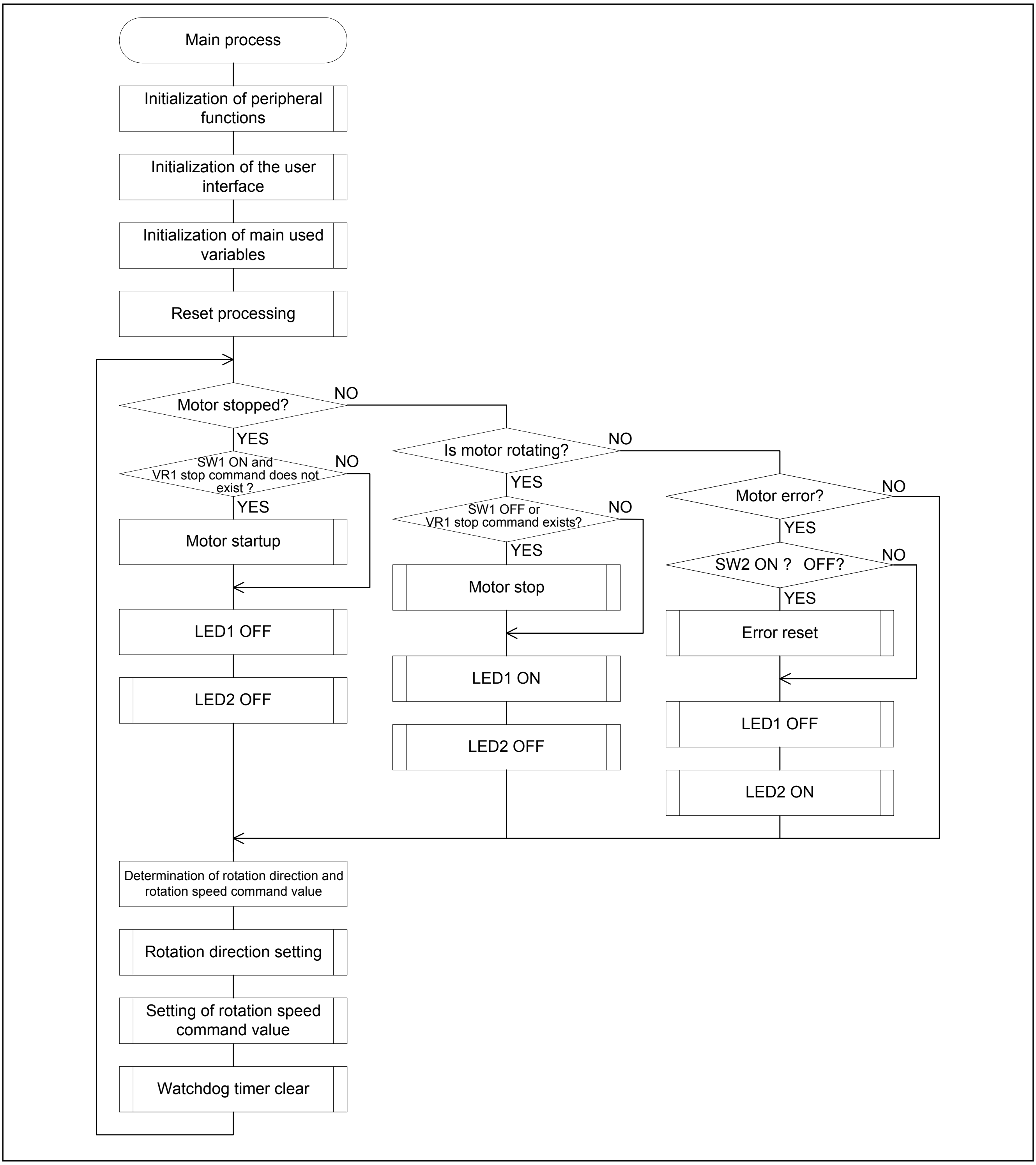
File name	Macro name	Definition value	Remark
mtr_ssns_hall_120.h	MTR_CARRIER_SET	1000 / MTR_CARRIER_FREQ * MTR_PWM_TIMER_FREQ - 1	PWM cycle register setting value
	MTR_START_DUTY_SET	(((MTR_CARRIER_SET + 1) / 100) * MTR_START_DUTY) - 1	PWM duty setting register initial value
	MTR_RATE_DUTY	MTR_START_DUTY / 100	PWM duty initial value
	MTR_RPM_CALC_BASE	60 * MTR_TAU1_FREQ / 2	Constant for speed measurement
	MTR_PATTERN_ERROR	0	Conducting pattern
	MTR_UP_PWM_VN_ON	1	
	MTR_UP_PWM_WN_ON	2	
	MTR_VP_PWM_UN_ON	3	
	MTR_VP_PWM_WN_ON	4	
	MTR_WP_PWM_UN_ON	5	
	MTR_WP_PWM_VN_ON	6	
	MTR_UP_ON_VN_PWM	7	
	MTR_UP_ON_WN_PWM	8	
	MTR_VP_ON_UN_PWM	9	
	MTR_VP_ON_WN_PWM	10	
	MTR_WP_ON_UN_PWM	11	
	MTR_WP_ON_VN_PWM	12	
	MTR_CW	0	Rotation direction setting value: CW
	MTR_CCW	1	Rotation direction setting value: CCW
	MTR_AVG_NEW	1 - MTR_AVG_OLD	LPF current value filter coefficient
	MTR_OVERSIZE_LIMIT	115	Speed deviation minimum value
	MTR_FLG_CLR	0	Constant for flag clear
	MTR_FLG_SET	1	Constant for flag setting
	MTR_STOP_WAIT_CNT	200	Period to wait for stop [ms]

