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Application Note

Inverter Control by V850 Series

Vector Control by Hole Sensor

V850E/IA1
V850E/IA2
V850E/IA3
V850E/IA4
V850E/MA3

Document No. U17338EJ1V0AN00 (1st edition)
Date Published December 2004 N CP(K)

[MEMO]

NOTES FOR CMOS DEVICES

① VOLTAGE APPLICATION WAVEFORM AT INPUT PIN

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

② HANDLING OF UNUSED INPUT PINS

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

③ PRECAUTION AGAINST ESD

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

④ STATUS BEFORE INITIALIZATION

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

⑤ POWER ON/OFF SEQUENCE

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

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

⑥ INPUT OF SIGNAL DURING POWER OFF STATE

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

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

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- Product release schedule
- Availability of related technical literature
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INTRODUCTION

Target Readers

This application note is intended for users who understand the functions of the V850E/IA1, V850E/IA2, V850E/IA3, V850E/IA4, and V850E/MA3, and who design application systems that use these microcontrollers. The applicable products are shown below.

- V850E/IA1
  Standard products: μPD703116, 70F3116
  Special products: μPD703116(A), 703116(A1), 70F3116(A), 70F3116(A1)
- V850E/IA2:
  Standard products: μPD703114, 70F3114
  Special products: μPD703114(A), 70F3114(A)
- V850E/IA3
  Standard products: μPD703183, 70F3184
- V850E/IA4
  Standard products: μPD703185, 703186, 70F3186
- V850E/MA3
  Standard products: μPD703131, 703131A, 703131Y, 703131AY, 703132, 703132A, 703132Y, 703132AY, 703133, 703133A, 703133Y, 703133AY, 703134, 703134A, 703134Y, 703134AY, 70F3134, 70F3134A, 70F3134Y, 70F3134AY

Purpose

The purpose of this application note is to help the user understand how a vector is controlled by the hole sensor using a brushless DC motor that uses PWM output and A/D converter input as a system example of the timer/counter function of the V850E/IA1, V850E/IA2, V850E/IA3, V850E/IA4, and V850E/MA3.

Organization

This application note is divided into the following sections.

- Control method
- Hardware configuration
- Software configuration
- Program list

How to Use This Manual

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

Cautions 1. Application examples in this manual are intended for the "standard" quality models for general-purpose electronic systems. When using an example in this manual for an application that requires the "special" quality grade, evaluate each component and circuit to be actually used to see if they satisfy the required quality standard.

2. To use this manual for special-grade products, read the part numbers as follows:

μPD703114 → μPD703114(A)
μPD70F3114 → μPD70F3114(A)
μPD703116 → μPD703116(A), 703116(A1)
μPD70F3116 → μPD70F3116(A), 70F3116(A1)

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

→ See the **V850E/IA1 Hardware User's Manual, V850E/IA2 Hardware User's Manual, V850E/IA3, V850E/IA4 Hardware User's Manual**, and **V850E/MA3 Hardware User's Manual**.

For details of instruction functions

→ See the **V850E1 Architecture User's Manual**.

Conventions

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

Related Documents

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

Documents related to V850E/IA1, V850E/IA2, V850E/IA3, V850E/IA4, V850E/MA3

Document Name	Document No.
V850E1 Architecture User's Manual	U14559E
V850E/IA1 Hardware User's Manual	U14492E
V850E/IA2 Hardware User's Manual	U15195E
V850E/IA3, V850E/IA4 Hardware User's Manual	U16543E
V850E/MA3 Hardware User's Manual	U16397E
V850E/IA1, V850E/IA2 AC Motor Inverter Control Using Vector Operation Application Note	U14868E
Inverter Control by V850 Series 120° Excitation Method Control by Zero-Cross Detection Application Note	U17209E
Inverter Control by V850 Series Vector Control by Encoder Application Note	U17324E
Inverter Control by V850 Series Vector Control by Hole Sensor Application Note	This manual

Documents related to development tools (user's manuals)

Document Name		Document No.
IE-V850E-MC, IE-V850E-MC-A (In-Circuit Emulator for V850E/IA1, V850E/IA2)		U14487E
IE-V850E1-CD-NW (PCMCIA Card Type On-Chip Debug Emulator for V850E/IA3, V850E/IA4, V850E/MA3)		U16647E
IE-703116-MC-EM1 (In-Circuit Emulator Option Board for V850E/IA1)		U14700E
IE-703114-MC-EM1 (In-Circuit Emulator Option Board for V850E/IA2)		U16533E
CA850 Ver. 3.00 C Compiler Package	Operation	U17293E
	C Language	U17291E
	Assembly Language	U17292E
	Link Directives	U17294E
PM+ Ver. 6.00		U17178E
ID850 Ver. 2.50 Integrated Debugger	Operation	U16217E
ID850NW Ver. 2.51 Integrated Debugger (for V850E/MA3)	Operation	U16454E
ID850NWC Ver. 2.51 Integrated Debugger (for V850E/IA3, V850E/IA4, V850E/MA3)	Operation	U16525E
ID850QB Ver. 2.80 Integrated Debugger (for V850E/IA3, V850E/IA4)	Operation	U16973E
TW850 Ver. 2.00 Performance Analysis Tuning Tool (for V850E/MA3)		U17241E
SM850 Ver. 2.50 System Simulator (for V850E/IA1, V850E/IA2)	Operation	U16218E
SM850 Ver. 2.00 or Later System Simulator (for V850E/IA1, V850E/IA2)	External Part User Open Interface Specifications	U14873E
SM+ System Simulator (for V850E/IA1, V850E/IA2)	Operation	U17246E
	User Open Interface	U17247E
RX850 Ver. 3.13 or Later Real-Time OS	Basics	U13430E
	Installation	U13410E
	Technical	U13431E
RX850 Pro Ver. 3.15 Real-Time OS	Basics	U13773E
	Installation	U13774E
	Technical	U13772E
RD850 Ver. 3.01 Task Debugger		U13737E
RD850 Pro Ver. 3.01 Task Debugger		U13916E
AZ850 Ver. 3.10 System Performance Analyzer		U14410E
PG-FP4 Flash Memory Programmer		U15260E

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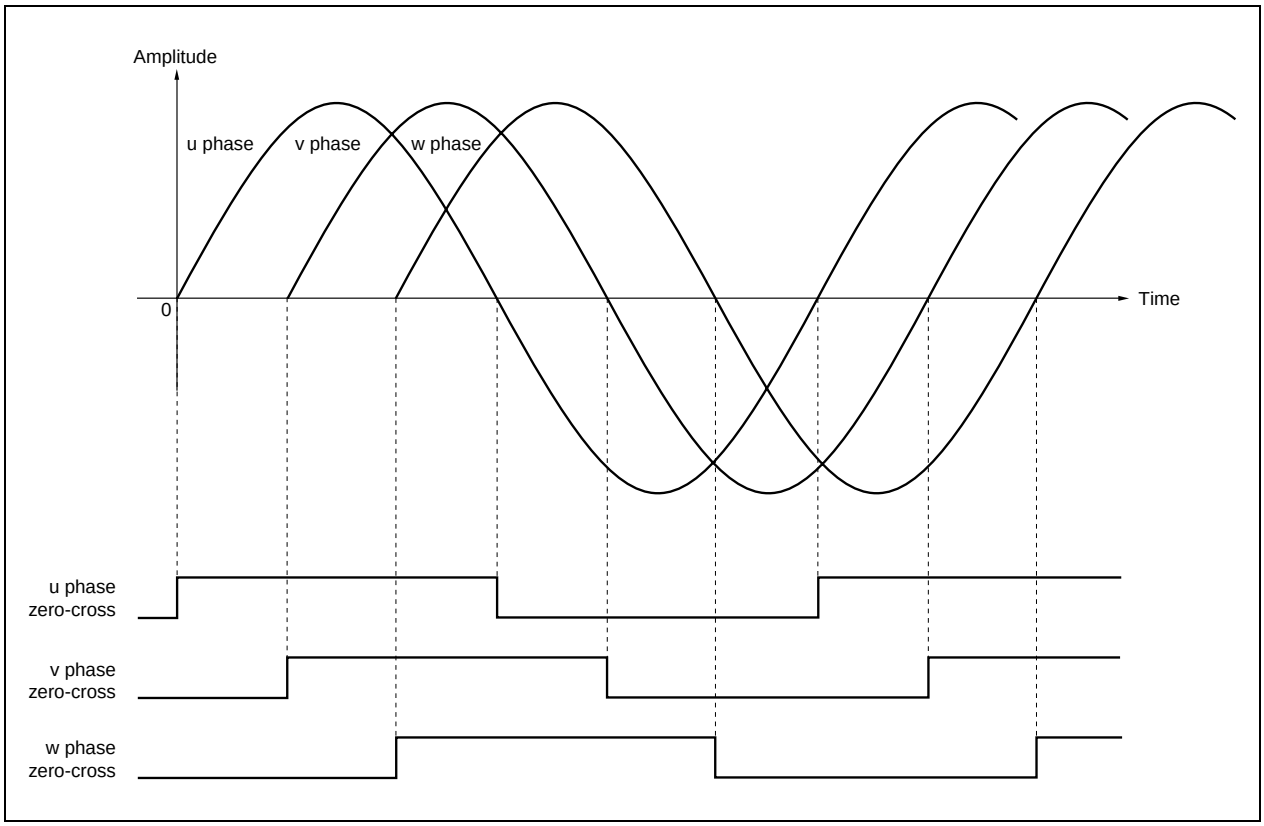
CHAPTER 1 CONTROL METHOD

1.1 Outline of Control by Hole Sensor

The detection block for position and speed detects the rotor position and speed by the zero-cross signal detected by hardware as shown in Figure 1-1, and it controls revolving only.

Figure 1-1. Zero-Cross Signal



1.1.1 Detection of rotor position

The zero-cross point shown in Figure 1-1 changes by 60°, and sets the base position. When the rotor is revolving uniformly, the speed between the previous zero-cross points and the current speed are about the same. The rotor position is estimated by the time from the zero-cross point to the current point.

1.1.2 Speed calculation

The speed is estimated by the difference between the previous rotor position and the current rotor position.

1.1.3 Initiation method

The position and speed cannot be estimated until revolving starts. Therefore, an initial revolution must be performed without control. After the power application of the previous control, the magnetic field is revolved a certain amount of times in the direction it is to be revolved with a constant voltage, and the vector control is performed from the stage where the rotor position was fixed.

1.2 Principle of Vector Control

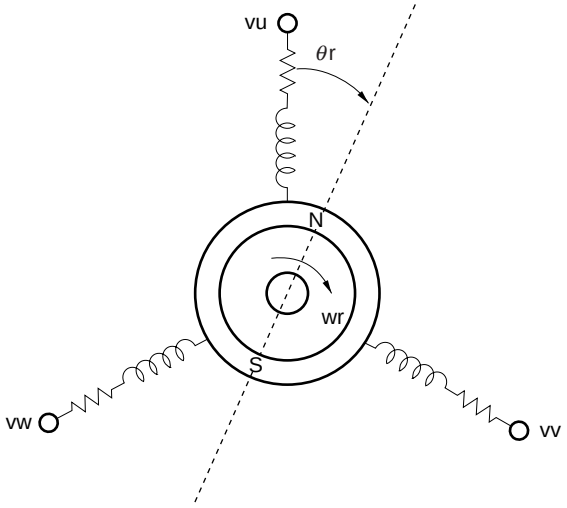
Typically, when controlling a 3-phase motor, voltage and current are indicated as 3-phase AC. However, 2-phase AC is easier to represent than 3-phase AC. Also, control is even simpler when representing biaxial DC rather than 2-phase AC.

When converting biaxial DC (d-q axes), numerous armature coils are connected to the commutator and wound in the radial direction, similar to a DC motor such as is shown in part (c) of Figure 1-2 below. Two voltage values, vd (d-axis voltage) and vq (q-axis voltage), are applied and two currents, id (d-axis current) and iq (q-axis current), flow across the brush that is situated along the d-q axis which rotates at the same speed as the electromagnetic field.

In the reference system, the current and voltage are controlled along the d-q axis in the same way as in DC motors.

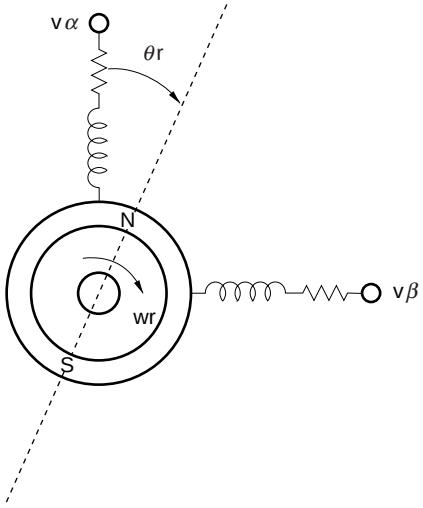
Figure 1-2. Equivalent Circuits (1/3)

(a) Equivalent circuit of 3-phase synchronous motor



Remark vu: u-phase voltage value
vv: v-phase voltage value
vw: w-phase voltage value
θr: Angle of revolution
N: N pole
S: S pole
wr: Angular velocity

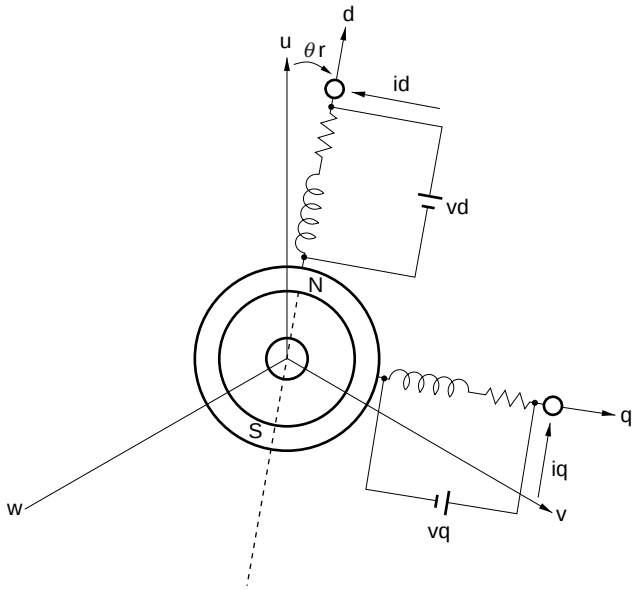
(b) Equivalent circuit using 2-phase AC



Remark vα: α axis voltage value
vβ: β axis voltage value
θr: Angle of revolution
N: N pole
S: S pole
wr: Angular velocity

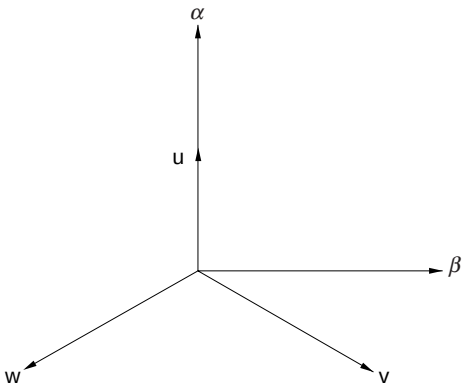
Figure 1-2. Equivalent Circuits (2/3)

(c) Equivalent circuit of biaxial DC type, (d-q) axes



Remark
- u: u phase
- v: v phase
- w: w phase
- θr: Angle of revolution
- N: N pole
- S: S pole
- d: d axis
- id: d-axis current value
- vd: d-axis voltage value
- q: q axis
- iq: q-axis current value
- vq: q-axis voltage value

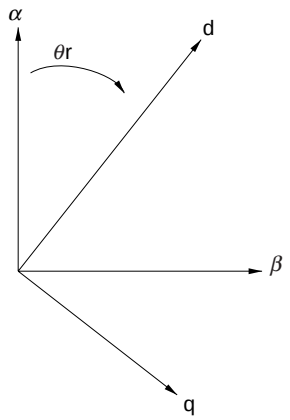
(d) Relationship between 3-phase and 2-phase AC coordinates



Remark
- u: u phase
- v: v phase
- w: w phase
- α: α axis
- β: β axis

Figure 1-2. Equivalent Circuits (3/3)

(e) Relationship between 2-phase AC and biaxial DC coordinates



Remark α: α axis
β: β axis
d: d axis
q: q axis
θr: Angle of revolution

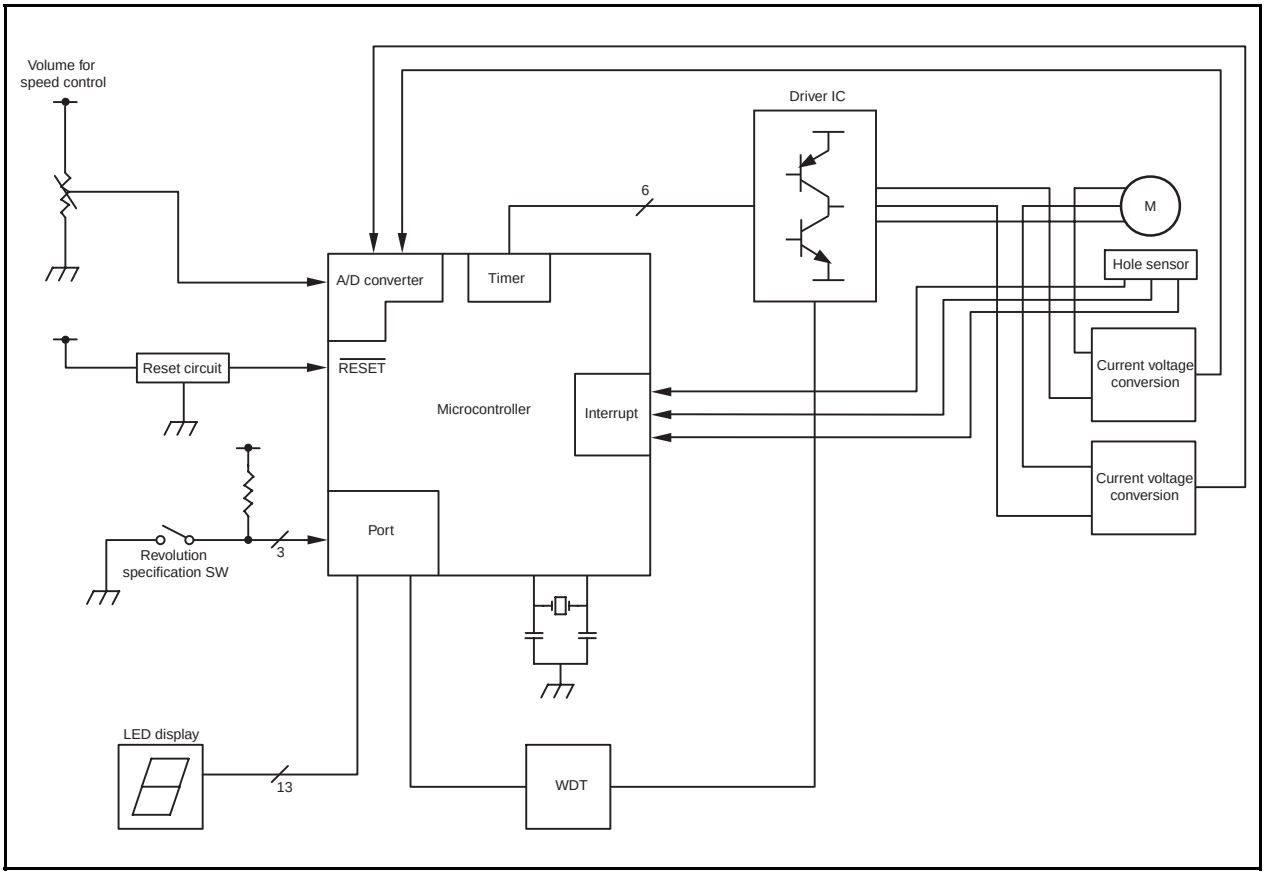
CHAPTER 2 HARDWARE CONFIGURATION

This chapter describes the hardware configuration.

2.1 Configuration

The reference system's main functions are described below. In this reference system, when the revolution specification switch is pressed after power application, the motor starts revolving in the direction specified.

Figure 2-1. Overall System Configuration



(1) Volume for speed control

Volume for increasing and decreasing the number of revolutions of the motor

(2) Revolution specification SW

CW, CCW, and STOP switches

(3) LED display

LED displaying the number of revolutions, operation time, etc.

(4) WDT

Watchdog timer

(5) Driver IC

Driver for driving motor

(6) Current voltage converter

Converting the motor driving current to voltage, used for detecting overcurrent

(7) Interrupt

Information of revolution and position from the hole sensor

2.2 Circuit Diagram

Figures 2-2 to 2-6 show diagrams of the sample reference system circuit.

This sample reference system circuit diagram includes the V850E/IA1, V850E/IA2, V850E/IA3, V850E/IA4, or V850E/MA3, a reset circuit, oscillator, a pin handling microcontroller peripheral block, operation mode switch block, LED output block, watchdog timer circuit block, drive circuit block, motor controller, and motor revolution indicator.

(1) Microcontroller and microcontroller peripheral block

The V850E/IA1, V850E/IA2, V850E/IA3, V850E/IA4, or V850E/MA3 includes a reset circuit, an oscillator that uses a resonator, and a block for handling the MODE pin and unused pins.

(2) Operation mode switch block

This block includes switches that set the operation mode as CW or CCW operation.

(3) LED output block

This block includes 16 LEDs, which are used to indicate the revolution speed (rpm), errors, etc.

(4) Watchdog timer circuit block

This block is specified to output stop signals when pulse output from the V850E/IA1, V850E/IA2, V850E/IA3, V850E/IA4, or V850E/MA3 stops for one ms or longer.

(5) Drive circuit block

The 6-phase outputs from the inverter timer are converted to U-, V-, and W-phase output for the motor driver. This drive circuit is not shown in detail in this example, since it varies depending on the motor's specifications.

(6) Motor controller

This block includes the HPS-3-AS, LM324, and other devices that are used to measure the motor's U and V drive currents via A/D conversion.

(7) Motor revolution indicator

This block includes a volume adjuster and the LM324 for setting the motor's revolution speed (rpm).

Figure 2-2. Circuit Diagram of V850E/IA1

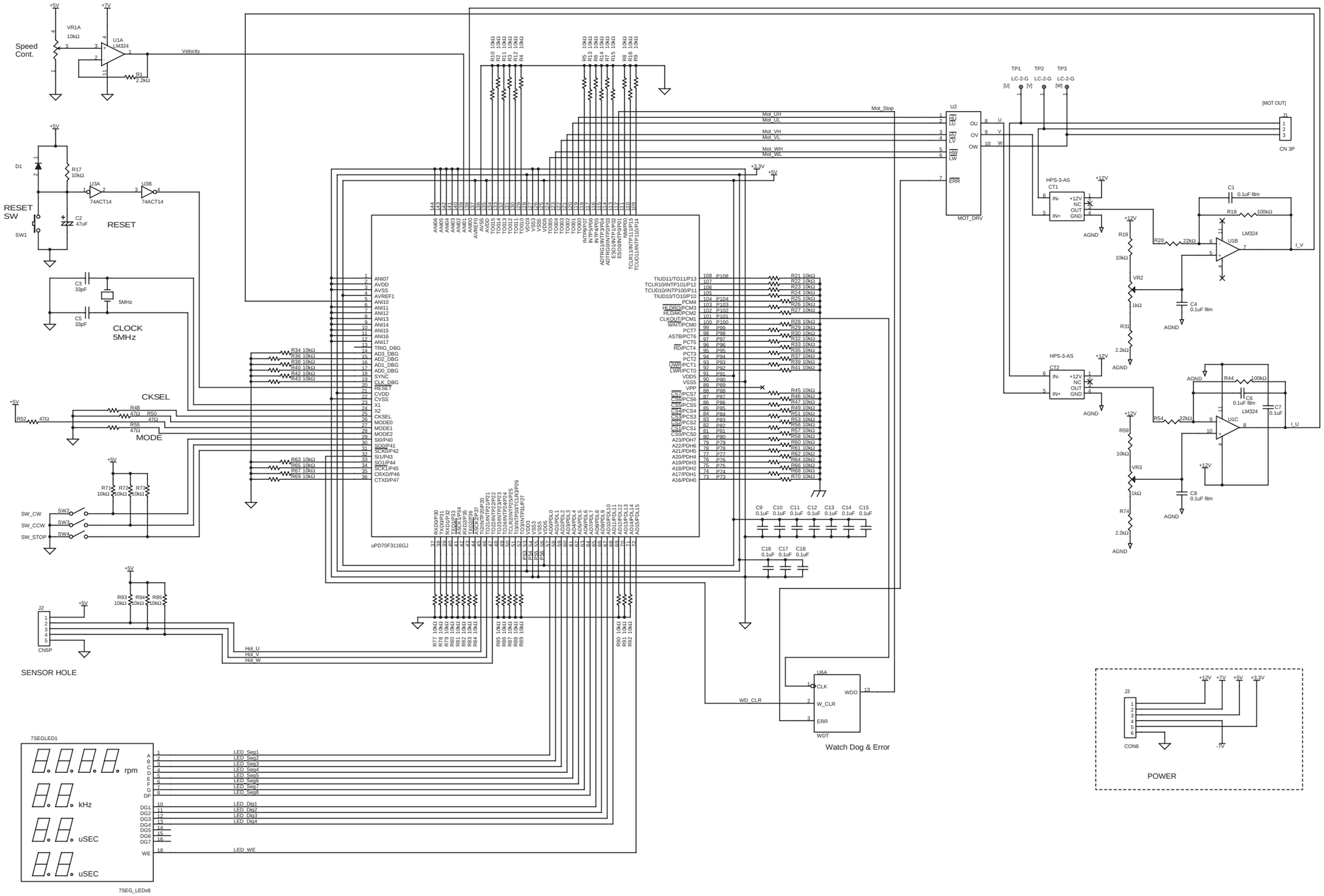


Figure 2-3. Circuit Diagram of V850E/IA2

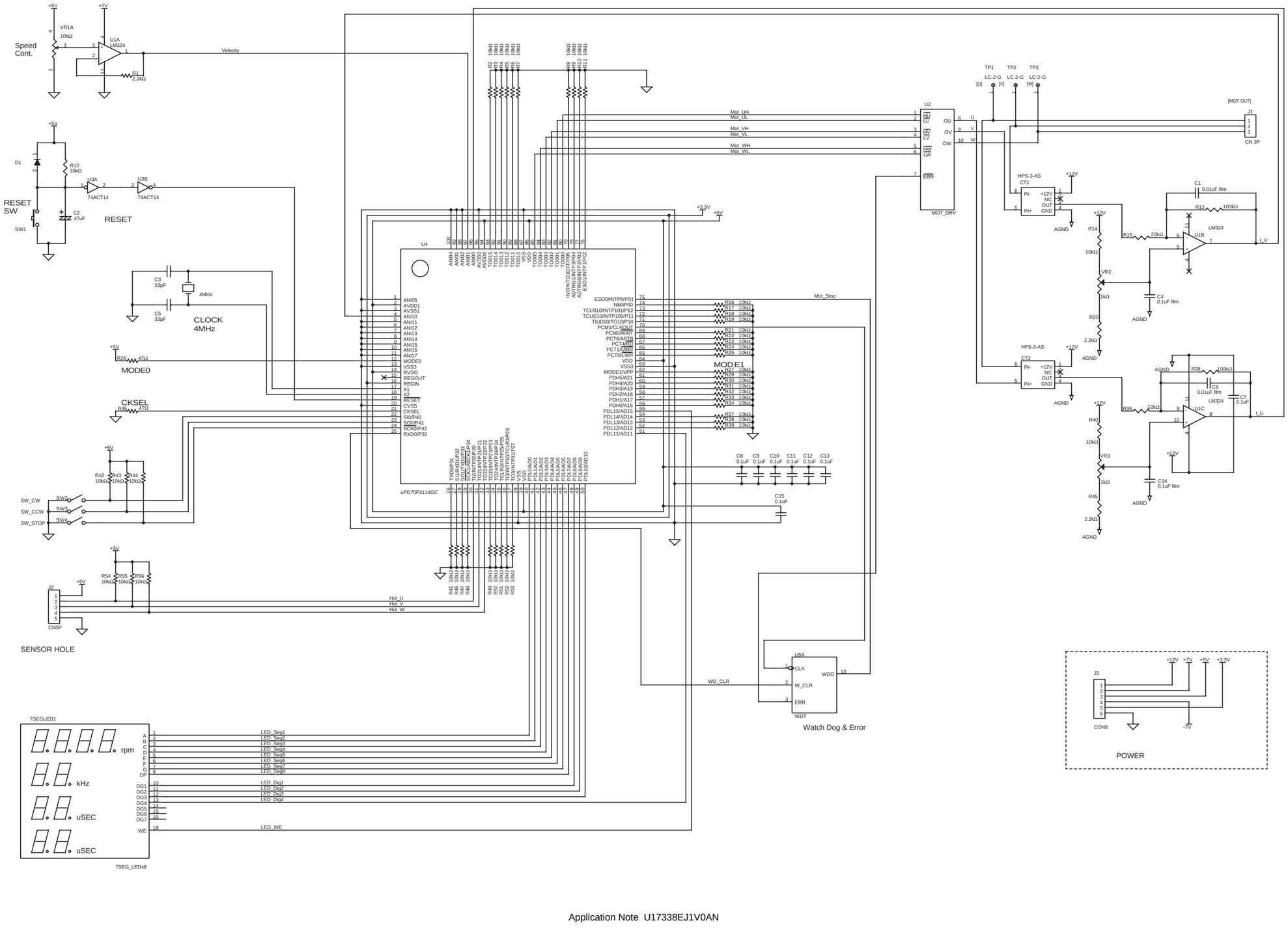


Figure 2-4. Circuit Diagram of V850E/IA3

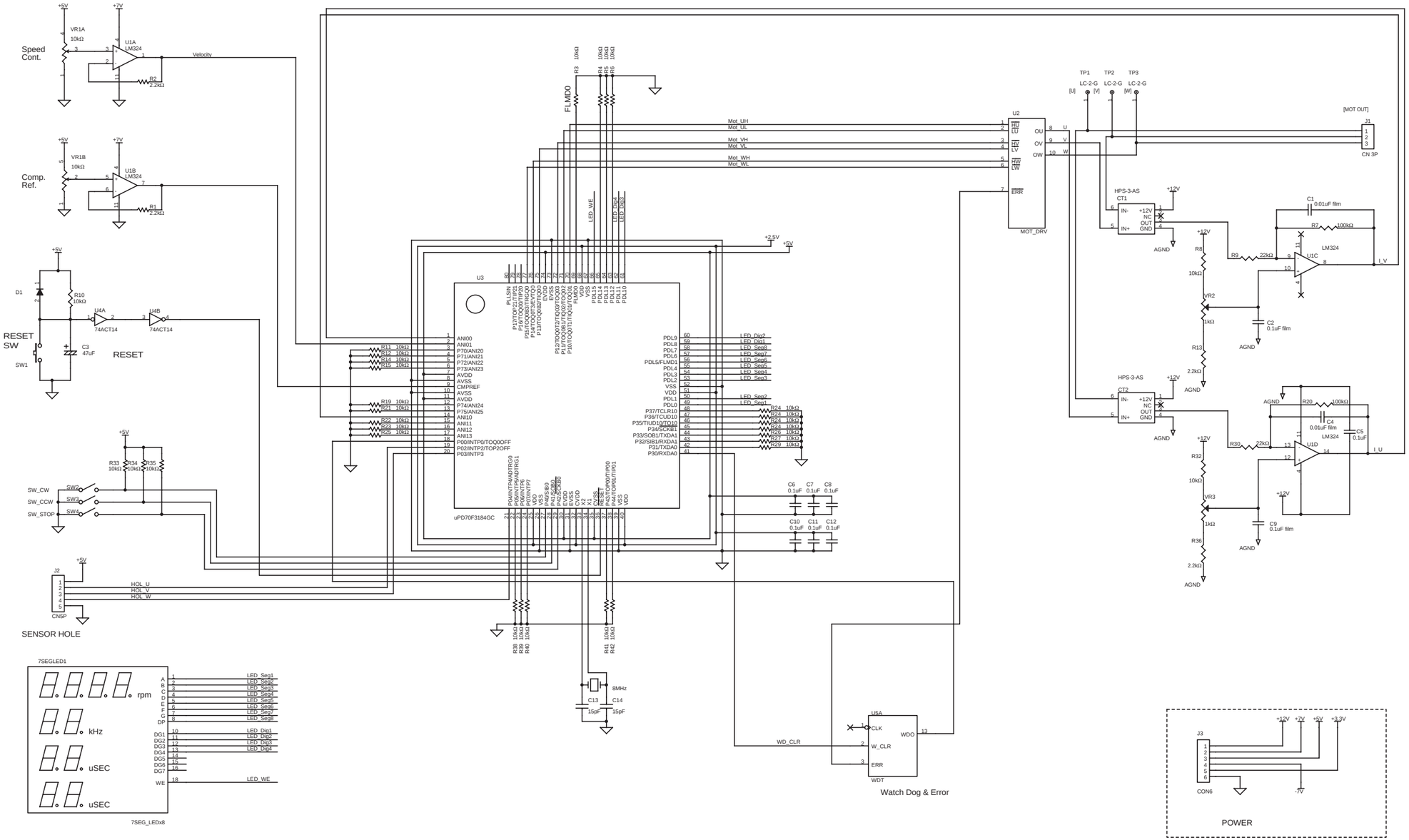


Figure 2-5. Circuit Diagram of V850E/IA4

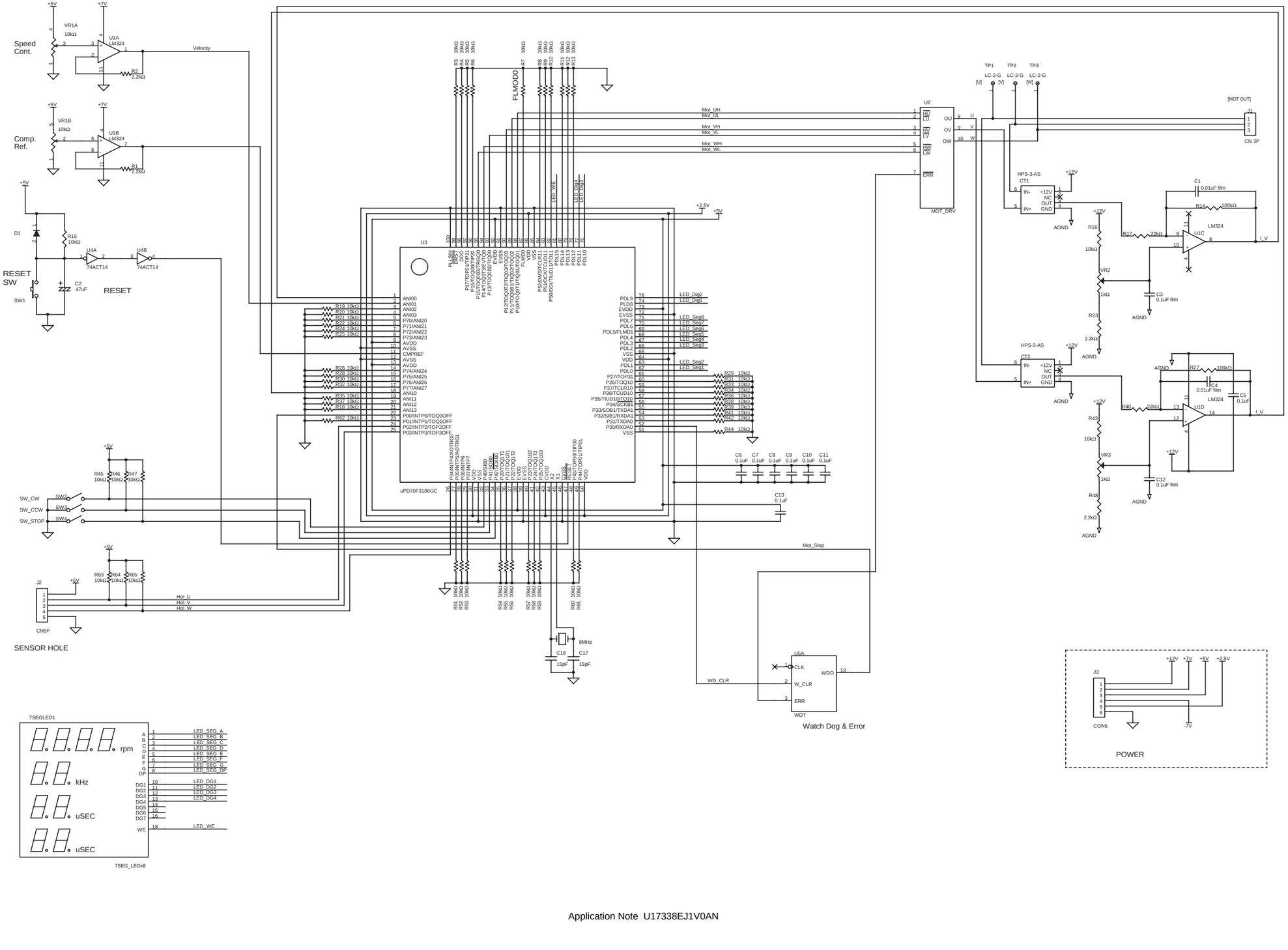
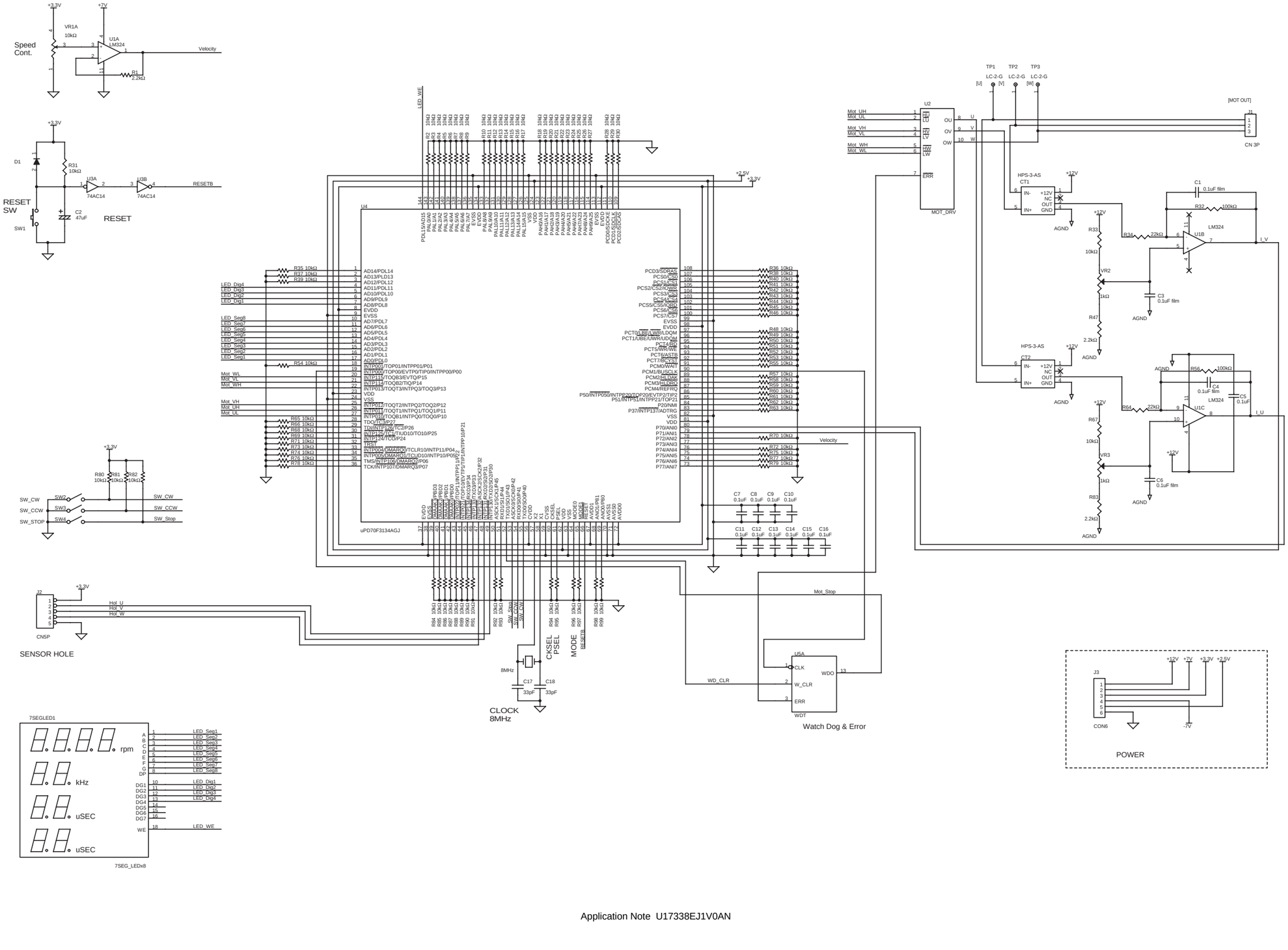


