RL78/F14

R01AN3811EJ0100
Rev.1.00
Mar.31.2017

Motor control by RL78/F14 micro controller sensorless 120 degrees conducting control of blushless DC motor (COMP)

Summary

This application note aims at explaining the sample program for operating the 3 phase brushless DC motor with sensorless 120 degrees conducting method, by using the functions of LR78/F14.

Sample program is only to be used as reference and Renesas Electronics Corporation does not guarantee the operations. Before 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/F14 (R5F10PLJ)

Contents

1. Overview

This application note describes an example of speed control by sensorless 120 degrees conducting method of brushless DC motor (here in after referred to as BLDC motor) by using micro controller RL78/F14.

1.1 Usage of the system

This system (sample program) enables 120 degrees conducting control by using an RL78/F14 micro controller mounted CPU board, an inverter board for motor control (ECU001-F14-12V note 1) and a BLDC motor. (BLY171S-15V-8000 note 2)

Notes: 1. Evaluation board "ECU001-F14-12V" is products of Desk Top Lab Inc.
(http://www.desktoplab.co.jp/)

2. BLDC Motor "BLY171S-15V-8000" is products of Anaheim Automation Inc..
(http://www.anaheimautomation.com/)

1.2 Development environment

(1) Software development environment

Integrated development environment	CS+ for CA, CX (V4.00.00) CS+ for CC (V5.00.00)
	IAR Embedded Workbench (Ver. 7.4.1.4269)
Build tool	CA78K0R (V1.72) CC-RL (V1.04.00)
	EWRL78 (Ver. 2.21.1)

(2) Hardware development environment

On-chip debug emulator	E1
Microcomputer used	RL78/F14(R5F10PLJ)
RL78/F14 mounted CPU board	ECU001-F14-12V
BLDC motor	BLY171S-15V-8000

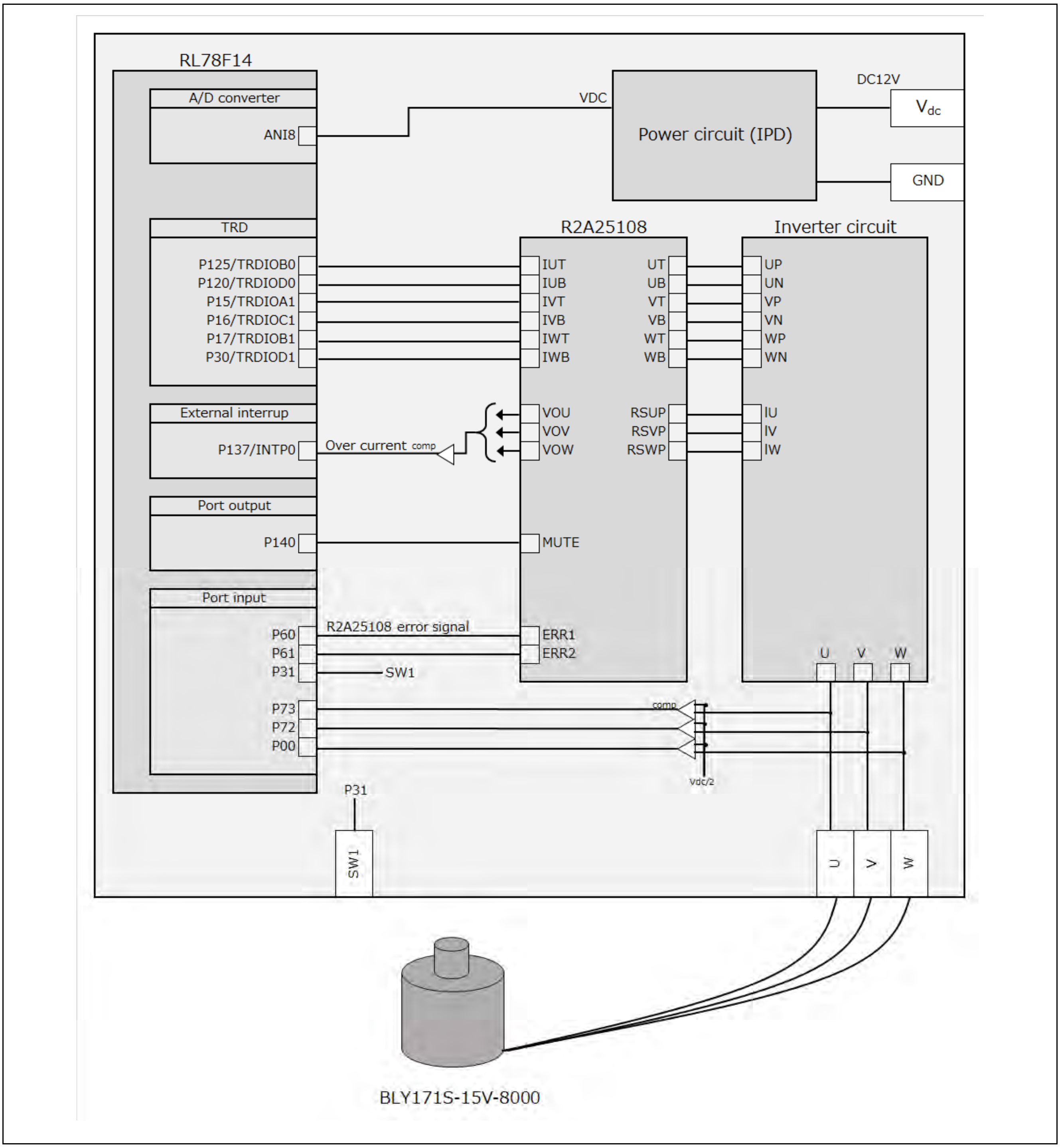
2. System overview

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 Terminal interface

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

Table 2-1 Terminal interface

Terminal name	Function
P73	Comparator input(U)
P72	Comparator input(V)
P00	Comparator input(W)
P86 / ANI8	VDC voltage measurement
P125 / TRDIOB0	Complementary PWM output (U_p)
P120 / TRDIOD0	Complementary PWM output (U_n)
P15 / TRDIOA1	Complementary PWM output (V_p)
P16 / TRDIOC1	Complementary PWM output (V_n)
P17 / TRDIOB1	Complementary PWM output (W_p)
P30 / TRDIOD1	Complementary PWM output (W_n)
P60	ERR1 input
P61	ERR2 input
P140	MUTE output
P31	SW Input

2.2.2 Peripheral functions

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

Please refer to "section 4 Description of peripheral functions" for details.

Table 2-2 Peripheral functions List

Peripheral function	Usage
Port (P00, P72, P73)	- Input Comparator signal (Position detect)
AD converter (ANI8)	- Bus voltage measurement
Timer RD (TRD)	PWM output using complementary PWM mode (3positive phases, 3 negative phases)
Port (P60, P61)	error detection (Over current detection, low voltage detection, heating load short detection)
Port (P15, P16, P17, P30, P120, P125, P140)	- motor control signal with port output - MUTE terminal control signal output
Timer Array Unit (TAU)	- 1 [ms] interval timer - Free-run timer for speed measurement

2.3 Software structure

2.3.1 Software file structure

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

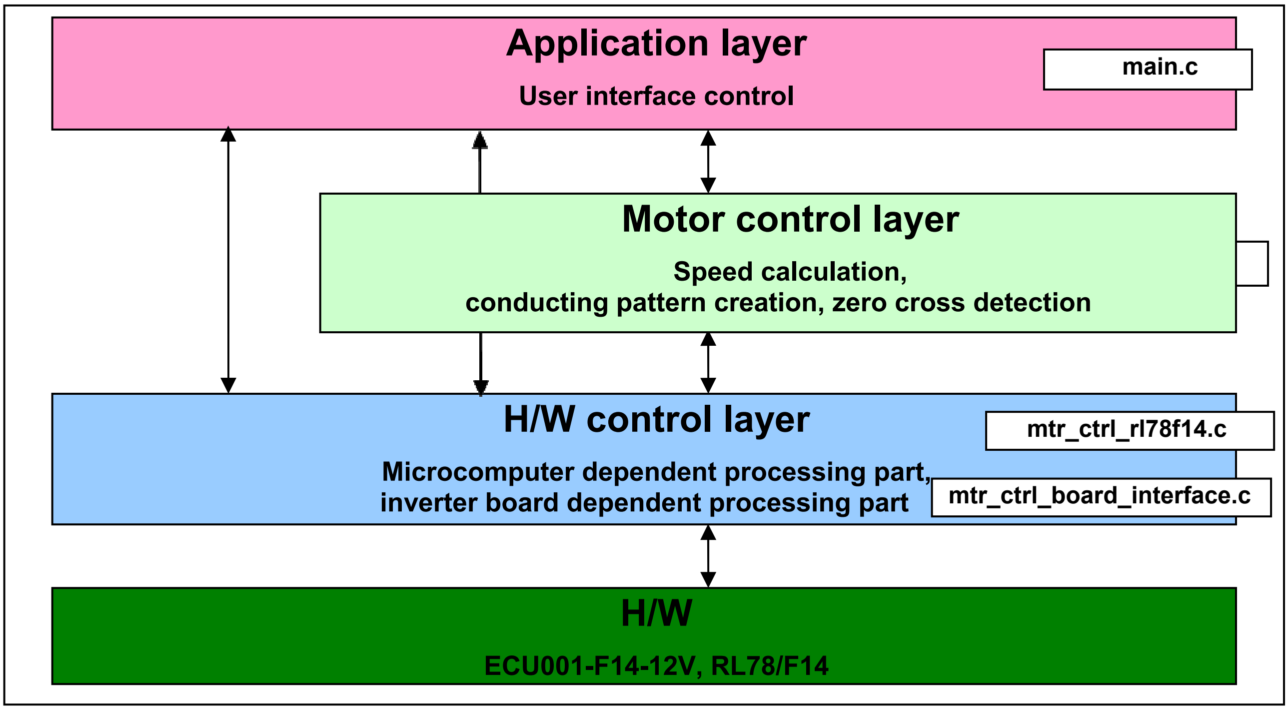
Table 2-3 Folders and files structure of sample program

RL78F14_120_SSLS_COMP_interMidi	inc	Iodefine.h	SFR definition file(CCRL)
		main.h	Main function, user interface control header
		mtr_ctrl_board_interface.h	Board dependent processing part header
		mtr_ctrl_rl78f14.h	RL78/F14 dependent processing part header
		mtr_ssns_less_120.h	Sensorless 120 degrees conducting control dependent part header
		rl78_common.h	Header for common definition
	src	main.c	Main function, user interface control
		mtr_ctrl_board_interface.c	Board dependent processing part
		mtr_ctrl_rl78f14.c	RL78/F14 dependent processing part
		mtr_interrupt.c	Interruption handler
		mtr_ssns_less_120.c	Sensorless 120 degrees conducting control dependent part
	asm	cstat.asm	Startup routine
		hwinit.asm	Hardware initialization
		stkinit.asm	Stack initialization

2.3.2 Modules 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 2-4.

Table 2-4 Software basic specifications

Item	Content
Control method	120-deg conducting method
Motor rotation start / stop	- Start by SW1 push down short time. - Stop by SW1 push down long time or driver error detection.
Position detection of rotor magnetic pole	Position detection by back EMF (every 60 degrees)
Carrier frequency (PWM)	10 [kHz]
Control cycle	- Execute zero cross detection from back EMF per carrier frequency. - Determination of PWM duty setting and conducting pattern.
Rotation speed control range	1000 [rpm] to 3500 [rpm] both CW / CCW.(8 Pole)
Rotation speed operation	- In pattern change, calculate rotate speed from elapse time of previous one. - Uses the interval timer for measurement of elapse time.
Speed control (Speed PI control)	Obtains the speed command value form speed command value setting function, 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 3 conditions: 1. Rotation speed exceeds 33000[rpm] (electrical angle). (Monitored for each 1 [ms]) 2. No zero cross detected for 20 [ms] in sensorless drive mode. 3. Detect error signal (err1, err2) from pre-driver

3. Motor control method

Sensorless 120 degrees conducting control and speed control of the BLDC motor, used in the sample program are explained here.