Table 5-9 Macro Definitions List (5/5)

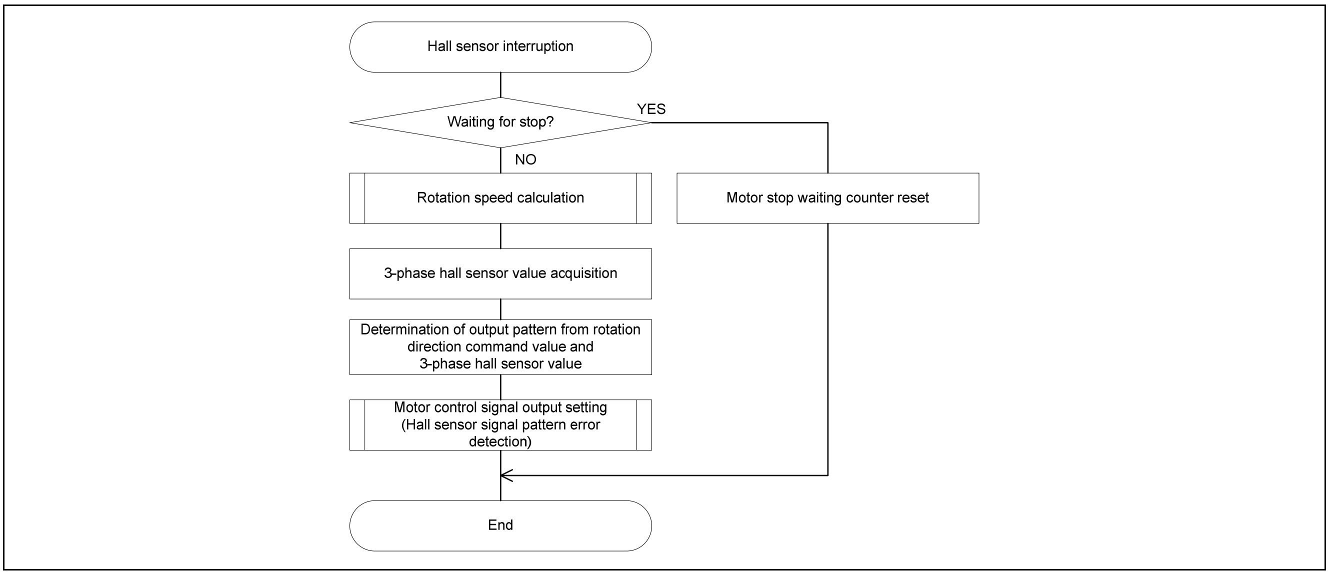
File name	Macro name	Definition value	Remark
mtr_ssns_hall_120.h	MTR_BOOT_MODE	0x00	BOOT mode
	MTR_HALL_120_MODE	0x03	Normal operation mode
	MTR_OVER_CURRENT_ERROR	1	Overcurrent error
	MTR_OVER_VOLTAGE_ERROR	2	Overvoltage error
	MTR_OVER_SPEED_ERROR	3	Rotation speed abnormality error
	MTR_TIMEOUT_ERROR	4	Timeout error
	MTR_HALL_ERROR	5	Hall sensor pattern error
	MTR_UNKNOWN_ERROR	0xff	Undefined error
	MTR_MODE_STOP	0	Stop status
	MTR_MODE_RUN	1	Rotating status
	MTR_MODE_ERROR	2	Error status
	MTR_SIZE_STATE	3	Status count
	MTR_EVENT_STOP	0	Motor stop event
	MTR_EVENT_RUN	1	Motor startup event
	MTR_EVENT_ERROR	2	Motor error event
	MTR_EVENT_RESET	3	Motor reset event
	MTR_SIZE_EVENT	4	Events count