Figure 2-6. Circuit Diagram of V850E/MA3

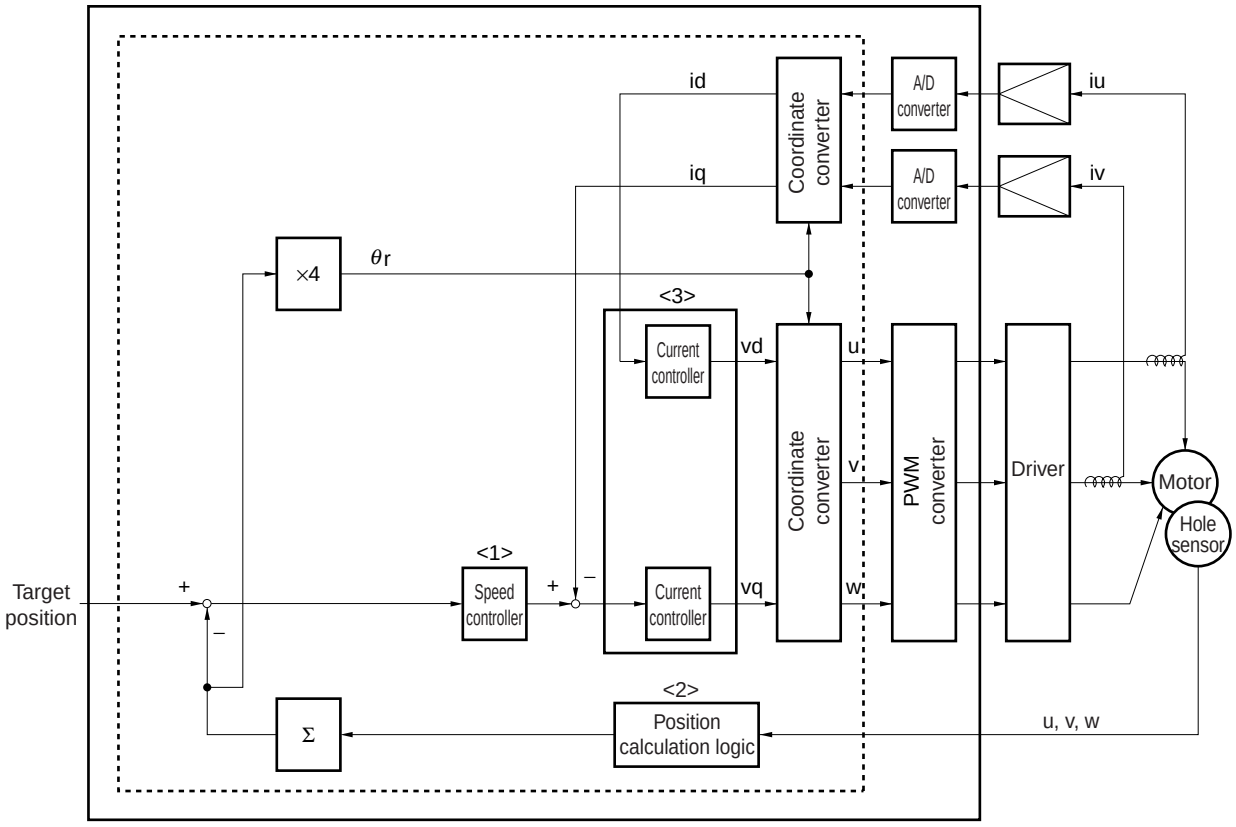


CHAPTER 3 SOFTWARE CONFIGURATION

3.1 Control Block

In the reference system, processing of timer interrupts is used to calculate control along the d-q axis (as is shown in Figure 3-1) and final output of the U, V, and W phase voltage values is performed by the inverter timer function of the target microcontroller.

Figure 3-1. Software Control Block Diagram of Reference System



<1> The target current value is calculated based on the differential between the target speed (previously set or calculated) and the current speed.

<2> If a target position has been set, speed conversion is performed based on the differential between the target position and the current position.

<3> The target voltage for the d-q axis is calculated based on the current return value converted for the d-q axis and the target current value.

Remark All processing enclosed in the solid line is internal to the target microcontroller.
Processing enclosed in the broken lines is performed by software.

3.2 Speed Control

In the reference system, PI (Proportion, Integral) control is used in the speed control block. The equations used for speed control are shown below.

d_speed = o_speed − now_speed
o_iqp = ksp × d_speed
o_iqi = o_iqi (n − 1) + (ksi × d_speed (n − 1))
o_iq = o_iqp + o_iqi (n)

Remark

d_speed:	Difference between target speed and current speed
o_speed:	Target speed
now_speed:	Current speed
o_iqp:	Speed proportion component current value
ksp:	Speed proportion constant
o_iqi:	Speed integral component current value
ksi:	Speed integral constant
o_iq:	Target current value
n:	Current component
n–1:	Previous component

3.3 Current Control

For current control, the d-axis current (id) and q-axis current (iq) are converted via the following equations to obtain a target voltage for each axis.

$o\_vd = ki \times (-id)$
$o\_vq = ki \times (o\_iq - iq)$

Remark
- o_vd: Target d-axis voltage
- ki: Current proportion gain
- id: d-axis current value
- o_vq: Target q-axis voltage
- o_iq: Target current value
- iq: q-axis current value

id and iq are obtained by converting current values for the u and v phases to d-q axis coordinates. The equations are shown below.

$id = iv \times \sin\theta r - iu \times \sin(\theta r - 2\pi/3)$
$iq = iv \times \cos\theta r - iu \times \cos(\theta r - 2\pi/3)$

Remark
- id: d-axis current value
- iq: q-axis current value
- iu: u-phase current value
- iv: v-phase current value
- θr: Angle of revolution

3.4 Three-Phase Voltage Conversion

The equations used to convert voltage values (vd and vq) calculated for the d-q axis to 3-phase coordinates are shown below.

$o\_vu = o\_vd \times \cos\theta r - o\_vq \times \sin\theta r$
$o\_vv = o\_vd \times \cos(\theta r - 2\pi/3) - o\_vq \times \sin(\theta r - 2\pi/3)$
$o\_vw = -o\_vu - o\_vv$

Remark
- o_vu: Target u-phase voltage
- o_vv: Target v-phase voltage
- o_vw: Target w-phase voltage
- o_vd: Target d-axis voltage
- o_vq: Target q-axis voltage
- θr: Angle of revolution

3.5 PWM Conversion

The calculated target voltage is output by an inverter timer.

3.6 Peripheral I/O

The following types of peripheral I/O functions are used in this reference system.

Table 3-1. List of Peripheral I/O Functions

Function	Peripheral I/O Function Name (V850E/IA1)	Peripheral I/O Function Name (V850E/IA2)	Peripheral I/O Function Name (V850E/IA3)	Peripheral I/O Function Name (V850E/IA4)	Peripheral I/O Function Name (V850E/MA3)
Inverter timer	Timer 00 (TM00)	Timer 00 (TM00)	Timer Q0 (TMQ0)	Timer Q0 (TMQ0)	Timer Q0 (TMQ0)
10 ms timer	Timer 21 (TM21)	Timer 21 (TM21)	Timer P0 (TMP0)	Timer P0 (TMP0)	Timer D0 (TMD0)
Motor control timer	Timer 3 (TM3)	Timer 3 (TM3)	Timer P1 (TMP1)	Timer P1 (TMP1)	Timer D1 (TMD1)
Speed measuring timer	Timer 4 (TM4)	Timer 4 (TM4)	Timer P2 (TMP2)	Timer P2 (TMP2)	Timer ENC10 (TMENC10)
Time measuring timer	Timer 3 (TM3)	Timer 3 (TM3)	Timer P1 (TMP1)	Timer P1 (TMP1)	Timer D1 (TMD1)
U-phase current	ANI00	ANI00	ANI00	ANI00	ANI0
V-phase current	ANI10	ANI10	ANI10	ANI10	ANI1
Setting speed (volume)	ANI01	ANI01	ANI01	ANI01	ANI3
U-phase hole sensor input	INTP20	INTP20	INTP2	INTP2	INTP130
V-phase hole sensor input	INTP21	INTP21	INTP3	INTP3	INTP131
W-phase hole sensor input	INTP22	INTP22	INTP4	INTP4	INTP132
CW key input	P40	P40	P40	P40	P40
CCW key input	P41	P41	P41	P41	P41
STOP key input	P42	P42	P42	P42	P42
WDT reset output	P43	P30	P30	P30	P43
LED output	PDL0 to PDL11, PDL15	PDL0 to PDL11, PDL15	PDL0 to PDL11, PDL15	PDL0 to PDL11, PDL15	PDL0 to PDL11, PDL15

(1) Description of peripheral I/O functions

(a) Inverter timer

Inverter timers are used to output PWM waveforms.

In this reference system, the settings are as shown below.

- 20 kHz symmetrical triangular waveform mode
- Dead time: 6 μs
- Inverter timer output: Low active
- When ESO0, TOQ0OFF, or $\overline{\text{INTP000}}$ pin input is at high level, PWM output is stopped.

(b) Motor control timer

Motor control timers are used to issue interrupts at a 50 μs interval.

(c) 10 ms timer

10 ms timers are used to issue interrupts at a 10 ms interval.

(d) Speed measuring timer

Used for measuring the revolution speed of the motor.

(e) Current value input

ANI00, ANI0 (V850E/MA3 only): U-phase current value (–5 to +5 A)

ANI10, ANI1 (V850E/MA3 only): V-phase current value (–5 to +5 A)

(f) Speed specification volume value input

ANI01 or ANI3 (V850E/MA3 only) is used to input a value from 0 to 1,023.

3.7 Software Processing Structure

The software processing structure is shown below.

Figure 3-2. Main Processing Structure

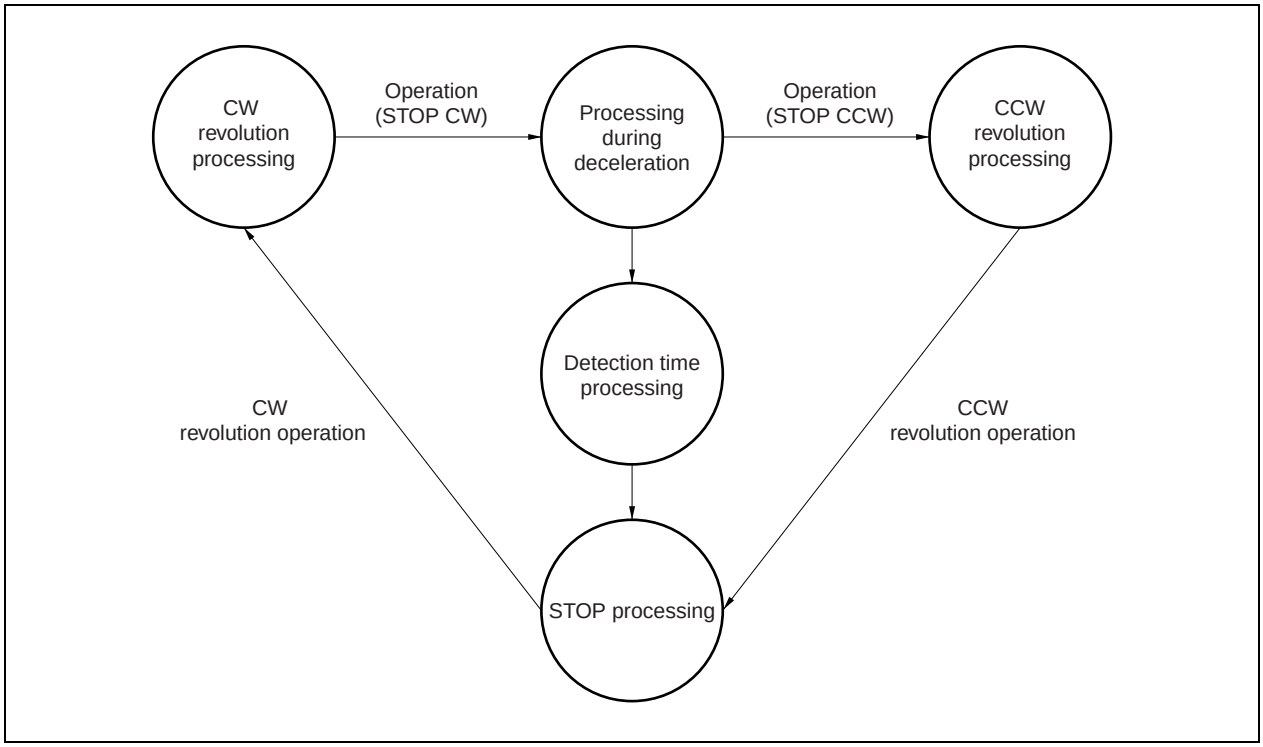
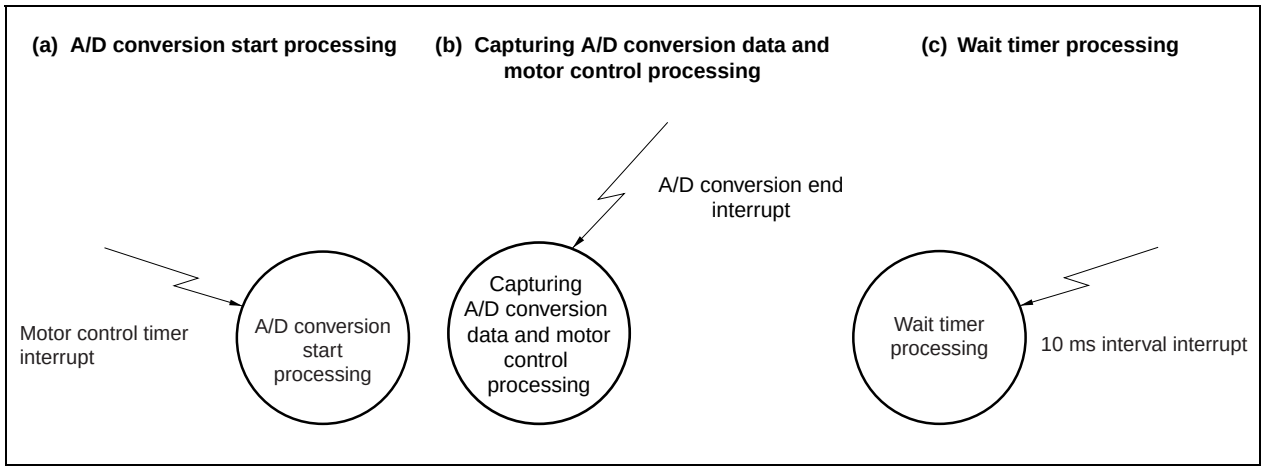


Figure 3-3. Interrupt Processing Structure



The status of the operation mode switch is monitored by the main processing, and processing is transferred to CW, CCW, and stop status. The motor is controlled in the specified status by using a motor control timer interrupt.

There are the following three motor control statuses.

- Stop status
  The motor is not controlled.
- Initial operation status
  Revolution control is performed until the position information from the hole sensor is input.
- Speed control status
  Feedback revolution control is performed so that the indication speed is attained.

3.8 Flowchart

3.8.1 Main processing

Figure 3-4 shows the flowchart of the main processing.

Figure 3-4. Main Processing

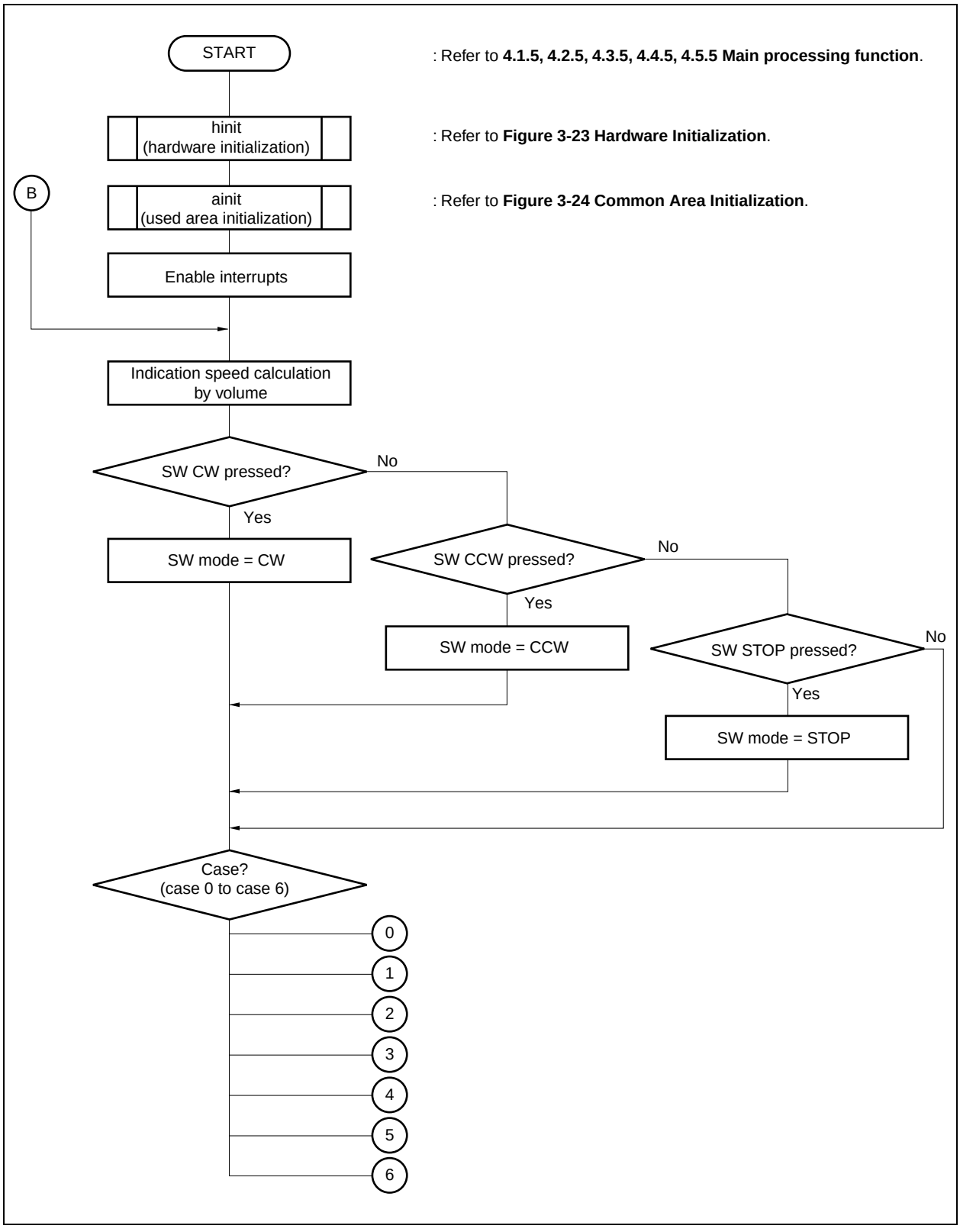


Figure 3-5. Case 0 (Processing During Stoppage)

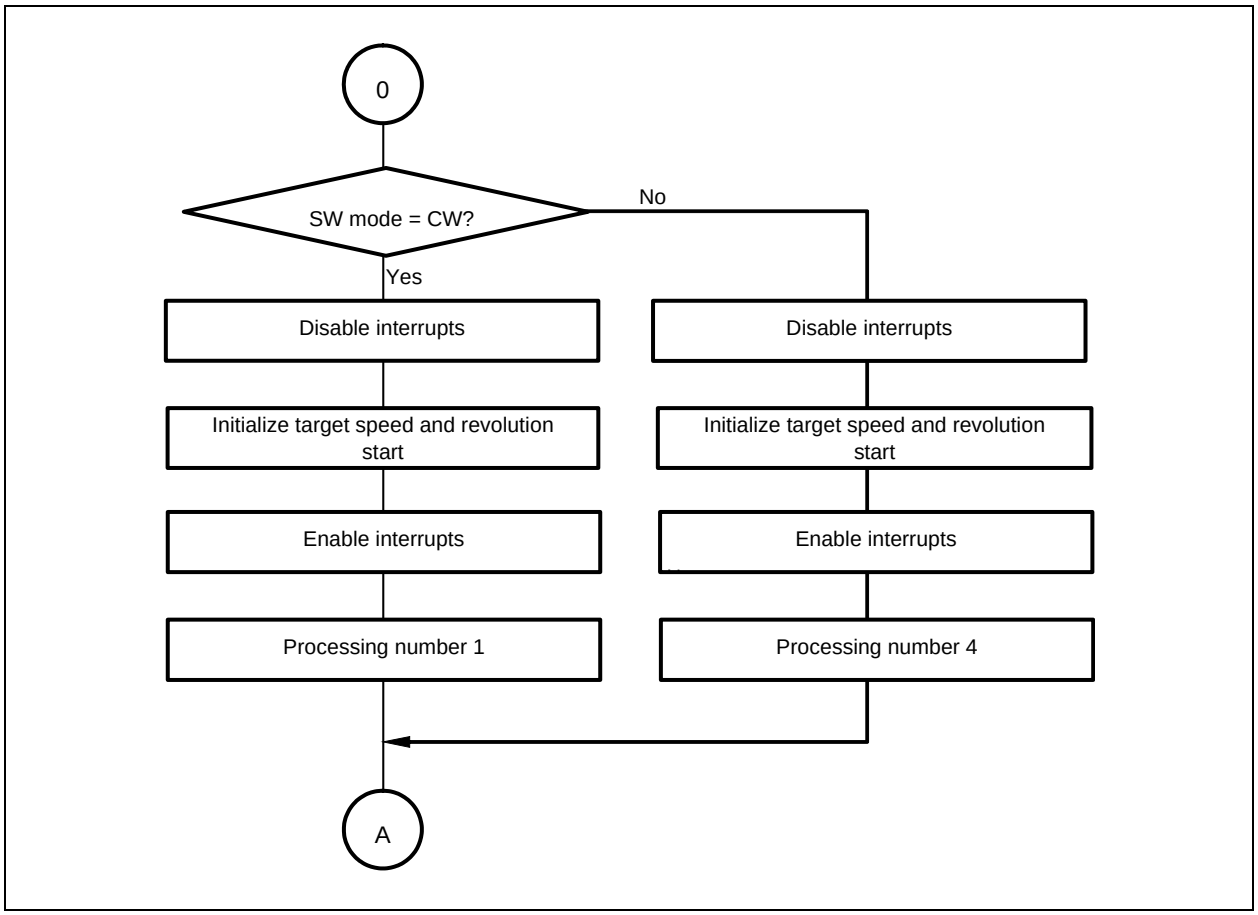


Figure 3-6. Case 1 (CW Acceleration Processing)

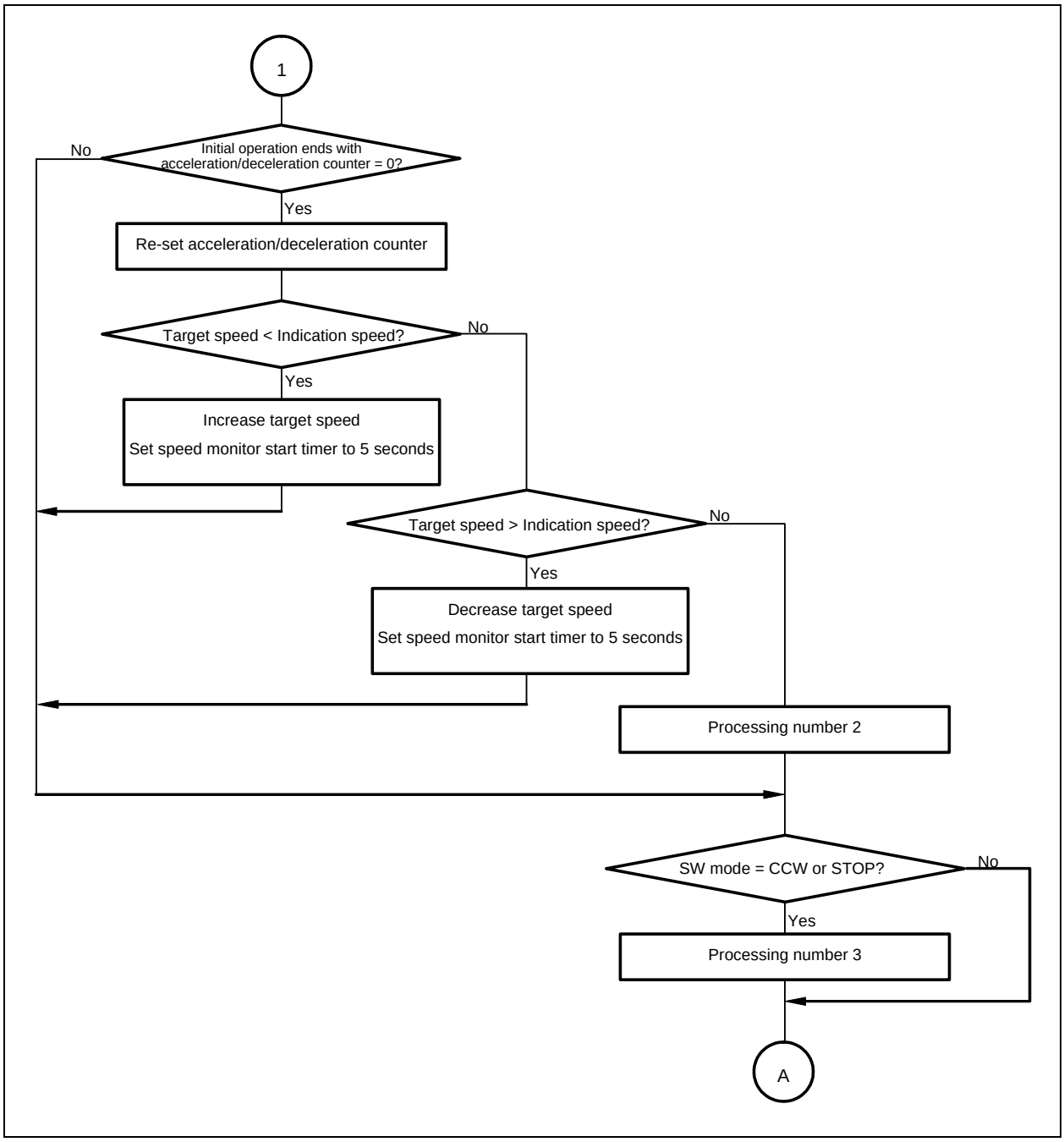


Figure 3-7. Case 2 (CW Constant-Speed Processing)

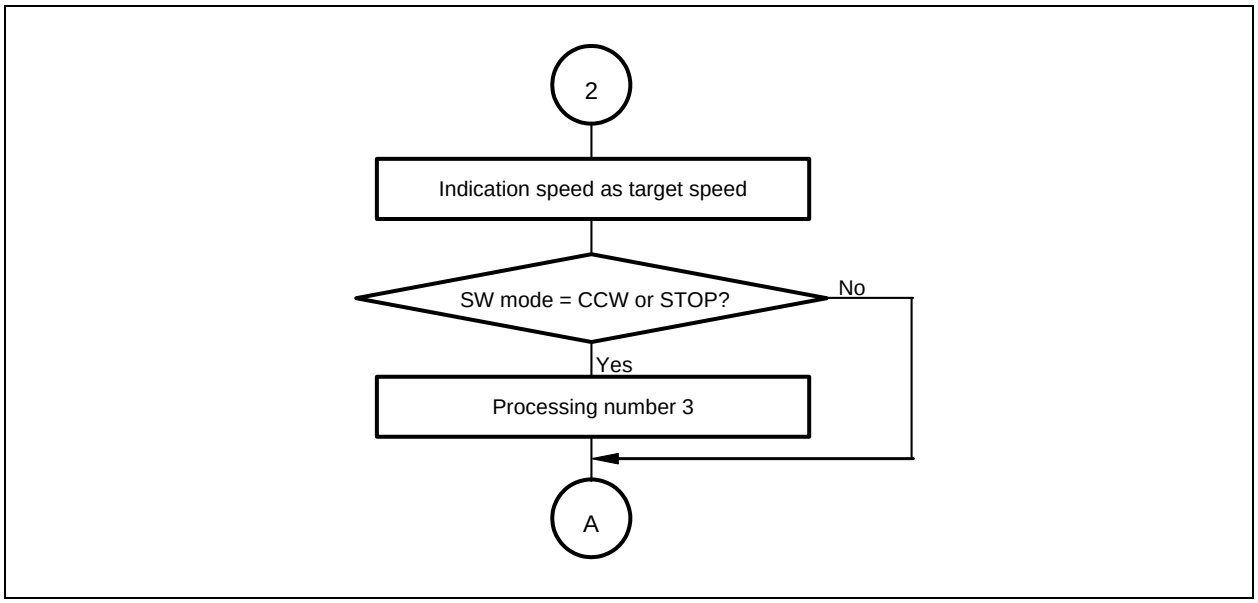


Figure 3-8. Case 3 (CW Stop Processing)

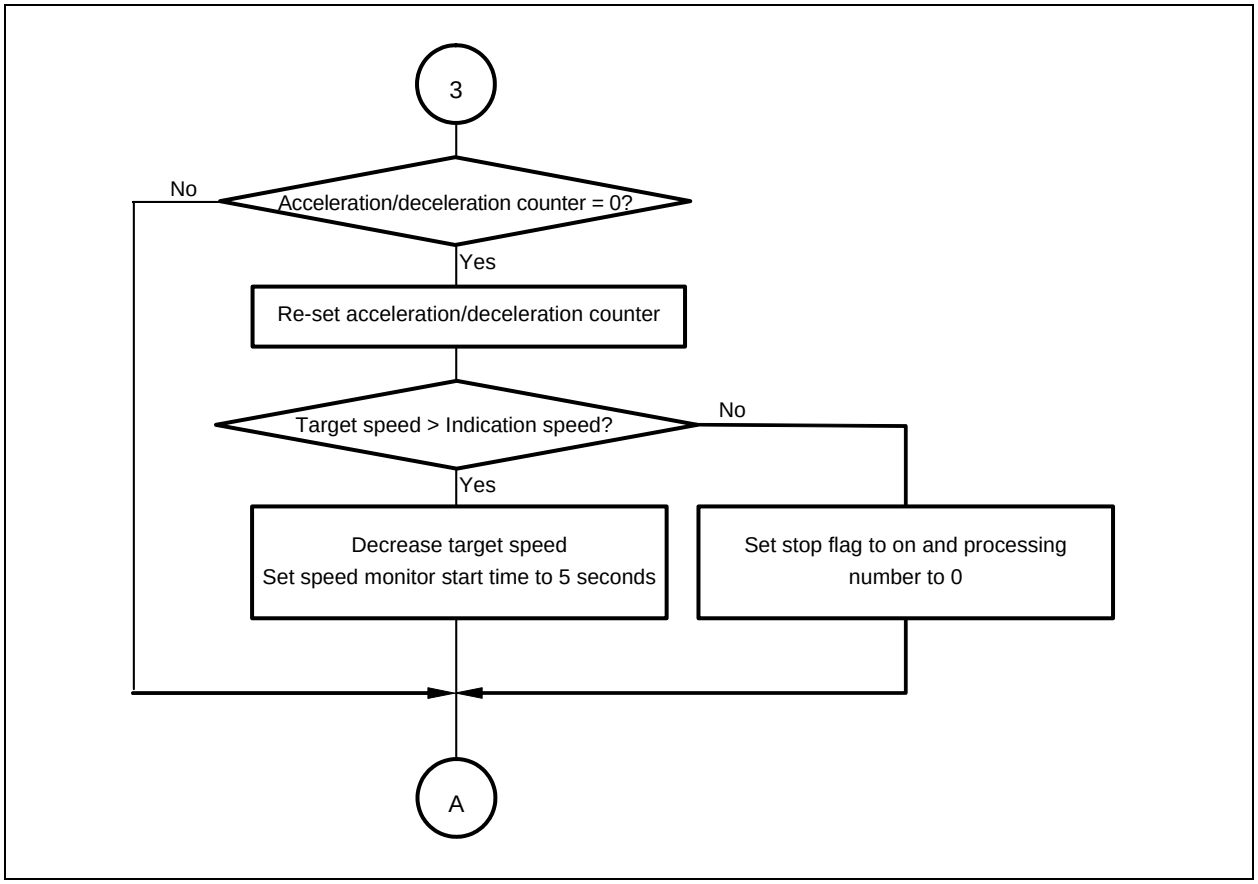


Figure 3-9. Case 4 (CCW Acceleration Processing)