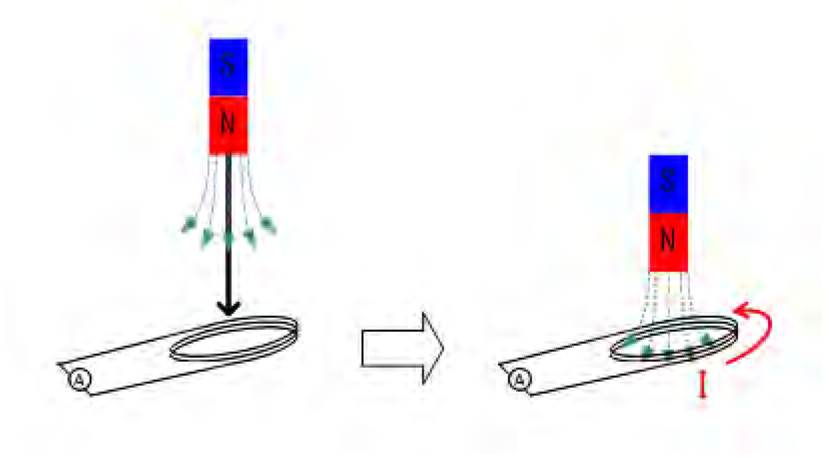
3.1 Sensorless 120 degrees conducting control of the BLDC motor

The sensorless control does not have a sensor for obtaining the permanent magnetic position, and hence the alternative to the sensor is required. The sensorless control of permanent magnetic synchronous motor, generally estimates the position by detecting the induced voltage (back-EMF).

The induced voltage in an closed circuit is proportion to the time rate of change of the magnetic flux through the circuit.

For example, consider the case where magnet gets close to the coil, as shown in Figure 3-1. In this case, since the interlinkage magnetic flux increase within the coil, coil generates the electromotive force that flows the current to prevent the increase of interlinkage magnetic flux in the direction of the figure. (The flux of opposite direction of the magnetic flux is occurred by the right-handed screw rule.)

Figure 3-1 Induced voltage depending on the coil magnet



This induced voltage E_m is expressed by the magnetic flux ϕ_m as the following formula.

$$E_m = \frac{d}{dt}\varphi_m \cdots (1)$$

This event occurs event in the rotating permanent magnetic synchronous motor. When the permanent magnet is rotating, the induced voltage is generated by constantly changing interlinkage magnetic flux of each phase.

Figure 3-2 Induced voltage in the rotating permanent magnetic synchronous motor

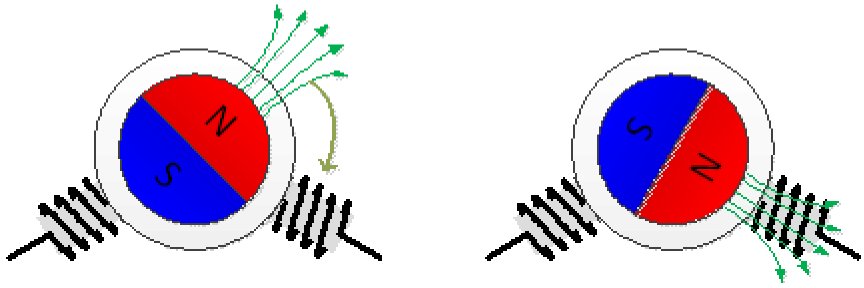
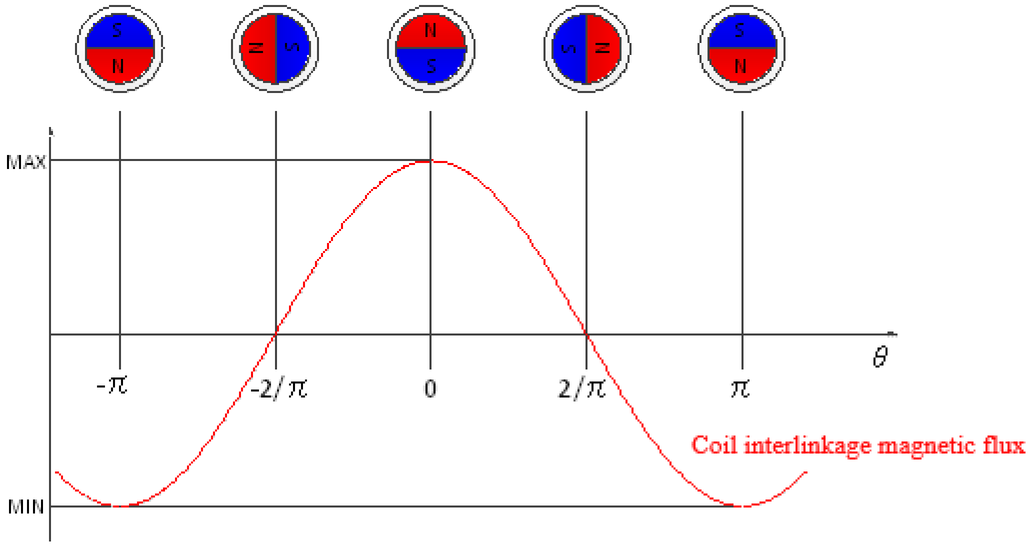


Figure 3-3 shows the variation of interlinkage magnetic flux in the U phase. Size of the interlinkage magnetic flux is shown on the vertical (Y) axis and phase of the permanent magnet is shown on the horizontal (X) axis. Also position for disposing the N pole of permanent magnet to coil is considered as $\theta = 0$.

Figure 3-3 Variation of interlinkage magnetic flux



The interlinkage magnetic flux of U phase changes in the cosine wave format.

If considered similarly for V phase, V phase and W phase deviate respectively by $2\pi/3$, $4\pi/3$ phase from U phase. The interlinkage magnetic flux of the three phases is expressed by the following formula.

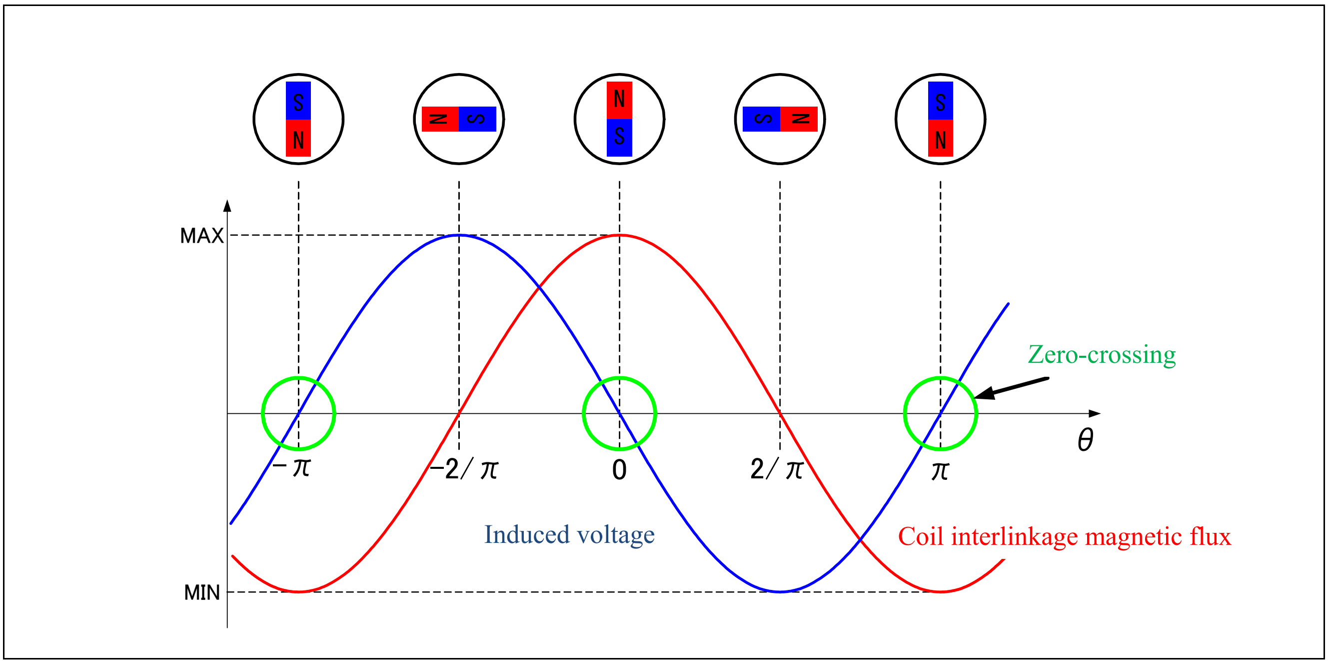
$$
\begin{aligned}
\varphi_u &= \varphi_m \cos\theta \\
\varphi_v &= \varphi_m \cos(\theta - \frac{2}{3}\pi) \\
\varphi_w &= \varphi_m \cos(\theta - \frac{4}{3}\pi)
\end{aligned}
$$

Also, the induced voltage of three phases is expressed by the following formula, by using formula (1), when the angle speed is considered as ω.

$$
\begin{aligned}
E_u &= \frac{d}{dt}\varphi_u = \frac{d}{dt}\varphi_m \cos\theta = -\omega\varphi_m \sin\theta = \omega\varphi_m \cos(\theta + \frac{\pi}{2}) \\
E_v &= \frac{d}{dt}\varphi_v = \frac{d}{dt}\varphi_m \cos(\theta - \frac{2}{3}\pi) = -\omega\varphi_m \sin(\theta - \frac{2}{3}\pi) = \omega\varphi_m \cos(\theta - \frac{\pi}{6}) \\
E_w & \frac{d}{dt}\varphi_w = \frac{d}{dt}\varphi_m \cos(\theta - \frac{4}{3}\pi) = -\omega\varphi_m \sin(\theta - \frac{4}{3}\pi) = \omega\varphi_m \cos(\theta - \frac{5}{6}\pi)
\end{aligned}
$$

From this formula, it is understood that the induced voltage lead of $\pi/2$ phase from permanent magnetic flux. This 位 mean that if the induced voltage can be detected, positon the permanent magnet can be estimated.

Figure 3-4 Zero-crossing of the induced voltage

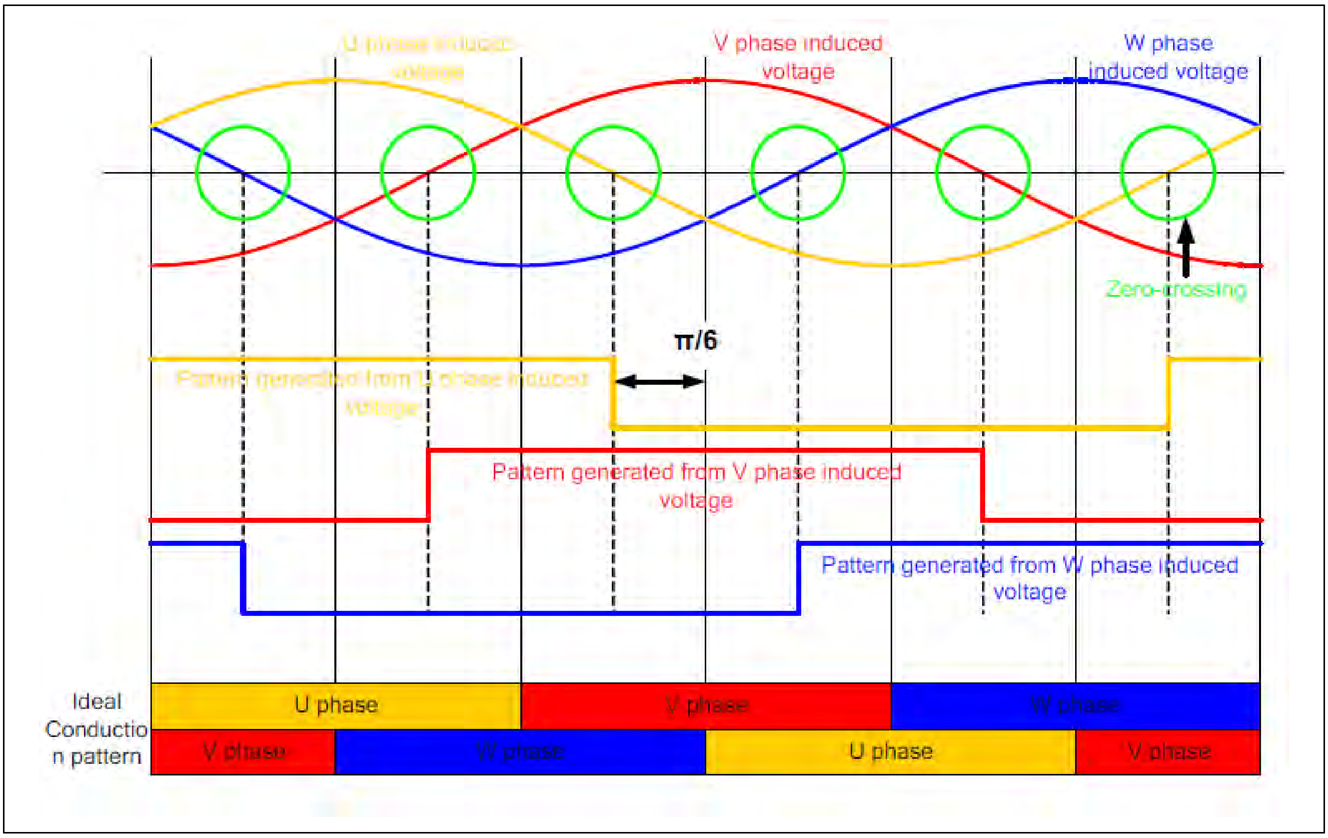


However, the induced voltage of each phase is not always detected while the motor is rotating.