5.7 Control flow (flow chart)

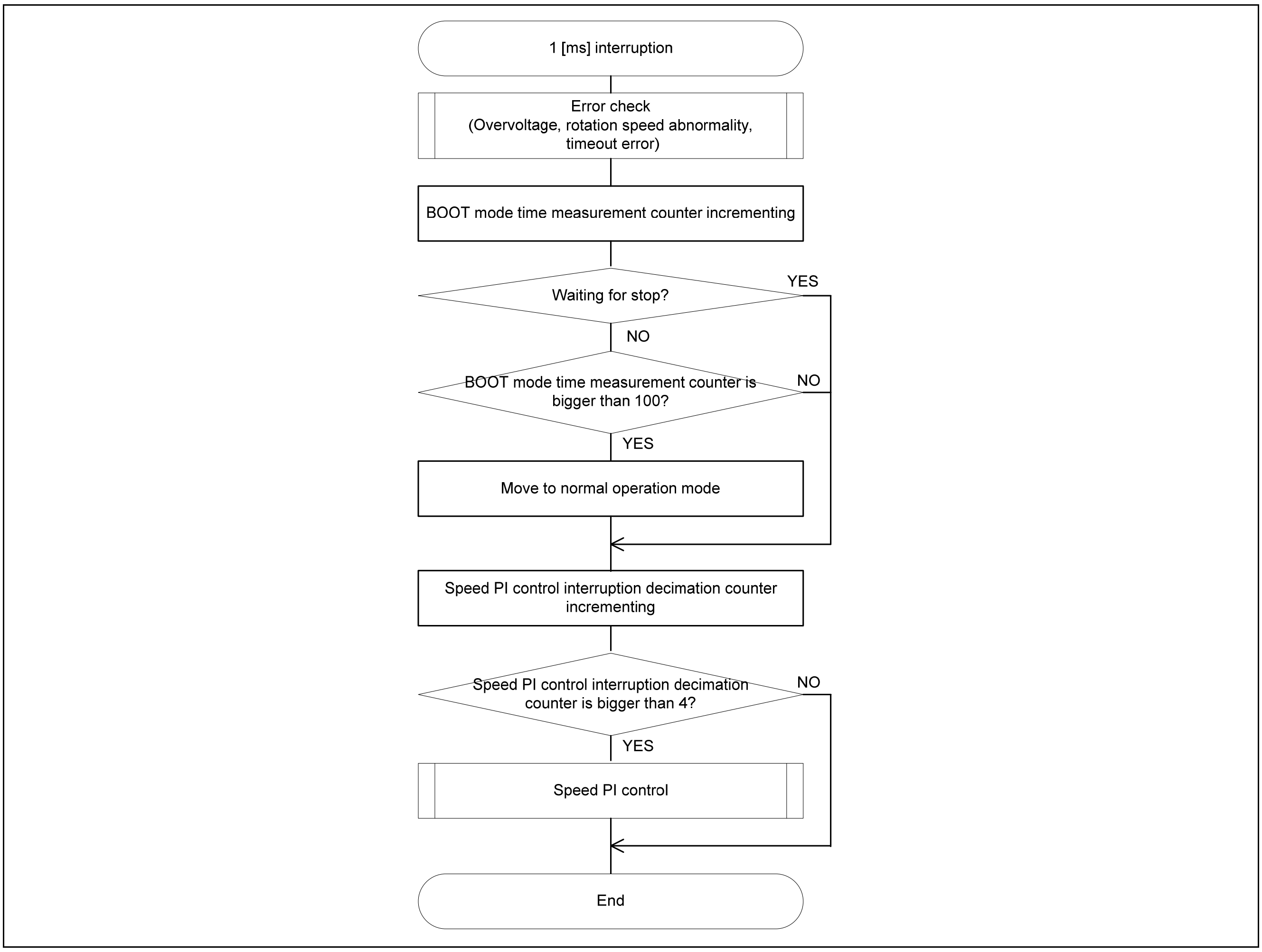
(1) Main process



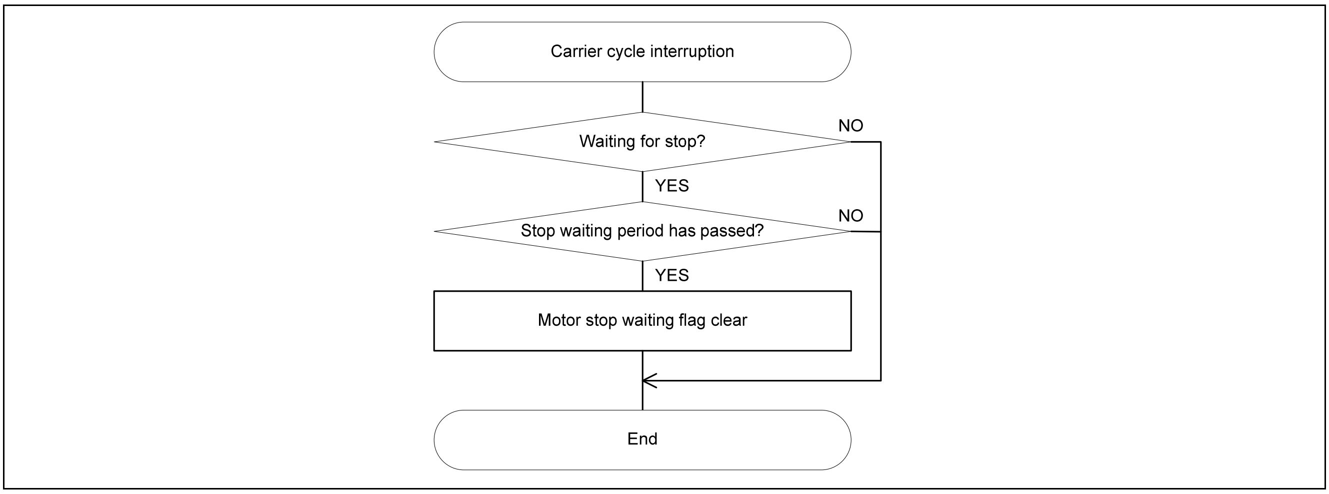
(2) Hall sensor interruption process



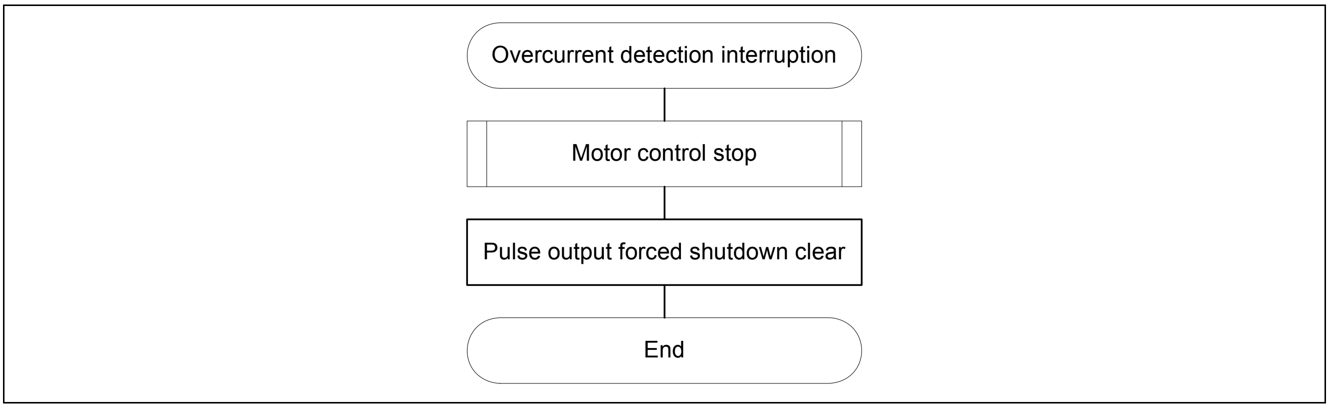
(3) 1 [ms] interruption process



(4) Carrier cycle interruption process



(5) Overcurrent interruption process



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Revision Record

Rev.	Date	Description	
		Page	Summary
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General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this manual, refer to the relevant sections of the manual. If the descriptions under General Precautions in the Handling of MPU/MCU Products and in the body of the manual differ from each other, the description in the body of the manual takes precedence.

1. Handling of Unused Pins
   Handle unused pins in accord with the directions given under Handling of Unused Pins in the manual.
   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.
2. Processing at Power-on
   The state of the product is undefined at the moment when power is supplied.
   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.
3. Prohibition of Access to Reserved Addresses
   — Access to reserved addresses is prohibited.
   The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.
4. Clock Signals
   — After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.
   When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.
5. Differences between Products
   — Before changing from one product to another, i.e. to one with a different type number, confirm that the change will not lead to problems.
   The characteristics of MPU/MCU in the same group but having different type numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different type numbers, implement a system-evaluation test for each of the products.

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