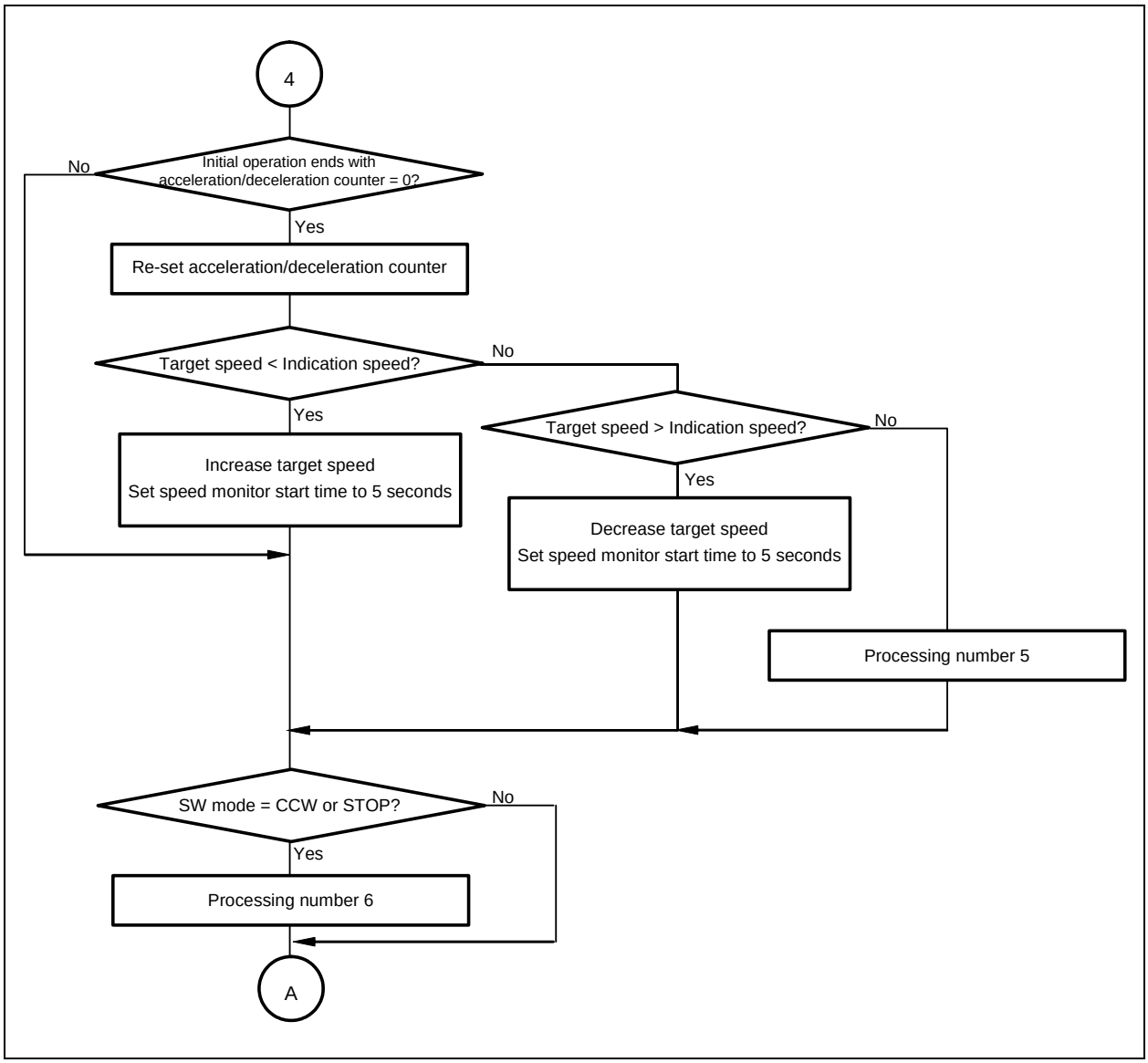


Figure 3-10. Case 5 (CCW Constant-Speed Processing)

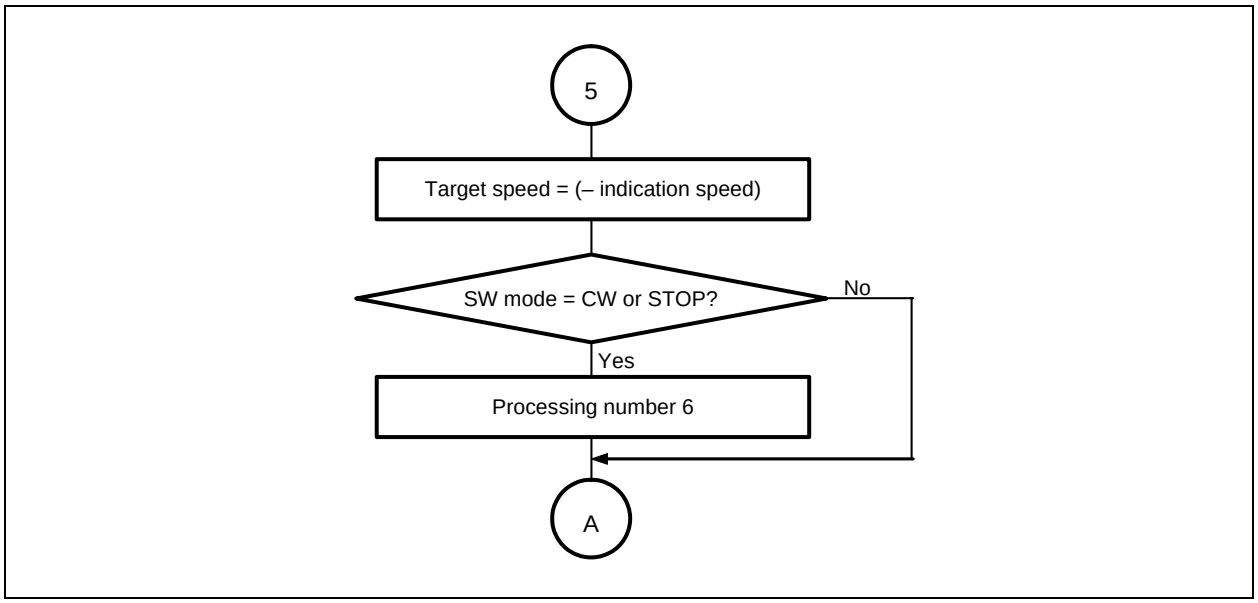


Figure 3-11. Case 6 (CCW Stop Processing)

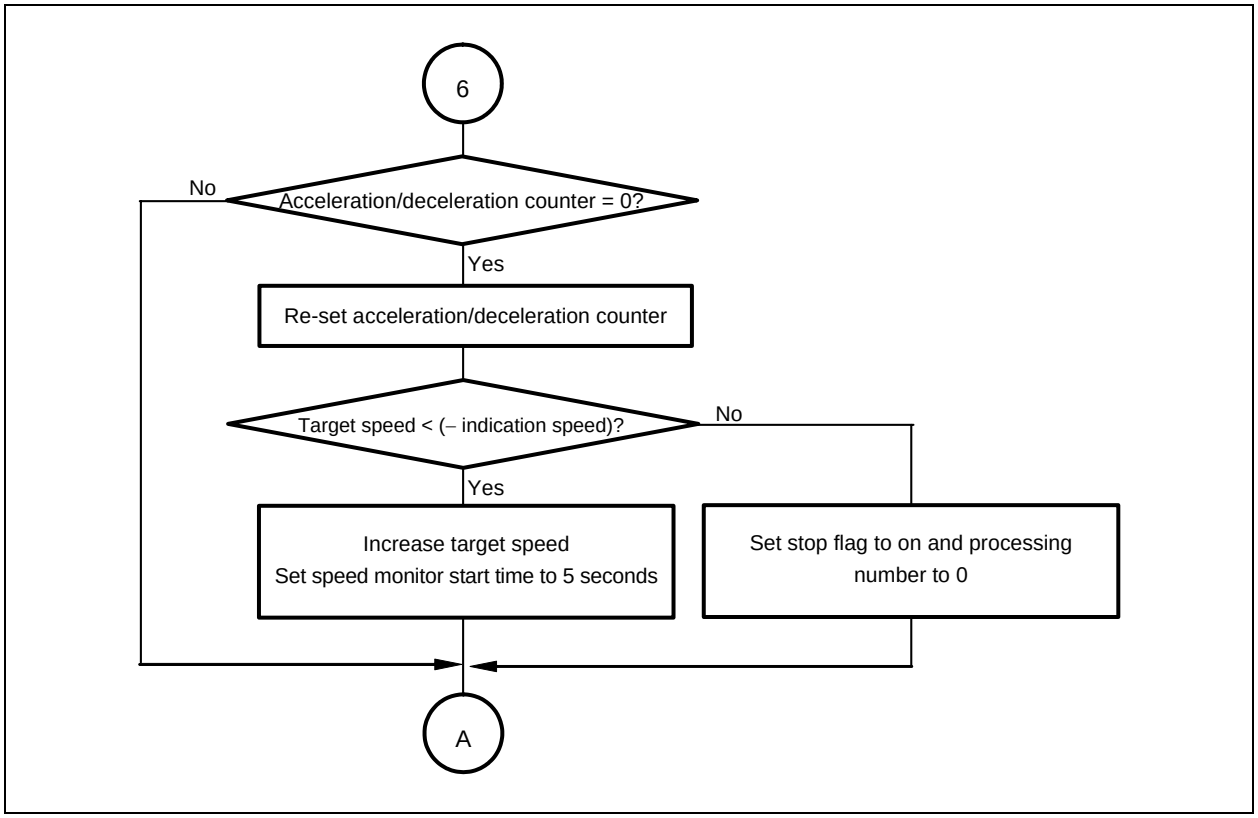
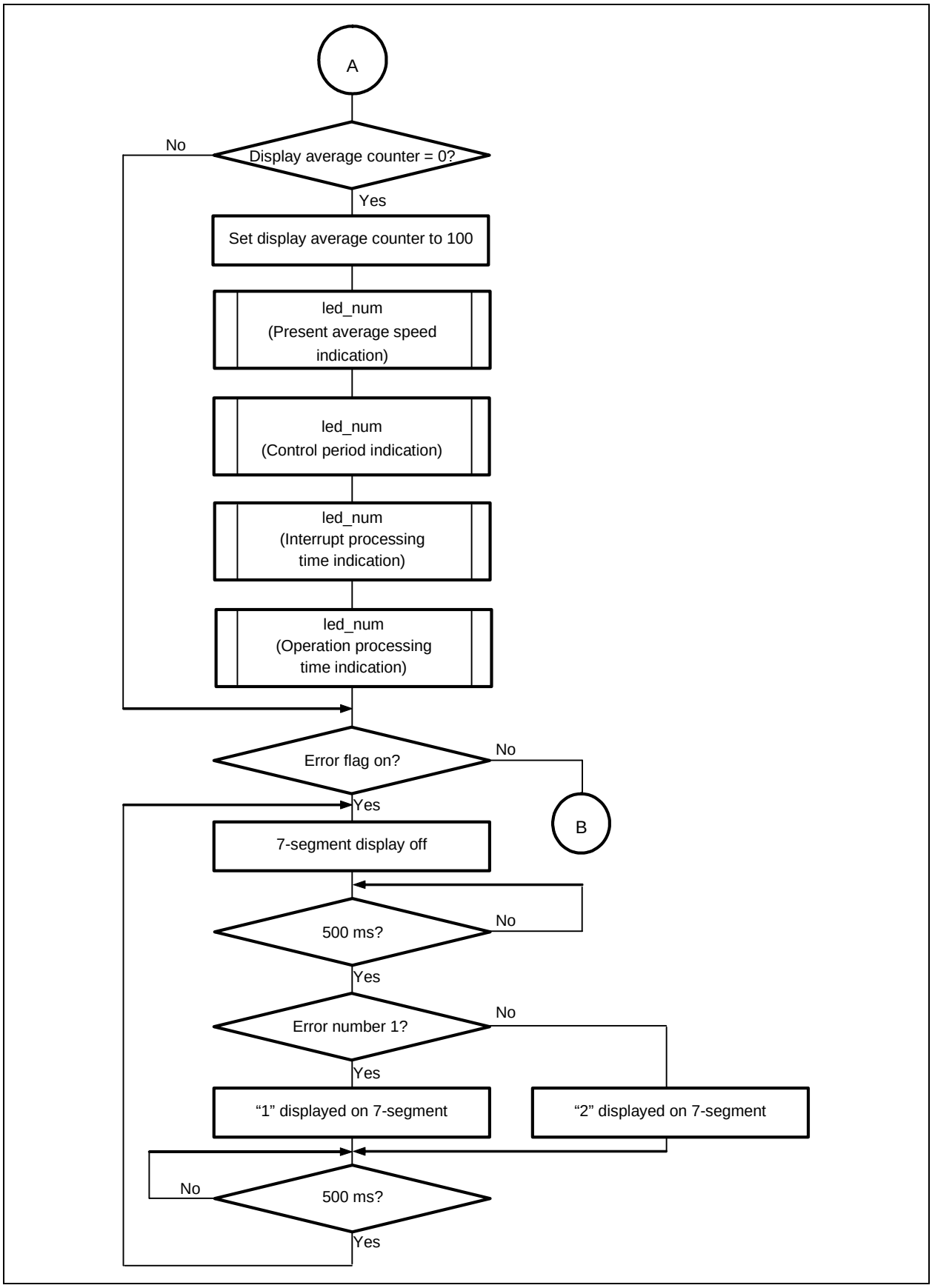
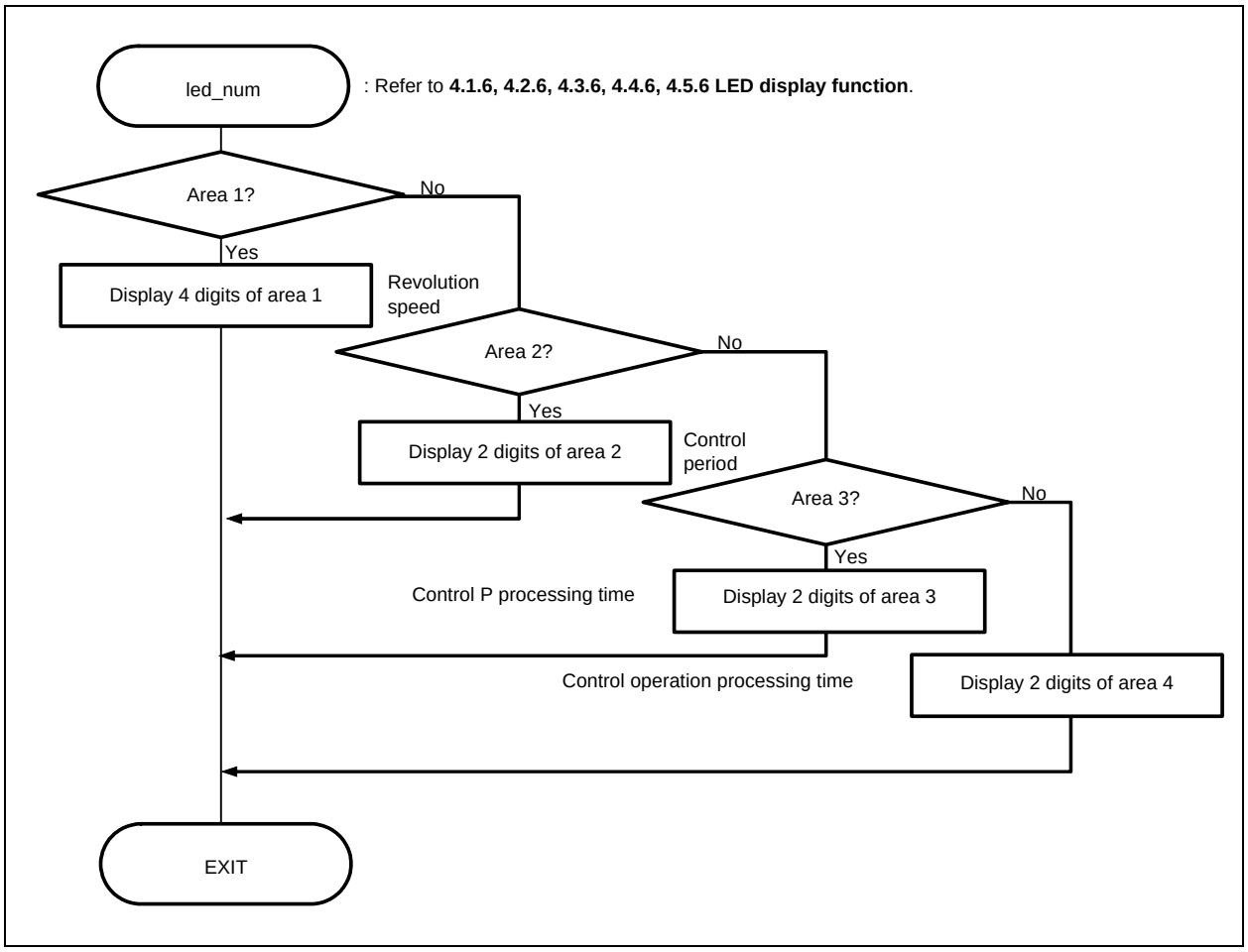


Figure 3-12. LED Display Processing



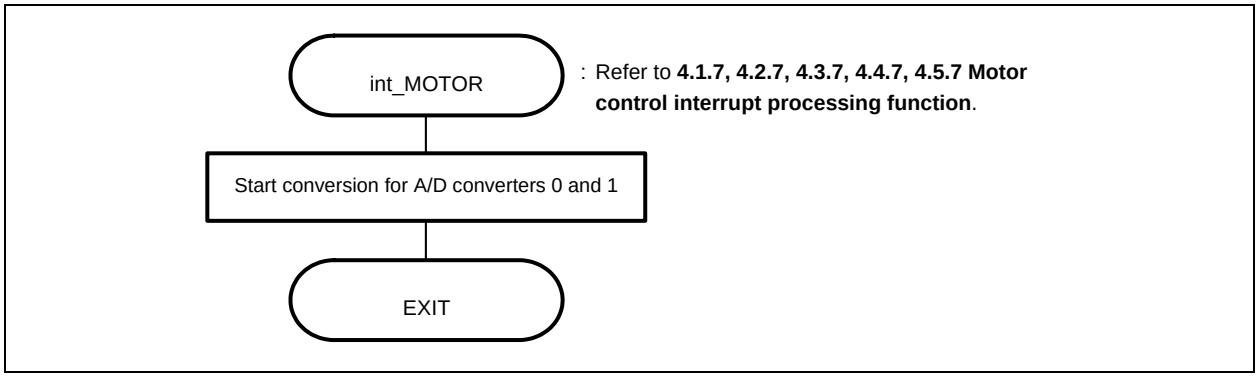
3.8.2 LED display

Figure 3-13. LED Display



3.8.3 Motor control timer interrupt processing

Figure 3-14. Motor Control Timer Interrupt Processing



3.8.4 Motor control processing

Figure 3-15. Control Interrupt Processing (1/5)

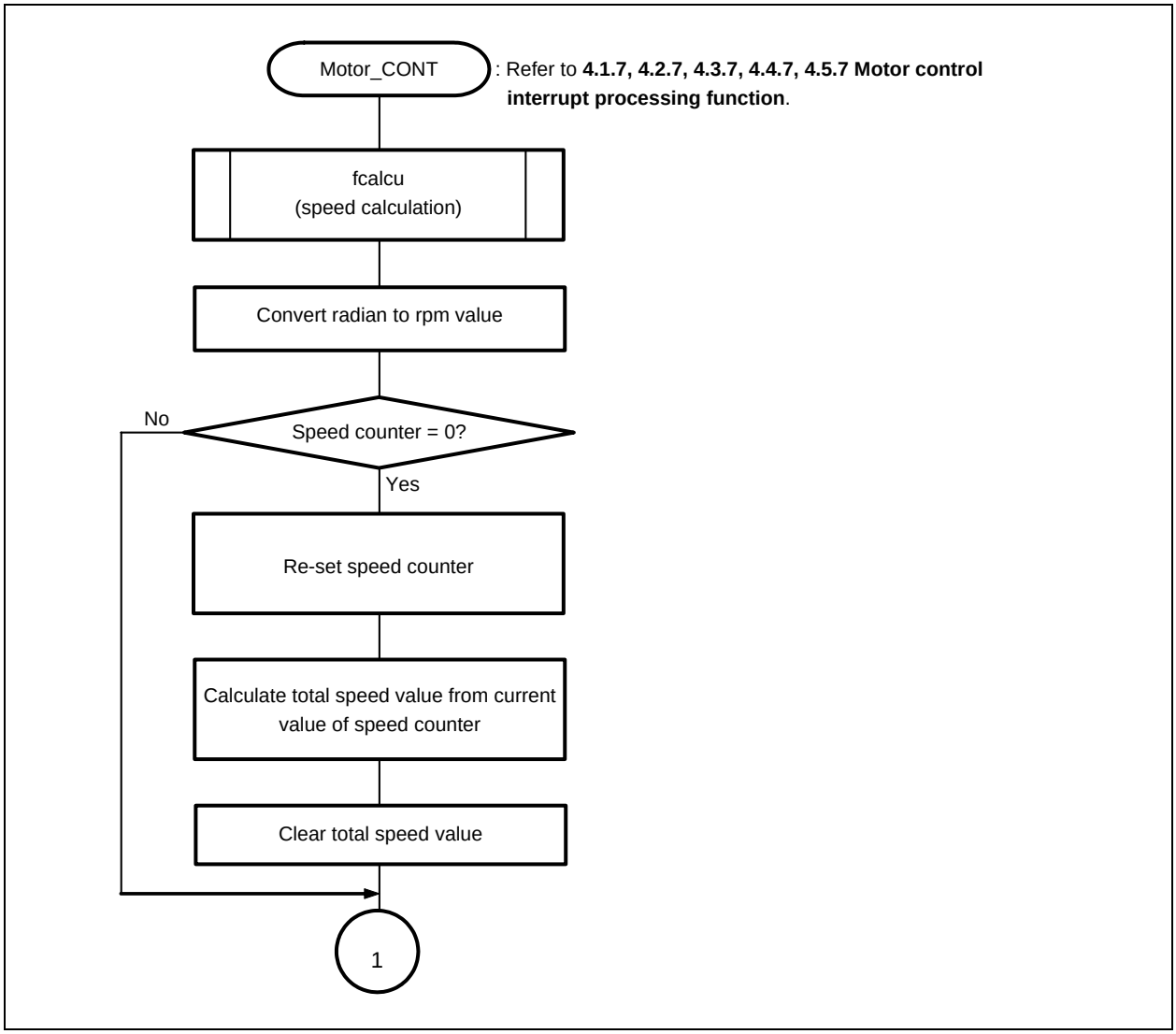
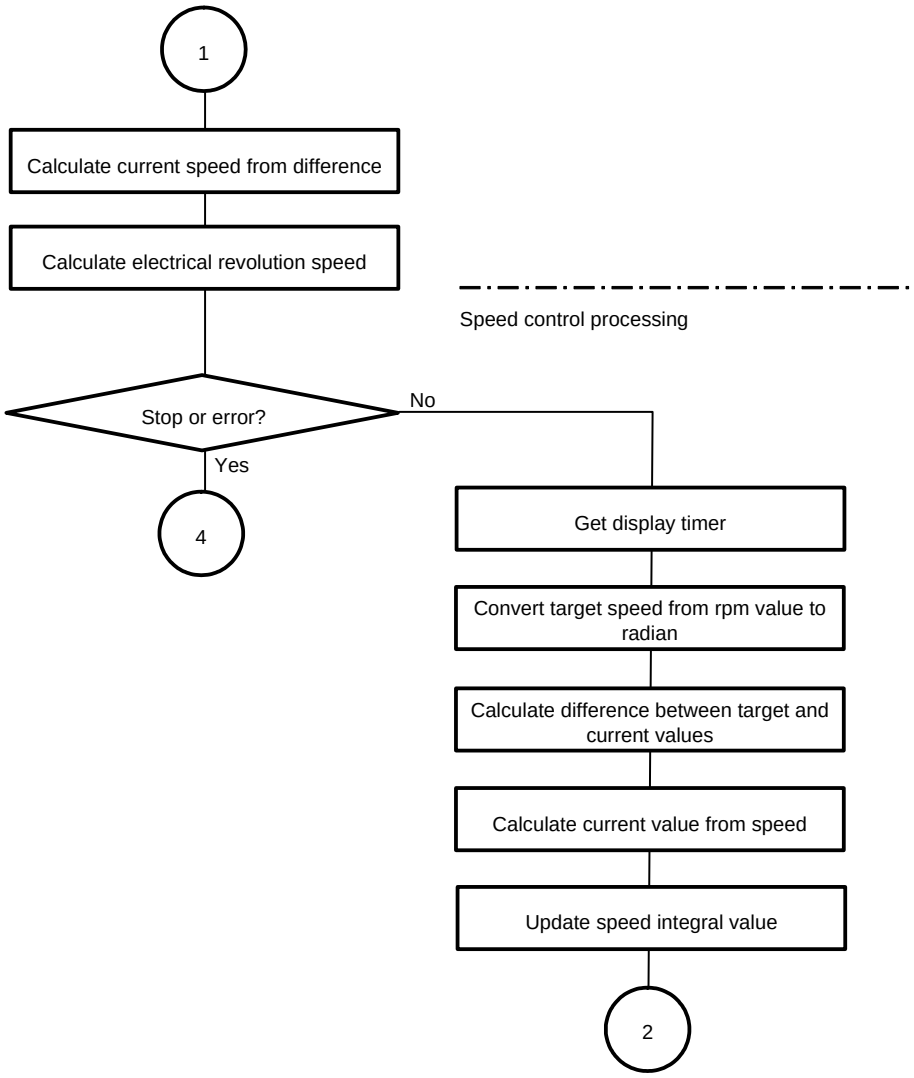


Figure 3-15. Control Interrupt Processing (2/5)



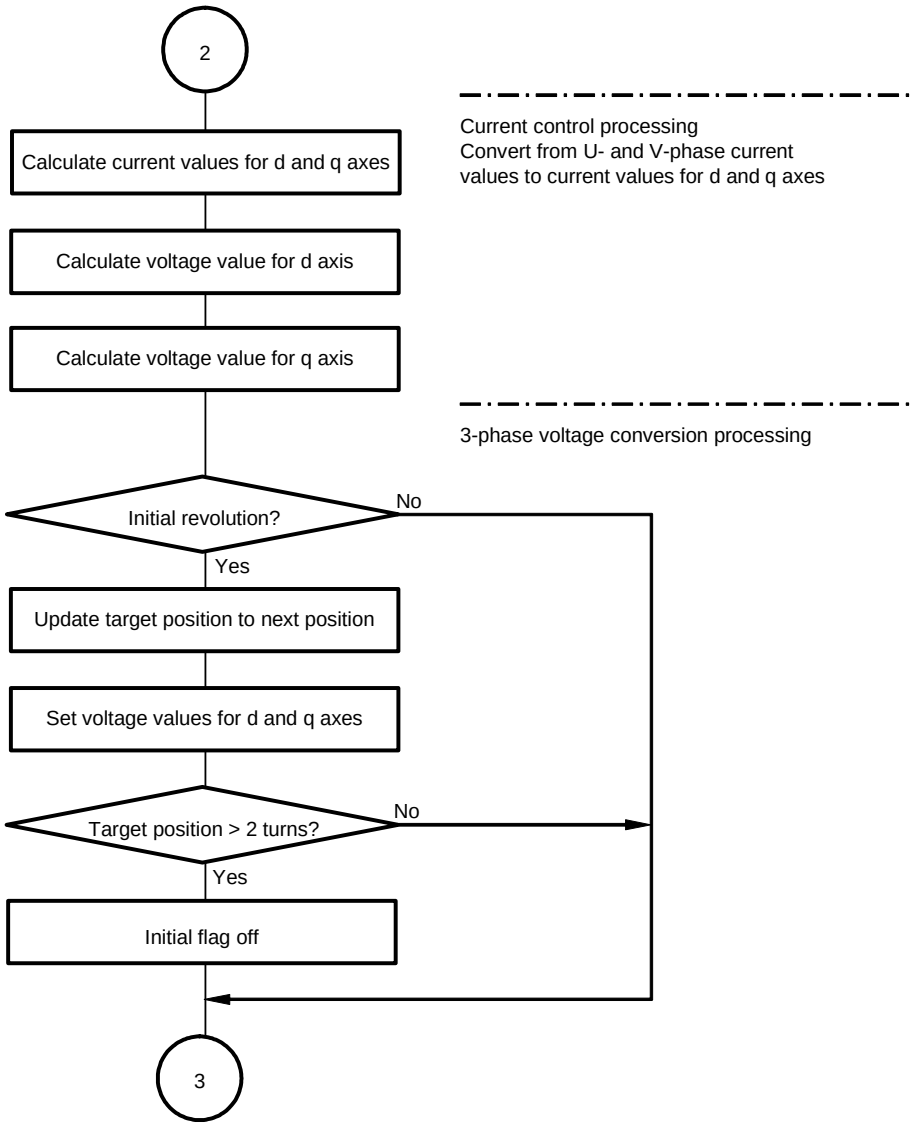
Remarks 1. Electrical revolution speed = Speed × Number of poles

2. Current value = (KSP × Speed difference + Speed integral value)/KSIGETA

3. Speed integral value = Previous speed integral value + KSI × Speed difference

4. KSI: Speed integral constant
KSIGETA: Speed integral constant jack-up constant
KSP: Speed proportion constant

Figure 3-15. Control Interrupt Processing (3/5)



Remarks 1. Voltage value for d axis = KI × (–d-axis current value)/KIGETA

2. Voltage value for q axis = KI × (Target current value for q axis – Current value for q axis)/KIGETA

3. KI: Current conversion constant

KIGETA: Current conversion constant jack-up constant

Figure 3-15. Control Interrupt Processing (4/5)

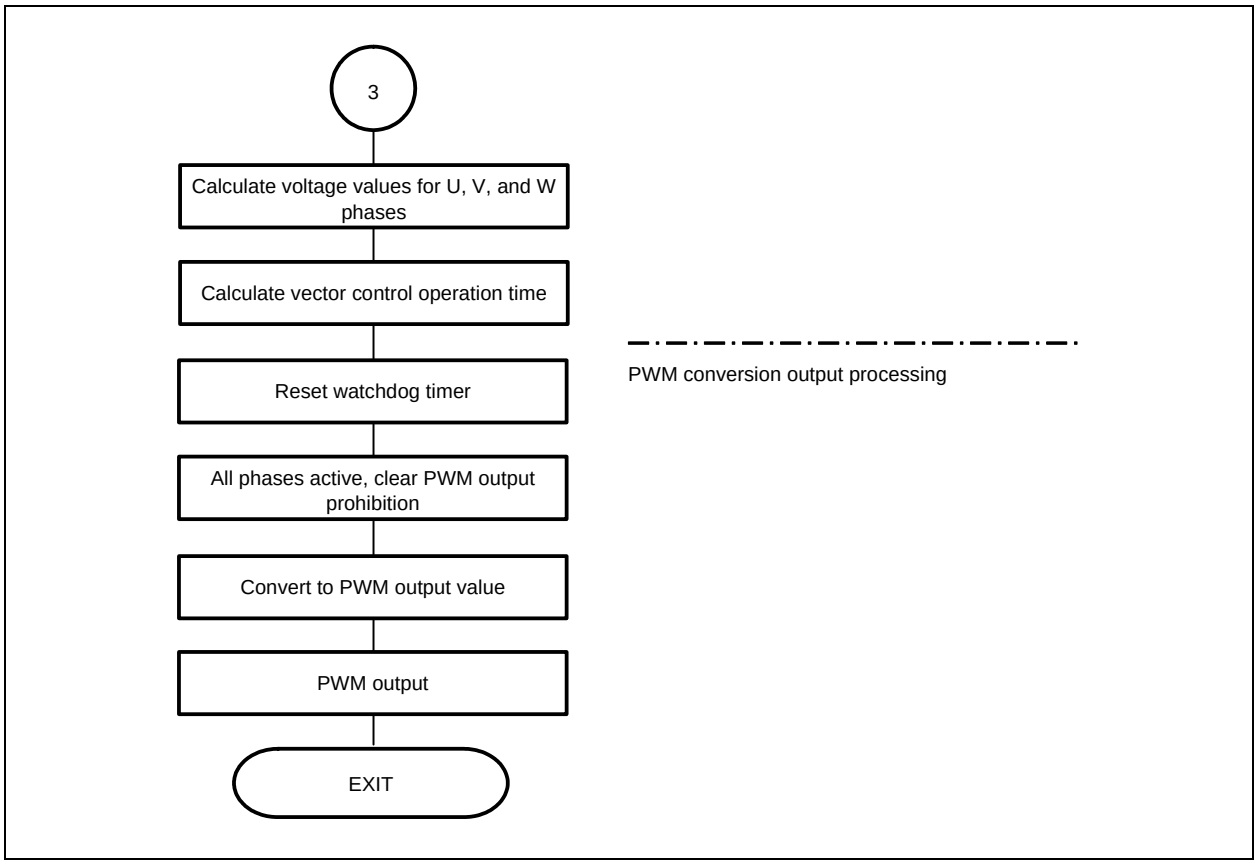
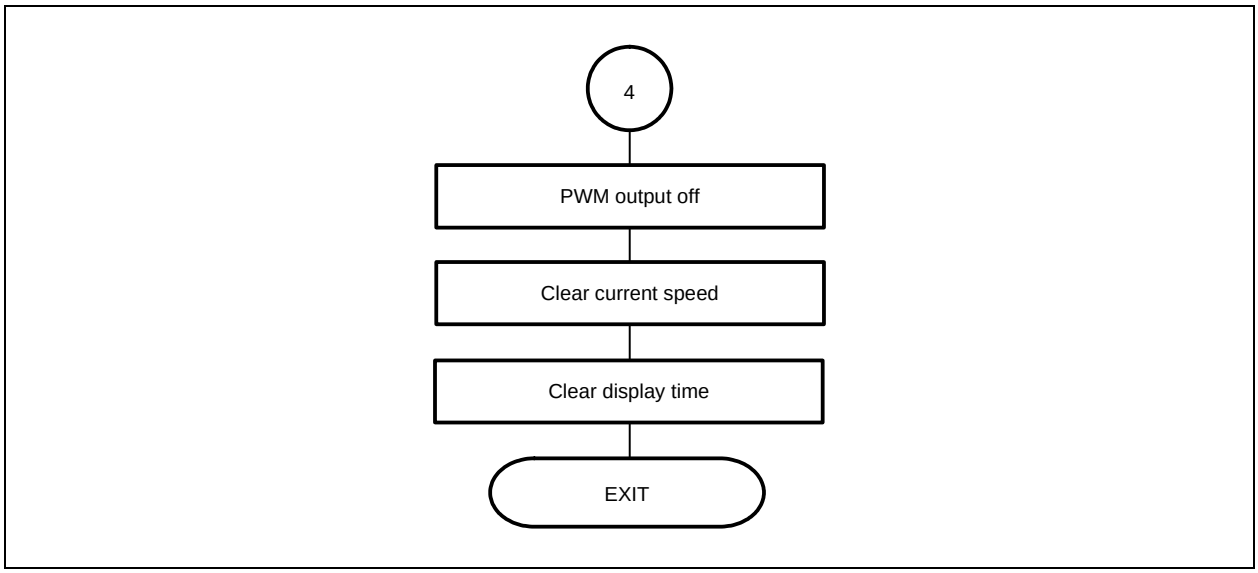
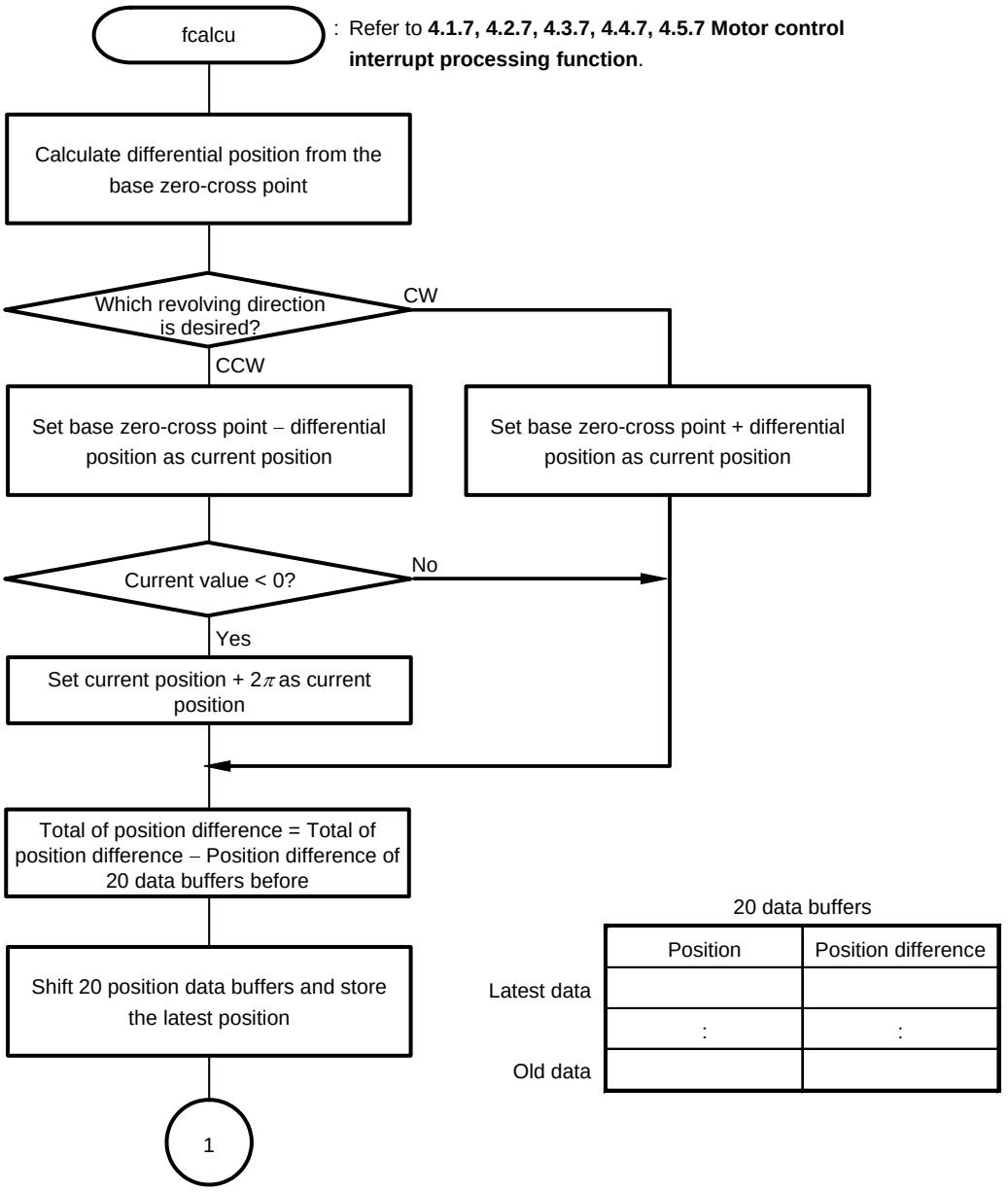