During the driving in 120 degrees conduction, conduction is performed to the two phases among the three phases and hence only the remaining one phase, to which conduction is not performed, can detect the induced voltage. Actually, position information is obtained by detecting the point of change in the sign of induced voltage (zero-crossing) occurring in mon-conducting phase, which can detect the induced voltage.

In the three phases motor, this zero-crossing occurs for total six times, i.e. twice in each phase, in one rotation (electrical angle) of the motor. This means that the position for every 60 degrees can be detected by this process in the same way as resolution of hall sensor.

Figure 3-5 Relation between conducting pattern and zero-crossing (Upper arm chopping)



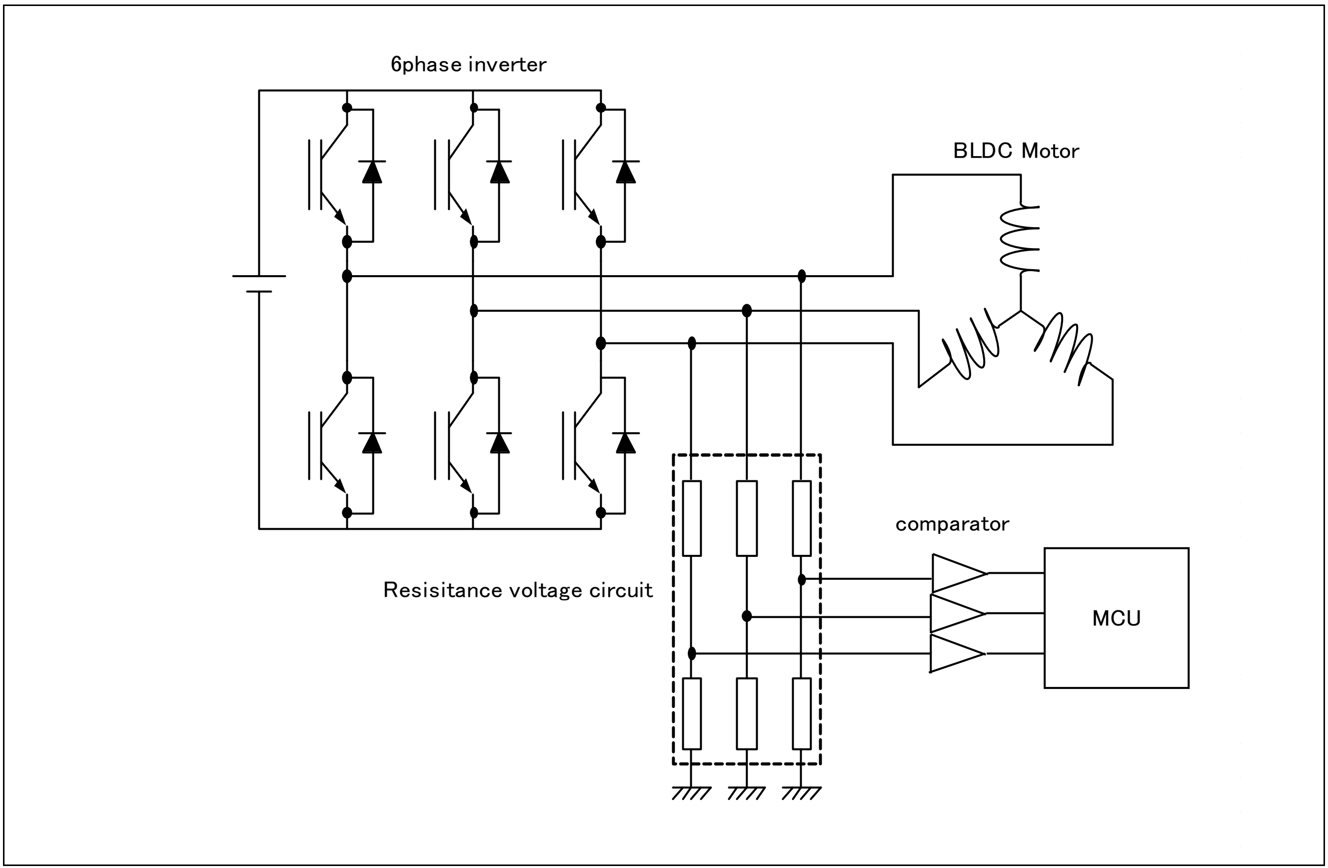
However, this zero-crossing detection signal cannot be used in the same way as the signal of the hall sensor.

The zero-crossing detection signal occurs at the point where phase is shifted $\pi/6$ from proper conducting pattern switching timing, as shown in Figure 3-5. Therefore, in the actual control, conducting pattern is switched at the point where phase is shifted $\pi/6$ from detecting the zero-crossing.

3.2 Zero-crossing detection method

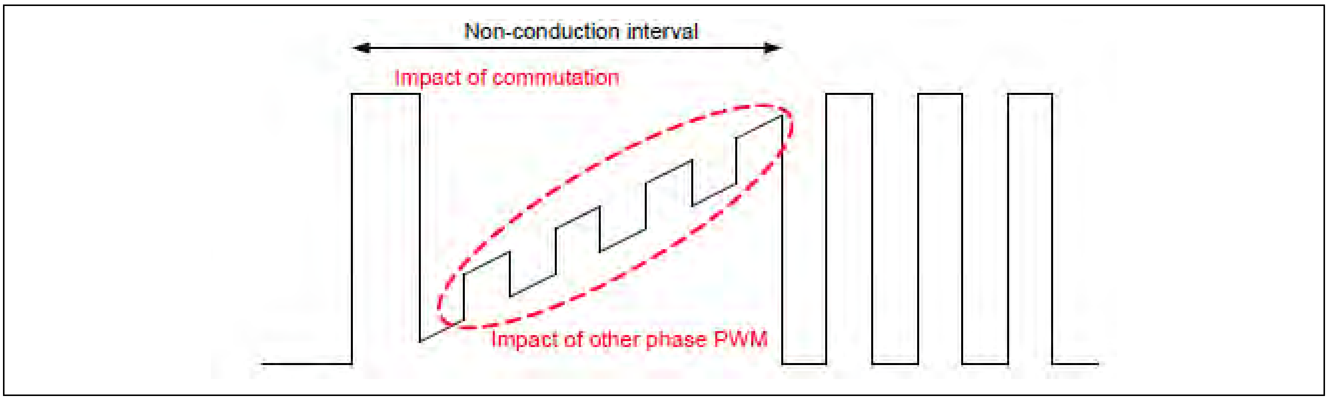
Various zero-crossing detection methods are used. The method of detecting the zero-crossing by comparing the value of induced voltage with the center point voltage by the software, using the A/D converter of microcomputer is introduced here. Since voltage is compared without the comparator, it is called as comparator less method.

Figure 3-6 Comparator less method



Actually detecting the induced voltage, commutation voltage occurring when switching the conducting patterns, and impact of the PWM of other phases must be considered. This impact is expressed in the format shown in Figure 3-7.

Figure 3-7 Overview diagram of impact of the commutation and other phase PWM



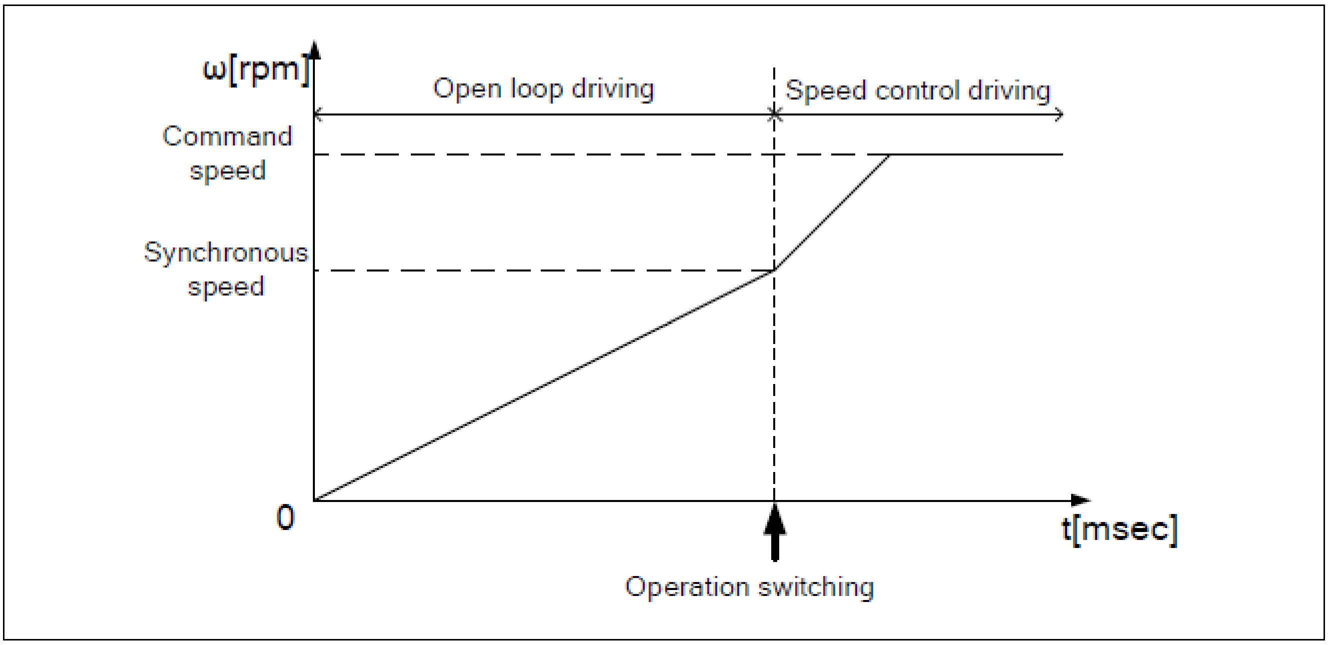
In this system, impact is removed by using the simple filter route and the software.

3.3 Start-up method

Induced voltage dues not occur unless the permanent magnet is rotating. This means that the position of magnet cannot be estimated by using the induced voltage, at the time of starting.

Therefore, start-up method in this system synchronizes speed of the permanent magnet by generating a routing magnetic field by forcibly switching the conducting pattern regardless of the position of permanent magnet.