Figure 3-15. Control Interrupt Processing (5/5)



3.8.5 Calculation processing of speed, etc.

Figure 3-16. Calculation Processing of Speed, etc. (1/2)



Remark Differential position from the base zero-cross point = $\pi/3 \times$ Differential position/Previous difference

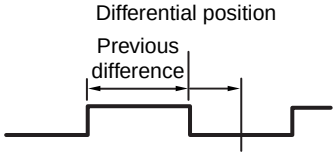
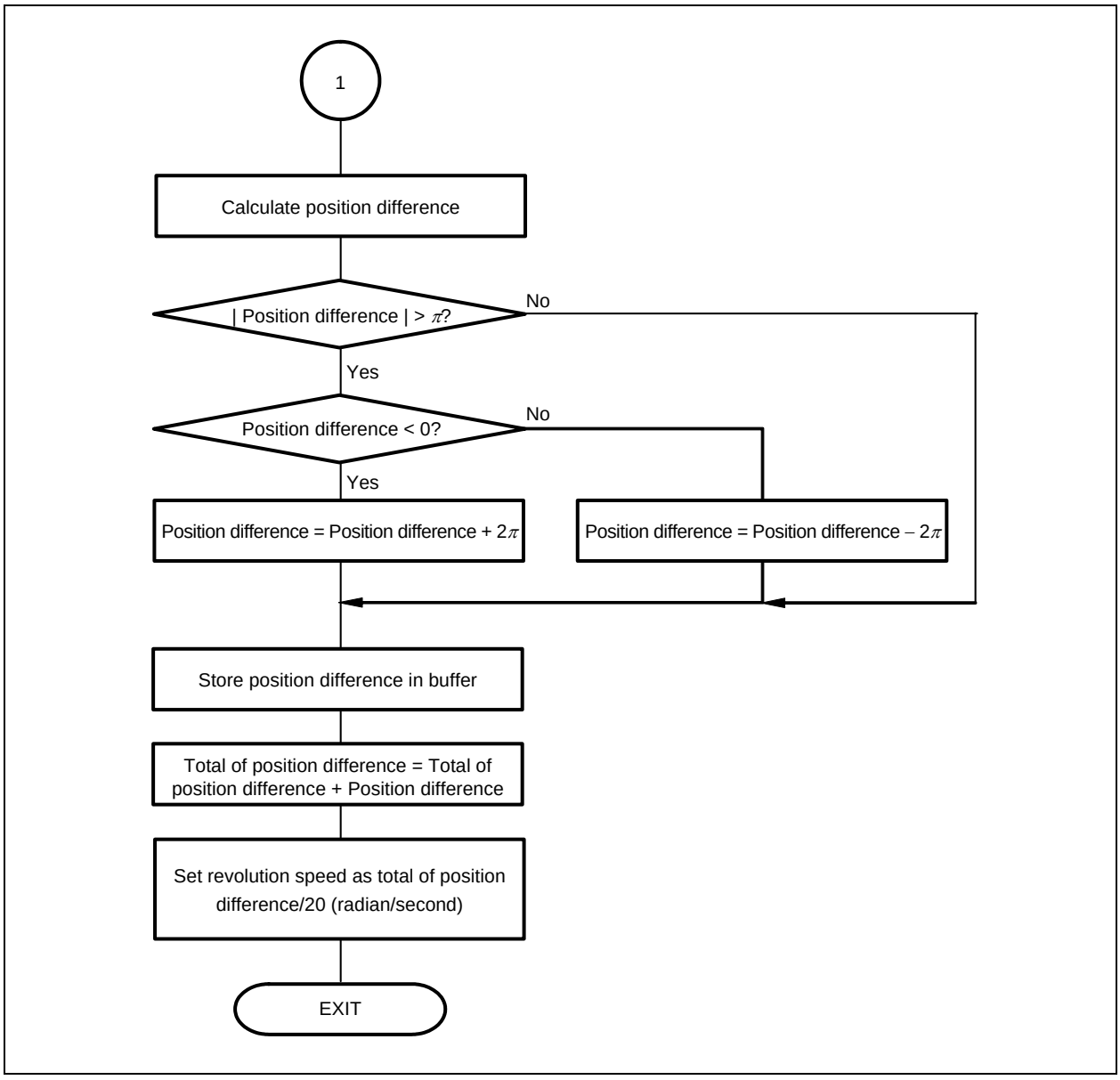
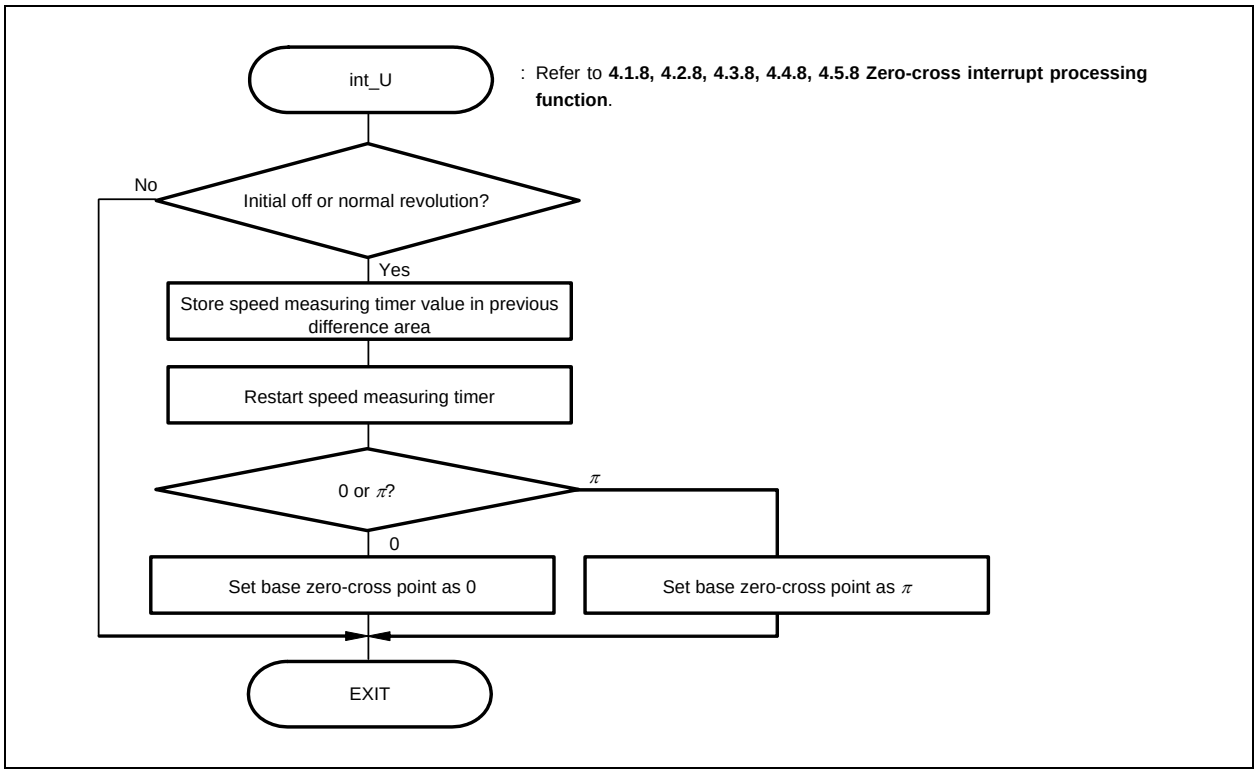


Figure 3-16. Calculation Processing of Speed, etc. (2/2)



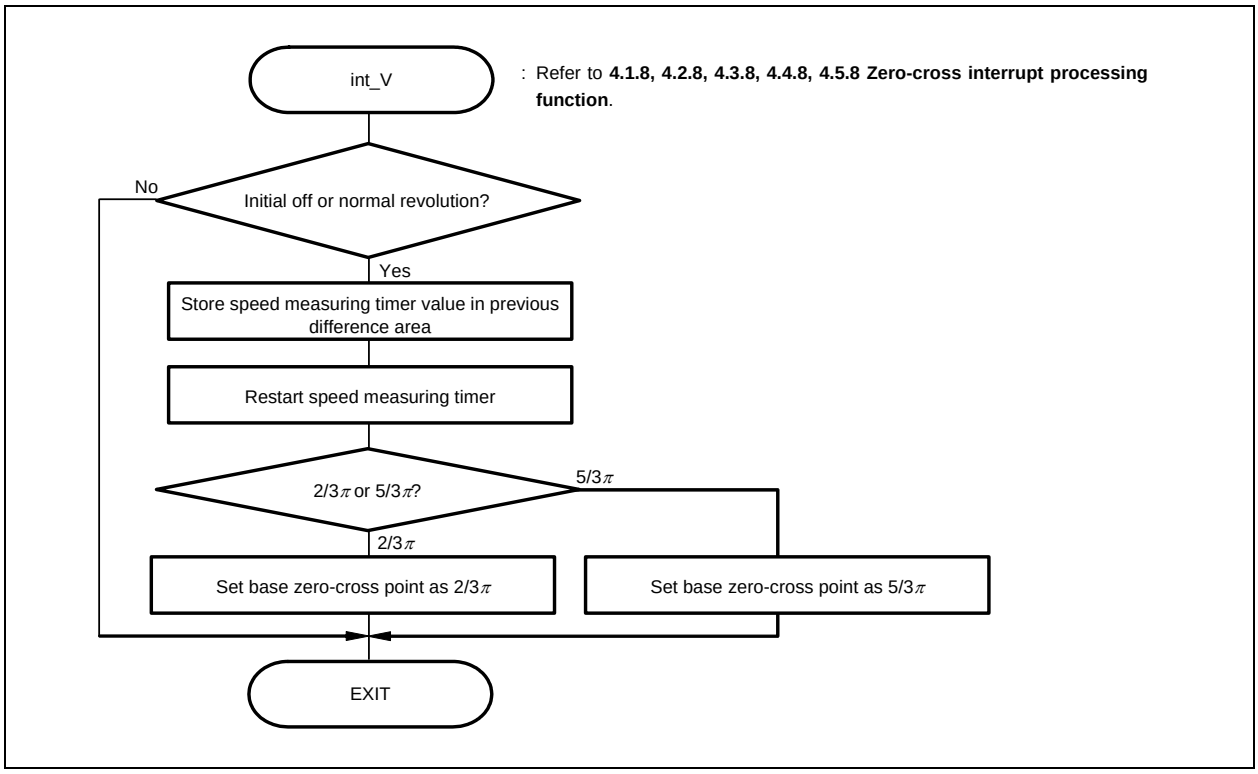
3.8.6 U zero-cross point interrupt processing

Figure 3-17. U Zero-Cross Point Interrupt Processing



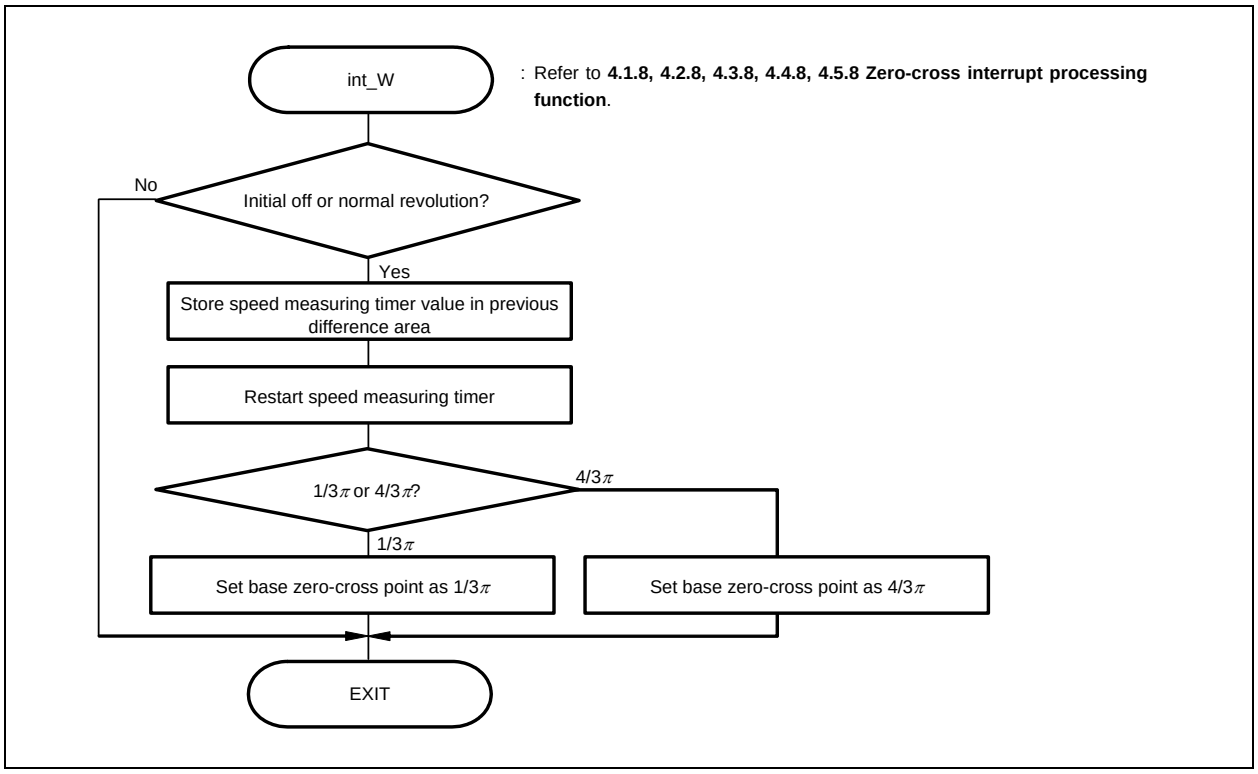
3.8.7 V zero-cross point interrupt processing

Figure 3-18. V Zero-Cross Point Interrupt Processing



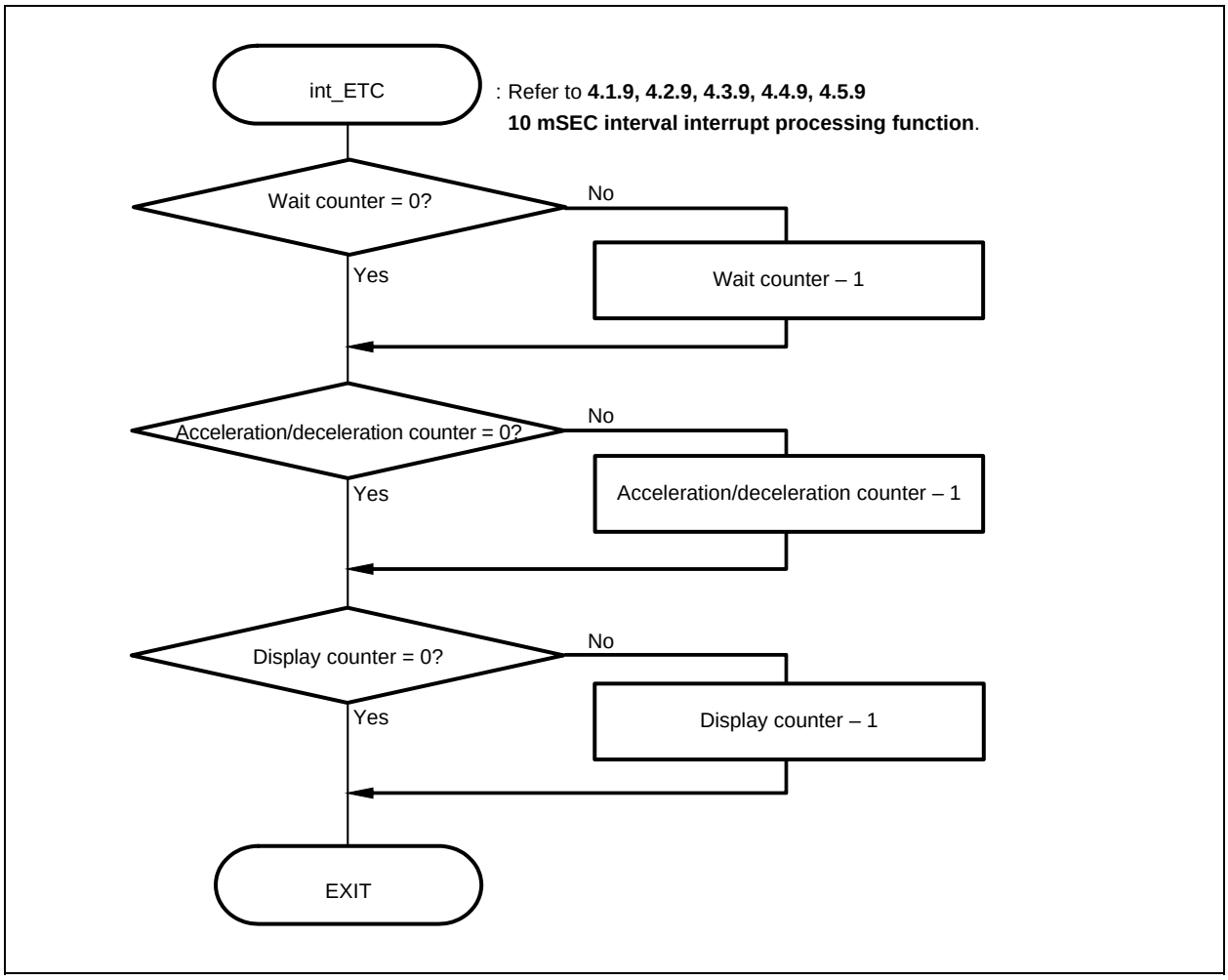
3.8.8 W zero-cross point interrupt processing

Figure 3-19. W Zero-Cross Point Interrupt Processing



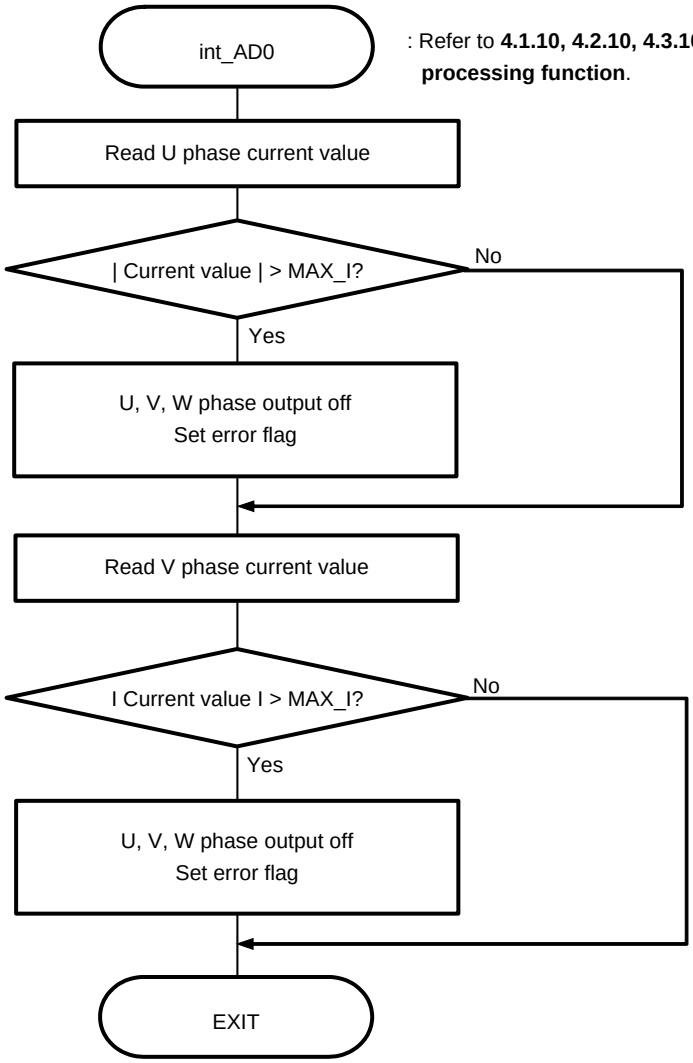
3.8.9 10 mSEC interval interrupt processing

Figure 3-20. 10 mSEC Interval Interrupt Processing



3.8.10 A/D converter channel 0 interrupt processing

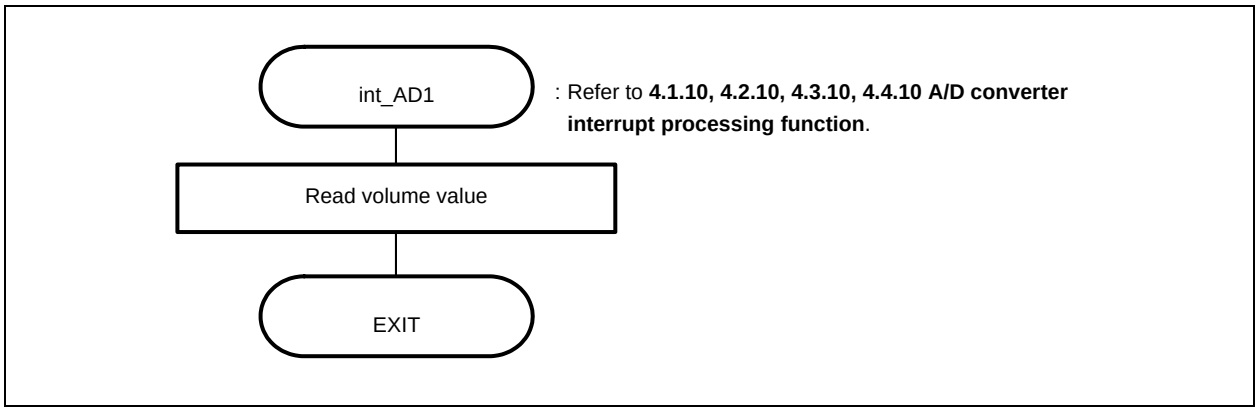
Figure 3-21. A/D Converter Channel 0 Interrupt Processing



Remark MAX_I: Maximum current value

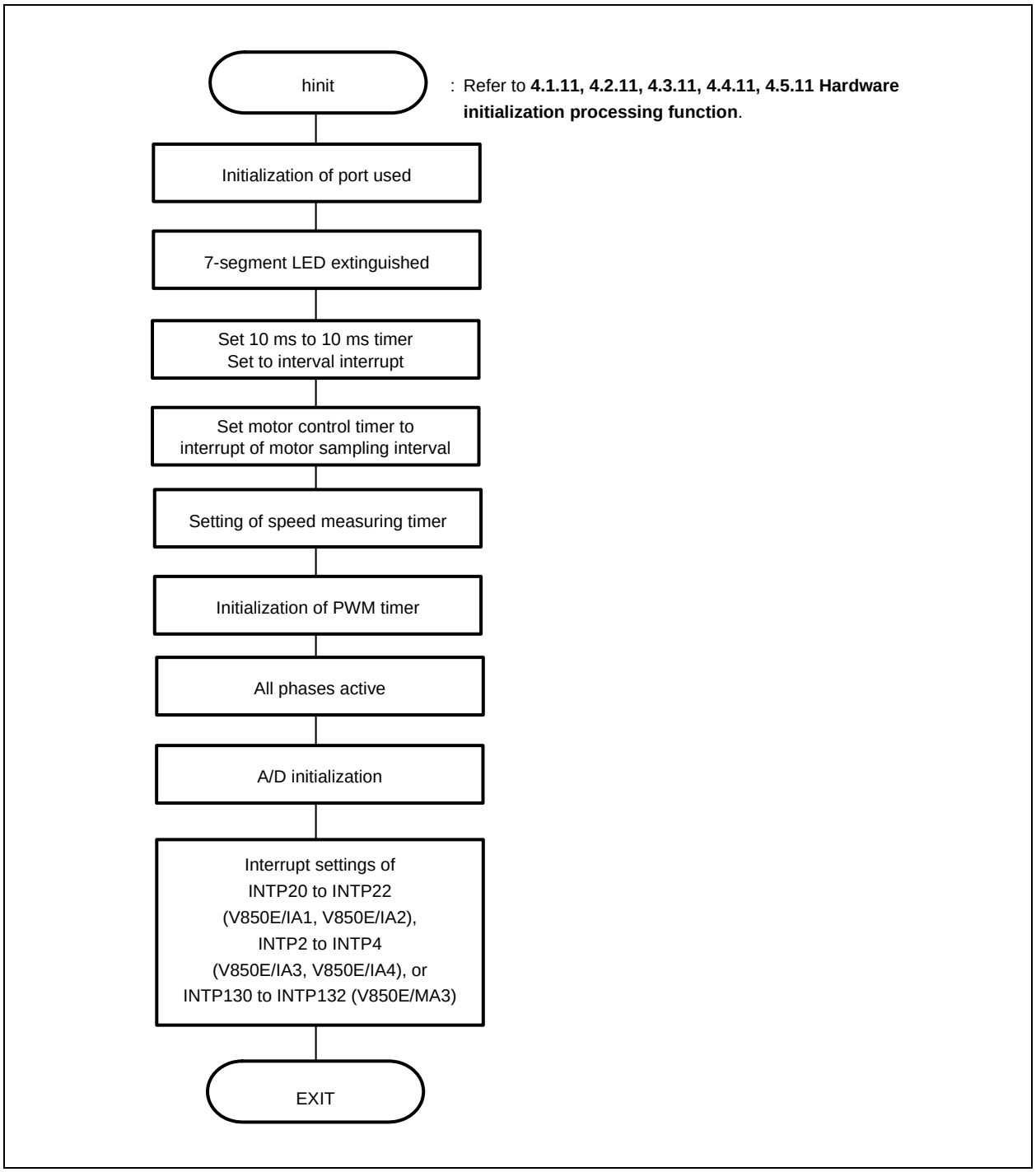
3.8.11 A/D converter channel 1 interrupt processing

Figure 3-22. A/D Converter Channel 1 Interrupt Processing



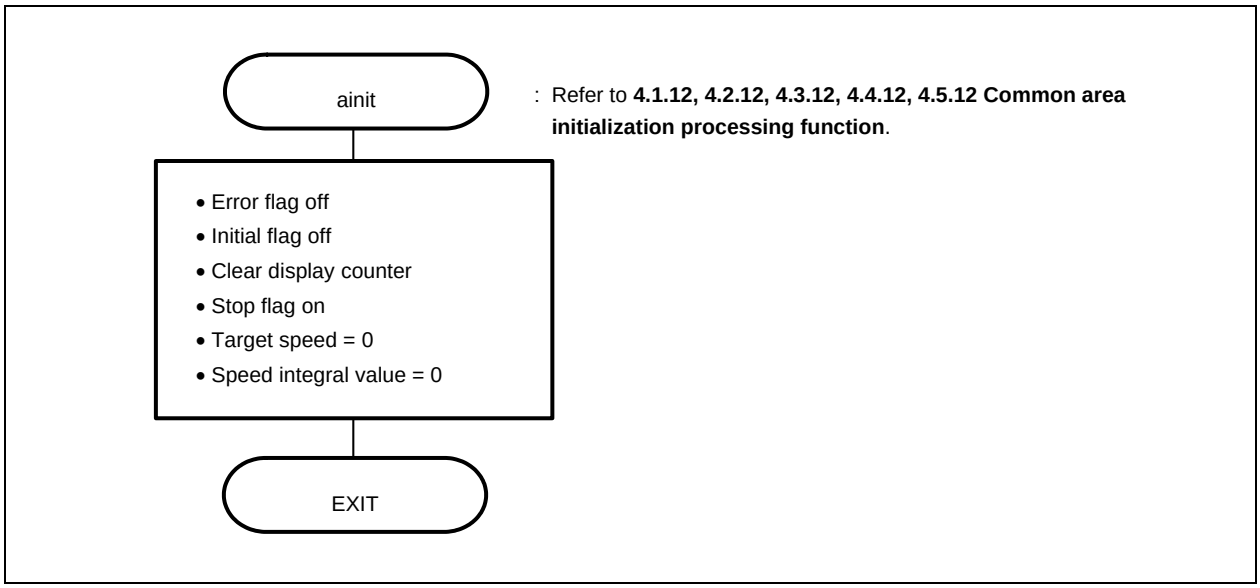
3.8.12 Hardware initialization

Figure 3-23. Hardware Initialization



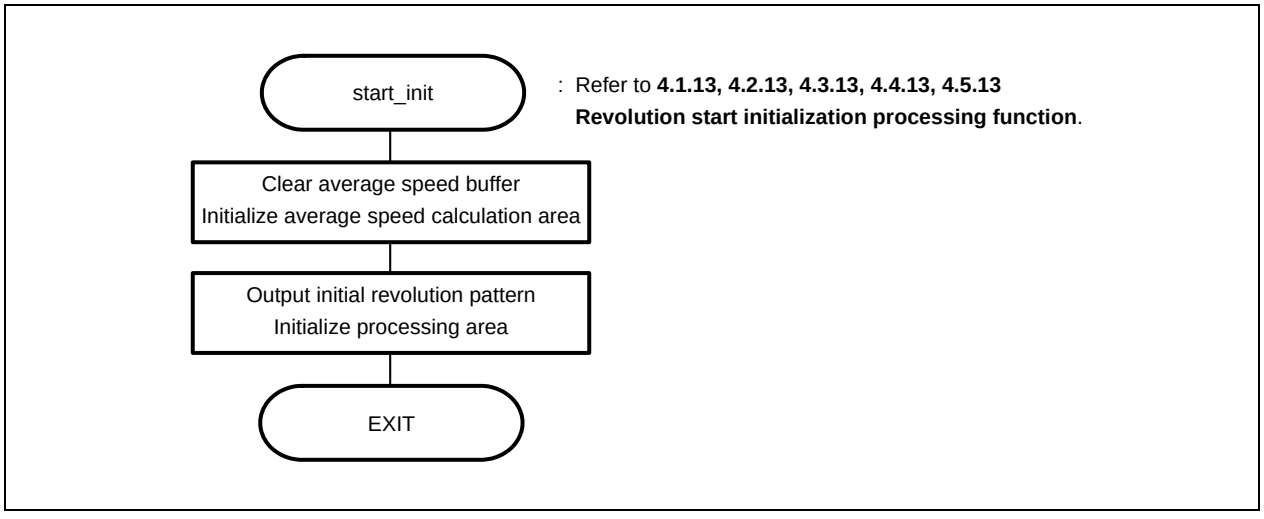
3.8.13 Common area initialization

Figure 3-24. Common Area Initialization



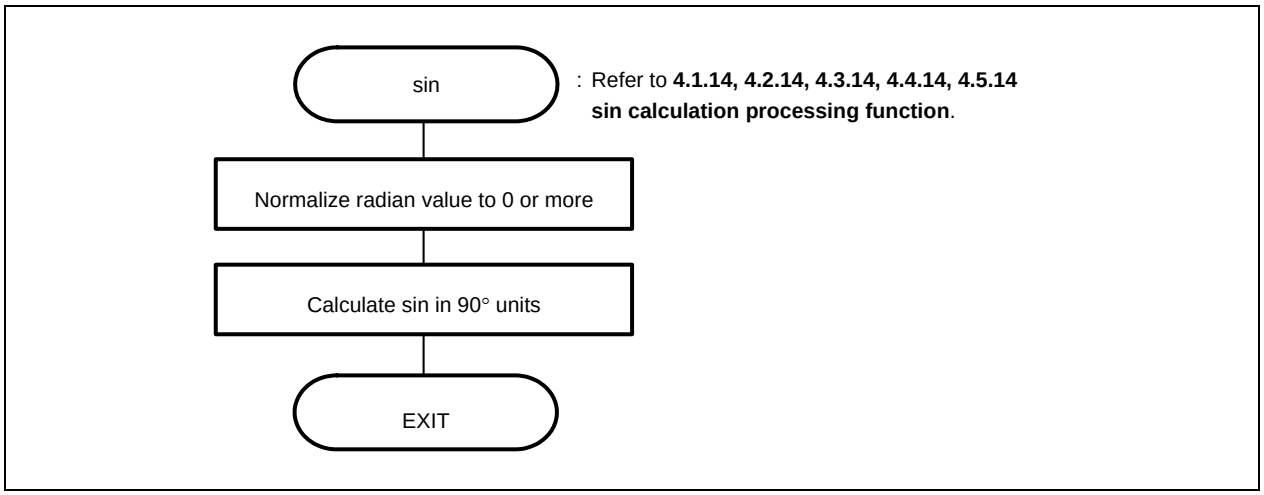
3.8.14 Revolution start initialization

Figure 3-25. Revolution Start Initialization



3.8.15 sin calculation

Figure 3-26. sin Calculation



3.9 Common Areas

The following table shows the major common areas used by the reference system.

Table 3-2. Common Area List

Symbol	Type	Usage	Set Value
error_flag	unsigned char	Error flag	0: No error ERR_NO1: Overcurrent ERR_NO2: Speed difference error
init_flag	unsigned char	Indicates initial revolution	ON: Initial revolution in progress OFF: Stop or normal revolution in progress
cont_time	unsigned short	Interrupt processing time	1 μs units
cont_time1	unsigned short	Vector operation time	1 μs units
disp_co	unsigned short	Average speed counter for display	
volume	unsigned short	Speed volume value	
timer_count	unsigned short	Time wait counter	10 ms units
accel_count	unsigned short	Acceleration/deceleration operation time counter	10 ms units
stop_flag	unsigned char	Stop flag	ON: Stopped OFF: Revolving
before_posi[21][2]	signed short	Position buffer	
total_sa	signed short	Position total difference	
sum_speed	signed int	Total value area for average speed calculation	0, 1, …
speed_co	signed int	Counter for average speed calculation	0, 1, …
now_speed	signed int	Present speed	rpm
object_speed	signed int	Target speed	rpm
d_speed	unsigned int	Display speed	rpm
iua	signed short	U-phase current	
iva	signed short	V-phase current	
o_iqai	signed int	Speed integral value	
base_position	signed int	Speed estimation value reference point	
sa_time	unsigned int	Speed measurement value	
timer_count	unsigned short	Time wait counter	
accel_count	unsigned short	Acceleration/deceleration operation time counter	
o_trm	signed int	Target position for initialization	

3.10 Tables

(1) LED output pattern

Contains display pattern data 0 to 9.

```
unsigned short led_pat[10] = { 0xfc. 0x60, ~ };
```

3.11 Constant Definitions

The following table shows the major constants used by the reference system.

Symbol	Usage	Value[Note]
PAI	π	3.141592
TH_U	Radian value, jack-up constant	1000
RAD	Radian value of one revolution	2 × PAI × TH_U
OFFSET	Original point OFFSET	1733
RPM_RADS	rpm → radian conversion constant	2 × PAI × TH_U/60
KSP	Speed proportion constant	500
KSI	Speed integral constant	50
KI	Current conversion constant	1
P	Number of motor poles	2
KSPGETA	Speed proportion constant jack-up constant	0
KSIGETA	Speed integral constant jack-up constant	9
KIGETA	Current conversion constant jack-up constant	9
SGETA	sin jack-up constant	14
PWM_TS	PWM cycle	80 μs
PWM_DATA	PWM set value	PWM_TS/0.03125
SPEED_MAX	Maximum speed	500 (3000 rpm)
SPEED_MINI	Minimum speed	100 (600 rpm)
SA_SPEED_MAX	Maximum speed difference	800
IQAMAX	Maximum speed integral value	40000000
MAX_I	Maximum current value	800
TS	Motor control period	80 μs
WATCH_START	Speed monitor start time, 10 ms	500
ACCEL_VAL_1ST	Initial acceleration/deceleration time constant	50
ACCEL_VAL	Acceleration/deceleration time constant	3
ACCEL_SPD	Acceleration/deceleration constant	50

Note Value used in the V850E/IA3 and V850E/IA4.
For the value used in the V850E/IA1, V850E/IA2, and V850E/MA3, check it with the program list.

CHAPTER 4 PROGRAM LIST

4.1 Program List (V850E/IA1)

4.1.1 Symbol definition

```
/************************************************************************** /
/*      Common area                                                        */
/************************************************************************** /
unsigned char   ram_start ;
unsigned char   error_flag ;          /* Error flag */
unsigned char   init_flag ;           /* Initial flag */
unsigned short  cont_time ;           /* Interrupt control time uSEC */
unsigned short  cont_time1 ;          /* Vector operation time uSEC */
unsigned short  disp_co ;             /* Interrupt control time display timer */
unsigned short  volume ;              /* Volume value */
unsigned short  timer_count ;         /* Time wait counter */
unsigned short  accel_count ;         /* Acceleration/deceleration operation time */
                                      /* counter */
unsigned char   stop_flag ;           /* Stop flag */
signed short    before_posi[21][2] ;  /* Position buffer */
signed short    total_sa ;            /* Position total difference */
signed int      sum_speed ;
signed int      speed_co ;
signed int      now_speed ;           /* Present speed rms */
signed int      object_speed ;        /* Target speed rms */
unsigned int    d_speed ;             /* Display speed rms */
unsigned char   ram_end ;

#pragma section const begin
const unsigned short led_pat[10] = { 0xfc, 0x60, 0xda, 0xf2, 0x66, 0xb6, 0xbe, 0xe0,
                                     0xfe, 0xe6 } ;
#pragma section const end
/************************************************************************** /
/*      Common flags                                                       */
/************************************************************************** /
extern unsigned char   ram_start ;
extern unsigned char   error_flag ;         /* Error flag */
extern unsigned char   init_flag ;          /* Initial flag */
extern unsigned short  cont_time ;          /* Interrupt control time uSEC */
extern unsigned short  cont_time1 ;         /* Vector operation time uSEC */
extern unsigned short  disp_co ;            /* Interrupt control time display timer */
extern unsigned short  volume ;             /* Volume value */
extern unsigned short  timer_count ;        /* Time wait counter */
extern unsigned short  accel_count ;        /* Acceleration/deceleration operation */
                                            /* time counter */
extern unsigned char   stop_flag ;          /* Stop flag */
```

```
extern signed short    before_posi[21][2] ; /* Position buffer */
extern signed short    total_sa ;           /* Position total difference */
extern signed int      sum_speed ;
extern signed int      speed_co ;
extern signed int      now_speed ;          /* Present speed rms */
extern signed int      object_speed ;       /* Target speed rms */
extern unsigned int    d_speed ;            /* Display speed rms */
extern unsigned char   ram_end ;

#pragma section const begin
extern const unsigned short led_pat[] ;;
#pragma section const end
/************************************************************************ /
/*     Motor common definition                                           */
/************************************************************************ /
extern signed short    iua ;              /* U-phase current */
extern signed short    iva ;              /* V-phase current */
extern signed int      o_iqai ;           /* Speed integral value area */
extern signed int      o_trm ;            /* Target position for initialization */
extern signed int      base_position ;    /* Speed estimation value reference point */
extern unsigned int    sa_time ;          /* Speed measurement value */
extern unsigned short  timer_count ;      /* Time wait counter */
extern unsigned short  accel_count ;      /* Acceleration/deceleration operation */
                                          /* time counter */
```

4.1.2 Constant definition

```
/************************************************************************ /
/*      I/O                                                              */
/************************************************************************ /
#define BASE_IO   0xc200000
#define LED11     3
#define LED12     2
#define LED13     1
#define LED14     0
#define LED21     5
#define LED22     4
#define LED31     7
#define LED32     6
#define LED41     9
#define LED42     8

#define DIPSW     0x10
#define SW        0x20
#define DA1       0x30
#define DA2       0x40
#define DA3       0x50
#define WRESET    0x60
```

```
#define MODE      0x70
/************************************************************************** /
/*      Constant                                                          */
/************************************************************************** /
#define ON        1
#define OFF       0
#define CW        1                     /* CW operation mode */
#define CCW       2                     /* CCW operation mode */
#define STOP      0                     /* Operation stop mode */
#define ERR_NO1   1                     /* Overcurrent error */
#define ERR_NO2   2                     /* Speed difference error */
/************************************************************************** /
/*      Motor constant                                                    */
/************************************************************************** /
#define PAI           3.14159265            /* π */
#define TH_U          1000                  /* Radian value jack-up constant */
#define RAD           (int)(2*PAI*TH_U)     /* Radian value of one revolution */
#define OFFSET        1945                  /* Original point OFFSET */
#define RPM_RADS      (int)((2*PAI*TH_U)/60) /* rpm -> radian conversion constant */
/* Motor constant */
#define KSP           500                   /* Speed proportion constant */
#define KSI           50                    /* Speed integral constant */
#define KI            1                     /* Current conversion constant */
#define P             2                     /* Number of poles */

#define KSPGETA       0                     /* KSP jack-up constant */
#define KSIGETA       9                     /* KSI jack-up constant */
#define KIGETA        9                     /* KI jack-up constant */
#define SGETA         14                    /* sin jack-up constant */

#define PWM_TS        50                    /* PWM cycle */
#define PWM_DATA      (PWM_TS/0.05)         /* PWM set value */
#define SPEED_MAX     3000                  /* Maximum speed rpm */
#define SPEED_MINI    600                   /* Minimum speed rpm */
#define SA_SPEED_MAX  800                   /* Maximum speed difference rpm */
#define IQAMAX        40000000              /* Maximum speed integral value */
#define MAX_I         800                   /* Maximum current value */
#define TS            200                   /* Motor control time interval uSEC */
#define WATCH_START   500                   /* Speed monitor start time 10 mSEC */
#define ACCEL_VAL_1ST 50                    /* Initial acceleration/deceleration */
                                            /* time constant */
#define ACCEL_VAL     3                     /* Acceleration/deceleration time */
                                            /* constant */
#define ACCEL_SPD     50                    /* Acceleration/deceleration constant */
/************************************************************************** /
/*      Function constant                                                 */
/************************************************************************** /
```

```
void            fcalcu( signed int *wrm, signed int *trm );
void            OUT_data( unsigned short reg, unsigned short data );
unsigned short  IN_data( int reg );
void            led_num( int no, long data ) ;
/************************************************************************** /
/*      Motor-related common area                                          */
/************************************************************************** /
signed short    iua ;           /* U-phase current */
signed short    iva ;           /* V-phase current */
signed int      o_iqai ;        /* Speed integral value area */
signed int      o_trm ;         /* Target position for initialization */
signed int      base_position ; /* Speed estimation value reference point */
unsigned int    sa_time ;       /* Speed measurement value */
unsigned short  timer_count ;   /* Time wait counter */
unsigned short  accel_count ;   /* Acceleration/deceleration operation time counter */
```

4.1.3 Interrupt handler setting

```
/************************************************************************** /
/*     Interrupt symbol table                                             */
/************************************************************************** /
       .extern _ _start
       .extern _int_MOTOR
       .extern _int_U
       .extern _int_V
       .extern _int_W
       .extern _int_AD0
       .extern _int_AD1
       .extern _int_ETC

       .globl V_RESET
       .globl V_U
       .globl V_V
       .globl V_W
       .globl V_ETC
       .globl V_MOTOR
       .globl V_AD0
       .globl V_AD1
#************************************************************************
       .section ".handler",text
V_RESET:
       jr       _start
V_U:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_U                  -- INTP20
```

```
V_V:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_V                  -- INTP21
V_W:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_W                  -- INTP22
V_ETC:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_ETC                -- Other timers
V_MOTOR:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_MOTOR              -- Speed control timer
V_AD0:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_AD0                -- A/D converter CH0
V_AD1:
       ld.w     [sp],r1
       add      4,sp
       jr       _int_AD1                -- A/D converter CH1

       .extern V_RESET
       .extern V_U
       .extern V_V
       .extern V_W
       .extern V_ETC
       .extern V_MOTOR
       .extern V_AD0
       .extern V_AD1
/************************************************************************** /
/*     Interrupt jump table                                                */
/************************************************************************** /
       .section ".vect_RESET",text
       mov      #V_RESET,r1
       jmp      [r1]

       .section ".id_NO",text
       .byte    0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff

       .section ".vect_U",text
       add      -4,sp
       st.w     r1,[r3]
       mov      #V_U,r1
       jmp      [r1]
```

```
        .section ".vect_V",text
        add      -4,sp
        st.w     r1,[r3]
        mov      #V_V,r1
        jmp      [r1]

        .section ".vect_W",text
        add      -4,sp
        st.w     r1,[r3]
        mov      #V_W,r1
        jmp      [r1]

        .section ".vect_ETC",text
        add      -4,sp
        st.w     r1,[r3]
        mov      #V_ETC,r1
        jmp      [r1]

        .section ".vect_MOTOR",text
        add      -4,sp
        st.w     r1,[r3]
        mov      #V_MOTOR,r1
        jmp      [r1]

        .section ".vect_AD0",text
        add      -4,sp
        st.w     r1,[r3]
        mov      #V_AD0,r1
        jmp      [r1]

        .section ".vect_AD1",text
        add      -4,sp
        st.w     r1,[r3]
        mov      #V_AD1,r1
        jmp      [r1]
```

4.1.4 Startup routine setting

```
#===============================================================================
# DESCRIPTIONS:
#      This assembly program is a sample of start-up module for ca850.
#    If you modified this program, you must assemble this file, and
#    locate a given directory.
#
```

```
#    Unless -G is specified, sections are located as the following.
#
#                 |       :       |
#                 |       :       |
#          tp -> -+-------------- + _ _start   _ _tp_TEXT
#                 | start up      |
#                 |-------------- |
# text section    |               |
#                 | user program  |
#                 |               |
#                 |-------------- |
#                 | library       |
#                -+-------------- +
#                 |               |
# sdata section   |               |
#                 |               |
#          gp -> -+-------------- +            _ _ssbss
#                 |               |
# sbss section    |               |
#                 |               |
#                 +-------------- + _ _stack   _ _esbss     _ _sbss
#                 | stack area    |
# bss section     |               |
#                 | 0x400 bytes   |
#          sp -> -+-------------- + _ _stack + STACKSIZE    _ _ebss
#                 |       :       |
#                 |       :       |
#                 |       :       |
#          ep -> -+-------------- + _ _ep_DATA
# tidata section  |               |
#                -+-------------- +
# sidata section  |               |
#                -+-------------- +
#                 |       :       |
#                 |       :       |
#
#==============================================================================
#------------------------------------------------------------------------------
#       special symbols
#------------------------------------------------------------------------------
        .extern _ _tp_TEXT, 4
        .extern _ _gp_DATA, 4
        .extern _ _ep_DATA, 4
        .extern _ _ssbss, 4
        .extern _ _esbss, 4
        .extern _ _sbss, 4
        .extern _ _ebss, 4
```

```
#------------------------------------------------------------------------------
#       C program main function
#------------------------------------------------------------------------------
        .extern _main


#------------------------------------------------------------------------------
#       dummy data declaration for creating sbss section
#------------------------------------------------------------------------------
        .sbss
        .lcomm _ _sbss_dummy, 0, 0


#------------------------------------------------------------------------------
#       system stack
#------------------------------------------------------------------------------
        .set   STACKSIZE, 0x400
        .bss
        .lcomm _ _stack, STACKSIZE, 4

#------------------------------------------------------------------------------
#       start up
#             pointers: tp - text pointer
#                       gp - global pointer
#                       sp - stack pointer
#                       ep - element pointer
#       exit status is set to r10
#------------------------------------------------------------------------------
        .text
        .align 4
        .globl _ _start
        .globl _exit
        .globl _ _exit
_ _start:
        mov      0x12,r10
        st.b     r10,VSWC[r0]               -- Set peripheral I/O wait

        mov      0x07,r10                   -- ×10
        st.b     r0,PHCMD[r0]
        st.b     r10,CKC[r0]                -- PLL xx multiplication
        nop
        nop
        nop
        nop
        nop

        mov      #_ _tp_TEXT, tp            -- set tp register
```

```
        mov     #_ _gp_DATA, gp             -- set gp register offset
        add     tp, gp                      -- set gp register
        mov     #_ _stack+STACKSIZE, sp     -- set sp register
        mov     #_ _ep_DATA, ep             -- set ep register
#
        mov     #_ _ssbss, r13              -- clear sbss section
        mov     #_ _esbss, r12
        cmp     r12, r13
        jnl     .L11
.L12:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L12
.L11:
#
        mov     #_ _sbss, r13               -- clear bss section
        mov     #_ _ebss, r12
        cmp     r12, r13
        jnl     .L14
.L15:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L15
.L14:
#
        jarl    _main, lp                   -- call main function
_ _exit:
        halt                                -- end of program
_ _startend:
        nop
#                                                                               #
#------------------------- end of start up module ----------------------------#
#                                                                               #
```

4.1.5 Main processing function

```
#include    "Common.h"
#include    "Motor.h"
#pragma     ioreg                           /* Peripheral I/O register definition */

static int save_psw;
/*************************************************************************** /
/*     3-phase motor control program                                        */
/*************************************************************************** /
void   main()
{
```

```
unsigned char  proc_no ;                        /* Present processing number */
signed int     speed ;                          /* Indication speed rms */
signed int     accel_spd ;
int            sw, sw_mode ;
/* */
   hinit() ;                                    /* Hardware initialization */
   ainit() ;                                    /* Initialization of area used */
   proc_no = 0 ;
   _ _EI();
   while( 1 ) {
      accel_spd = ( SPEED_MAX - SPEED_MINI ) / 100;
      speed  = ( ( SPEED_MAX - SPEED_MINI ) * volume  / 1024 )
               + SPEED_MINI ;                   /* Indication speed calculation by volume */
      sw =  ~IN_data( SW ) & 0x07 ;             /* Read operation button */
      if  ( sw == 1 ) {
         sw_mode = CW ;
      } else if  ( sw == 2 ) {
         sw_mode = CCW ;
      } else if  ( sw == 4 ) {
         sw_mode = STOP ;
      }
      switch( proc_no ) {
/* STOP processing */
         case 0 :
            if  ( sw_mode == CW ) {
               _ _DI() ;
               object_speed  = SPEED_MINI ;     /* Set target speed to minimum value */
               stop_flag = OFF ;
               timer_count = WATCH_START ;      /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ;    /* Set acceleration/deceleration counter */
               init_flag = 2 ;                  /* CCW initial request */
               start_init() ;                   /* Initialize revolution start */
               _ _EI() ;
               proc_no = 1 ;                    /* Set next processing number */
            } else if  ( sw_mode == CCW ) {
               _ _DI() ;
               stop_flag = OFF ;                /* Stop flag off */
               object_speed = -SPEED_MINI ;     /* Set target speed to minimum value */
               timer_count = WATCH_START ;      /* Set speed monitor start time to */
                                                /* 5 SEC */
               accel_count = ACCEL_VAL_1ST ;    /* Set acceleration/deceleration counter */
               init_flag = 3 ;                  /* CCW initial request */
               start_init() ;                   /* Initialize revolution start */
               _ _EI() ;
               proc_no = 4 ;                    /* Set CCW processing number */
            }
            break ;
/* CW processing, acceleration */
```

```
          case 1 :
             if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                if  ( object_speed  < speed ) {
                   object_speed += accel_spd ;
                   if  ( object_speed > speed ) object_speed = speed;
                   timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                } else if ( object_speed  > speed ) {
                   object_speed -= accel_spd ;
                   if  ( object_speed < speed ) object_speed = speed;
                   timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                } else {
                   proc_no = 2 ;               /* Constant-speed processing */
                }
             }
             if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
                proc_no = 3 ;                  /* Deceleration, set processing number */
             }
             break ;
/* CW processing, constant-speed */
          case 2 :
             object_speed = speed ;
             if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
                proc_no = 3 ;                  /* Deceleration, set processing number */
             }
             break ;
/* CW stop processing */
          case 3 :
             if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                if  ( object_speed  > SPEED_MINI ) {
                   object_speed -= accel_spd ;
                   if  ( object_speed < SPEED_MINI ) object_speed = SPEED_MINI;
                   timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                } else {
                   stop_flag = ON ;            /* Stop flag on */
                   proc_no = 0 ;               /* Set stop processing number */
                }
             }
             break ;
/* CCW processing, acceleration */
          case 4 :
             if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                if  ( object_speed  < -speed ) {
                   object_speed += accel_spd ;
                   if  ( object_speed > -speed ) object_speed = -speed;
                   timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
```

```
                } else if ( object_speed  > -speed ) {
                    object_speed -= accel_spd ;
                    if  ( object_speed < -speed ) object_speed = -speed;
                    timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                } else {
                    proc_no = 5 ;               /* Constant-speed processing */
                }
            }
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
                proc_no = 6 ;                   /* Deceleration, set processing number */
            }
            break ;
/* CCW processing, constant-speed */
          case 5 :
            object_speed = -speed ;
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
                proc_no = 6 ;                   /* Deceleration, set processing number */
            }
            break ;
/* CCW stop processing */
          case 6 :
            if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;       /* Set acceleration/deceleration counter */
                if  ( object_speed  < -SPEED_MINI ) {
                    object_speed += accel_spd ;
                    if  ( object_speed > -SPEED_MINI ) object_speed = -SPEED_MINI;
                    timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                } else {
                    stop_flag = ON ;            /* Stop flag on */
                    proc_no = 0 ;               /* Set stop processing number */
                }
            }
            break ;
      }

      if  ( ( proc_no == 2 ) || ( proc_no == 5 ) ) {
          if  (  timer_count == 0 ) {
              if  ( abs( object_speed - now_speed ) > SA_SPEED_MAX ) {
                  error_flag = ERR_NO2 ;        /* Set error No. */
              }
          }
      }

      if  ( disp_co == 0 ) {
          led_num(1, d_speed / 100 );           /* Number of revolutions */
          d_speed = 0 ;
          disp_co = 100 ;
          if  ( abs(now_speed) == 0 ) {
```

```
            disp_co = 0;
         }
         led_num(2, 1000/PWM_TS );            /* Carrier frequency */
         led_num(3, cont_time );              /* Overall processing time */
         led_num(4, cont_time1 );             /* Vector operation processing time */
      }
      if  ( error_flag ) {
         while( 1 ) {
            OUT_data( LED41, ~0x00 ) ;        /* LED display off */
            OUT_data( LED42, ~0x00 ) ;
            timer_count = 50 ;
            while( timer_count ) ;
            if  ( error_flag == ERR_NO1 ) {
               OUT_data( LED41, ~0x9e ) ;     /* E1 display */
               OUT_data( LED42, ~0x60 ) ;
            } else if ( error_flag == ERR_NO2 ) {
               OUT_data( LED41, ~0x9e ) ;     /* E2 display */
               OUT_data( LED42, ~0xda ) ;
            } else {
               OUT_data( LED41, ~0x9e ) ;     /* E3 display */
               OUT_data( LED42, ~0xf2 ) ;
            }
            timer_count = 50 ;
            while( timer_count ) ;
         }
      }
   }
}
```

4.1.6 LED display function

```
/************************************************************************** /
/*     LED value display subroutine                                        */
/*              no  : Display area number (1 to 4)                         */
/*              data: Display data (0 to 99)                               */
/************************************************************************** /
void led_num( int no, long data )
{
   if  ( no == 1 ) {
      data = data % 10000;
      OUT_data( LED11, ~led_pat[data/1000]&0xff ) ;
      OUT_data( LED12, ~led_pat[(data%1000)/100]&0xff ) ;
      OUT_data( LED13, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED14, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 2 ) {
      OUT_data( LED21, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED22, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 3 ) {
```

```
      OUT_data( LED31, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED32, ~led_pat[data%10]&0xff ) ;
   } else {
      OUT_data( LED41, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED42, ~led_pat[data%10]&0xff ) ;
   }
}
/************************************************************************** /
/*     External I/O output subroutine                                     */
/*              reg : Output register number                              */
/*              data: Output data                                         */
/************************************************************************** /
void   OUT_data( unsigned short reg, unsigned short data )
{
      if  ( reg == WRESET ) {
            P4.3 = 0;
            data = 1;                       /* Dummy step */
            P4.3 = 1;
      } else {
            PDL = data | ( reg << 8 );
            PDL = reg | ( reg << 8 ) | 0x8000;
      }
}
/************************************************************************** /
/*     External I/O input subroutine                                      */
/*           reg: Input register number                                   */
/************************************************************************** /
unsigned short  IN_data( int reg )
{
unsigned char *po;
/*  */
      if    ( reg == SW ) {
              return P4;
      } else {
              return 0;
      }
}
```

4.1.7 Motor control interrupt processing function

```
#include    "Common.h"
#include    "Motor.h"
#pragma     ioreg           /* Peripheral I/O register definition */
/************************************************************************** /
/*      Motor control timer interrupt processing                          */
/************************************************************************** /
_ _interrupt
```

```
void    int_MOTOR(void)
{
   ADSCM00 = 0x8001 ;        /* Start AD0 */
   ADSCM10 = 0x8000 ;        /* Start AD1 */
}
/************************************************************************** /
/*      Motor control processing                                          */
/************************************************************************** /
void   Motor_CONT(void)
{
signed int    wrm, wre, trm, tre ;
signed int    o_wre, we, o_iqap, o_iqa ;
signed int    ida, iqa, o_vda1, o_vqa1 ;
signed int    o_vd0, o_vq0, o_vda, o_vqa ;
signed int    o_vua, o_vva, o_vwa, wiua, wiva ;
signed int    s_time, wk ;
/*  */
/************************************************************************** /
/*      Calculation processing of speed and rotor position                */
/************************************************************************** /
   fcalcu( &wrm, &trm ) ;
   sum_speed += ( wrm * TH_U / RPM_RADS ) ; /* Radian -> rpm */
   if  ( --speed_co == 0 ) {
       speed_co = 100000 / TS ;             /* Set 100 mSEC counter value */
       now_speed = sum_speed / speed_co ;
       sum_speed = 0 ;
   }
   wre = wrm * P ;
   tre = ( trm * P + OFFSET ) % RAD ;
/************************************************************************** /
/*      Speed control processing                                          */
/************************************************************************** /
   if  ( ( stop_flag == OFF ) && ( error_flag == 0 ) ) {
       s_time = TM3 ;
       o_wre = object_speed * RPM_RADS * P / TH_U ;     /* rpm -> radian conversion */
       we = o_wre - wre ;
       o_iqap = ( ( wre * KSP ) + ( we * KSP ) ) >> KSPGETA ;
       o_iqa = o_iqap + ( o_iqai >> KSIGETA ) ;

       if  ( o_iqai > IQAMAX ) {
          o_iqai = IQAMAX ;
       } else if ( o_iqai < -IQAMAX ) {
          o_iqai = -IQAMAX ;
       } else {
          o_iqai += ( KSI * we ) ;
       }
/************************************************************************** /
/*      Current control processing                                        */
```

```
/************************************************************************** /
      ida = ( ( ( iva * sin( tre ) ) - ( iua * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      iqa = ( ( ( iva * sin( tre + RAD/4 ) ) - ( iua * sin( tre + 11*RAD/12 ) ) ) ) >> SGETA ;

      o_vda = ( KI * -ida ) >> KIGETA ;
      o_vqa = ( KI * ( o_iqa  - iqa )  ) >> KIGETA ;
/************************************************************************** /
/*      3-phase voltage conversion processing                               */
/************************************************************************** /
      if ( init_flag == 2 ) {                          /* CW initial processing */
         o_trm += ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm > ( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else if ( init_flag == 3 ) {                   /* CCW initial processing */
         o_trm -= ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm < -( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else {
         o_trm = 0 ;
      }
      o_vua  = ( ( ( o_vda * sin( tre + RAD/4 ) ) - ( o_vqa * sin( tre ) ) ) ) >> SGETA ;
      o_vva  = ( ( ( o_vda * sin( tre + 11*RAD/12 ) ) - ( o_vqa * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      o_vwa  = -o_vua - o_vva ;

      cont_time1 = ( TM3 - s_time ) * 10 / 16;       /* Convert to uSEC */
/************************************************************************** /
/*      PWM conversion output processing                                    */
/************************************************************************** /
      OUT_data( WRESET, 0 ) ;                 /* Reset watchdog timer */
      POER0 = 0x3f ;                          /* All phases active */
      TUC00 = 0x02 ;                          /* Clear PWM output prohibition */
/* PWM counter value calculation output */
      o_vua += ( PWM_DATA  / 2 ) ;
      o_vva += ( PWM_DATA  / 2 ) ;
      o_vwa += ( PWM_DATA  / 2 ) ;

      if  ( o_vua <= 0 ) {
         o_vua = 1 ;
      } else if  ( o_vua >= PWM_DATA  ) {
         o_vua = PWM_DATA  - 1 ;
```

```
      }
      if  ( o_vva <= 0 ) {
         o_vva = 1 ;
      } else if  ( o_vva >= PWM_DATA  ) {
         o_vva = PWM_DATA  - 1 ;
      }
      if  ( o_vwa <= 0 ) {
         o_vwa = 1 ;
      } else if  ( o_vwa >= PWM_DATA  ) {
         o_vwa = PWM_DATA  - 1 ;
      }

      BFCM00 = o_vua ;
      BFCM01 = o_vva ;
      BFCM02 = o_vwa ;
   } else {
      POER0 = 0 ;                      /* PWM output off */
      now_speed = 0;
      cont_time1 = 0;
   }
}
/************************************************************************** /
/*     Calculation processing of speed, etc.                               */
/************************************************************************** /
void   fcalcu( signed int *wrm, signed int *trm )
{
signed short  es_trm, cur_time, delta, i ;
signed int    wwrm, wk, *p1, *p2;
//
//      Speed and position calculation from zero-cross point
//
   cur_time = TM4 ;
   delta = ( (RAD/6/P) * cur_time ) / sa_time ;  /* Calculation of rotor position */
                                                 /* difference from reference */
                                                 /* position (radian) */
   if  ( object_speed >= 0 ) {
      es_trm = base_position + delta;
   } else {
      es_trm = base_position - delta;
      if  ( es_trm < 0 ) es_trm += (RAD/P);
   }

   total_sa -= before_posi[20][1] ;

   p1 = (int *)before_posi[19] ;
   p2 = (int *)before_posi[20] ;
   for ( i = 0; i <= 19 ; i++ ) {
      *p2-- = *p1-- ;
```

```
    }
    before_posi[0][0] = *trm = es_trm % (RAD/P) ;

    wk = before_posi[0][0] - before_posi[1][0] ;
    if  ( abs(wk) > (RAD/2/P) ) {
        if  ( wk < 0 ) {
            wk = (RAD/P) + wk ;
        } else {
            wk = wk - (RAD/P) ;
        }
    }

    before_posi[1][1] = wk ;
    total_sa += wk ;                          /* Total difference in average buffer */

    wwrm = ( total_sa * ( 1000000 / 20 / TH_U ) / TS );
    *wrm = wwrm ;                              /* Speed  radian/second */
}
```

4.1.8 Zero-cross interrupt processing function

```
/************************************************************************** /
/*      U zero-cross point interrupt                                       */
/************************************************************************** /
_ _interrupt
void   int_U(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TM4 ;
        TMC4  = 0x61;
        TMC4  = 0x63;                          /* Restart timer */

        if  ( ~P2 & 0x04 ) {                   /* Check W phase */
            base_position = 0 ;
        } else {
            base_position = RAD/2/P ;
        }
    }
}
/************************************************************************** /
/*     V zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void   int_V(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TM4 ;
        TMC4  = 0x61;
```

```
        TMC4  = 0x63;                           /* Restart timer */

        if  ( ~P2 & 0x01 ) {
            base_position = RAD/3/P ;
        } else {
            base_position = RAD*5/6/P ;
        }
    }
}
/************************************************************************** /
/*     W zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void   int_W(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TM4 ;
        TMC4  = 0x61;
        TMC4  = 0x63;                           /* Restart timer */

        if  ( ~P2 & 0x02 ) {
            base_position = RAD*2/3/P ;
        } else {
            base_position = RAD/6/P ;
        }
    }
}
```

4.1.9 10 mSEC interval interrupt processing function

```
/************************************************************************** /
/*     Other timer interrupt processing (10 mSEC interval)                 */
/************************************************************************** /
_ _multi_interrupt
void   int_ETC(void)
{
/* Wait timer processing */
    if  ( timer_count != 0 ) {
        timer_count -= 1 ;
    }
/* Acceleration/deceleration timer processing */
    if  ( accel_count != 0 ) {
        accel_count -= 1 ;
    }
/* */
    if  ( disp_co != 0 ) {
        d_speed += abs( now_speed ) ;
        disp_co -= 1 ;
```

```
    }
}
```

4.1.10 A/D converter interrupt processing function

```
/************************************************************************** /
/*     A/D converter interrupt processing for U-phase current and speed volume */
/************************************************************************** /
_ _multi_interrupt
void   int_AD0(void)
{
    iua = (( ADCR00 & 0x3ff ) - 0x200) ;
    if  ( abs(iua) > MAX_I ) {
        POER0 = 0 ;                         /* PWM output off */
        error_flag = ERR_NO1 ;              /* Set error No. */
    }
    volume = 1023 - ( ADCR01 & 0x3ff ) ;    /* Set volume value */
    Motor_CONT() ;
    cont_time = TM3 * 10 / 16;              /* Convert to uSEC */
}
/************************************************************************** /
/*      A/D converter interrupt processing for V-phase current                */
/************************************************************************** /
_ _interrupt
void   int_AD1(void)
{
    iva = (( ADCR10 & 0x3ff ) - 0x200) ;
    if  ( abs(iva) > MAX_I ) {
        POER0 = 0 ;                         /* PWM output off */
        error_flag = ERR_NO1 ;              /* Set error No. */
    }
}
```

4.1.11 Hardware initialization processing function

```
/************************************************************************** /
/*     Hardware (peripheral I/O) initialization                              */
/************************************************************************** /
void   hinit( void )
{
/* Port mode register initialization */
    PM4 = 0xf7 ;
    PMDL = 0x0000 ;

    OUT_data( LED11, 0xff ) ;               /* LED OFF */
    OUT_data( LED12, 0xff ) ;
    OUT_data( LED13, 0xff ) ;
    OUT_data( LED14, 0xff ) ;
```

```
    OUT_data( LED21, 0xff ) ;
    OUT_data( LED22, 0xff ) ;
    OUT_data( LED31, 0xff ) ;
    OUT_data( LED32, 0xff ) ;
    OUT_data( LED41, 0xff ) ;
    OUT_data( LED42, 0xff ) ;
/* Set 10 mSEC timer TM2 */
    STOPTE0 = 0x0000;
    PRM02 = 0x01;                          /* Select fXX/2 */
    CSE0 = 0x0028;                         /* Select fCLK/64 (3.2 uSEC) */
    TCRE0 = 0x2000;                        /* Start timer */
    CVSE50 = 1562*2 ;                      /* 10 mSEC */
    CMSE050 = 0x2400;
    CC2IC5 = 0x06;
/* Set motor control interrupt timer TM3 */
    PRM03 = 1 ;                            /* fCLK = fXX */
    TMC30 = 0x51;                          /* fXX = 4 MHz*10/64(1.6 uSEC) */
    TMC31 = 0x09 ;
    CC30  = TS * 10 / 16 ;                 /* TS uSEC interval */
    TMC30 = 0x53;                          /* Start timer */
    CC3IC0 = 0x02;                         /* Reset interrupt mask */
/* Set speed measuring timer TM4 */
    TMC4  = 0x61;                          /* fXX(4 MHz*10/2)/128(6.4 uSEC) */
    CM4   = 0xffff;
    TMC4  = 0x63;                          /* TM4 start */
/* TM00 initialization */
    PRM01 = 0 ;                            /* fCLK = fXX/2 */
    SPEC0 = 0x0000 ;
    TOMR0 = 0x80 ;                         /* Set output mode */
    PSTO0 = 0x00 ;                         /* Disable real-time output */
    BFCM00 =  PWM_DATA /2 ;                /* Set duty to 50 */
    BFCM01 =  PWM_DATA /2 ;                /* Set duty to 50 */
    BFCM02 =  PWM_DATA /2 ;                /* Set duty to 50 */
    BFCM03 =  PWM_DATA ;                   /* Set PWM cycle */
    DTRR0 = 40*3 ;                         /* Dead time 6 uSEC */
    POER0 = 0x3f ;                         /* All phases active */
    TMC00 = 0x8018 ;                       /* Start TMPWM timer */
/* Set A/D */
    ADSCM00 = 0x0001 ;
    ADSCM10 = 0x0000 ;
    ADIC0   = 0x03 ;
    ADIC1   = 0x03 ;
/* Set zero-cross signal interrupt pin */
    FEM0   = 0x0c ;                        /* INTP20 both-edge interrupt */
    CC2IC0 = 0x01 ;
    FEM1   = 0x0c ;                        /* INTP21 both-edge interrupt */
    CC2IC1 = 0x01 ;
    FEM2   = 0x0c ;                        /* INTP22 both-edge interrupt */
```

```
    CC2IC2 = 0x01 ;
}
```

4.1.12 Common area initialization processing function

```
/************************************************************************** /
/*     Common area initialization                                          */
/************************************************************************** /
void   ainit( void )
{
/* Initialization of flags */
    error_flag = 0 ;                    /* Clear error flag */
    init_flag = OFF ;                   /* Initial flag off */
    disp_co = 100 ;
    d_speed = 0 ;
/* Motor control area initialization */
    stop_flag = ON ;                    /* Stop flag on */
    object_speed = 0 ;                  /* Target speed 0 */
    o_iqai = 0 ;                        /* Speed integral value 0 */
    o_trm = 0 ;
}
```

4.1.13 Revolution start initialization processing function

```
/************************************************************************** /
/*     Revolution start initialization                                     */
/************************************************************************** /
void   start_init( void )
{
    int  i;
/*  */
    for ( i = 0 ; i < 21 ; i++ ) before_posi[i][1] = 0;
    total_sa = 0 ;
    sum_speed = 0 ;
    speed_co = 100000 / TS ;
}
```