Figure 3-8 Diagram of start-up operation



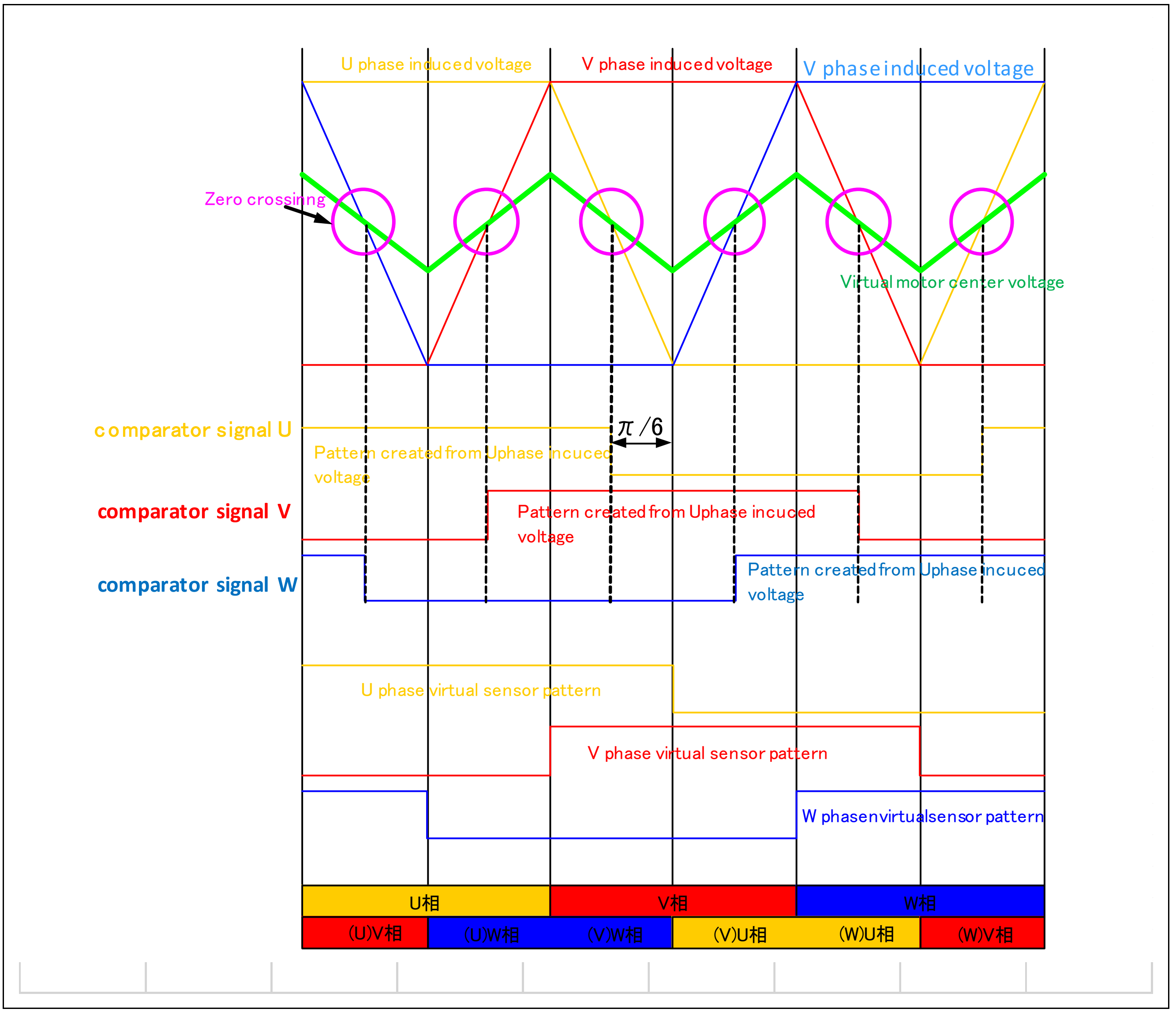
3.4 Position estimate operation

In this system, the virtual center voltage of the motor is calculated by the sum of A/D conversion voltage of each phase in each PWM control cycle. The pattern of ‘1’ ‘0’ is created by comparing the virtual motor center voltage with each phase voltage.

Then, the conduction pattern is created by shifted $\pi/6$.

$\pi/6$ is estimated from the number of PWM control between zero-crossing.

Figure 3-9 conduction pattern (Upper arm chopping)

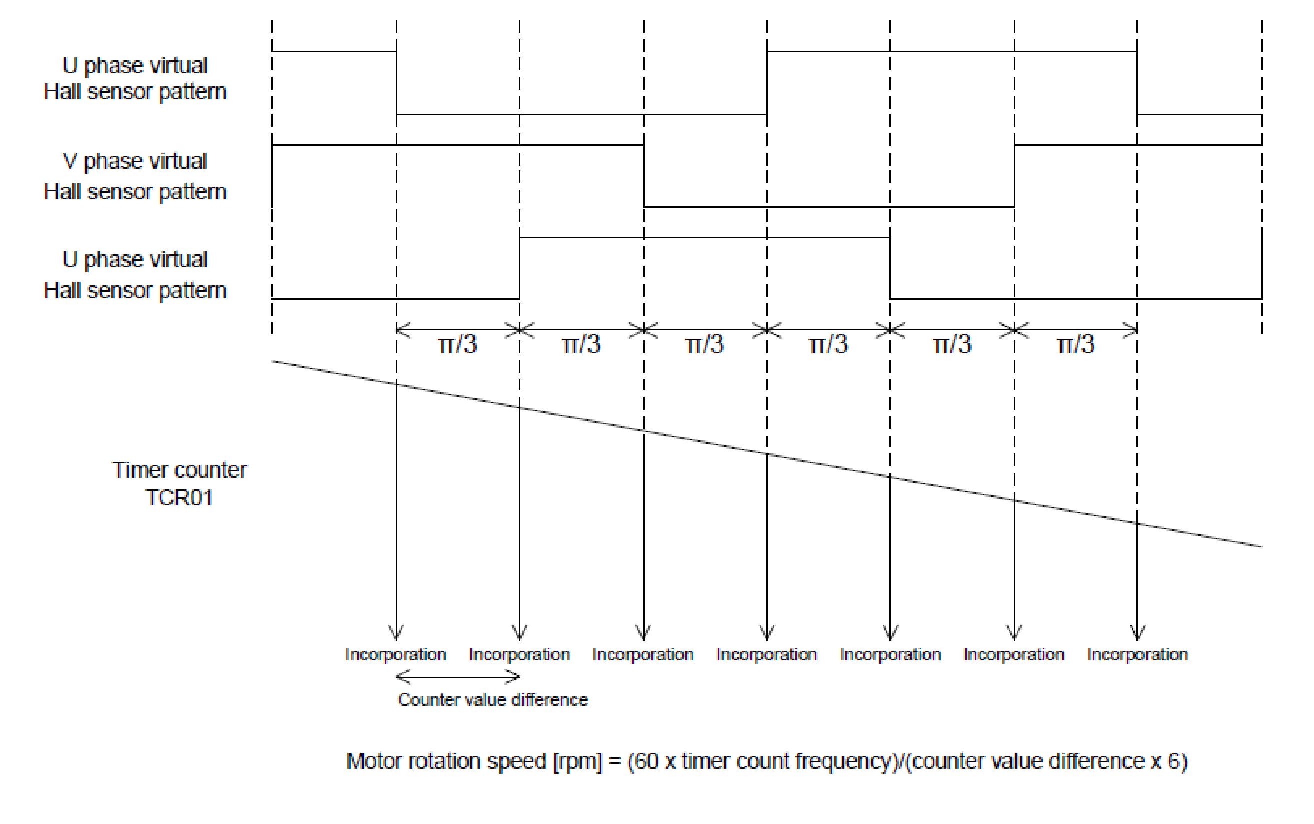


3.5 Speed control

In this system, the motor rotation speed is calculated from a difference between the previous and current timer values by detecting the zero-crossing, at the time of switching the patterns while having the timer of channel 1 of timer array unit performed free running.

Furthermore, in this system, the calculation result is processed LPF.

Figure 3-10 Method of calculating the motor rotation speed



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

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

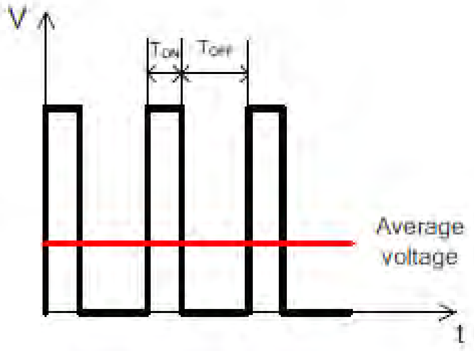
V: Command value voltage err: Deviation of rotation speed command value and rotation speed calculation value

K_P: Proportional gain K_I: 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 Figure 3-11.

Figure 3-11 PWM control

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



Modulation factor ‘m’ is defined as follows.

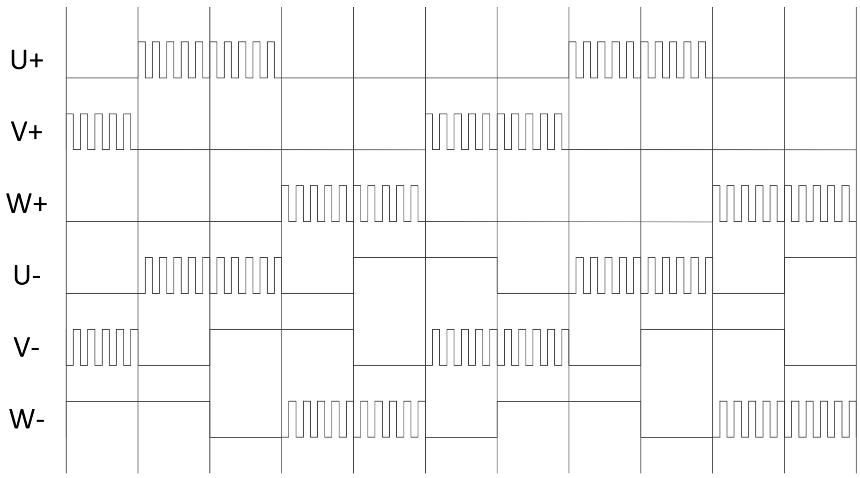
$$m = \frac{V}{E}$$

m : Modulation factor V: Command value voltage E: Inverter bus voltage

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

In this system, complementary PWM chopping (120 degrees) is adopted and thus output voltage and speed are controlled. An example of motor control signal output waveforms at the time of complementary PWM is given in Figure 3-12.

Figure 3-12 Waveform of complementary PWM chopping (120 degrees)



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
- 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
INTP0	Valid edge	Falling edge	Over current detection
	Interruption priority level	0	

4.2 A/D converter function

A/D converter converts the analog input to digital value. The target microcontroller (RL78/F14), incorporates one circuit of 10bit A/D converter. Analog input of twelve 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.

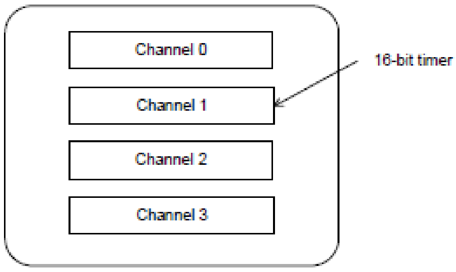
Table 4-2 A/D converter setting details

Channel	Item	Content	Usage
ANI8	Conversion time	3.563 [us]	Inverter bus voltage
	Channel selection mode	Select mode	
	Conversion operation mode	One-shot conversion mode	
	Conversion starting conditions	Software trigger	

4.3 Timer Array Unit TAUS function

The Timer Array Unit TAUS consists of four 16bit timers. Each 16-bit timer 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



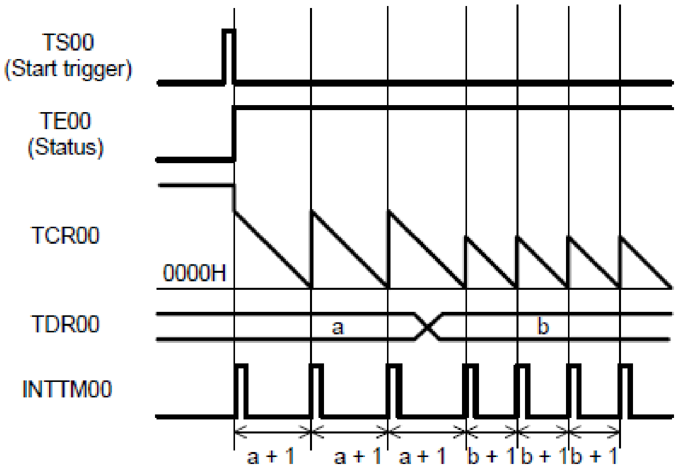
In this system, the Timer Array Unit is set as given in Table 4-3.