4.1.14 sin calculation processing function

```
/************************************************************************** /
/*     sin x                                                               */
/*          Data                                                           */
/*            Radian unit                                                  */
/*          Return value                                                   */
/*            Sign value*16384                                             */
/************************************************************************** /
int sin( int x )
{
```

```
    x = x % RAD ;
    if  ( x < 0 ) x += RAD ;
    if  ( x < (RAD/4) ){
        return sins( x ) ;
    } else if ( x < (RAD/2) ) {
        return sins( (RAD/2) - x ) ;
    } else if ( x < (RAD*3/4) ) {
        return -sins( x - (RAD/2) ) ;
    } else {
        return -sins( RAD - x ) ;
    }
}
/*****************************************************************************/
int sins( int x )
{
short z1, z2, z3, z4, z5 ;
/*  */
    if  ( x <= (RAD/8) ) {
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z3 = z1 * z2 >> SGETA ;
        z5 = z2 * z3 >> SGETA ;
        return ( (12868*z1) - (1322*z3) + (40*z5) ) >> SGETA ;
    } else {
        x = (RAD/4) - x ;
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z4 = z2 * z2 >> SGETA ;
        return ( (268432772) - (5050*z2) + (252*z4) ) >> SGETA ;
    }
}
```

4.1.15 Link directive file for V850E/IA1

```
/************************************************************************** /
/*     Link directive file for V850E/IA1                                    */
/************************************************************************** /
VECT_RESET: !LOAD ?RX V0x0000000 {
       .vect_RESET  = $PROGBITS ?AX .vect_RESET;
};
ID_NO: !LOAD ?RX V0x0000070 {
       .id_NO  = $PROGBITS ?AX .id_NO;
};
VECT_U: !LOAD ?RX V0x00001f0 {
       .vect_U  = $PROGBITS ?AX .vect_U;
};
VECT_V: !LOAD ?RX V0x0000200 {
       .vect_V  = $PROGBITS ?AX .vect_V;
```

```
};
VECT_W: !LOAD ?RX V0x0000210 {
       .vect_W  = $PROGBITS ?AX .vect_W;
};
VECT_ETC: !LOAD ?RX V0x0000240 {
       .vect_ETC  = $PROGBITS ?AX .vect_ETC;
};
VECT_MOTOR: !LOAD ?RX V0x0000260 {
       .vect_MOTOR  = $PROGBITS ?AX .vect_MOTOR;
};
VECT_AD0: !LOAD ?RX V0x00003a0 {
       .vect_AD0  = $PROGBITS ?AX .vect_AD0;
};
VECT_AD1: !LOAD ?RX V0x00003b0 {
       .vect_AD1  = $PROGBITS ?AX .vect_AD1;
};

HANDLER: !LOAD ?RX V0x00001000 {
       .handler  = $PROGBITS ?AX .handler;
};
TEXT:  !LOAD ?RX {
       .text  = $PROGBITS ?AX .text;
};

CONST : !LOAD ?R {
       .const = $PROGBITS ?A .const;
};

DATA : !LOAD ?RW V0x0fffc000 {
       .data  = $PROGBITS ?AW  ;
       .sdata = $PROGBITS ?AWG ;
       .sbss  = $NOBITS   ?AWG ;
       .bss   = $NOBITS   ?AW  ;
};

_ _tp_TEXT @ %TP_SYMBOL;
_ _gp_DATA @ %GP_SYMBOL &_ _tp_TEXT{DATA};
_ _ep_DATA @ %EP_SYMBOL;
```

4.2 Program List (V850E/IA2)

4.2.1 Symbol definition

```
/************************************************************************** /
/*      Common area                                                        */
/************************************************************************** /
unsigned char   ram_start ;
unsigned char   error_flag ;           /* Error flag */
unsigned char   init_flag ;            /* Initial flag */
unsigned short  cont_time ;            /* Interrupt control time uSEC */
unsigned short  cont_time1 ;           /* Vector operation time uSEC */
unsigned short  disp_co ;              /* Interrupt control time display timer */
unsigned short  volume ;               /* Volume value */
unsigned short  timer_count ;          /* Time wait counter */
unsigned short  accel_count ;          /* Acceleration/deceleration operation time */
                                       /* counter */
unsigned char   stop_flag ;            /* Stop flag */
signed short    before_posi[21][2] ;   /* Position buffer */
signed short    total_sa ;             /* Position total difference */
signed int      sum_speed ;
signed int      speed_co ;
signed int      now_speed ;            /* Present speed rms */
signed int      object_speed ;         /* Target speed rms */
unsigned int    d_speed ;              /* Display speed rms */
unsigned char   ram_end ;

#pragma section const begin
const unsigned short led_pat[10] = { 0xfc, 0x60, 0xda, 0xf2, 0x66, 0xb6, 0xbe, 0xe0,
                                     0xfe, 0xe6 } ;
#pragma section const end
/************************************************************************** /
/*     Common flags                                                        */
/************************************************************************** /
extern unsigned char   ram_start ;
extern unsigned char   error_flag ;         /* Error flag */
extern unsigned char   init_flag ;          /* Initial flag */
extern unsigned short  cont_time ;          /* Interrupt control time uSEC */
extern unsigned short  cont_time1 ;         /* Vector operation time uSEC */
extern unsigned short  disp_co ;            /* Interrupt control time display timer */
extern unsigned short  volume ;             /* Volume value */
extern unsigned short  timer_count ;        /* Time wait counter */
extern unsigned short  accel_count ;        /* Acceleration/deceleration operation */
                                            /* time counter */
extern unsigned char   stop_flag ;          /* Stop flag */
extern signed short    before_posi[21][2] ; /* Position buffer */
extern signed short    total_sa ;           /* Position total difference */
extern signed int      sum_speed ;
```

```
extern signed int      speed_co ;
extern signed int      now_speed ;          /* Present speed rms */
extern signed int      object_speed ;       /* Target speed rms */
extern unsigned int    d_speed ;            /* Display speed rms */
extern unsigned char   ram_end ;

#pragma section const begin
extern const unsigned short led_pat[] ;;
#pragma section const end
/************************************************************************** /
/*     Motor common definition                                             */
/************************************************************************** /
extern signed short    iua ;              /* U-phase current */
extern signed short    iva ;              /* V-phase current */
extern signed int      o_iqai ;           /* Speed integral value area */
extern signed int      o_trm ;            /* Target position for initialization */
extern signed int      base_position ;    /* Speed estimation value reference point */
extern unsigned int    sa_time ;          /* Speed measurement value */
extern unsigned short  timer_count ;      /* Time wait counter */
extern unsigned short  accel_count ;      /* Acceleration/deceleration operation */
                                          /* time counter */
```

4.2.2 Constant definition

```
/************************************************************************** /
/*      I/O                                                                */
/************************************************************************** /
#define BASE_IO     0xc200000
#define LED11       3
#define LED12       2
#define LED13       1
#define LED14       0
#define LED21       5
#define LED22       4
#define LED31       7
#define LED32       6
#define LED41       9
#define LED42       8

#define DIPSW       0x10
#define SW          0x20
#define DA1         0x30
#define DA2         0x40
#define DA3         0x50
#define WRESET      0x60
#define MODE        0x70
/************************************************************************** /
/*      Constant                                                           */
```

```
/************************************************************************** /
#define ON          1
#define OFF         0
#define CW          1                    /* CW operation mode */
#define CCW         2                    /* CCW operation mode */
#define STOP        0                    /* Operation stop mode */
#define ERR_NO1     1                    /* Overcurrent error */
#define ERR_NO2     2                    /* Speed difference error */
/************************************************************************** /
/*      Motor constant                                                     */
/************************************************************************** /
#define PAI           3.14159265           /* π */
#define TH_U          1000                 /* Radian value  jack-up constant */
#define RAD           (int)(2*PAI*TH_U)    /* Radian value of one revolution */
#define OFFSET        1945                 /* Original point OFFSET */
#define RPM_RADS      (int)((2*PAI*TH_U)/60) /* rpm -> radian conversion constant */
/* Motor constant */
#define KSP           500                  /* Speed proportion constant */
#define KSI           50                   /* Speed integral constant */
#define KI            1                    /* Current conversion constant */
#define P             2                    /* Number of poles */

#define KSPGETA       0                    /* KSP jack-up constant */
#define KSIGETA       9                    /* KSI jack-up constant */
#define KIGETA        9                    /* KI jack-up constant */
#define SGETA         14                   /* sin jack-up constant */

#define PWM_TS        50                   /* PWM cycle */
#define PWM_DATA      (PWM_TS/0.05)        /* PWM set value */
#define SPEED_MAX     3000                 /* Maximum speed rpm */
#define SPEED_MINI    600                  /* Minimum speed rpm */
#define SA_SPEED_MAX  800                  /* Maximum speed difference rpm */
#define IQAMAX        40000000             /* Maximum speed integral value */
#define MAX_I         800                  /* Maximum current value */
#define TS            200                  /* Motor control time interval uSEC */
#define WATCH_START   500                  /* Speed monitor start time 10 mSEC */
#define ACCEL_VAL_1ST 50                   /* Initial acceleration/deceleration */
                                           /* time constant */
#define ACCEL_VAL     3                    /* Acceleration/deceleration time */
                                           /* constant */
#define ACCEL_SPD     50                   /* Acceleration/deceleration constant */
/************************************************************************** /
/*      Function constant                                                  */
/************************************************************************** /
void            fcalcu( signed int *wrm, signed int *trm );
void            OUT_data( unsigned short reg, unsigned short data );
unsigned short  IN_data( int reg );
void            led_num( int no, long data ) ;
```

```
/************************************************************************** /
/*      Motor-related common area                                          */
/************************************************************************** /
signed short     iua ;          /* U-phase current */
signed short     iva ;          /* V-phase current */
signed int       o_iqai ;       /* Speed integral value area */
signed int       o_trm ;        /* Target position for initialization */
signed int       base_position ; /* Speed estimation value reference point */
unsigned int     sa_time ;      /* Speed measurement value */
unsigned short   timer_count ;  /* Time wait counter */
unsigned short   accel_count ;  /* Acceleration/deceleration operation time counter */
```

4.2.3 Interrupt handler setting

```
/************************************************************************** /
/*    Interrupt symbol table                                               */
/************************************************************************** /
      .extern _ _start
      .extern _int_MOTOR
      .extern _int_U
      .extern _int_V
      .extern _int_W
      .extern _int_AD0
      .extern _int_AD1
      .extern _int_ETC

      .globl V_RESET
      .globl V_U
      .globl V_V
      .globl V_W
      .globl V_ETC
      .globl V_MOTOR
      .globl V_AD0
      .globl V_AD1
#************************************************************************
      .section ".handler",text
V_RESET:
      Jr      _ _start
V_U:
      ld.w    [sp],r1
      add     4,sp
      jr      _int_U              -- INTP20
V_V:
      ld.w    [sp],r1
      add     4,sp
      jr      _int_V              -- INTP21
V_W:
      ld.w    [sp],r1
```

```
      add     4,sp
      jr      _int_W              -- INTP22
V_ETC:
      ld.w    [sp],r1
      add     4,sp
      jr      _int_ETC            -- Other timers
V_MOTOR:
      ld.w    [sp],r1
      add     4,sp
      jr      _int_MOTOR          -- Speed control timer
V_AD0:
      ld.w    [sp],r1
      add     4,sp
      jr      _int_AD0            -- A/D converter CH0
V_AD1:
      ld.w    [sp],r1
      add     4,sp
      jr      _int_AD1            -- A/D converter CH1

      .extern V_RESET
      .extern V_U
      .extern V_V
      .extern V_W
      .extern V_ETC
      .extern V_MOTOR
      .extern V_AD0
      .extern V_AD1
/************************************************************************** /
/*    Interrupt jump table                                                 */
/************************************************************************** /
      .section ".vect_RESET",text
      mov     #V_RESET,r1
      jmp     [r1]

      .section ".id_NO",text
      .byte   0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff

      .section ".vect_U",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_U,r1
      jmp     [r1]

      .section ".vect_V",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_V,r1
      jmp     [r1]
```

```
      .section ".vect_W",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_W,r1
      jmp     [r1]

      .section ".vect_ETC",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_ETC,r1
      jmp     [r1]

      .section ".vect_MOTOR",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_MOTOR,r1
      jmp     [r1]

      .section ".vect_AD0",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_AD0,r1
      jmp     [r1]

      .section ".vect_AD1",text
      add     -4,sp
      st.w    r1,[r3]
      mov     #V_AD1,r1
      jmp     [r1]
```

4.2.4 Startup routine setting

```
#===============================================================================
# DESCRIPTIONS:
#      This assembly program is a sample of start-up module for ca850.
#    If you modified this program, you must assemble this file, and
#    locate a given directory.
#
#    Unless -G is specified, sections are located as the following.
#
#                |       :       |
#                |       :       |
#          tp -> -+-------------- + _ _start   _ _tp_TEXT
#                | start up      |
#                |-------------- |
# text section   |               |
#                | user program  |
```

```
#                |              |
#                |------------- |
#                | library      |
#               -+------------- +
#                |              |
# sdata section  |              |
#                |              |
#          gp -> -+------------- +           _ _ssbss
#                |              |
# sbss section   |              |
#                |              |
#                +------------- + _ _stack   _ _esbss     _ _sbss
#                | stack area   |
# bss section    |              |
#                | 0x400 bytes  |
#          sp -> -+------------- + _ _stack + STACKSIZE    _ _ebss
#                |      :       |
#                |      :       |
#                |      :       |
#          ep -> -+------------- + _ _ep_DATA
# tidata section |              |
#               -+------------- +
# sidata section |              |
#               -+------------- +
#                |      :       |
#                |      :       |
#
#==============================================================================
#------------------------------------------------------------------------------
#     special symbols
#------------------------------------------------------------------------------
      .extern _ _tp_TEXT, 4
      .extern _ _gp_DATA, 4
      .extern _ _ep_DATA, 4
      .extern _ _ssbss, 4
      .extern _ _esbss, 4
      .extern _ _sbss, 4
      .extern _ _ebss, 4


#------------------------------------------------------------------------------
#     C program main function
#------------------------------------------------------------------------------
      .extern _main


#------------------------------------------------------------------------------
#     dummy data declaration for creating sbss section
```

```
#------------------------------------------------------------------------------
       .sbss
       .lcomm _ _sbss_dummy, 0, 0


#------------------------------------------------------------------------------
#      system stack
#------------------------------------------------------------------------------
       .set   STACKSIZE, 0x400
       .bss
       .lcomm _ _stack, STACKSIZE, 4

#------------------------------------------------------------------------------
#      start up
#           pointers: tp - text pointer
#                     gp - global pointer
#                     sp - stack pointer
#                     ep - element pointer
#      exit status is set to r10
#------------------------------------------------------------------------------
        .text
        .align 4
        .globl _ _start
        .globl _exit
        .globl _ _exit
_ _start:
        mov     0x02,r10
        st.b    r10,VSWC[r0]                    -- Set peripheral I/O wait

        mov     0x07,r10                        -- ×10
        st.b    r0,PHCMD[r0]
        st.b    r10,CKC[r0]                     -- PLL xx multiplication
        nop
        nop
        nop
        nop
        nop

        mov     #_ _tp_TEXT, tp                 -- set tp register
        mov     #_ _gp_DATA, gp                 -- set gp register offset
        add     tp, gp                          -- set gp register
        mov     #_ _stack+STACKSIZE, sp         -- set sp register
        mov     #_ _ep_DATA, ep                 -- set ep register
#
        mov     #_ _ssbss, r13                  -- clear sbss section
        mov     #_ _esbss, r12
        cmp     r12, r13
        jnl     .L11
```

```
.L12:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L12
.L11:
#
        mov     #_ _sbss, r13                   -- clear bss section
        mov     #_ _ebss, r12
        cmp     r12, r13
        jnl     .L14
.L15:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L15
.L14:
#
        jarl    _main, lp                       -- call main function
_ _exit:
        halt                                    -- end of program
_ _startend:
        nop
#                                                                               #
#------------------------- end of start up module ----------------------------#
#                                                                               #
```

4.2.5 Main processing function

```
#include    "Common.h"
#include    "Motor.h"
#pragma     ioreg                       /* Peripheral I/O register definition */

static int save_psw;
/*************************************************************************** /
/*     3-phase motor control program                                        */
/*************************************************************************** /
void    main()
{
unsigned char   proc_no ;                       /* Present processing number */
signed int      speed ;                         /* Indication speed rms */
signed  int     accel_spd ;
int             sw, sw_mode ;
/* */
   hinit() ;                                    /* Hardware initialization */
   ainit() ;                                    /* Initialization of area used */
   proc_no = 0 ;
   _ _EI();
```

```
   while( 1 ) {
      accel_spd = ( SPEED_MAX - SPEED_MINI ) / 100;
      speed  = ( ( SPEED_MAX - SPEED_MINI ) * volume  / 1024 )
               + SPEED_MINI ;                 /* Indication speed calculation by volume */
      sw =  ~IN_data( SW ) & 0x07 ;           /* Read operation button */
      if  ( sw == 1 ) {
         sw_mode = CW ;
      } else if  ( sw == 2 ) {
         sw_mode = CCW ;
      } else if  ( sw == 4 ) {
         sw_mode = STOP ;
      }
      switch( proc_no ) {
/* STOP processing */
         case 0 :
            if  ( sw_mode == CW ) {
               _ _DI() ;
               object_speed  = SPEED_MINI ;   /* Set target speed to minimum value */
               stop_flag = OFF ;
               timer_count = WATCH_START ;    /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ;  /* Set acceleration/deceleration counter */
               init_flag = 2 ;                /* CCW initial request */
               start_init() ;                 /* Initialize revolution start */
               _ _EI() ;
               proc_no = 1 ;                  /* Set next processing number */
            } else if  ( sw_mode == CCW ) {
               _ _DI() ;
               stop_flag = OFF ;              /* Stop flag off */
               object_speed = -SPEED_MINI ;   /* Set target speed to minimum value */
               timer_count = WATCH_START ;    /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ;  /* Set acceleration/deceleration counter */
               init_flag = 3 ;                /* CCW initial request */
               start_init() ;                 /* Initialize revolution start */
               _ _EI() ;
               proc_no = 4 ;                  /* Set CCW processing number */
            }
            break ;
/* CW processing, acceleration */
         case 1 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
               if  ( object_speed  < speed ) {
                  object_speed += accel_spd ;
                  if  ( object_speed > speed ) object_speed = speed;
                  timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
               } else if ( object_speed  > speed ) {
                  object_speed -= accel_spd ;
                  if  ( object_speed < speed ) object_speed = speed;
```

```
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else {
                proc_no = 2 ;               /* Constant-speed processing */
            }
        }
        if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
            proc_no = 3 ;                   /* Deceleration, set processing number */
        }
        break ;
/* CW processing, constant-speed */
      case 2 :
        object_speed = speed ;
        if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
            proc_no = 3 ;                   /* Deceleration, set processing number */
        }
        break ;
/* CW stop processing */
      case 3 :
        if  ( accel_count == 0 ) {
            accel_count = ACCEL_VAL ;       /* Set acceleration/deceleration counter */
            if  ( object_speed  > SPEED_MINI ) {
                object_speed -= accel_spd ;
                if  ( object_speed < SPEED_MINI ) object_speed = SPEED_MINI;
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else {
                stop_flag = ON ;            /* Stop flag on */
                proc_no = 0 ;               /* Set stop processing number */
            }
        }
        break ;
/* CCW processing, acceleration */
      case 4 :
        if  ( accel_count == 0 ) {
            accel_count = ACCEL_VAL ;       /* Set acceleration/deceleration counter */
            if  ( object_speed  < -speed ) {
                object_speed += accel_spd ;
                if  ( object_speed > -speed ) object_speed = -speed;
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else if ( object_speed  > -speed ) {
                object_speed -= accel_spd ;
                if  ( object_speed < -speed ) object_speed = -speed;
                timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
            } else {
                proc_no = 5 ;               /* Constant-speed processing */
            }
        }
        if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
            proc_no = 6 ;                   /* Deceleration, set processing number */
```

```
            }
            break ;
/* CCW processing, constant-speed */
         case 5 :
            object_speed = -speed ;
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
               proc_no = 6 ;                  /* Deceleration, set processing number */
            }
            break ;
/* CCW stop processing */
         case 6 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
               if  ( object_speed  < -SPEED_MINI ) {
                  object_speed += accel_spd ;
                  if  ( object_speed > -SPEED_MINI ) object_speed = -SPEED_MINI;
                  timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
               } else {
                  stop_flag = ON ;            /* Stop flag on */
                  proc_no = 0 ;               /* Set stop processing number */
               }
            }
            break ;
      }

      if  ( ( proc_no == 2 ) || ( proc_no == 5 ) ) {
         if  (  timer_count == 0 ) {
            if  ( abs( object_speed - now_speed ) > SA_SPEED_MAX ) {
               error_flag = ERR_NO2 ;         /* Set error No.*/
            }
         }
      }

      if  ( disp_co == 0 ) {
         led_num(1, d_speed / 100 );          /* Number of revolutions */
         d_speed = 0 ;
         disp_co = 100 ;
         if  ( abs(now_speed) == 0 ) {
            disp_co = 0;
         }
         led_num(2, 1000/PWM_TS );            /* Carrier frequency */
         led_num(3, cont_time );              /* Overall processing time */
         led_num(4, cont_time1 );             /* Vector operation processing time */
      }
      if  ( error_flag ) {
         while( 1 ) {
            OUT_data( LED41, ~0x00 ) ;        /* LED display off */
            OUT_data( LED42, ~0x00 ) ;
```

```
            timer_count = 50 ;
            while( timer_count ) ;
            if  ( error_flag == ERR_NO1 ) {
               OUT_data( LED41, ~0x9e ) ;     /* E1 display */
               OUT_data( LED42, ~0x60 ) ;
            } else if ( error_flag == ERR_NO2 ) {
               OUT_data( LED41, ~0x9e ) ;     /* E2 display */
               OUT_data( LED42, ~0xda ) ;
            } else {
               OUT_data( LED41, ~0x9e ) ;     /* E3 display */
               OUT_data( LED42, ~0xf2 ) ;
            }
            timer_count = 50 ;
            while( timer_count ) ;
         }
      }
   }
}
```

4.2.6 LED display function

```
/************************************************************************** /
/*      LED value display subroutine                                      */
/*              no   : Display area number (1 to 4)                       */
/*              data : Display data (0 to 99)                             */
/************************************************************************** /
void led_num( int no, long data )
{
   if  ( no == 1 ) {
       data = data % 10000;
       OUT_data( LED11, ~led_pat[data/1000]&0xff ) ;
       OUT_data( LED12, ~led_pat[(data%1000)/100]&0xff ) ;
       OUT_data( LED13, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED14, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 2 ) {
       OUT_data( LED21, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED22, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 3 ) {
       OUT_data( LED31, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED32, ~led_pat[data%10]&0xff ) ;
   } else {
       OUT_data( LED41, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED42, ~led_pat[data%10]&0xff ) ;
   }
}
/************************************************************************** /
/*     External I/O output subroutine                                     */
/*              reg  : Output register number                             */
```

```
/*              data : Output data                                              */
/******************************************************************************* /
void   OUT_data( unsigned short reg, unsigned short data )
{
       if  ( reg == WRESET ) {
              P3.0 = 0;
              data = 1;                       /* Dummy step */
              P3.0 = 1;
       } else {
              PDL = data | ( reg << 8 );
              PDL = reg | ( reg << 8 ) | 0x8000;
       }
}
/******************************************************************************* /
/*     External I/O input subroutine                                           */
/*              reg : Input register number                                    */
/******************************************************************************* /
unsigned short  IN_data( int reg )
{
unsigned char *po;
/*  */
       if    ( reg == SW ) {
              return P4;
       } else {
              return 0;
       }
}
```

4.2.7 Motor control interrupt processing function

```
#include     "Common.h"
#include     "Motor.h"
#pragma      ioreg                    /* Peripheral I/O register definition */
/******************************************************************************* /
/*     Motor control timer interrupt processing                                */
/******************************************************************************* /
_ _interrupt
void    int_MOTOR(void)
{
   ADSCM00 = 0x8001 ;                 /* Start AD0 */
   ADSCM10 = 0x8000 ;                 /* Start AD1 */
}
/******************************************************************************* /
/*     Motor control processing                                                */
/******************************************************************************* /
void   Motor_CONT(void)
{
signed int   wrm, wre, trm, tre ;
```

```
signed int   o_wre, we, o_iqap, o_iqa ;
signed int   ida, iqa, o_vda1, o_vqa1 ;
signed int   o_vd0, o_vq0, o_vda, o_vqa ;
signed int   o_vua, o_vva, o_vwa, wiua, wiva ;
signed int   s_time, wk ;
/*  */
/************************************************************************** */
/*     Calculation processing of speed and rotor position                   */
/************************************************************************** */
   fcalcu( &wrm, &trm ) ;
   sum_speed += ( wrm * TH_U / RPM_RADS ) ;    /* Radian -> rpm */
   if  ( --speed_co == 0 ) {
       speed_co = 100000 / TS ;                /* Set 100 mSEC counter value */
       now_speed = sum_speed / speed_co ;
       sum_speed = 0 ;
   }
   wre = wrm * P ;
   tre = ( trm * P + OFFSET ) % RAD ;
/************************************************************************** */
/*     Speed control processing                                             */
/************************************************************************** */
   if  ( ( stop_flag == OFF ) && ( error_flag == 0 ) ) {
       s_time = TM3 ;
       o_wre = object_speed * RPM_RADS * P / TH_U ;    /* rpm -> radian conversion */
       we = o_wre - wre ;
       o_iqap = ( ( wre * KSP ) + ( we * KSP ) ) >> KSPGETA ;
       o_iqa = o_iqap + ( o_iqai >> KSIGETA ) ;

       if  ( o_iqai > IQAMAX ) {
          o_iqai = IQAMAX ;
       } else if ( o_iqai < -IQAMAX ) {
          o_iqai = -IQAMAX ;
       } else {
          o_iqai += ( KSI * we ) ;
       }
/************************************************************************** */
/*     Current control processing                                           */
/************************************************************************** */
       ida = ( ( ( iva * sin( tre ) ) - ( iua * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
       iqa = ( ( ( iva * sin( tre + RAD/4 ) ) - ( iua * sin( tre + 11*RAD/12 ) ) ) ) >> SGETA ;

       o_vda = ( KI * -ida ) >> KIGETA ;
       o_vqa = ( KI * ( o_iqa  - iqa )  ) >> KIGETA ;
/************************************************************************** */
/*     3-phase voltage conversion processing                                */
/************************************************************************** */
       if ( init_flag == 2 ) {                          /* CW initial processing */
          o_trm += ( SPEED_MINI * TS / 20000 ) ;
```

```
            tre = ( o_trm * P ) % RAD ;
            o_vda = 0 ;
            o_vqa = 100 ;
            if  ( o_trm > ( 2 * RAD ) ) {
               init_flag = 0;
            }
         } else if ( init_flag == 3 ) {                    /* CCW initial processing */
            o_trm -= ( SPEED_MINI * TS / 20000 ) ;
            tre = ( o_trm * P ) % RAD ;
            o_vda = 0 ;
            o_vqa = 100 ;
            if  ( o_trm < -( 2 * RAD ) ) {
               init_flag = 0;
            }
         } else {
            o_trm = 0 ;
         }
         o_vua  = ( ( ( o_vda * sin( tre + RAD/4 ) ) - ( o_vqa * sin( tre ) ) ) ) >> SGETA ;
         o_vva  = ( ( ( o_vda * sin( tre + 11*RAD/12 ) ) - ( o_vqa * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
         o_vwa  = -o_vua - o_vva ;

         cont_time1 = ( TM3 - s_time ) * 10 / 16;       /* Convert to uSEC */
/************************************************************************** /
/*     PWM conversion output processing                                    */
/************************************************************************** /
         OUT_data( WRESET, 0 ) ;                /* Reset watchdog timer */
         POER0 = 0x3f ;                         /* All phases active */
         TUC00 = 0x02 ;                         /* Clear PWM output prohibition */
/* PWM counter value calculation output */
         o_vua += ( PWM_DATA  / 2 ) ;
         o_vva += ( PWM_DATA  / 2 ) ;
         o_vwa += ( PWM_DATA  / 2 ) ;

         if  ( o_vua <= 0 ) {
            o_vua = 1 ;
         } else if  ( o_vua >= PWM_DATA  ) {
            o_vua = PWM_DATA  - 1 ;
         }
         if  ( o_vva <= 0 ) {
            o_vva = 1 ;
         } else if  ( o_vva >= PWM_DATA  ) {
            o_vva = PWM_DATA  - 1 ;
         }
         if  ( o_vwa <= 0 ) {
            o_vwa = 1 ;
         } else if  ( o_vwa >= PWM_DATA  ) {
            o_vwa = PWM_DATA  - 1 ;
         }
```

```
        BFCM00 = o_vua ;
        BFCM01 = o_vva ;
        BFCM02 = o_vwa ;
    } else {
        POER0 = 0 ;                     /* PWM output off */
        now_speed = 0;
        cont_time1 = 0;
    }
}
/************************************************************************** /
/*     Calculation processing of speed, etc.                               */
/************************************************************************** /
void    fcalcu( signed int *wrm, signed int *trm )
{
signed short    es_trm, cur_time, delta, i ;
signed int      wwrm, wk, *p1, *p2;
//
//      Speed and position calculation from zero-cross point
//
    cur_time = TM4 ;
    delta = ( (RAD/6/P) * cur_time ) / sa_time ; /* Calculation of rotor position */
                                                 /* difference from reference */
                                                 /* position (radian) */
    if  ( object_speed >= 0 ) {
        es_trm = base_position + delta;
    } else {
        es_trm = base_position - delta;
        if  ( es_trm < 0 ) es_trm += (RAD/P);
    }

    total_sa -= before_posi[20][1] ;

    p1 = (int *)before_posi[19] ;
    p2 = (int *)before_posi[20] ;
    for ( i = 0; i <= 19 ; i++ ) {
        *p2-- = *p1-- ;
    }
    before_posi[0][0] = *trm = es_trm % (RAD/P) ;

    wk = before_posi[0][0] - before_posi[1][0] ;
    if  ( abs(wk) > (RAD/2/P) ) {
        if  ( wk < 0 ) {
            wk = (RAD/P) + wk ;
        } else {
            wk = wk - (RAD/P) ;
        }
    }
```

```
    before_posi[1][1] = wk ;
    total_sa += wk ;                          /* Total difference in average buffer */

    wwrm = ( total_sa * ( 1000000 / 20 / TH_U ) / TS );
    *wrm = wwrm ;                             /* Speed  radian/second */
}
```

4.2.8 Zero-cross interrupt processing function

```
/************************************************************************** /
/*     U zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void    int_U(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TM4 ;
        TMC4  = 0x61;
        TMC4  = 0x63;                         /* Restart timer */

        if  ( ~P2 & 0x04 ) {                  /* Check W phase */
            base_position = 0 ;
        } else {
            base_position = RAD/2/P ;
        }
    }
}
/************************************************************************** /
/*     V zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void    int_V(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TM4 ;
        TMC4  = 0x61;
        TMC4  = 0x63;                         /* Restart timer */

        if  ( ~P2 & 0x01 ) {
            base_position = RAD/3/P ;
        } else {
            base_position = RAD*5/6/P ;
        }
    }
}
/************************************************************************** /
/*     W zero-cross point interrupt                                        */
```

```
/************************************************************************** /
_ _interrupt
void    int_W(void)
{
   if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
       sa_time =  TM4 ;
       TMC4  = 0x61;
       TMC4  = 0x63;                          /* Restart timer */

       if  ( ~P2 & 0x02 ) {
          base_position = RAD*2/3/P ;
       } else {
          base_position = RAD/6/P ;
       }
   }
}
```

4.2.9 10 mSEC interval interrupt processing function

```
/************************************************************************** /
/*     Other timer interrupt processing (10 mSEC interval)                  */
/************************************************************************** /
_ _multi_interrupt
void    int_ETC(void)
{
unsigned short dummy ;
/* Wait timer processing */
   if  ( timer_count != 0 ) {
       timer_count -= 1 ;
   }
/* Acceleration/deceleration timer processing */
   if  ( accel_count != 0 ) {
       accel_count -= 1 ;
   }
/* */
   if  ( disp_co != 0 ) {
       d_speed += abs( now_speed ) ;
       disp_co -= 1 ;
   }
}
```

4.2.10 A/D converter interrupt processing function

```
/************************************************************************** /
/*     A/D converter interrupt processing for U-phase current and speed volume */
/************************************************************************** /
_ _multi_interrupt
void   int_AD0(void)
```

```
{
    iua = (( ADCR00 & 0x3ff ) - 0x200) ;
    if  ( abs(iua) > MAX_I ) {
        POER0 = 0 ;                             /* PWM output off */
        error_flag = ERR_NO1 ;                  /* Set error No. */
    }
    volume = 1023 - ( ADCR01 & 0x3ff ) ;        /* Set volume value */
    Motor_CONT() ;
    cont_time = TM3 * 10 / 16;                  /* Convert to uSEC */
}
/************************************************************************** /
/*     A/D converter interrupt processing for V-phase current              */
/************************************************************************** /
_ _interrupt
void   int_AD1(void)
{
    iva = (( ADCR10 & 0x3ff ) - 0x200) ;
    if  ( abs(iva) > MAX_I ) {
        POER0 = 0 ;                             /* PWM output off */
        error_flag = ERR_NO1 ;                  /* Set error No. */
    }
}
```

4.2.11 Hardware initialization processing function

```
/************************************************************************** /
/*     Hardware (peripheral I/O) initialization                            */
/************************************************************************** /
void    hinit( void )
{
/* Port mode register initialization */
    PM3 = 0xfe ;
    PM4 = 0xf7 ;
    PMDL = 0x0000 ;

    OUT_data( LED11, 0xff ) ;                   /* LED OFF */
    OUT_data( LED12, 0xff ) ;
    OUT_data( LED13, 0xff ) ;
    OUT_data( LED14, 0xff ) ;
    OUT_data( LED21, 0xff ) ;
    OUT_data( LED22, 0xff ) ;
    OUT_data( LED31, 0xff ) ;
    OUT_data( LED32, 0xff ) ;
    OUT_data( LED41, 0xff ) ;
    OUT_data( LED42, 0xff ) ;
/* Set 10 mSEC timer TM2 */
    STOPTE0 = 0x0000;
    PRM02 = 0x01;                               /* Select fXX/2 */
```

```
    CSE0 = 0x0028;                              /* Select fCLK/64 (3.2 uSEC) */
    TCRE0 = 0x2000;                             /* Start timer */
    CVSE50 = 1562*2 ;                           /* 10 mSEC */
    CMSE050 = 0x2400;
    CC2IC5 = 0x06;
/* Set motor control interrupt timer TM3 */
    PRM03 = 1 ;                                 /* fCLK = fXX */
    TMC30 = 0x51;                               /* fXX = 4MHz*10/64(1.6 uSEC) */
    TMC31 = 0x09 ;
    CC30  = TS * 10 / 16 ;                      /* TS uSEC interval */
    TMC30 = 0x53;                               /* Start timer */
    CC3IC0 = 0x02;                              /* Reset interrupt mask */
/* Set speed measuring timer TM4 */
    TMC4  = 0x61;                               /* fXX(4 MHz*10/2)/128(6.4 uSEC) */
    CM4   = 0xffff;
    TMC4  = 0x63;                               /* TM4 start */
/* TM00 initialization */
    PRM01 = 0 ;                                 /* fCLK = fXX/2 */
    SPEC0 = 0x0000 ;
    TOMR0 = 0x80 ;                              /* Set output mode */
    PSTO0 = 0x00 ;                              /* Disable real-time output */
    BFCM00 =  PWM_DATA /2 ;                     /* Set duty to 50 */
    BFCM01 =  PWM_DATA /2 ;                     /* Set duty to 50 */
    BFCM02 =  PWM_DATA /2 ;                     /* Set duty to 50 */
    BFCM03 =  PWM_DATA  ;                       /* Set PWM cycle */
    DTRR0 = 40*3 ;                              /* Dead time 6 uSEC */
    POER0 = 0x3f ;                              /* All phases active */
    TMC00 = 0x8018 ;                            /* Start TMPWM timer */
/* Set A/D */
    ADSCM00 = 0x0001 ;
    ADSCM10 = 0x0000 ;
    ADIC0   = 0x03 ;
    ADIC1   = 0x03 ;
/* Set zero-cross signal interrupt pin */
    FEM0   = 0x0c ;                             /* INTP20 both-edge interrupt */
    CC2IC0 = 0x01 ;
    FEM1   = 0x0c ;                             /* INTP21 both-edge interrupt */
    CC2IC1 = 0x01 ;
    FEM2   = 0x0c ;                             /* INTP22 both-edge interrupt */
    CC2IC2 = 0x01 ;
}
```