Table 4-3 Timer Array Unit Setting Details

Channel	Item	Content	Usage
Channel 0	Operation mode of timer	Interval timer	Timer for generating 1[ms]
	Source clock	CK00	
	Count clock frequency	24 [MHz]	
	Interruption cycle	1 [ms]	
	Setting value of Timer data resistor 0 (TDR00)	23999(1 [ms]/(1/24 [MHz]))－1)	
Channel 1	Operation mode of timer	Interval timer	Timer for speed calculation
	Source clock	CK01	
	Count clock frequency	93.75 [kHz]	
	Interruption cycle	Not use	
	Setting value of Timer data resistor 0 (TDR00)	65535	

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

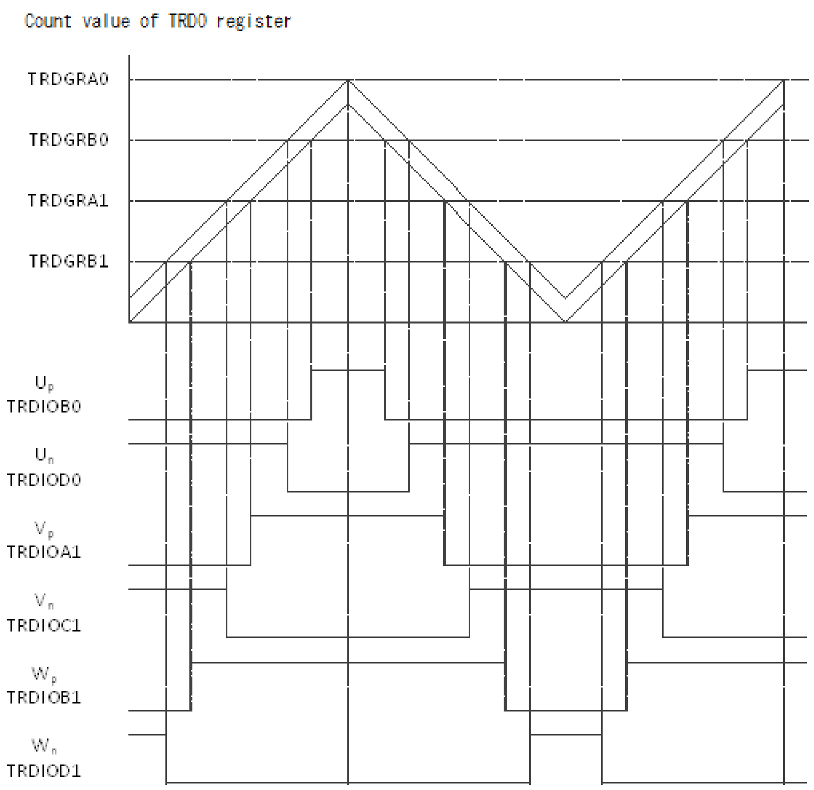
Timer used	Item	Content	Usage
Timer RD	Mode used	Complementary PWM mode	6 phase PWM output
	PWM cycle	100 [us]	
	Dead time	2.0 [us]	
	Count frequency	48 [MHz]	
	Output level	Initial output is ”Low”, Active level is ”High”	
	Buffer operation	Valid	
	Pulse output forced shutdown control	Valid (Output value at the time of shutdown: Hi-Z)	
	Output port	Refer to Figure 4-3	

Note:

In complementary PWM 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 complementary PWM mode



4.5 Calculation of PWM duty setting using modulation factor

This part summarizes how to set duty in complementary PWM mode.

As first, calculate positive phase active level width by using modulation rate in section 3.5. Next, calculate setting value of TRDGRB0, TRDGRA1, and TRDGRB1 registers that output positive phase active level width.

Positive phase active level width = PWM cycle * modulation rate

TRDGRB0 = TRDGRA1 = TRDGRB1 = TRDGRA1 - TRD0 + 1 - Positive phase active level width

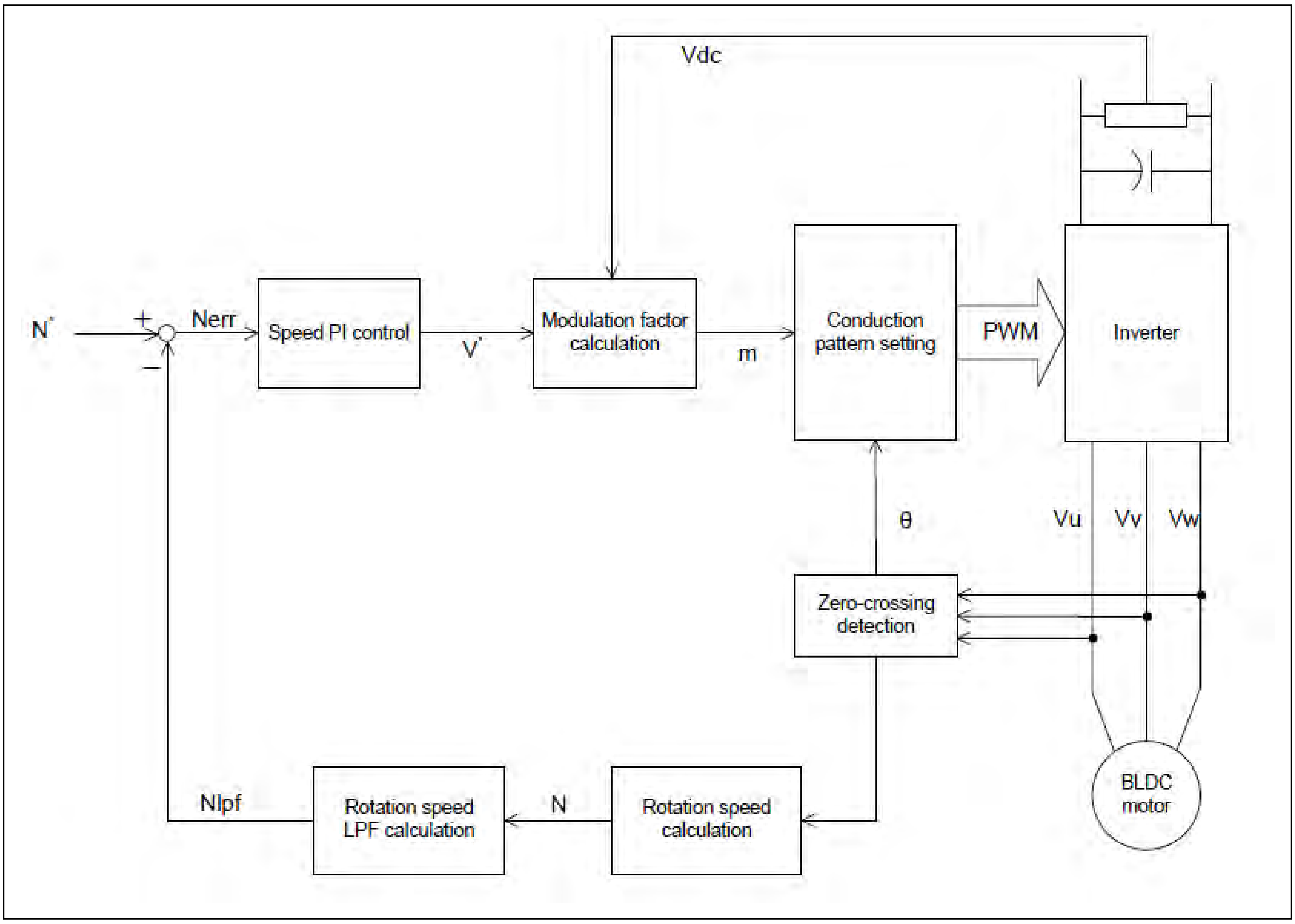
5. Description of control program

Control program of this system is explained here.

5.1 Control block diagram

In the sample program, a motor is driven by open loop control. After that, control is performed according to the following block diagram.

Figure 5-1 Control block diagram



Name	Meaning
N	Rotation speed
Nlpt	Rotation speed after LPF
N*	Rotation speed command value
Nerr	Rotation speed deviation
V*	Voltage command value
Vdc	Inverter bus voltage
m	Modulation factor
PWM	PWM output signal
Vu, Vv, Vw	Phase voltage
Hu, Hv, Hw	Hall sensor signal
θ	Rotor position

Function is given below.

(1) Position detection of permanent magnet

Permanent magnetic position is detected by the zero-crossing of each phase of U, V and W.

(2) Rotation speed calculation

Rotation speed is calculated form the timer counter (TCR01) at the timing of detecting zero-crossing. 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 of inverter from breakage due to over current, over voltage, and over speed.

5.2 Contents of control

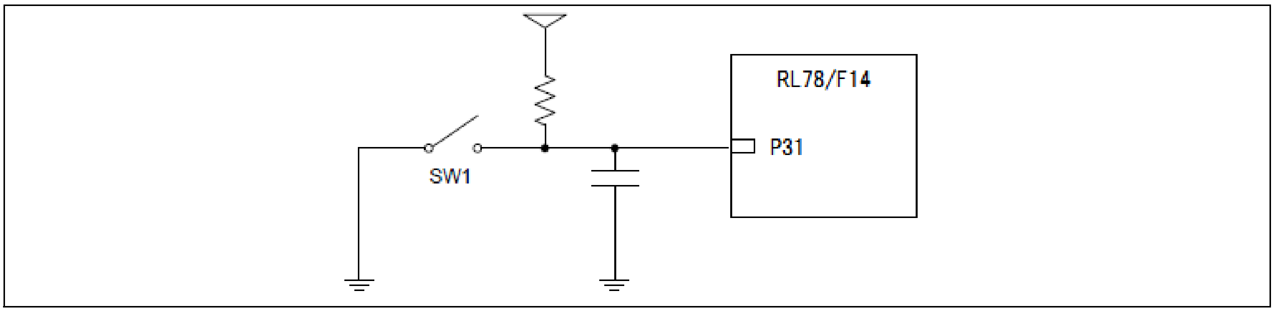
5.2.1 Motor start/stop

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

A general-purpose port (P31) is assigned to SW1. The sample program reads the P31 port within the main loop. When SW1 is pushed short time, it is judged that the start switch is on. On the other hand, when SW1 is pushed long time, the program determined to stop the motor.

When push SW1 while the motor is start, a rotation speed command value is changed by software.

Figure 5-2 Conceptual diagram of start switch external circuit



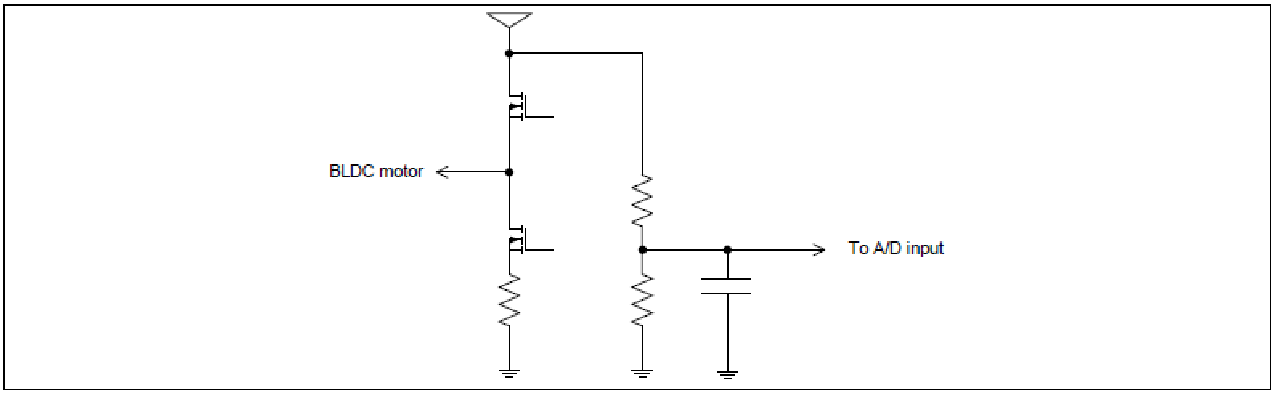
5.2.2 Inverter bus voltage

Inverter bus voltage is measured as given in Table 5-1. It is use for modulation factor calculation san overvoltage detection. (When an overvoltage is detected, PWM is stopped.)

Table 5-1 Inverter voltage conversion ratio

Item	Conversion ratio (Inverter voltage Vdc: A/D conversion value)	Channel
Inverter bus voltage	0 [V] to 26 [V] : 000H to 03FFH	ANI8

Figure 5-3 Conceptual diagram of inverter voltage measurement external circuit



5.2.3 3 phase voltage of motor

(1) U, V, W phase voltage

Voltage of U, V and W phase is calculated and is used for zero-crossing judgment by comparator.