4.2.12 Common area initialization processing function

```
/************************************************************************** /
/*     Common area initialization                                          */
/************************************************************************** /
void   ainit( void )
```

```
{
/* Initialization of flags */
   error_flag = 0 ;                          /* Clear error flag */
   init_flag = OFF ;                         /* Initial flag off */
   disp_co = 100 ;
   d_speed = 0 ;
/* Motor control area initialization */
   stop_flag = ON ;                          /* Stop flag on */
   object_speed = 0 ;                        /* Target speed 0 */
   o_iqai = 0 ;                              /* Speed integral value 0 */
   o_trm = 0 ;
}
```

4.2.13 Revolution start initialization processing function

```
/************************************************************************** /
/*     Revolution start initialization                                     */
/************************************************************************** /
void    start_init( void )
{
   int  i;
/*  */
   for ( i = 0 ; i < 21 ; i++ ) before_posi[i][1] = 0;
   total_sa = 0 ;
   sum_speed = 0 ;
   speed_co = 100000 / TS ;
}
```

4.2.14 sin calculation processing function

```
/************************************************************************** /
/*     sin x                                                               */
/*          Data                                                           */
/*            Radian unit                                                  */
/*          Return value                                                   */
/*            Sign value*16384                                             */
/************************************************************************** /
int sin( int x )
{
   x = x % RAD ;
   if  ( x < 0 ) x += RAD ;
   if  ( x < (RAD/4) ){
      return sins( x ) ;
   } else if ( x < (RAD/2) ) {
      return sins( (RAD/2) - x ) ;
   } else if ( x < (RAD*3/4) ) {
      return -sins( x - (RAD/2) ) ;
   } else {
```

```
        return -sins( RAD - x ) ;
    }
}
/*****************************************************************************/
int sins( int x )
{
short z1, z2, z3, z4, z5 ;
/*  */
    if  ( x <= (RAD/8) ) {
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z3 = z1 * z2 >> SGETA ;
        z5 = z2 * z3 >> SGETA ;
        return ( (12868*z1) - (1322*z3) + (40*z5) ) >> SGETA ;
    } else {
        x = (RAD/4) - x ;
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z4 = z2 * z2 >> SGETA ;
        return ( (268432772) - (5050*z2) + (252*z4) ) >> SGETA ;
    }
}
```

4.2.15 Link directive file for V850E/IA2

```
/*************************************************************************** */
/*     Link directive file for V850E/IA2                                     */
/*************************************************************************** */
VECT_RESET: !LOAD ?RX V0x0000000 {
        .vect_RESET  = $PROGBITS ?AX .vect_RESET;
};
ID_NO: !LOAD ?RX V0x0000070 {
        .id_NO  = $PROGBITS ?AX .id_NO;
};
VECT_U: !LOAD ?RX V0x00001f0 {
        .vect_U  = $PROGBITS ?AX .vect_U;
};
VECT_V: !LOAD ?RX V0x0000200 {
        .vect_V  = $PROGBITS ?AX .vect_V;
};
VECT_W: !LOAD ?RX V0x0000210 {
        .vect_W  = $PROGBITS ?AX .vect_W;
};
VECT_ETC: !LOAD ?RX V0x0000240 {
        .vect_ETC  = $PROGBITS ?AX .vect_ETC;
};
VECT_MOTOR: !LOAD ?RX V0x0000260 {
        .vect_MOTOR  = $PROGBITS ?AX .vect_MOTOR;
```

```
};
VECT_AD0: !LOAD ?RX V0x00003a0 {
        .vect_AD0  = $PROGBITS ?AX .vect_AD0;
};
VECT_AD1: !LOAD ?RX V0x00003b0 {
        .vect_AD1  = $PROGBITS ?AX .vect_AD1;
};

HANDLER: !LOAD ?RX V0x00001000 {
        .handler  = $PROGBITS ?AX .handler;
};
TEXT:  !LOAD ?RX {
        .text  = $PROGBITS ?AX .text;
};

CONST : !LOAD ?R {
        .const = $PROGBITS ?A .const;
};

DATA : !LOAD ?RW V0x0fffc000 {
        .data  = $PROGBITS ?AW  ;
        .sdata = $PROGBITS ?AWG ;
        .sbss  = $NOBITS   ?AWG ;
        .bss   = $NOBITS   ?AW  ;
};

_ _tp_TEXT @ %TP_SYMBOL;
_ _gp_DATA @ %GP_SYMBOL &_ _tp_TEXT{DATA};
_ _ep_DATA @ %EP_SYMBOL;
```

4.3 Program List (V850E/IA3)

4.3.1 Symbol definition

```
/************************************************************************** /
/*     Common area                                                         */
/************************************************************************** /
unsigned char   ram_start ;
unsigned char   error_flag ;         /* Error flag */
unsigned char   init_flag ;          /* Initial flag */
unsigned short  cont_time ;          /* Interrupt control time uSEC */
unsigned short  cont_time1 ;         /* Vector operation time uSEC */
unsigned short  disp_co ;            /* Interrupt control time display timer */
unsigned short  volume ;             /* Volume value */
unsigned short  timer_count ;        /* Time wait counter */
unsigned short  accel_count ;        /* Acceleration/deceleration operation time counter */
unsigned char   stop_flag ;          /* Stop flag */
signed short    before_posi[21][2] ; /* Position buffer */
signed short    total_sa ;           /* Position total difference */
signed int      sum_speed ;
signed int      speed_co ;
signed int      now_speed ;          /* Present speed rms */
signed int      object_speed ;       /* Target speed rms */
unsigned int    d_speed ;            /* Display speed rms */
unsigned char   ram_end ;

#pragma section const begin
const unsigned short led_pat[10] = { 0xfc, 0x60, 0xda, 0xf2, 0x66, 0xb6, 0xbe, 0xe0, 0xfe,
                                     0xe6 } ;
#pragma section const end
/************************************************************************** /
/*     Common flags                                                        */
/************************************************************************** /
extern unsigned char   ram_start ;
extern unsigned char   error_flag ;         /* Error flag */
extern unsigned char   init_flag ;          /* Initial flag */
extern unsigned short  cont_time ;          /* Interrupt control time uSEC */
extern unsigned short  cont_time1 ;         /* Vector operation time uSEC */
extern unsigned short  disp_co ;            /* Interrupt control time display timer */
extern unsigned short  volume ;             /* Volume value */
extern unsigned short  timer_count ;        /* Time wait counter */
extern unsigned short  accel_count ;        /* Acceleration/deceleration operation */
                                            /* time counter */
extern unsigned char   stop_flag ;          /* Stop flag */
extern signed short    before_posi[21][2] ; /* Position buffer */
extern signed short    total_sa ;           /* Position total difference */
extern signed int      sum_speed ;
extern signed int      speed_co ;
```

```
extern signed int      now_speed ;          /* Present speed rms */
extern signed int      object_speed ;       /* Target speed rms */
extern unsigned int    d_speed ;            /* Display speed rms */
extern unsigned char   ram_end ;

#pragma section const begin
extern const unsigned short led_pat[] ;;
#pragma section const end
/************************************************************************** /
/*     Motor common definition                                             */
/************************************************************************** /
extern signed short    iua ;              /* U-phase current */
extern signed short    iva ;              /* V-phase current */
extern signed int      o_iqai ;           /* Speed integral value area */
extern signed int      o_trm ;            /* Target position for initialization */
extern signed int      base_position ;    /* Speed estimation value reference point */
extern unsigned int    sa_time ;          /* Speed measurement value */
extern unsigned short  timer_count ;      /* Time wait counter */
extern unsigned short  accel_count ;      /* Acceleration/deceleration operation */
                                          /* time counter */
```

4.3.2 Constant definition

```
/************************************************************************** /
/*     I/O                                                                 */
/************************************************************************** /
#define BASE_IO     0xc200000
#define LED11       0x03
#define LED12       0x02
#define LED13       0x01
#define LED14       0x00
#define LED21       0x05
#define LED22       0x04
#define LED31       0x07
#define LED32       0x06
#define LED41       0x09
#define LED42       0x08

#define DIPSW       0x0f
#define SW          0x0e
#define DA1         0x0a
#define DA2         0x0b
#define DA3         0x0c
#define WRESET      0x0d
#define MODE        0x10
/************************************************************************** /
/*     Constant                                                            */
/************************************************************************** /
```

```
#define ON          1
#define OFF         0
#define CW          1                    /* CW operation mode */
#define CCW         2                    /* CCW operation mode */
#define STOP        0                    /* Operation stop mode */
#define ERR_NO1     1                    /* Overcurrent error */
#define ERR_NO2     2                    /* Speed difference error  */
/************************************************************************** /
/*    Motor constant                                                       */
/************************************************************************** /
#define PAI           3.14159265           /* π */
#define TH_U          1000                 /* Radian value  jack-up constant */
#define RAD           (int)(2*PAI*TH_U)    /* Radian value of one revolution */
#define OFFSET        1733                 /* Original point OFFSET */
#define RPM_RADS      (int)((2*PAI*TH_U)/60) /* rpm -> radian conversion constant */
/* Motor constant */
#define KSP           500                  /* Speed proportion constant */
#define KSI           50                   /* Speed integral constant */
#define KI            1                    /* Current conversion constant */
#define P             2                    /* Number of poles */

#define KSPGETA       0                    /* KSP jack-up constant */
#define KSIGETA       9                    /* KSI jack-up constant */
#define KIGETA        9                    /* KI jack-up constant */
#define SGETA         14                   /* sin jack-up constant */

#define PWM_TS        80                   /* PWM cycle */
#define PWM_DATA      (PWM_TS/0.03125)     /* PWM set value */
#define SPEED_MAX     3000                 /* Maximum speed rpm */
#define SPEED_MINI    600                  /* Minimum speed rpm */
#define SA_SPEED_MAX  800                  /* Maximum speed difference rpm */
#define IQAMAX        40000000             /* Maximum speed integral value */
#define MAX_I         800                  /* Maximum current value */
#define TS            80                   /* Motor control time interval uSEC */
#define WATCH_START   500                  /* Speed monitor start time 10 mSEC */
#define ACCEL_VAL_1ST 50                   /* Initial acceleration/deceleration */
                                           /* time constant */
#define ACCEL_VAL     3                    /* Acceleration/deceleration time constant */
#define ACCEL_SPD     50                   /* Acceleration/deceleration constant */
/************************************************************************** /
/*     Function constant                                                   */
/************************************************************************** /
void              fcalcu( signed int *wrm, signed int *trm );
void              OUT_data( unsigned short reg, unsigned short data );
unsigned short    IN_data( int reg );
void              led_num( int no, long data ) ;
/************************************************************************** /
/*     Motor-related common area                                           */
```

```
/************************************************************************** /
signed short      iua ;            /* U-phase current */
signed short      iva ;            /* V-phase current */
signed int        o_iqai ;         /* Speed integral value area */
signed int        o_trm ;          /* Target position for initialization */
signed int        base_position ;  /* Speed estimation value reference point */
unsigned int      sa_time ;        /* Speed measurement value */
unsigned short    timer_count ;    /* Time wait counter */
unsigned short    accel_count ;    /* Acceleration/deceleration operation time counter */
```

4.3.3 Interrupt handler setting

```
/************************************************************************** /
/*     Interrupt symbol table                                              */
/************************************************************************** /
       .extern _ _start
       .extern _int_MOTOR
       .extern _int_U
       .extern _int_V
       .extern _int_W
       .extern _int_AD0
       .extern _int_AD1
       .extern _int_ETC

       .globl V_RESET
       .globl V_U
       .globl V_V
       .globl V_W
       .globl V_ETC
       .globl V_MOTOR
       .globl V_AD0
       .globl V_AD1
#************************************************************************
       .section ".handler",text
V_RESET:
       jr     _ _start
V_U:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_U                  -- INTP2
V_V:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_V                  -- INTP3
V_W:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_W                  -- INTP4
```

```
V_ETC:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_ETC                  -- Other timers
V_MOTOR:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_MOTOR                -- Speed control timer
V_AD0:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_AD0                  -- A/D converter CH0
V_AD1:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_AD1                  -- A/D converter CH1

       .extern V_RESET
       .extern V_U
       .extern V_V
       .extern V_W
       .extern V_ETC
       .extern V_MOTOR
       .extern V_AD0
       .extern V_AD1
/************************************************************************** /
/*     Interrupt jump table                                                */
/************************************************************************** /
       .section ".vect_RESET",text
       mov    #V_RESET,r1
       jmp    [r1]

       .section ".id_NO",text
       .byte  0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff

       .section ".vect_U",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_U,r1
       jmp    [r1]

       .section ".vect_V",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_V,r1
       jmp    [r1]

       .section ".vect_W",text
```

```
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_W,r1
       jmp    [r1]

       .section ".vect_ETC",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_ETC,r1
       jmp    [r1]

       .section ".vect_MOTOR",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_MOTOR,r1
       jmp    [r1]

       .section ".vect_AD0",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_AD0,r1
       jmp    [r1]

       .section ".vect_AD1",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_AD1,r1
       jmp    [r1]
```

4.3.4 Startup routine setting

```
#===============================================================================
# DESCRIPTIONS:
#      This assembly program is a sample of start-up module for ca850.
#    If you modified this program, you must assemble this file, and
#    locate a given directory.
#
#    Unless -G is specified, sections are located as the following.
#
#                |       :       |
#                |       :       |
#          tp -> -+-------------- + _ _start   _ _tp_TEXT
#                 | start up      |
#                 |-------------- |
# text section    |               |
#                 | user program  |
#                 |               |
#                 |-------------- |
```

```
#                | library       |
#               -+-------------- +
#                |               |
# sdata section  |               |
#                |               |
#          gp -> -+-------------- +           _ _ssbss
#                |               |
# sbss section   |               |
#                |               |
#                +-------------- + _ _stack   _ _esbss     _ _sbss
#                | stack area    |
# bss section    |               |
#                | 0x400 bytes   |
#          sp -> -+-------------- + _ _stack + STACKSIZE    _ _ebss
#                |       :       |
#                |       :       |
#                |       :       |
#          ep -> -+-------------- + _ _ep_DATA
# tidata section |               |
#               -+-------------- +
# sidata section |               |
#               -+-------------- +
#                |       :       |
#                |       :       |
#
#============================================================================
#----------------------------------------------------------------------------
#     special symbols
#----------------------------------------------------------------------------
      .extern _ _tp_TEXT, 4
      .extern _ _gp_DATA, 4
      .extern _ _ep_DATA, 4
      .extern _ _ssbss, 4
      .extern _ _esbss, 4
      .extern _ _sbss, 4
      .extern _ _ebss, 4


#----------------------------------------------------------------------------
#     C program main function
#----------------------------------------------------------------------------
      .extern _main


#----------------------------------------------------------------------------
#     dummy data declaration for creating sbss section
#----------------------------------------------------------------------------
      .sbss
```

```
       .lcomm _ _sbss_dummy, 0, 0


#-------------------------------------------------------------------------------
#      system stack
#-------------------------------------------------------------------------------
       .set    STACKSIZE, 0x400
       .bss
       .lcomm  _ _stack, STACKSIZE, 4

#-------------------------------------------------------------------------------
#      start up
#          pointers:  tp - text pointer
#                     gp - global pointer
#                     sp - stack pointer
#                     ep - element pointer
#      exit status is set to r10
#-------------------------------------------------------------------------------
        .text
        .align 4
        .globl _ _start
        .globl _exit
        .globl _ _exit
_ _start:
        mov     13,r10                  -- 500 kHz to 64 MHz
        st.b    r10,VSWC[r0]            -- Set peripheral I/O wait

        mov     0x03,r10                -- PLL
        st.b    r10,PLLCTL[r0]

        mov     0x00,r10
        st.b    r10,PRCMD[r0]
        st.b    r10,PCC[r0]
        nop
        nop
        nop
        nop
        nop

        mov     #_ _tp_TEXT, tp         -- set tp register
        mov     #_ _gp_DATA, gp         -- set gp register offset
        add     tp, gp                  -- set gp register
        mov     #_ _stack+STACKSIZE, sp -- set sp register
        mov     #_ _ep_DATA, ep         -- set ep register
#
        mov     #_ _ssbss, r13          -- clear sbss section
        mov     #_ _esbss, r12
        cmp     r12, r13
```

```
        jnl     .L11
.L12:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L12
.L11:
#
        mov     #_ _sbss, r13              -- clear bss section
        mov     #_ _ebss, r12
        cmp     r12, r13
        jnl     .L14
.L15:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L15
.L14:
#
        jarl    _main, lp                  -- call main function
_ _exit:
        halt                               -- end of program
_ _startend:
        nop
#                                                                              #
#------------------------- end of start up module ----------------------------#
#                                                                              #
```

4.3.5 Main processing function

```
#include     "Common.h"
#include     "Motor.h"
#pragma      ioreg                         /* Peripheral I/O register definition */

static int save_psw;
/************************************************************************** /
/*     3-phase motor control program                                        */
/************************************************************************** /
void   main()
{
unsigned char    proc_no ;                 /* Present processing number */
signed int       speed ;                   /* Indication speed rms */
signed int       accel_spd ;
int              sw, sw_mode ;
/* */
   hinit() ;                               /* Hardware initialization */
   ainit() ;                               /* Initialization of area used */
   proc_no = 0 ;
```

```
   _ _EI();
   while( 1 ) {
      accel_spd = ( SPEED_MAX - SPEED_MINI ) / 100;
      speed  = ( ( SPEED_MAX - SPEED_MINI ) * volume  / 1024 )
               + SPEED_MINI ;                /* Indication speed calculation by volume */
      sw =  ~IN_data( SW ) & 0x07 ;          /* Read operation button */
      if  ( sw == 1 ) {
         sw_mode = CW ;
      } else if  ( sw == 2 ) {
         sw_mode = CCW ;
      } else if  ( sw == 4 ) {
         sw_mode = STOP ;
      }
      switch( proc_no ) {
/* STOP processing */
         case 0 :
            if  ( sw_mode == CW ) {
               _ _DI() ;
               object_speed  = SPEED_MINI ;  /* Set target speed to minimum value */
               stop_flag = OFF ;
               timer_count = WATCH_START ;   /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ; /* Set acceleration/deceleration counter */
               init_flag = 2 ;               /* CCW initial request */
               start_init() ;                /* Initialize revolution start */
               _ _EI() ;
               proc_no = 1 ;                 /*Set next processing number */
            } else if  ( sw_mode == CCW ) {
               _ _DI() ;
               stop_flag = OFF ;             /* Stop flag off */
               object_speed = -SPEED_MINI ;  /* Set target speed to minimum value */
               timer_count = WATCH_START ;   /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ; /* Set acceleration/deceleration counter */
               init_flag = 3 ;               /* CCW initial request */
               start_init() ;                /* Initialize revolution start */
               _ _EI() ;
               proc_no = 4 ;                 /* Set CCW processing number */
            }
            break ;
/* CW processing, acceleration */
         case 1 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;     /* Set acceleration/deceleration counter */
               if  ( object_speed  < speed ) {
                  object_speed += accel_spd ;
                  if  ( object_speed > speed ) object_speed = speed;
                  timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
               } else if ( object_speed  > speed ) {
                  object_speed -= accel_spd ;
```

```
                    if  ( object_speed < speed ) object_speed = speed;
                    timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else {
                    proc_no = 2 ;              /* Constant-speed processing */
                }
            }
            if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
                proc_no = 3 ;                  /* Deceleration, set processing number */
            }
            break ;
/* CW processing, constant-speed */
          case 2 :
            object_speed = speed ;
            if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
                proc_no = 3 ;                  /* Deceleration, set processing number */
            }
            break ;
/* CW stop processing */
          case 3 :
            if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                if  ( object_speed  > SPEED_MINI ) {
                    object_speed -= accel_spd ;
                    if  ( object_speed < SPEED_MINI ) object_speed = SPEED_MINI;
                    timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else {
                    stop_flag = ON ;           /* Stop flag on */
                    proc_no = 0 ;              /* Set stop processing number */
                }
            }
            break ;
/* CCW processing, acceleration */
          case 4 :
            if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                if  ( object_speed  < -speed ) {
                    object_speed += accel_spd ;
                    if  ( object_speed > -speed ) object_speed = -speed;
                    timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else if ( object_speed  > -speed ) {
                    object_speed -= accel_spd ;
                    if  ( object_speed < -speed ) object_speed = -speed;
                    timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else {
                    proc_no = 5 ;              /* Constant-speed processing */
                }
            }
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
```

```
                proc_no = 6 ;                /* Deceleration, set processing number */
            }
            break ;
/* CCW processing, constant-speed */
         case 5 :
            object_speed = -speed ;
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
                proc_no = 6 ;                /* Deceleration, set processing number */
            }
            break ;
/* CCW stop processing */
         case 6 :
            if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;    /* Set acceleration/deceleration counter */
                if  ( object_speed  < -SPEED_MINI ) {
                    object_speed += accel_spd ;
                    if  ( object_speed > -SPEED_MINI ) object_speed = -SPEED_MINI;
                    timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else {
                    stop_flag = ON ;         /* Stop flag on */
                    proc_no = 0 ;            /* Set stop processing number */
                }
            }
            break ;
         }

         if  ( ( proc_no == 2 ) || ( proc_no == 5 ) ) {
            if  (  timer_count == 0 ) {
                if  ( abs( object_speed - now_speed ) > SA_SPEED_MAX ) {
                    error_flag = ERR_NO2 ;   /* Set error No. */
                }
            }
         }

         if  ( disp_co == 0 ) {
            led_num(1, d_speed / 100 );      /* Number of revolutions */
            d_speed = 0 ;
            disp_co = 100 ;
            if  ( abs(now_speed) == 0 ) {
                disp_co = 0;
            }
            led_num(2, 1000/PWM_TS );        /* Carrier frequency */
            led_num(3, cont_time );          /* Overall processing time */
            led_num(4, cont_time1 );         /* Vector operation processing time */
         }
         if  ( error_flag ) {
            while( 1 ) {
                OUT_data( LED41, ~0x00 ) ;   /* LED display off */
```

```
                OUT_data( LED42, ~0x00 ) ;
                timer_count = 50 ;
                while( timer_count ) ;
                if  ( error_flag == ERR_NO1 ) {
                   OUT_data( LED41, ~0x9e ) ; /* E1 display */
                   OUT_data( LED42, ~0x60 ) ;
                } else if ( error_flag == ERR_NO2 ) {
                   OUT_data( LED41, ~0x9e ) ; /* E2 display */
                   OUT_data( LED42, ~0xda ) ;
                } else {
                   OUT_data( LED41, ~0x9e ) ; /* E3 display */
                   OUT_data( LED42, ~0xf2 ) ;
                }
                timer_count = 50 ;
                while( timer_count ) ;
             }
          }
   }
}
```

4.3.6 LED display function

```
/************************************************************************** /
/*     LED value display subroutine                                        */
/*             no   : Display area number (1 to 4)                         */
/*             data : Display data (0 to 99)                               */
/************************************************************************** /
void led_num( int no, long data )
{
   if  ( no == 1 ) {
       data = data % 10000;
       OUT_data( LED11, ~led_pat[data/1000]&0xff ) ;
       OUT_data( LED12, ~led_pat[(data%1000)/100]&0xff ) ;
       OUT_data( LED13, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED14, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 2 ) {
       OUT_data( LED21, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED22, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 3 ) {
       OUT_data( LED31, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED32, ~led_pat[data%10]&0xff ) ;
   } else {
       OUT_data( LED41, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED42, ~led_pat[data%10]&0xff ) ;
   }
}
/************************************************************************** /
/*     External I/O output subroutine                                      */
```

```
/*             reg  : Output register number                                  */
/*             data : Output data                                             */
/********************************************************************************/
void   OUT_data( unsigned short reg, unsigned short data )
{
       if  ( reg == WRESET ) {
              P3.0 = 0;
              data = 1;                      /* Dummy step */
              P3.0 = 1;
       } else {
              PDL = data | ( reg << 8 );
              PDL = reg | ( reg << 8 ) | 0x8000;
       }
}
/********************************************************************************/
/*     External I/O input subroutine                                            */
/*             reg : Input register number                                      */
/********************************************************************************/
unsigned short  IN_data( int reg )
{
unsigned char *po;
/*  */
       if    ( reg == SW ) {
              return P4;
       } else {
              return 0;
       }
}
```

4.3.7 Motor control interrupt processing function

```
#include   "Common.h"
#include   "Motor.h"
#pragma    ioreg                           /* Peripheral I/O register definition */
/********************************************************************************/
/*     Motor control timer interrupt processing                                 */
/********************************************************************************/
_ _interrupt
void    int_MOTOR(void)
{
   ADA0M0 = 0xB0 ;                         /* Start AD0 */
   ADA1M0 = 0xA0 ;                         /* Start AD1 */
}
/********************************************************************************/
/*     Motor control processing                                                 */
/********************************************************************************/
void   Motor_CONT(void)
{
```

```
signed int   wrm, wre, trm, tre ;
signed int   o_wre, we, o_iqap, o_iqa ;
signed int   ida, iqa, o_vda1, o_vqa1 ;
signed int   o_vd0, o_vq0, o_vda, o_vqa ;
signed int   o_vua, o_vva, o_vwa, wiua, wiva ;
signed int   s_time, wk ;
/*  */
/************************************************************************** /
/*     Calculation processing of speed and rotor position                  */
/************************************************************************** /
   fcalcu( &wrm, &trm ) ;
   sum_speed += ( wrm * TH_U / RPM_RADS ) ;    /* Radian -> rpm */
   if  ( --speed_co == 0 ) {
      speed_co = 100000 / TS ;                 /* Set 100 mSEC counter value */
      now_speed = sum_speed / speed_co ;
      sum_speed = 0 ;
   }
   wre = wrm * P ;
   tre = ( trm * P + OFFSET ) % RAD ;
/************************************************************************** /
/*     Speed control processing                                            */
/************************************************************************** /
   if  ( ( stop_flag == OFF ) && ( error_flag == 0 ) ) {
      s_time = TP1CNT ;
      o_wre = object_speed * RPM_RADS * P / TH_U ;      /* rpm -> radian conversion */
      we = o_wre - wre ;
      o_iqap = ( ( wre * KSP ) + ( we * KSP ) ) >> KSPGETA ;
      o_iqa = o_iqap + ( o_iqai >> KSIGETA ) ;

      if  ( o_iqai > IQAMAX ) {
         o_iqai = IQAMAX ;
      } else if ( o_iqai < -IQAMAX ) {
         o_iqai = -IQAMAX ;
      } else {
         o_iqai += ( KSI * we ) ;
      }
/************************************************************************** /
/*     Current control processing                                          */
/************************************************************************** /
      ida = ( ( ( iva * sin( tre ) ) - ( iua * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      iqa = ( ( ( iva * sin( tre + RAD/4 ) ) - ( iua * sin( tre + 11*RAD/12 ) ) ) ) >> SGETA ;

      o_vda = ( KI * -ida ) >> KIGETA ;
      o_vqa = ( KI * ( o_iqa  - iqa )  ) >> KIGETA ;
/************************************************************************** /
/*     3-phase voltage conversion processing                               */
/************************************************************************** /
      if ( init_flag == 2 ) {                        /* CW initial processing */
```

```
         o_trm += ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm > ( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else if ( init_flag == 3 ) {                    /* CCW initial processing */
         o_trm -= ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm < -( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else {
         o_trm = 0 ;
      }
      o_vua  = ( ( ( o_vda * sin( tre + RAD/4 ) ) - ( o_vqa * sin( tre ) ) ) ) >> SGETA ;
      o_vva  = ( ( ( o_vda * sin( tre + 11*RAD/12 ) ) - ( o_vqa * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      o_vwa  = -o_vua - o_vva ;

      cont_time1 = ( TP1CNT - s_time ) ;      /* Convert to uSEC */
/************************************************************************** /
/*     PWM conversion output processing                                    */
/************************************************************************** /
      OUT_data( WRESET, 0 ) ;                /* Reset watchdog timer */
      HZA0CTL0 |= 0x04;                      /* PWM output on */
/* PWM counter value calculation output */
      o_vua += ( PWM_DATA  / 2 ) ;
      o_vva += ( PWM_DATA  / 2 ) ;
      o_vwa += ( PWM_DATA  / 2 ) ;

      if  ( o_vua <= 0 ) {
         o_vua = 1 ;
      } else if  ( o_vua >= PWM_DATA  ) {
         o_vua = PWM_DATA  - 1 ;
      }
      if  ( o_vva <= 0 ) {
         o_vva = 1 ;
      } else if  ( o_vva >= PWM_DATA  ) {
         o_vva = PWM_DATA  - 1 ;
      }
      if  ( o_vwa <= 0 ) {
         o_vwa = 1 ;
      } else if  ( o_vwa >= PWM_DATA  ) {
         o_vwa = PWM_DATA  - 1 ;
      }
```

```
        TQ0CCR1 = o_vua ;
        TQ0CCR2 = o_vva ;
        TQ0CCR3 = o_vwa ;
    } else {
        HZA0CTL0 |= 0x08;               /* PWM output off */
        now_speed = 0;
        cont_time1 = 0;
    }
}
/************************************************************************** /
/*     Calculation processing of speed, etc.                               */
/************************************************************************** /
void   fcalcu( signed int *wrm, signed int *trm )
{
signed short   es_trm, cur_time, delta, i ;
signed int     wwrm, wk, *p1, *p2;
//
//     Speed and position calculation from zero-cross point
//
    cur_time = TP2CNT ;
    delta = ( (RAD/6/P) * cur_time ) / sa_time ; /* Calculation of rotor position */
                                                 /* difference from reference */
                                                 /* position (radian) */
    if  ( object_speed >= 0 ) {
        es_trm = base_position + delta;
    } else {
        es_trm = base_position - delta;
        if  ( es_trm < 0 ) es_trm += (RAD/P);
    }

    total_sa -= before_posi[20][1] ;

    p1 = (int *)before_posi[19] ;
    p2 = (int *)before_posi[20] ;
    for ( i = 0; i <= 19 ; i++ ) {
        *p2-- = *p1-- ;
    }
    before_posi[0][0] = *trm = es_trm % (RAD/P) ;

    wk = before_posi[0][0] - before_posi[1][0] ;
    if  ( abs(wk) > (RAD/2/P) ) {
        if  ( wk < 0 ) {
            wk = (RAD/P) + wk ;
        } else {
            wk = wk - (RAD/P) ;
        }
    }
```

```
    before_posi[1][1] = wk ;
    total_sa += wk ;                          /* Total difference in average buffer */

    wwrm = ( total_sa * ( 1000000 / 20 / TH_U ) / TS );
    *wrm = wwrm ;                             /* Speed  radian/second */
}
```

4.3.8 Zero-cross interrupt processing function

```
/************************************************************************** /
/*     U zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void     int_U(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TP2CNT ;
        TP2CTL0  &= ~0x80;
        TP2CTL0  |= 0x80;                     /* Restart timer */

        if  ( ~P0 & 0x10 ) {                  /* Check W phase */
            base_position = 0 ;
        } else {
            base_position = RAD/2/P ;
        }
    }
}
/************************************************************************** /
/*     V zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void    int_V(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TP2CNT ;
        TP2CTL0  &= ~0x80;
        TP2CTL0  |= 0x80;                     /* Restart timer */

        if  ( ~P0 & 0x04 ) {                  /* Check U phase */
            base_position = RAD/3/P ;
        } else {
            base_position = RAD*5/6/P ;
        }
    }
}
/************************************************************************** /
/*     W zero-cross point interrupt                                        */
```

```
/************************************************************************** /
_ _interrupt
void    int_W(void)
{
   if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
       sa_time =  TP2CNT ;
       TP2CTL0  &= ~0x80;
       TP2CTL0  |= 0x80;                       /* Restart timer */

       if  ( ~P0 & 0x08 ) {                    /* Check V phase */
          base_position = RAD*2/3/P ;
       } else {
          base_position = RAD/6/P ;
       }
   }
}
```

4.3.9 10 mSEC interval interrupt processing function

```
/************************************************************************** /
/*     Other timer interrupt processing (10 mSEC interval)                  */
/************************************************************************** /
_ _multi_interrupt
void   int_ETC(void)
{
/* Wait timer processing */
   if  ( timer_count != 0 ) {
       timer_count -= 1 ;
   }
/* Acceleration/deceleration timer processing */
   if  ( accel_count != 0 ) {
       accel_count -= 1 ;
   }
/* */
   if  ( disp_co != 0 ) {
       d_speed += abs( now_speed ) ;
       disp_co -= 1 ;
   }
}
```

4.3.10 A/D converter interrupt processing function

```
/************************************************************************** /
/*     A/D converter interrupt processing for U-phase current and speed volume */
/************************************************************************** /
_ _multi_interrupt
void   int_AD0(void)
{
```

```
    iua = (( ( ADA0CR0 >> 6 ) & 0x3ff ) - 0x200) ;
    if  ( abs(iua) > MAX_I ) {
        HZA0CTL0 |= 0x08 ;                          /* PWM output off */
        error_flag = ERR_NO1 ;                      /* Set error No. */
    }
    volume = 1023 - ( ( ADA0CR1 >> 6 ) & 0x3ff ) ;  /* Set volume value */
    Motor_CONT() ;
    cont_time = TP1CNT;                             /* Convert to uSEC */
}
/************************************************************************** /
/*     A/D converter interrupt processing for volume                       */
/************************************************************************** /
_ _interrupt
void   int_AD1(void)
{
    iva = (( ADA1CR0 & 0x3ff ) - 0x200) ;
    if  ( abs(iva) > MAX_I ) {
        HZA0CTL0 |= 0x08 ;                          /* PWM output off */
        error_flag = ERR_NO1 ;                      /* Set error No. */
    }
}
```