5.2.4 Rotation speed operations

The rotation speed is calculated by using zero-crossing detection and free run timer (TAUS channel 01). In the timing of pattern switching by zero-crossing detection, counter value of free run timer is obtained from on the difference with the previously obtained value. Based on the difference sped is calculated by the following formula.

Rotation speed (N) = (60 * 93.75 [kHz]) / {(last counter value – current counter value) * 6}

Notes:

1. 93.75 [kHz] = (count click frequency of free-run timer)
2. (*6) is done at the period of obtaining the counter value is ‘pi /3’.

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

5.2.5 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): 0.00001
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.

5.2.6 System protection function

This control program has the following 5 types of error status and enables emergency stop functions in case of occurrence of respective error.

- Pre-driver error

The error signal (ERR1 and ERR2) of over voltage error, under voltage error and short detection error from pre-driver is monitored with general ports, CPU performs emergency stop.

The ERR1 use P60, the ERR2 use P61. A kind of external notification errors and combination of terminals are shown in Table 5-2.

Table 5-2 A kind of external notification errors and combination of terminals

A kind of errors	ERR1 (P60)	ERR2 (P61)
Over voltage detection	Low	High
Under voltage detection	Low	Low
short detection	High	Low
No Error	High	High

- Over current error

An emergency stop signal (overcurrent detection) from hardware forces the program to execute high impedance output to PWM the output port (emergency stop without involving CPU). The INTP0 port is used.

- 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 33000 [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.

- Induced voltage signal pattern error

The patterns created from each phase voltage of U, V and W are monitored. When an error pattern is detected, CPU performs emergency stop.

5.3 System resources

5.3.1 Interruption

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

Table 5-3 Interruption resources

Interruption	Interruption handler	Interruption occurrence condition	Main function
Carrier synchronous (INTTRD0)	void mtr_carrier_interrupt(void)	100 [us] (10 [kHz])	- Zero-crossing detection processing - Conducting pattern switching - Rotation speed operation - Clearing the motor stop determination counter value
Interval timer interruption (INTTM00)	void mtr_tau0_interrupt(void)	1 [ms] (1 [kHz])	- Speed PI control - Error monitoring - Control start time measurement
Over current detection interruption (INTP0)	void mtr_over_current_interrupt(void)	Over current detection	- Over current 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 settings

Channel	Measurement signal	Range of setting value	Remark
ANI8	Inverter bus voltage	26 [V] / 5 [V]	Used in modulation factor calculation, over voltage protection

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	P73	Comparator signal input (U phase)	
	P72	Comparator signal input (V phase)	
	P00	Comparator signal input (W phase)	
	P60	ERR1 port input	
	P61	ERR2 port input	
	P31	SW1 port input	Change motor speed
Output	P140	MUTE port control signal output	
	P125	U phase upper arm motor control signal port output (Up)	Logic setting is ‘High’ active.
	P120	U phase lower arm motor control signal port output (Un)	
	P15	V phase upper arm motor control signal port output (Vp)	
	P16	V phase lower arm motor control signal port output (Vn)	
	P17	W phase upper arm motor control signal port output (Wp)	
	P30	W phase lower arm motor control signal port output (Wn)	

5.3.4 PWM output part

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

Table 5-6 PWM signal

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 List of control functions (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
	check_sw() Input: (uint8) sw_mode / current SW mode Output: (uint8) sw_mode / current SW mode	Obtaining the SW pushed status.
	change_ref_speed_in_stages() Input: None Output: None	Change reference speed in stages.
mtr_ctrl_board_interface.c	get_sw1() Input: None Output: (uint8) tmp_port / level of SW1	Obtaining the status of SW1
mtr_ssns_less_120.c	R_MTR_InitSequence() Input: None Output: None	Initialization for 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 - Wait motor stop
	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 - Conducting pattern determination - Motor control signal creation function call

Table 5-7 List of control functions (2/3)

File name	Function overview	Processing overview
mtr_ssns_less_120.c	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
	mtr_detect_zerocross() Input: None Output: None	- zero-crossing detection - create timing of conducting pattern modification
	mtr_25108_err() Input: None Output: None	Error detection from pre-driver (overvoltage, under voltage, short detection)
	get_comparator_signal() Input: None Output: None	U, V, W phases comparator data
mtr_interrupt.c	mtr_over_current_interrupt () Input: None Output: None	- Motor control error function call
	mtr_tau0_interrupt() Input: None Output: None	- Error check Function call - Calling speed PI control function every 5 [ms] - Open loop starting control
	mtr_carrier_interrupt() Input: None Output: None	- zero-crossing detection function call - Compare match flag (IFMA) clear function call

Table 5-7 List of control functions (3/3)

File name	Function overview	Processing overview
mtr_ctrl_rl78f14.c	R_MTR_InitHardware() Input: None Output: None	Initializing clock and peripheral functions
	R_MTR_InitClock() Input: None Output: None	Initializing clock
	R_MTR_InitIoPort() Input: None Output: None	Initializing I/O ports
	R_MTR_InitTAU() Input: None Output: None	Initializing timer array unit
	R_MTR_InitTRD() Input: None Output: None	Initializing timer RD
	R_MTR_InitADC() Input: None Output: None	Initializing A/D convertor
	R_MTR_InitExtInt() Input: None Output: None	Initializing external interrupts
	init_ui() Input: None Output: None	Initializing user usage peripheral functions
	mtr_ctrl_start() Input: None Output: None	Starting TAU0
	mtr_ctrl_stop() Input: None Output: None	- Stopping timer RD - Stopping TAU0 - Changing the motor control output port to inactive status - Waiting motor stop
	mtr_ctrl_error() Input: None Output: None	- Stopping timer RD - Stopping TAU0 - Changing the motor control output port to inactive status
	mtr_change_pattern() Input: (uint8)pattern / conducting pattern Output: None	- Setting output pattern - 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	Executing A/D conversion
	clear_wdt() Input: None Output: None	Clearing the watchdog timer
	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

Variable name	Type	Content	Remark
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_u1_openloop_period	uint8	Period of open-loop drive	-
g_u1_cnt_openloop_period	uint8	Counter of period for open-loop drive	-Counter of 1[ms] interrupt
g_u1_cnt_openloop_pattern	uint8	Counter of changing pattern for open-loop drive	-
g_u1_cnt_openloop_duty	uint8	Duty counter	Counter for the number of the times of duty value addition
g_u1_cnt_stabilize_time	uint8	Stabilization time counter	Counter for stabilization time after duty adjust
g_u2_cnt_wait_stop	uint16	Counter for waiting for motor stop	Counter for waiting for motor stop
g_u1_flg_wait_stop	uint8	Motor stop waiting flag	0: Not motor stop waiting state 1: Motor stop waiting state
g_u2_run_mode	uint16	Operation mode management	0: Initialization mode 1: Open loop mode 3: Normal operation mode
g_u1_error_status	uint8	Error status management	1: Overcurrent error 2: Overvoltage error 3: Over speed error 4: Timeout error 7: Induction voltage pattern error 8: Under voltage error 9: Short error (0xff: Non-definition error)
g_u1_mode_system	uint8	State management	0: Stop mode 1: Run mode 2: Error mode
g_u1_chattering	uint8	Counter of chattering time	For chattering removal
g_u1_phase_u	uint8	U phase voltage level	0: Low level 1: High level
g_u1_phase_v	uint8	V phase voltage level	0: Low level 1: High level
g_u1_phase_w	uint8	W phase voltage level	0: Low level 1: High level
g_u1_phase_u_buf	uint8	Buffer of U phase voltage level	0: Low level 1: High level
g_u1_phase_v_buf	uint8	Buffer of V phase voltage level	0: Low level 1: High level
g_u1_phase_w_buf	uint8	Buffer of W phase voltage level	0: Low level 1: High level

5.6 Macro definitions

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

Table 5-9 Macro definitions list (1/6)

File name	Macro name	Definition value	Remark
main.h	SW_ON	0	active level
	SW_OFF	1	inactive level
	SW_MODE_NONE	0	SW1 is not pushed
	SW_MODE_SHORT	1	SW1 pushed short time
	SW_MODE_LONG	2	SW1 pushed long time
	CHATTERING_CNT	100	Chattering removal
	PUSH_CNT	0xF000	Using for judge SW1 pushed long time
	PUSH_CNT_CLR	0x0000	Counter clear value
	SOFT_STOP_SPEED	0	0 speed [rpm] (mechanical angle)
	SOFT_MIN_SPEED	1000	min speed [rpm] (mechanical angle)
	SOFT_MAX_SPEED	3500	max speed [rpm] (mechanical angle)
	SOFT_DIFF_SPEED	500	increment / decrement difference speed [rpm] (mechanical angle)
	REF_SPEED_DECEL	0	deceleration reference speed
	REF_SPEED_ACCEL	1	acceleration reference speed

Table 5-9 Macro definitions list (2/6)

File name	Macro name	Definition value	Remark
mtr_ctrl_rl78f14.h	MTR_PWM_TIMER_FREQ	48	Timer RD count frequency [MHz]
	MTR_TAU1_FREQ	93750	Timer Array Unit channel 1 count frequency [Hz]
	MTR_PORT_MODE_UP	P12.5	U phase port mode
	MTR_PORT_MODE_UN	P12.0	U phase port mode
	MTR_PORT_MODE_VP	P1.5	V phase port mode
	MTR_PORT_MODE_VN	P1.6	V phase port mode
	MTR_PORT_MODE_WP	P1.7	W phase port mode
	MTR_PORT_MODE_WN	P3.0	W phase port mode
	MTR_PORT_MODE_CTL_UP	PMC12.0	Port mode control
	MTR_PORT_MODE_CTL_UN	PMC12.5	Port mode control
	MTR_PORT_UP	P12.5	U phase (positive phase) output port
	MTR_PORT_UN	P12.0	U phase (negative phase) output port
	MTR_PORT_VP	P1.5	V phase (positive phase) output port
	MTR_PORT_VN	P1.6	V phase (negative phase) output port
	MTR_PORT_WP	P1.7	W phase (positive phase) output port
	MTR_PORT_WN	P3.0	W phase (negative phase) output port
	MTR_TAU1_CNT	TCR01	Timer count register for speed measurement
	MTR_PORT_MODE_ERR1	PM6.0	input port mode of ERR1
	MTR_PORT_MODE_ERR2	PM6.1	input port mode of ERR2
	MTR_PORT_ERR1	P6.0	input port of ERR1
	MTR_PORT_ERR2	P6.1	input port of ERR2
	MTR_PORT_PULLUP_ERR1	PU6.0	port pull up of ERR1
	MTR_PORT_PULLUP_ERR2	PU6.1	port pull up of ERR2
	MTR_PORT_MODE_SW1	PM3.1	input port mode of SW1
	MTR_PORT_SW1	P3.1	input port of SW1
	MTR_PORT_PULLUP_SW1	PU3.1	input port pullup of SW1
	MTR_PORT_MODE_MUTE	PM14.0	output port mode of MUTE
	MTR_PORT_MUTE	P14.0	output port of MUTE
	MTR_PORT_MODE_COMP_U	PM7.3	U phase comparator port mode
	MTR_PORT_MODE_COMP_V	PM7.2	V phase comparator port mode
	MTR_PORT_MODE_COMP_W	PM0.0	W phase comparator port mode
	MTR_PORT_COMP_U	P7.3	U phase comparator output port
	MTR_PORT _COMP_V	P7.2	V phase comparator output port
	MTR_PORT _COMP_W	P0.0	W phase comparator output port
	MTR_PORT_MODE_CTL_V	PMC7.2	Port mode control
	MTR_PORT_MODE_CTL_W	PMC7.3	Port mode control
	MTR_PORT_MODE_ADCCH_VDC	PM8.6	input port mode of ADC (VDC)
	MTR_ADCCH_VDC	8	VDC voltage A/D conversion channel
	MTR_MAX_VDC	12	Limit of the voltage command value [V]
	MTR_VDC_RESOLUTION	26 / 1023	Inverter bus voltage resolution

Table 5-9 Macro definitions list (3/6)

File name	Macro name	Definition value	Remark
mtr_ssns_less_120.h	MTR_CARRIER_FREQ	10.0f	PWM carrier frequency [kHz]
	MTR_DEADTIME_US	2.0f	Dead time value [us]
	MTR_START_DUTY	15	PWM duty initial value [%]
	MTY_OPENLOOP_CHANGE_DUTY_CNT	15	The number of the times of duty value addition
	MTY_OPENLOOP_CHANGE_DUTY_OFFSET	6	The one time of additional value of duty
	MTY_OPENLOOP_STABILIZE_TIME	39	The number of stabilization time after duty value adjust
	MTR_OPENLOOP_START_PERIOD	25	Default open-loop drive period
	MTR_OPENLOOP_CHANGE_CNT	84	The number of pattern changes in the same frequency (open-loop)
	MTR_CHANGE_MODE_PERIOD	15	changing period open-loop drive to sensorless drive
	MTR_PATTERN_CW_U_V	3	CW conducting pattern value
	MTR_PATTERN_CW_U_W	1	
	MTR_PATTERN_CW_V_W	5	
	MTR_PATTERN_CW_V_U	4	
	MTR_PATTERN_CW_W_U	6	
	MTR_PATTERN_CW_W_V	2	
	MTR_PATTERN_CCW_U_V	2	CCW conducting pattern value
	MTR_PATTERN_CCW_W_V	6	
	MTR_PATTERN_CCW_W_U	4	
	MTR_PATTERN_CCW_V_U	5	
	MTR_PATTERN_CCW_V_W	1	
	MTR_PATTERN_CCW_U_W	3	

Table 5-9 Macro definitions list (4/6)

File name	Macro name	Definition value	Remark
mtr_ssns_less_120.h	MTR_SPEED_PI_DECIMATION	4	Speed PI control decimation count
	MTR_SPEED_PI_KP	0.00001f	Proportional term gain
	MTR_SPEED_PI_KI	0.00001f	Integral term gain
	MTR_AVG_OLD	0.3f	LPF previous value filter coefficient
	MTR_CARRIER_SET	(1000 / MTR_CARRIER_FREQ * MTR_PWM_TIMER_FREQ - 1)	Set value of carrier wave frequency
	MTR_PWM_DEAD_TIME	(MTR_PWM_TIMER_FREQ * MTR_DEADTIME_US)	Dead time (period)
	MTR_START_DUTY_SET	(((((MTR_CARRIER_SET + 1) / 100) * MTR_START_DUTY) / 2) + MTR_PWM_DEAD_TIME - 1)	Set value of default duty
	MTR_PWM_PERIOD	(((MTR_CARRIER_SET + 1) / 2) + MTR_PWM_DEAD_TIME)	Set value of PWM period (Set to TRDGA0 register)
	MTR_RATE_DUTY	(MTR_START_DUTY / 100)	Set value of initial voltage
	MTR_MAX_PWM_DUTY	((((MTR_CARRIER_SET + 1) / 100) * 95) - 1)	Max limit value of duty (95%)
	MTR_MIN_PWM_DUTY	((((MTR_CARRIER_SET + 1) / 100) * 5) - 1)	Min limit value of duty (5%)
	MTR_SPEED_LIMIT	33000	Over speed limit(electrical angle)[rpm]
	MTR_OVERVOLTAGE_LIMIT	15	Over voltage limit[V]
	MTR_TIMEOUT_CNT	20	Undetected time = MTR_TIMEOUT_CNT * 1[ms]
	MTR_SHIFT_ADJUST	1	Constant for adjust conducting pattern change timing
	MTR_RPM_CALC_BASE	(60 * MTR_TAU1_FREQ / 6)	Constant for speed measurement: 60[sec] * TAU1 timer frequency[Hz] / 6(times)
	MTR_OVERSIZE_LIMIT	38	Speed deviation minimum value
	MTR_STOP_WAIT_CNT	200	TAU0 interrupt period(50[us]) * MTR_STOP_WAIT_CNT = motor stop waiting time

Table 5-9 Macro definitions list (5/6)

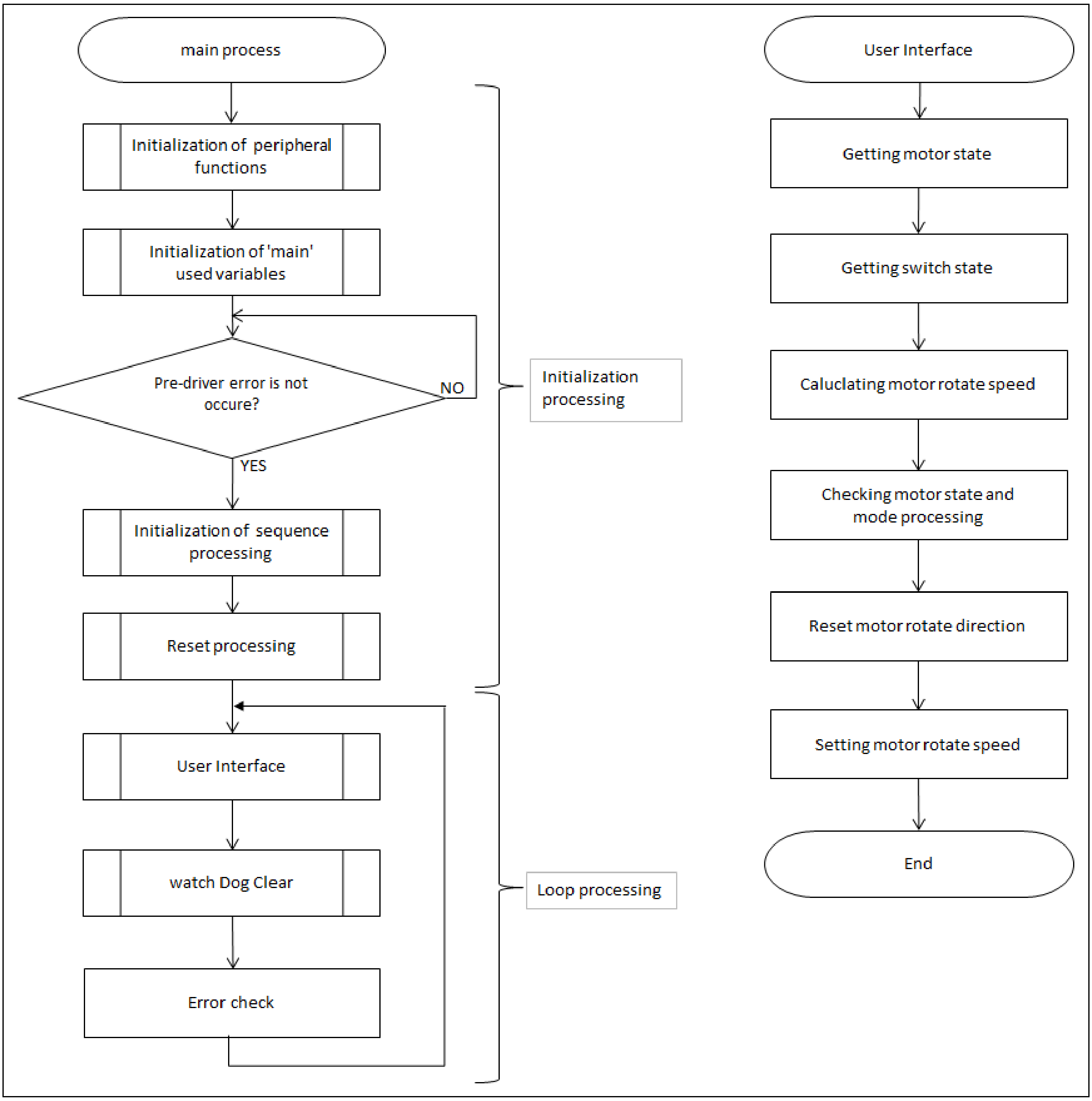
File name	Macro name	Definition value	Remark
mtr_ssns_less_120.h	MTR_PATTERN_ERROR	0	Conducting pattern
	MTR_U_PWM_VN_ON	1	
	MTR_V_PWM_WN_ON	2	
	MTR_W_PWM_UN_ON	3	
	MTR_U_PWM_WN_ON	4	
	MTR_V_PWM_UN_ON	5	
	MTR_W_PWM_VN_ON	6	
	MTR_CW	0	CW
	MTR_CCW	1	CCW
	MTR_AVG_NEW	(1 - MTR_AVG_OLD)	factor of weighted average
	MTR_OVERSIZE_LIMIT	38	Speed deviation minimum value
	MTR_FLG_CLR	0	for flag clear
	MTR_FLG_SET	1	for flag set
	MTR_STOP_WAIT_CNT	200	motor stop waiting time = TAU0 interrupt period(50[us]) * MTR_STOP_WAIT_CNT
	MTR_POLE_PAIR	8	pole pairs

Table 5-9 Macro definitions list (6/6)

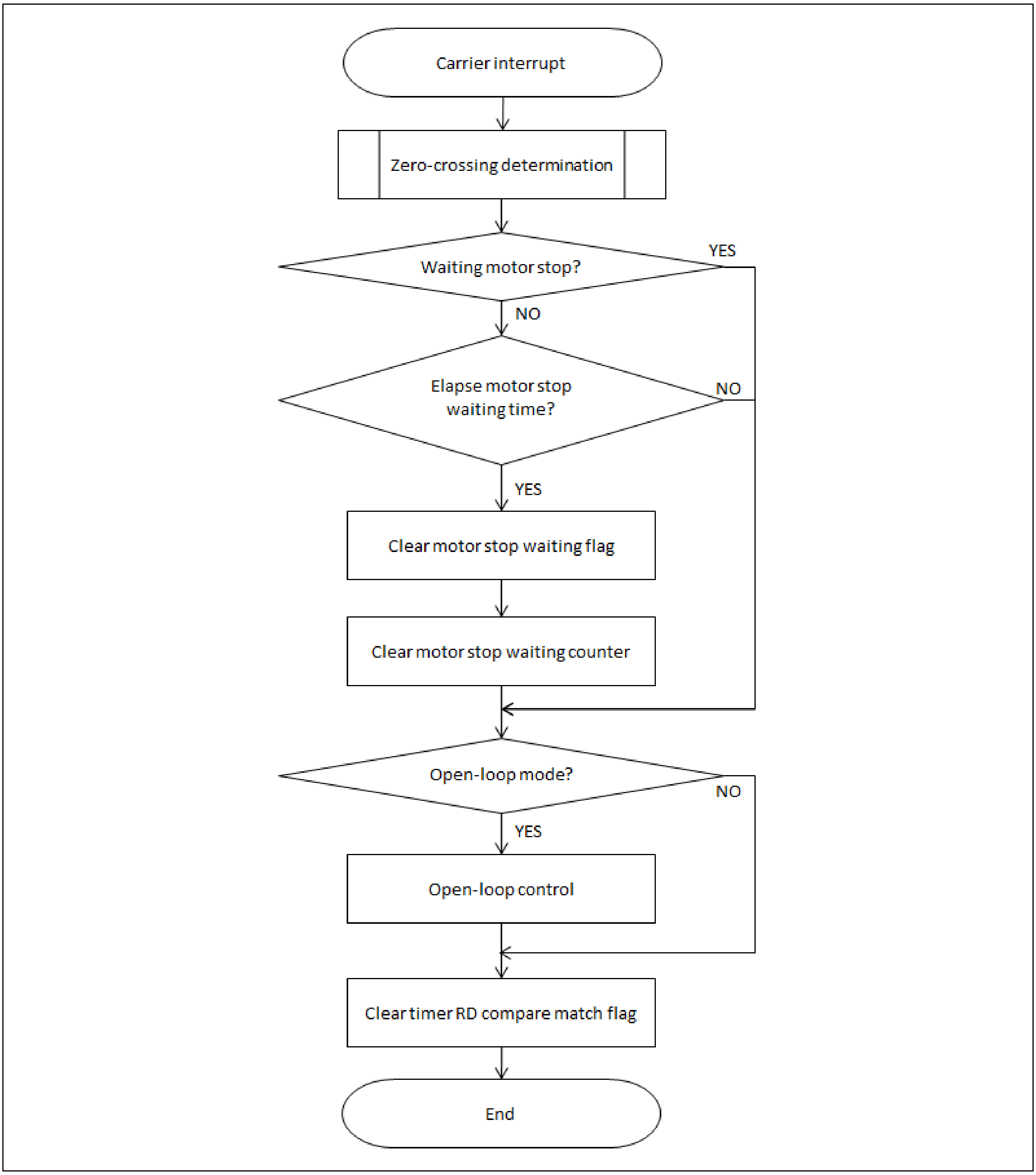
File name	Macro name	Definition value	Remark
mtr_ssns_less_120.h	MTR_INITIAL_MODE	0x00	Initialization mode
	MTR_OPENLOOP_MODE	0x01	Open loop mode
	MTR_BEMF_120_MODE	0x03	Sensorless operation mode
	MTR_OVER_CURRENT_ERROR	1	Overcurrent error
	MTR_OVER_VOLTAGE_ERROR	2	Overvoltage error
	MTR_OVER_SPEED_ERROR	3	Rotation speed abnormality error
	MTR_TIMEOUT_ERROR	4	Timeout error
	MTR_BEMF_ERROR	7	Induced voltage pattern error
	MTR_UNDER_VOLTAGE_ERROR	8	Under voltage error
	MTR_SHORT_ERROR	9	Short 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)

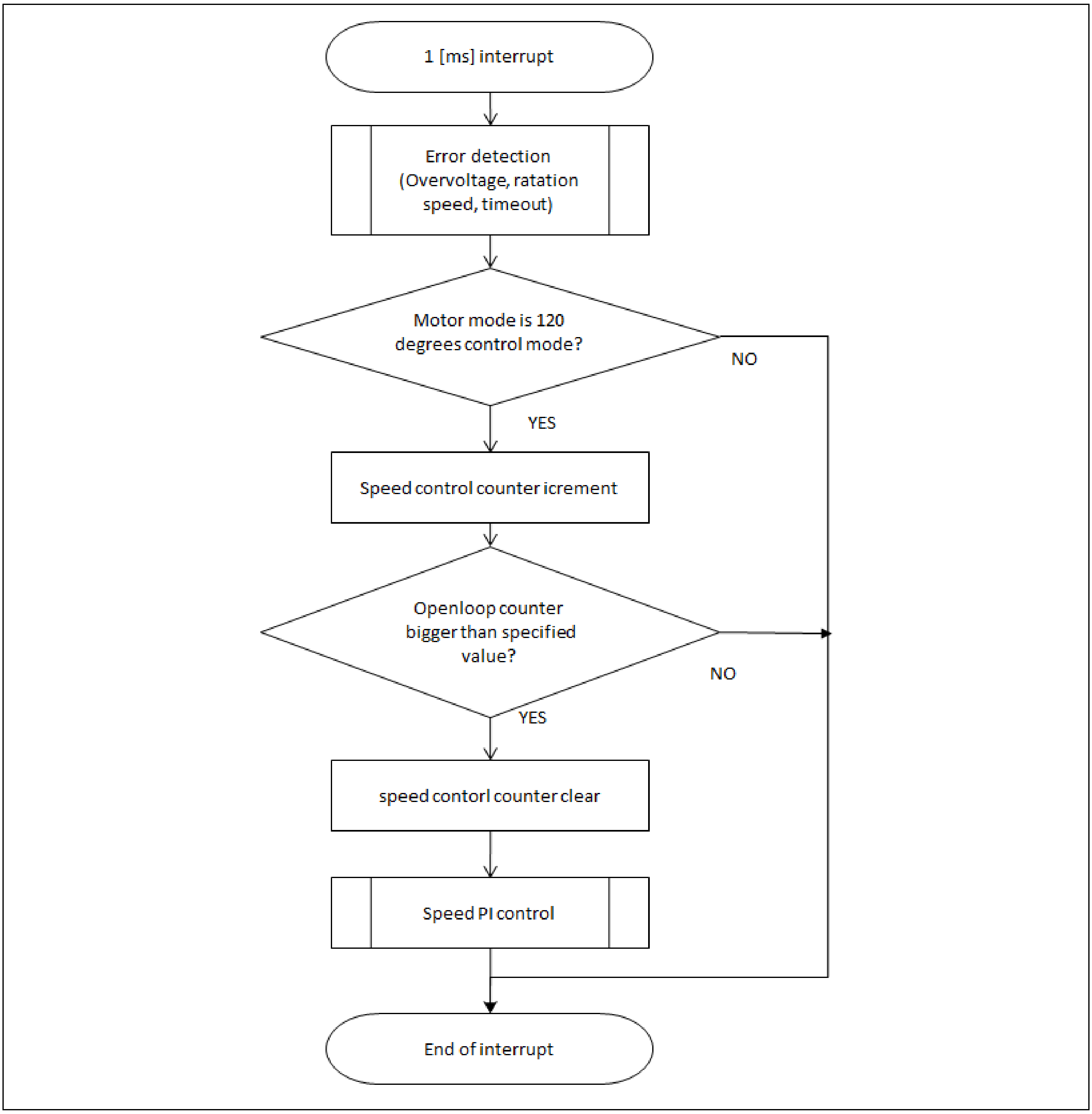
(1) Main process



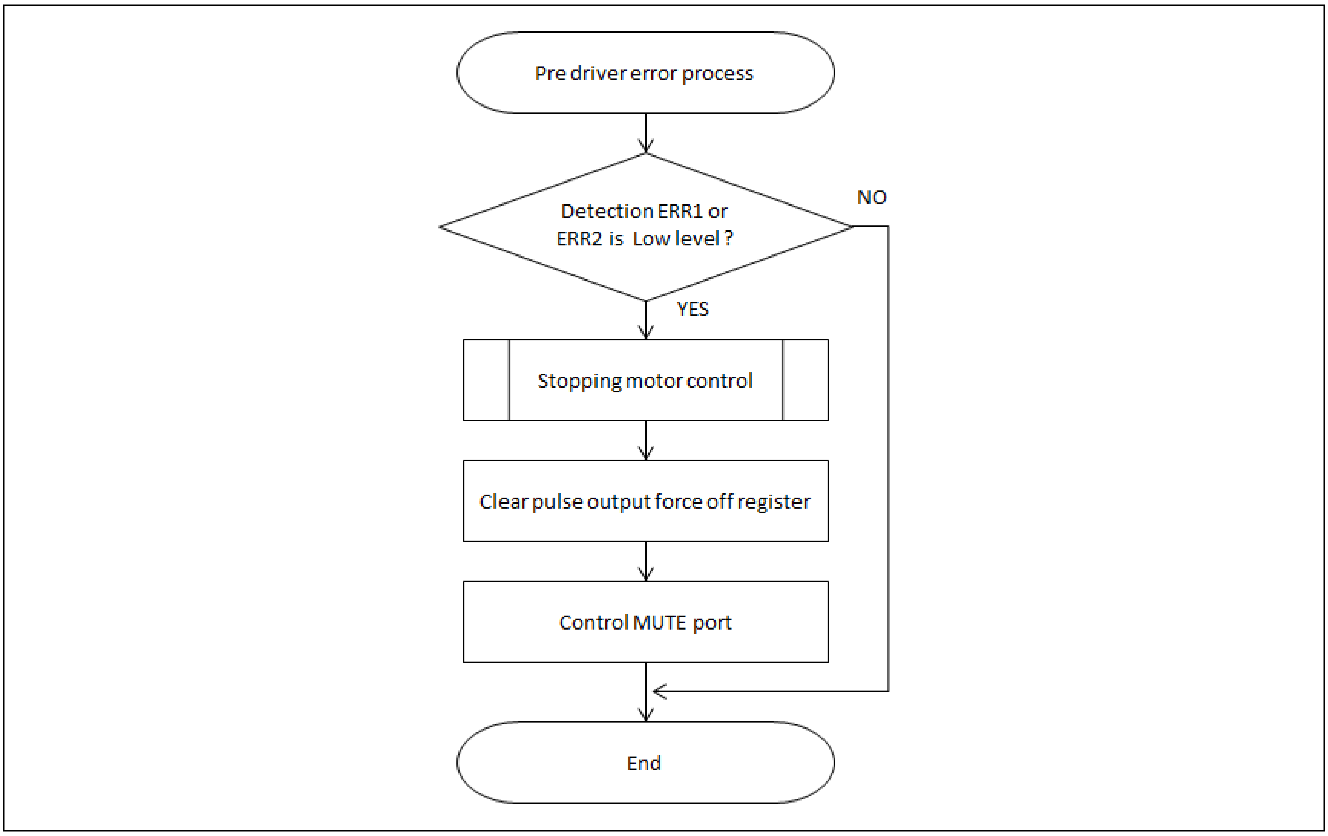
(2) Carrier cycle interruption process



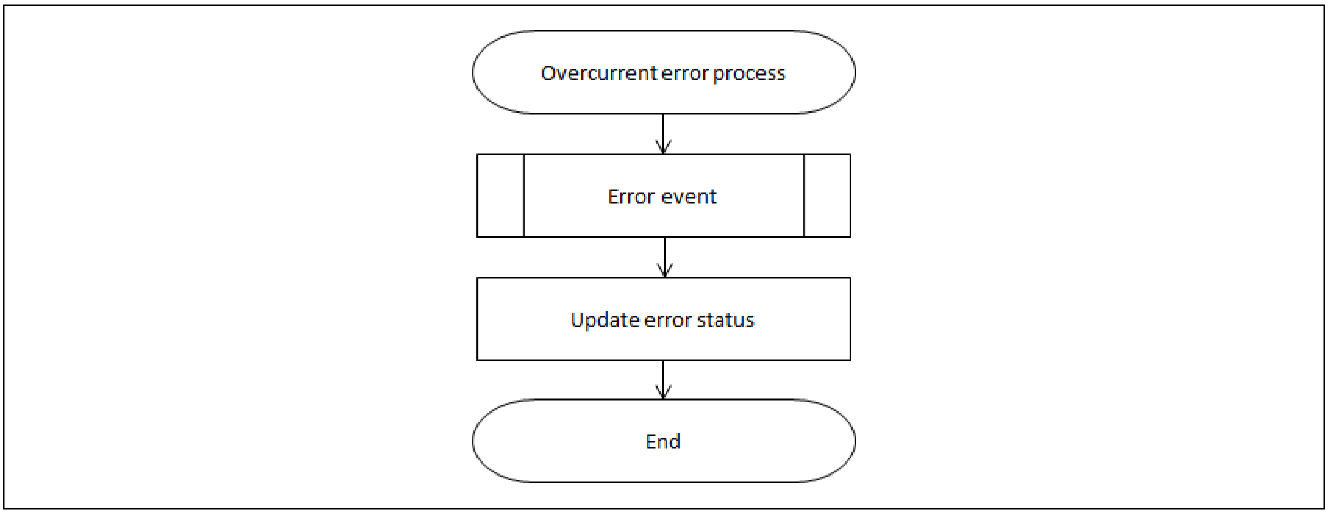
(3) 1 [ms] interruption process



(4) Pre-driver error process



(5) Overcurrent interrupts process



Website and Support

Renesas Electronics Website
http://www.renesas.com/

Inquiries
http://www.renesas.com/contact/

Revision History

Rev.	Data	Description	
		Page	Summary
1.00	Mar.31.2017	—	First edition issued

SALES OFFICES

Renesas Electronics Corporation

http://www.renesas.com

Refer to "http://www.renesas.com/" for the latest and detailed information.

Renesas Electronics America Inc.
2801 Scott Boulevard Santa Clara, CA 95050-2549, U.S.A.
Tel: +1-408-588-6000, Fax: +1-408-588-6130

Renesas Electronics Canada Limited
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3
Tel: +1-905-237-2004

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-585-100, Fax: +44-1628-585-900

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
Room 1709, Quantum Plaza, No.27 ZhiChunLu Haidian District, Beijing 100191, P.R.China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, P. R. China 200333
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

Renesas Electronics Hong Kong Limited
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2265-6688, Fax: +852 2886-9022

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics India Pvt. Ltd.
No.777C, 100 Feet Road, HAL II Stage, Indiranagar, Bangalore, India
Tel: +91-80-67208700, Fax: +91-80-67208777

Renesas Electronics Korea Co., Ltd.
12F., 234 Teheran-ro, Gangnam-Gu, Seoul, 135-080, Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5141

Colophon 6.0