4.3.11 Hardware initialization processing function

```
/************************************************************************** /
/*     Hardware (peripheral I/O) initialization                            */
/************************************************************************** /
void   hinit( void )
{
/* Port mode register initialization */
    PM3 = 0xfe ;
    PM4 = 0xff ;
    PMDL  = 0x0000 ;

    OUT_data( LED11, 0xff ) ;   /* LED OFF */
    OUT_data( LED12, 0xff ) ;
    OUT_data( LED13, 0xff ) ;
    OUT_data( LED14, 0xff ) ;
    OUT_data( LED21, 0xff ) ;
    OUT_data( LED22, 0xff ) ;
    OUT_data( LED31, 0xff ) ;
    OUT_data( LED32, 0xff ) ;
    OUT_data( LED41, 0xff ) ;
    OUT_data( LED42, 0xff ) ;
/* Set 10 mSEC timer TMP0 */
    TP0CTL0 = 0x05 ;            /* Select fXX/64 */
    TP0CTL1 = 0x00 ;            /* Select interval timer mode */
    TP0CCR0 = 10000 ;           /* 10 mSEC */
```

```
    TP0CTL0 |= 0x80 ;           /* Start timer */
    TP0CCIC0= 0x06;
/* Set motor control interrupt timer TMP1 */
    TP1CTL0 = 0x05 ;            /* Select fXX/64 */
    TP1CTL1 = 0x00 ;            /* Select interval timer mode */
    TP1CCR0 = TS ;              /* TS uSEC */
    TP1CTL0 |= 0x80 ;           /* Start timer */
    TP1CCIC0= 0x01;
/* Set speed measuring timer TMP2 */
    TP2CTL0 = 0x05 ;            /* Select fXX/64 */
    TP2CTL1 = 0x05 ;            /* Select free-running timer mode */
    TP2CTL0 |= 0x80 ;           /* Start timer */
/* TMQ0 initialization */
    TQ0CTL0 = 0x00;             /* fXX/2 (64 MHz/2 = 32 MHz) */
    TQ0CTL1 = 0x07;             /* Select 6-phase PWM output mode */
    TQ0IOC0 = 0x55;             /* Positive phase normal output, output enabled */
    TQ0IOC1 = 0x00;             /* TIQ00 to TIQ03, EVTQ0, and TRGQ0 pins of TMQ0 */
    TQ0IOC2 = 0x00;             /* are not used */
    TQ0OPT0 = 0x00;             /* Select comparison mode */
    TQ0CCR0 = PWM_DATA ;        /* Carrier wave cycle 20 kHz */
    TQ0CCR1 = PWM_DATA /2;      /* Set U-phase duty to 50 */
    TQ0CCR2 = PWM_DATA /2;      /* Set V-phase duty to 50 */
    TQ0CCR3 = PWM_DATA /2;      /* Set W-phase duty to 50 */
    TQ0DTC  = 180;              /* Dead time 6 uSEC */
    TQ0OPT1 = 0x00;             /* No culling, no crest and valley interrupts are used */

    TQ0OPT2 = 0x04;             /* • No culling between reloads */
                                /* • Clear and re-count dead time counter */
                                /* • Output A/D trigger output of INTTP0CC0 */
                                /*   interrupt during counting up */
                                /* • A/D trigger output of INTTP0CC0 interrupt enabled */

    TQ0IOC3 = 0xfc;             /* Negative phase inverted output, output enabled */
    PMC1 = 0x3F;                /* Alternate-function mode */
    PFCE1 = 0x00;               /* Select TOQ0T1 to TOQ0T3 or TOQ0B1 to TOQ0B3 output */
    PFC1 = 0x00;

    HZA0CTL0 = 0x00;
    HZA0CTL0 = 0xD0;            /* High-impedance operation enabled */
                                /* TOQ0OFF pin rising edge valid */
    HZA2CTL0 = 0x00;            /* High-impedance off due to analog input */
    TQ0CTL0 |= 0x80;            /* Start 6-phase PWM output mode */
/* Set A/D */
    ADA0M0 = 0x30 ;             /* ANI00, ANI01 */
    ADA0M1 = 0x01 ;
    ADA0S  = 0x01 ;
    OP0CTL0 = 0x00 ;            /* Operational amplifier invalid */
    OP0CTL1 = 0x00 ;            /* Comparator invalid */
```

```
    AD0IC  = 0x03 ;

    ADA1M0 = 0x20 ;             /* ANI10 */
    ADA1M1 = 0x01 ;
    ADA1S  = 0x00 ;
    OP1CTL0 = 0x00 ;            /* Operational amplifier invalid */
    OP1CTL1 = 0x00 ;            /* Comparator invalid */
    AD1IC  = 0x03 ;
/* Set zero-cross signal interrupt pin */
    PMC0   = 0x1c ;
    INTR0  = 0x1c ;             /* INTP2, INTP3, INTP4 both-edge interrupt */
    INTF0  = 0x1c ;
    PIC2   = 0x01 ;
    PIC3   = 0x01 ;
    PIC4   = 0x01 ;
}
```

4.3.12 Common area initialization processing function

```
/************************************************************************** /
/*     Common area initialization                                          */
/************************************************************************** /
void    ainit( void )
{
/* Initialization of flags */
    error_flag = 0 ;                    /* Clear error flag */
    init_flag = OFF ;                   /* Initial flag off */
    disp_co = 100 ;
    d_speed = 0 ;
/* Motor control area initialization */
    stop_flag   = ON ;                  /* Stop flag on */
    object_speed = 0 ;                  /* Target speed 0 */
    o_iqai = 0 ;                        /* Speed integral value 0 */
    o_trm = 0 ;
}
```

4.3.13 Revolution start initialization processing function

```
/************************************************************************** /
/*     Revolution start initialization                                     */
/************************************************************************** /
void   start_init( void )
{
    int  i;
/*  */
    for ( i = 0 ; i < 21 ; i++ ) before_posi[i][1] = 0;
    total_sa = 0 ;
    sum_speed = 0 ;
```

```
    speed_co = 100000 / TS ;
}
```

4.3.14 sin calculation processing function

```
/************************************************************************** /
/*     sin x                                                               */
/*          Data                                                           */
/*            Radian unit                                                  */
/*          Return value                                                   */
/*            Sign value*16384                                             */
/************************************************************************** /
int sin( int x )
{
    x = x % RAD ;
    if  ( x < 0 ) x += RAD ;
    if  ( x < (RAD/4) ){
        return sins( x ) ;
    } else if ( x < (RAD/2) ) {
        return sins( (RAD/2) - x ) ;
    } else if ( x < (RAD*3/4) ) {
        return -sins( x - (RAD/2) ) ;
    } else {
        return -sins( RAD - x ) ;
    }
}
/*************************************************************************/
int sins( int x )
{
short z1, z2, z3, z4, z5 ;
/*  */
    if  ( x <= (RAD/8) ) {
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z3 = z1 * z2 >> SGETA ;
        z5 = z2 * z3 >> SGETA ;
        return ( (12868*z1) - (1322*z3) + (40*z5) ) >> SGETA ;
    } else {
        x = (RAD/4) - x ;
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z4 = z2 * z2 >> SGETA ;
        return ( (268432772) - (5050*z2) + (252*z4) ) >> SGETA ;
    }
}
```

4.3.15 Link directive file for V850E/IA3

```
/************************************************************************** /
/*     Link directive file for V850E/IA3                                    */
/************************************************************************** /
VECT_RESET: !LOAD ?RX V0x00000000 {
        .vect_RESET  = $PROGBITS ?AX .vect_RESET;
};
ID_NO: !LOAD ?RX V0x00000070 {
        .id_NO  = $PROGBITS ?AX .id_NO;
};
VECT_U: !LOAD ?RX V0x00000090 {
        .vect_U  = $PROGBITS ?AX .vect_U;
};
VECT_V: !LOAD ?RX V0x000000a0 {
        .vect_V  = $PROGBITS ?AX .vect_V;
};
VECT_W: !LOAD ?RX V0x000000b0 {
        .vect_W  = $PROGBITS ?AX .vect_W;
};
VECT_ETC: !LOAD ?RX V0x00000250 {
        .vect_ETC  = $PROGBITS ?AX .vect_ETC;
};
VECT_MOTOR: !LOAD ?RX V0x00000280 {
        .vect_MOTOR  = $PROGBITS ?AX .vect_MOTOR;
};
VECT_AD0: !LOAD ?RX V0x00000400 {
        .vect_AD0  = $PROGBITS ?AX .vect_AD0;
};
VECT_AD1: !LOAD ?RX V0x00000410 {
        .vect_AD1  = $PROGBITS ?AX .vect_AD1;
};

HANDLER: !LOAD ?RX V0x00001000 {
        .handler  = $PROGBITS ?AX .handler;
};
TEXT:  !LOAD ?RX {
        .text  = $PROGBITS ?AX .text;
};

CONST : !LOAD ?R {
        .const = $PROGBITS ?A .const;
};

DATA : !LOAD ?RW  V0xffffd800 {
        .data  = $PROGBITS ?AW  ;
        .sdata = $PROGBITS ?AWG ;
        .sbss  = $NOBITS   ?AWG ;
```

```
        .bss    = $NOBITS   ?AW  ;
};

_ _tp_TEXT @ %TP_SYMBOL;
_ _gp_DATA @ %GP_SYMBOL &_ _tp_TEXT{DATA};
_ _ep_DATA @ %EP_SYMBOL;
```

4.4 Program List (V850E/IA4)

4.4.1 Symbol definition

```
/************************************************************************** /
/*     Common area                                                         */
/************************************************************************** /
unsigned char   ram_start ;
unsigned char   error_flag ;         /* Error flag */
unsigned char   init_flag ;          /* Initial flag */
unsigned short  cont_time ;          /* Interrupt control time uSEC */
unsigned short  cont_time1 ;         /* Vector operation time uSEC */
unsigned short  disp_co ;            /* Interrupt control time display timer */
unsigned short  volume ;             /* Volume value */
unsigned short  timer_count ;        /* Time wait counter */
unsigned short  accel_count ;        /* Acceleration/deceleration operation time counter */
unsigned char   stop_flag ;          /* Stop flag */
signed short    before_posi[21][2] ; /* Position buffer */
signed short    total_sa ;           /* Position total difference */
signed int      sum_speed ;
signed int      speed_co ;
signed int      now_speed ;          /* Present speed rms */
signed int      object_speed ;       /* Target speed rms */
unsigned int    d_speed ;            /* Display speed rms */
unsigned char   ram_end ;

#pragma section const begin
const unsigned short led_pat[10] = { 0xfc, 0x60, 0xda, 0xf2, 0x66, 0xb6, 0xbe, 0xe0,
                                     0xfe, 0xe6 } ;
#pragma section const end
/************************************************************************** /
/*     Common flags                                                        */
/************************************************************************** /
extern unsigned char    ram_start ;
extern unsigned char    error_flag ;         /* Error flag */
extern unsigned char    init_flag ;          /* Initial flag */
extern unsigned short   cont_time ;          /* Interrupt control time uSEC */
extern unsigned short   cont_time1 ;         /* Vector operation time uSEC */
extern unsigned short   disp_co ;            /* Interrupt control time display timer */
extern unsigned short   volume ;             /* Volume value */
extern unsigned short   timer_count ;        /* Time wait counter */
extern unsigned short   accel_count ;        /* Acceleration/deceleration operation */
                                             /* time counter */
extern unsigned char    stop_flag ;          /* Stop flag */
extern signed short     before_posi[21][2] ; /* Position buffer */
extern signed short     total_sa ;           /* Position total difference */
extern signed int       sum_speed ;
extern signed int       speed_co ;
```

```
extern signed int      now_speed ;          /* Present speed rms */
extern signed int      object_speed ;       /* Target speed rms */
extern unsigned int    d_speed ;            /* Display speed rms */
extern unsigned char   ram_end ;

#pragma section const begin
extern  const unsigned short led_pat[] ;;
#pragma section const end
/************************************************************************** /
/*     Motor common definition                                             */
/************************************************************************** /
extern signed short    iua ;            /* U-phase current */
extern signed short    iva ;            /* V-phase current */
extern signed int      o_iqai ;         /* Speed integral value area */
extern signed int      o_trm ;          /* Target position for initialization */
extern signed int      base_position ;  /* Speed estimation value reference point */
extern unsigned int    sa_time ;        /* Speed measurement value */
extern unsigned short  timer_count ;    /* Time wait counter */
extern unsigned short  accel_count ;    /* Acceleration/deceleration operation */
                                        /* time counter */
```

4.4.2 Constant definition

```
/************************************************************************** /
/*     I/O                                                                 */
/************************************************************************** /
#define BASE_IO       0xc200000
#define LED11         0x03
#define LED12         0x02
#define LED13         0x01
#define LED14         0x00
#define LED21         0x05
#define LED22         0x04
#define LED31         0x07
#define LED32         0x06
#define LED41         0x09
#define LED42         0x08

#define DIPSW         0x0f
#define SW            0x0e
#define DA1           0x0a
#define DA2           0x0b
#define DA3           0x0c
#define WRESET        0x0d
#define MODE          0x10
/************************************************************************** /
/*     Constant                                                            */
/************************************************************************** /
```

```
#define ON            1
#define OFF           0
#define CW            1                      /* CW operation mode */
#define CCW           2                      /* CCW operation mode */
#define STOP          0                      /* Operation stop mode */
#define ERR_NO1       1                      /* Overcurrent error */
#define ERR_NO2       2                      /* Speed difference error  */
/************************************************************************** /
/*      Motor constant                                                     */
/************************************************************************** /
#define PAI           3.14159265            /* π */
#define TH_U          1000                  /* Radian value  jack-up constant */
#define RAD           (int)(2*PAI*TH_U)     /* Radian value of one revolution */
#define OFFSET        1733                  /* Original point OFFSET */
#define RPM_RADS      (int)((2*PAI*TH_U)/60)/* rpm -> radian conversion constant */
/* Motor constant */
#define KSP           500                   /* Speed proportion constant */
#define KSI           50                    /* Speed integral constant */
#define KI            1                     /* Current conversion constant */
#define P             2                     /* Number of poles */

#define KSPGETA       0                     /* KSP jack-up constant */
#define KSIGETA       9                     /* KSI jack-up constant */
#define KIGETA        9                     /* KI jack-up constant */
#define SGETA         14                    /* sin jack-up constant */

#define PWM_TS        80                    /* PWM cycle */
#define PWM_DATA      (PWM_TS/0.03125)      /* PWM set value */
#define SPEED_MAX     3000                  /* Maximum speed rpm */
#define SPEED_MINI    600                   /* Minimum speed rpm */
#define SA_SPEED_MAX  800                   /* Maximum speed difference rpm */
#define IQAMAX        40000000              /* Maximum speed integral value */
#define MAX_I         800                   /* Maximum current value */
#define TS            80                    /* Motor control time interval uSEC */
#define WATCH_START   500                   /* Speed monitor start time 10 mSEC */
#define ACCEL_VAL_1ST 50                    /* Initial acceleration/deceleration */
                                            /* time constant */
#define ACCEL_VAL     3                     /* Acceleration/deceleration time constant */
#define ACCEL_SPD     50                    /* Acceleration/deceleration constant */
/************************************************************************** /
/*     Function constant                                                   */
/************************************************************************** /
void            fcalcu( signed int *wrm, signed int *trm );
void            OUT_data( unsigned short reg, unsigned short data );
unsigned short  IN_data( int reg );
void            led_num( int no, long data ) ;
/************************************************************************** /
/*     Motor-related common area                                           */
```

```
/************************************************************************** /
signed short    iua ;           /* U-phase current */
signed short    iva ;           /* V-phase current */
signed int      o_iqai ;        /* Speed integral value area */
signed int      o_trm ;         /* Target position for initialization */
signed int      base_position ; /* Speed estimation value reference point */
unsigned int    sa_time ;       /* Speed measurement value */
unsigned short  timer_count ;   /* Time wait counter */
unsigned short  accel_count ;   /* Acceleration/deceleration operation time counter */
```

4.4.3 Interrupt handler setting

```
/************************************************************************** /
/*     Interrupt symbol table                                              */
/************************************************************************** /
       .extern _ _start
       .extern _int_MOTOR
       .extern _int_U
       .extern _int_V
       .extern _int_W
       .extern _int_AD0
       .extern _int_AD1
       .extern _int_ETC

       .globl V_RESET
       .globl V_U
       .globl V_V
       .globl V_W
       .globl V_ETC
       .globl V_MOTOR
       .globl V_AD0
       .globl V_AD1
#************************************************************************
       .section ".handler",text
V_RESET:
       Jr     _ _start
V_U:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_U                  -- INTP2
V_V:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_V                  -- INTP3
V_W:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_W                  -- INTP4
```

```
V_ETC:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_ETC                  -- Other timers
V_MOTOR:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_MOTOR                -- Speed control timer
V_AD0:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_AD0                  -- A/D converter CH0
V_AD1:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_AD1                  -- A/D converter CH1

       .extern V_RESET
       .extern V_U
       .extern V_V
       .extern V_W
       .extern V_ETC
       .extern V_MOTOR
       .extern V_AD0
       .extern V_AD1
/************************************************************************** /
/*     Interrupt jump table                                                */
/************************************************************************** /
       .section ".vect_RESET",text
       mov    #V_RESET,r1
       jmp    [r1]

       .section ".id_NO",text
       .byte   0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff

       .section ".vect_U",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_U,r1
       jmp    [r1]

       .section ".vect_V",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_V,r1
       jmp    [r1]

       .section ".vect_W",text
```

```
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_W,r1
       jmp    [r1]

       .section ".vect_ETC",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_ETC,r1
       jmp    [r1]

       .section ".vect_MOTOR",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_MOTOR,r1
       jmp    [r1]

       .section ".vect_AD0",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_AD0,r1
       jmp    [r1]

       .section ".vect_AD1",text
       add    -4,sp
       st.w   r1,[sp]
       mov    #V_AD1,r1
       jmp    [r1]
```

4.4.4 Startup routine setting

```
#=============================================================================
# DESCRIPTIONS:
#      This assembly program is a sample of start-up module for ca850.
#    If you modified this program, you must assemble this file, and
#    locate a given directory.
#
#    Unless -G is specified, sections are located as the following.
#
#                  |       :       |
#                  |       :       |
#           tp -> -+-------------- + _ _start    _ _tp_TEXT
#                  | start up      |
#                  |-------------- |
# text section     |               |
#                  | user program  |
#                  |               |
#                  |-------------- |
```

```
#                  | library       |
#                 -+-------------- +
#                  |               |
# sdata section    |               |
#                  |               |
#           gp -> -+-------------- +             _ _ssbss
#                  |               |
# sbss section     |               |
#                  |               |
#                  +-------------- + _ _stack    _ _esbss   _ _sbss
#                  | stack area    |
# bss section      |               |
#                  | 0x400 bytes   |
#           sp -> -+-------------- + _ _stack + STACKSIZE   _ _ebss
#                  |       :       |
#                  |       :       |
#                  |       :       |
#           ep -> -+-------------- + _ _ep_DATA
# tidata section   |               |
#                 -+-------------- +
# sidata section   |               |
#                 -+-------------- +
#                  |       :       |
#                  |       :       |
#
#==============================================================================
#------------------------------------------------------------------------------
#     special symbols
#------------------------------------------------------------------------------
      .extern _ _tp_TEXT, 4
      .extern _ _gp_DATA, 4
      .extern _ _ep_DATA, 4
      .extern _ _ssbss, 4
      .extern _ _esbss, 4
      .extern _ _sbss, 4
      .extern _ _ebss, 4


#------------------------------------------------------------------------------
#     C program main function
#------------------------------------------------------------------------------
      .extern _main


#------------------------------------------------------------------------------
#     dummy data declaration for creating sbss section
#------------------------------------------------------------------------------
      .sbss
```

```
       .lcomm  _ _sbss_dummy, 0, 0


#-------------------------------------------------------------------------------
#      system stack
#-------------------------------------------------------------------------------
       .set    STACKSIZE, 0x400
       .bss
       .lcomm  _ _stack, STACKSIZE, 4

#-------------------------------------------------------------------------------
#      start up
#           pointers:  tp - text pointer
#                      gp - global pointer
#                      sp - stack pointer
#                      ep - element pointer
#      exit status is set to r10
#-------------------------------------------------------------------------------
        .text
        .align 4
        .globl _ _start
        .globl _exit
        .globl _ _exit
_ _start:
        mov     13,r10                          -- 500 kHz to 64 MHz
        st.b    r10,VSWC[r0]                    -- Set peripheral I/O wait

        mov     0x03,r10                        -- PLL
        st.b    r10,PLLCTL[r0]

        mov     0x00,r10
        st.b    r10,PRCMD[r0]
        st.b    r10,PCC[r0]
        nop
        nop
        nop
        nop
        nop

        mov     #_ _tp_TEXT, tp                 -- set tp register
        mov     #_ _gp_DATA, gp                 -- set gp register offset
        add     tp, gp                          -- set gp register
        mov     #_ _stack+STACKSIZE, sp         -- set sp register
        mov     #_ _ep_DATA, ep                 -- set ep register
#
        mov     #_ _ssbss, r13                  -- clear sbss section
        mov     #_ _esbss, r12
        cmp     r12, r13
```

```
        jnl     .L11
.L12:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L12
.L11:
#
        mov     #_ _sbss, r13                   -- clear bss section
        mov     #_ _ebss, r12
        cmp     r12, r13
        jnl     .L14
.L15:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L15
.L14:
#
        jarl    _main, lp                       -- call main function
_ _exit:
        halt                                    -- end of program
_ _startend:
        nop
#                                                                               #
#-------------------------- end of start up module ----------------------------#
#                                                                               #
```

4.4.5 Main processing function

```
#include   "Common.h"
#include   "Motor.h"
#pragma    ioreg                            /* Peripheral I/O register definition */

static int save_psw;
/************************************************************************** /
/*     3-phase motor control program                                       */
/************************************************************************** /
void    main()
{
unsigned char    proc_no ;                   /* Present processing number */
signed int       speed ;                     /* Indication speed rms */
signed int       accel_spd ;
int              sw, sw_mode ;
/* */
   hinit() ;                                 /* Hardware initialization */
   ainit() ;                                 /* Initialization of area used */
   proc_no = 0 ;
```

```
   _ _EI();
   while( 1 ) {
      accel_spd = ( SPEED_MAX - SPEED_MINI ) / 100;
      speed  = ( ( SPEED_MAX - SPEED_MINI ) * volume  / 1024 )
               + SPEED_MINI ;               /* Indication speed calculation by volume */
      sw =  ~IN_data( SW ) & 0x07 ;         /* Read operation button */
      if  ( sw == 1 ) {
         sw_mode = CW ;
      } else if  ( sw == 2 ) {
         sw_mode = CCW ;
      } else if  ( sw == 4 ) {
         sw_mode = STOP ;
      }
      switch( proc_no ) {
/* STOP processing */
         case 0 :
            if  ( sw_mode == CW ) {
               _ _DI() ;
               object_speed  = SPEED_MINI ; /* Set target speed to minimum value */
               stop_flag = OFF ;
               timer_count = WATCH_START ;  /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ;/* Set acceleration/deceleration counter */
               init_flag = 2 ;              /* CCW initial request */
               start_init() ;               /* Initialize revolution start */
               _ _EI() ;
               proc_no = 1 ;                /* Set next processing number */
            } else if  ( sw_mode == CCW ) {
               _ _DI() ;
               stop_flag = OFF ;            /* Stop flag off */
               object_speed = -SPEED_MINI ; /* Set target speed to minimum value */
               timer_count = WATCH_START ;  /* Set speed monitor start time to 5 SEC */
               accel_count = ACCEL_VAL_1ST ;/* Set acceleration/deceleration counter */
               init_flag = 3 ;              /* CCW initial request */
               start_init() ;               /* Initialize revolution start */
               _ _EI() ;
               proc_no = 4 ;                /* Set CCW processing number */
            }
            break ;
/* CW processing, acceleration */
         case 1 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;    /* Set acceleration/deceleration counter */
               if  ( object_speed  < speed ) {
                  object_speed += accel_spd ;
                  if  ( object_speed > speed ) object_speed = speed;
                  timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
               } else if ( object_speed  > speed ) {
                  object_speed -= accel_spd ;
```

```
                if  ( object_speed < speed ) object_speed = speed;
                timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
            } else {
                proc_no = 2 ;            /* Constant-speed processing */
            }
        }
        if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
            proc_no = 3 ;                /* Deceleration, set processing number */
        }
        break ;
/* CW processing, constant-speed */
      case 2 :
        object_speed = speed ;
        if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
            proc_no = 3 ;                /* Deceleration, set processing number */
        }
        break ;
/* CW stop processing */
      case 3 :
        if  ( accel_count == 0 ) {
            accel_count = ACCEL_VAL ;    /* Set acceleration/deceleration counter */
            if  ( object_speed  > SPEED_MINI ) {
                object_speed -= accel_spd ;
                if  ( object_speed < SPEED_MINI ) object_speed = SPEED_MINI;
                timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
            } else {
                stop_flag = ON ;         /* Stop flag on */
                proc_no = 0 ;            /* Set stop processing number */
            }
        }
        break ;
/* CCW processing, acceleration */
      case 4 :
        if  ( accel_count == 0 ) {
            accel_count = ACCEL_VAL ;    /* Set acceleration/deceleration counter */
            if  ( object_speed  < -speed ) {
                object_speed += accel_spd ;
                if  ( object_speed > -speed ) object_speed = -speed;
                timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
            } else if ( object_speed  > -speed ) {
                object_speed -= accel_spd ;
                if  ( object_speed < -speed ) object_speed = -speed;
                timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
            } else {
                proc_no = 5 ;            /* Constant-speed processing */
            }
        }
        if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
```

```
                proc_no = 6 ;                /* Deceleration, set processing number */
            }
            break ;
/* CCW processing, constant-speed */
         case 5 :
            object_speed = -speed ;
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
               proc_no = 6 ;                 /* Deceleration, set processing number */
            }
            break ;
/* CCW stop processing */
         case 6 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;     /* Set acceleration/deceleration counter */
               if  ( object_speed  < -SPEED_MINI ) {
                  object_speed += accel_spd ;
                  if  ( object_speed > -SPEED_MINI ) object_speed = -SPEED_MINI;
                  timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
               } else {
                  stop_flag = ON ;           /* Stop flag on */
                  proc_no = 0 ;              /* Set stop processing number */
               }
            }
            break ;
      }

      if  ( ( proc_no == 2 ) || ( proc_no == 5 ) ) {
         if  (  timer_count == 0 ) {
            if  ( abs( object_speed - now_speed ) > SA_SPEED_MAX ) {
               error_flag = ERR_NO2 ;        /* Set error No. */
            }
         }
      }

      if  ( disp_co == 0 ) {
         led_num(1, d_speed / 100 );          /* Number of revolutions */
         d_speed = 0 ;
         disp_co = 100 ;
         if  ( abs(now_speed) == 0 ) {
            disp_co = 0;
         }
         led_num(2, 1000/PWM_TS );            /* Carrier frequency */
         led_num(3, cont_time );              /* Overall processing time */
         led_num(4, cont_time1 );             /* Vector operation processing time */
      }
      if  ( error_flag ) {
         while( 1 ) {
            OUT_data( LED41, ~0x00 ) ;        /* LED display off */
```

```
            OUT_data( LED42, ~0x00 ) ;
            timer_count = 50 ;
            while( timer_count ) ;
            if  ( error_flag == ERR_NO1 ) {
               OUT_data( LED41, ~0x9e ) ;   /* E1 display */
               OUT_data( LED42, ~0x60 ) ;
            } else if ( error_flag == ERR_NO2 ) {
               OUT_data( LED41, ~0x9e ) ;   /* E2 display */
               OUT_data( LED42, ~0xda ) ;
            } else {
               OUT_data( LED41, ~0x9e ) ;   /* E3 display */
               OUT_data( LED42, ~0xf2 ) ;
            }
            timer_count = 50 ;
            while( timer_count ) ;
         }
      }
   }
}
```

4.4.6 LED display function

```
/************************************************************************** /
/*     LED value display subroutine                                        */
/*              no   : Display area number (1 to 4)                        */
/*              data : Display data (0 to 99)                              */
/************************************************************************** /
void led_num( int no, long data )
{
   if  ( no == 1 ) {
      data = data % 10000;
      OUT_data( LED11, ~led_pat[data/1000]&0xff ) ;
      OUT_data( LED12, ~led_pat[(data%1000)/100]&0xff ) ;
      OUT_data( LED13, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED14, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 2 ) {
      OUT_data( LED21, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED22, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 3 ) {
      OUT_data( LED31, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED32, ~led_pat[data%10]&0xff ) ;
   } else {
      OUT_data( LED41, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED42, ~led_pat[data%10]&0xff ) ;
   }
}
/************************************************************************** /
/*     External I/O output subroutine                                      */
```

```
/*             reg  : Output register number                                */
/*             data : Output data                                           */
/***************************************************************************** /
void   OUT_data( unsigned short reg, unsigned short data )
{
       if  ( reg == WRESET ) {
              P3.0 = 0;
              data = 1;                      /* Dummy step */
              P3.0 = 1;
       } else {
              PDL = data | ( reg << 8 );
              PDL = reg | ( reg << 8 ) | 0x8000;
       }
}
/***************************************************************************** /
/*     External I/O input subroutine                                        */
/*              reg : Input register number                                 */
/***************************************************************************** /
unsigned short  IN_data( int reg )
{
unsigned char *po;
/*  */
       if    ( reg == SW ) {
              return P4;
       } else {
              return 0;
       }
}
```

4.4.7 Motor control interrupt processing function

```
#include   "Common.h"
#include   "Motor.h"
#pragma    ioreg                           /* Peripheral I/O register definition */
/***************************************************************************** /
/*     Motor control timer interrupt processing                             */
/***************************************************************************** /
_ _interrupt
void   int_MOTOR(void)
{
   ADA0M0 = 0xB0 ;                         /* Start AD0 */
   ADA1M0 = 0xA0 ;                         /* Start AD1 */
}
/***************************************************************************** /
/*     Motor control processing                                             */
/***************************************************************************** /
void   Motor_CONT(void)
{
```

```
signed int   wrm, wre, trm, tre ;
signed int   o_wre, we, o_iqap, o_iqa ;
signed int   ida, iqa, o_vda1, o_vqa1 ;
signed int   o_vd0, o_vq0, o_vda, o_vqa ;
signed int   o_vua, o_vva, o_vwa, wiua, wiva ;
signed int   s_time, wk ;
signed short now_enc, sa_enc ;
/*  */
/************************************************************************** /
/*     Calculation processing of speed and rotor position                  */
/************************************************************************** /
   fcalcu( &wrm, &trm ) ;
   sum_speed += ( wrm * TH_U / RPM_RADS ) ; /* Radian -> rpm */
   if  ( --speed_co == 0 ) {
      speed_co = 100000 / TS ;             /* Set 100 mSEC counter value */
      now_speed = sum_speed / speed_co ;
      sum_speed = 0 ;
   }
   wre = wrm * P ;
   tre = ( trm * P + OFFSET ) % RAD ;
/************************************************************************** /
/*     Speed control processing                                            */
/************************************************************************** /
   if  ( ( stop_flag == OFF ) && ( error_flag == 0 ) ) {
      s_time = TP1CNT ;
      o_wre = object_speed * RPM_RADS * P / TH_U ;      /* rpm -> radian conversion */
      we = o_wre - wre ;
      o_iqap = ( ( wre * KSP ) + ( we * KSP ) ) >> KSPGETA ;
      o_iqa = o_iqap + ( o_iqai >> KSIGETA ) ;

      if  ( o_iqai > IQAMAX ) {
         o_iqai = IQAMAX ;
      } else if ( o_iqai < -IQAMAX ) {
         o_iqai = -IQAMAX ;
      } else {
         o_iqai += ( KSI * we ) ;
      }
/************************************************************************** /
/*     Current control processing                                          */
/************************************************************************** /
      ida = ( ( ( iva * sin( tre ) ) - ( iua * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      iqa = ( ( ( iva * sin( tre + RAD/4 ) ) - ( iua * sin( tre + 11*RAD/12 ) ) ) ) >> SGETA ;

      o_vda = ( KI * -ida ) >> KIGETA ;
      o_vqa = ( KI * ( o_iqa  - iqa )  ) >> KIGETA ;
/************************************************************************** /
/*     3-phase voltage conversion processing                               */
/************************************************************************** /
```

```
      if ( init_flag == 2 ) {                          /* CW initial processing */
         o_trm += ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm > ( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else if ( init_flag == 3 ) {                  /* CCW initial processing */
         o_trm -= ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm < -( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else {
         o_trm = 0 ;
      }
      o_vua  = ( ( ( o_vda * sin( tre + RAD/4 ) ) - ( o_vqa * sin( tre ) ) ) ) >> SGETA ;
      o_vva  = ( ( ( o_vda * sin( tre + 11*RAD/12 ) ) - ( o_vqa * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      o_vwa  = -o_vua - o_vva ;

      cont_time1 = ( TP1CNT - s_time ) ;      /* Convert to uSEC */
/************************************************************************** /
/*     PWM conversion output processing                                    */
/************************************************************************** /
      OUT_data( WRESET, 0 ) ;                 /* Reset watchdog timer */
      HZA0CTL0 |= 0x04;                       /* PWM output on */
/* PWM counter value calculation output */
      o_vua += ( PWM_DATA  / 2 ) ;
      o_vva += ( PWM_DATA  / 2 ) ;
      o_vwa += ( PWM_DATA  / 2 ) ;

      if  ( o_vua <= 0 ) {
         o_vua = 1 ;
      } else if  ( o_vua >= PWM_DATA  ) {
         o_vua = PWM_DATA  - 1 ;
      }
      if  ( o_vva <= 0 ) {
         o_vva = 1 ;
      } else if  ( o_vva >= PWM_DATA  ) {
         o_vva = PWM_DATA  - 1 ;
      }
      if  ( o_vwa <= 0 ) {
         o_vwa = 1 ;
      } else if  ( o_vwa >= PWM_DATA  ) {
         o_vwa = PWM_DATA  - 1 ;
```

```
        }

        TQ0CCR1 = o_vua ;
        TQ0CCR2 = o_vva ;
        TQ0CCR3 = o_vwa ;
    } else {
        HZA0CTL0 |= 0x08;               /* PWM output off */
        now_speed = 0;
        cont_time1 = 0;
    }
}
/************************************************************************** /
/*     Calculation processing of speed, etc.                               */
/************************************************************************** /
void     fcalcu( signed int *wrm, signed int *trm )
{
signed short     es_trm, cur_time, delta, i ;
signed int       wwrm, wk, *p1, *p2;
//
//     Speed and position calculation from zero-cross point
//
    cur_time = TP2CNT ;
    delta = ( (RAD/6/P) * cur_time ) / sa_time ;  /* Calculation of rotor position */
                                                  /* difference from reference */
                                                  /* position (radian) */
    if  ( object_speed >= 0 ) {
        es_trm = base_position + delta;
    } else {
        es_trm = base_position - delta;
        if  ( es_trm < 0 ) es_trm += (RAD/P);
    }

    total_sa -= before_posi[20][1] ;

    p1 = (int *)before_posi[19] ;
    p2 = (int *)before_posi[20] ;
    for ( i = 0; i <= 19 ; i++ ) {
        *p2-- = *p1-- ;
    }
    before_posi[0][0] = *trm = es_trm % (RAD/P) ;

    wk = before_posi[0][0] - before_posi[1][0] ;
    if  ( abs(wk) > (RAD/2/P) ) {
        if  ( wk < 0 ) {
            wk = (RAD/P) + wk ;
        } else {
            wk = wk - (RAD/P) ;
        }
```

```
    }

    before_posi[1][1] = wk ;
    total_sa += wk ;                        /* Total difference in average buffer */

    wwrm = ( total_sa * ( 1000000 / 20 / TH_U ) / TS );
    *wrm = wwrm ;                           /* Speed  radian/second */
}
```

4.4.8 Zero-cross interrupt processing function

```
/************************************************************************** /
/*      U zero-cross point interrupt                                       */
/************************************************************************** /
_ _interrupt
void   int_U(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TP2CNT ;
        TP2CTL0  &= ~0x80;
        TP2CTL0  |= 0x80;                   /* Restart timer */

        if  ( ~P0 & 0x10 ) {                /* Check W phase */
            base_position = 0 ;
        } else {
            base_position = RAD/2/P ;
        }
    }
}
/************************************************************************** /
/*     V zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void    int_V(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time =  TP2CNT ;
        TP2CTL0  &= ~0x80;
        TP2CTL0  |= 0x80;                   /* Restart timer */

        if  ( ~P0 & 0x04 ) {                /* Check U phase */
            base_position = RAD/3/P ;
        } else {
            base_position = RAD*5/6/P ;
        }
    }
}
/************************************************************************** /
```

```
/*     W zero-cross point interrupt                                          */
/************************************************************************** /
_ _interrupt
void    int_W(void)
{
   if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
       sa_time =  TP2CNT ;
       TP2CTL0  &= ~0x80;
       TP2CTL0  |= 0x80;                    /* Restart timer */

       if  ( ~P0 & 0x08 ) {                 /* Check V phase */
          base_position = RAD*2/3/P ;
       } else {
          base_position = RAD/6/P ;
       }
   }
}
```

4.4.9 10 mSEC interval interrupt processing function

```
/************************************************************************** /
/*     Other timer interrupt processing (10 mSEC interval)                  */
/************************************************************************** /
_ _multi_interrupt
void    int_ETC(void)
{
/* Wait timer processing */
   if  ( timer_count != 0 ) {
       timer_count -= 1 ;
   }
/* Acceleration/deceleration timer processing */
   if  ( accel_count != 0 ) {
       accel_count -= 1 ;
   }
/* */
   if  ( disp_co != 0 ) {
       d_speed += abs( now_speed ) ;
       disp_co -= 1 ;
   }
}
```

4.4.10 A/D converter interrupt processing function

```
/************************************************************************** /
/*     A/D converter interrupt processing for U-phase current and speed volume */
/************************************************************************** /
_ _multi_interrupt
void   int_AD0(void)
```

```
{
   iua = (( ( ADA0CR0 >> 6 ) & 0x3ff ) - 0x200) ;
   if  ( abs(iua) > MAX_I ) {
      HZA0CTL0 |= 0x08 ;                          /* PWM output off */
      error_flag = ERR_NO1 ;                      /* Set error No. */
   }
   volume = 1023 - ( ( ADA0CR1 >> 6 ) & 0x3ff ) ;  /* Set volume value */
   Motor_CONT() ;
   cont_time = TP1CNT;                            /* Convert to uSEC */
}
/************************************************************************** /
/*      A/D converter interrupt processing for volume                      */
/************************************************************************** /
_ _interrupt
void    int_AD1(void)
{
   iva = (( ADA1CR0 & 0x3ff ) - 0x200) ;
   if  ( abs(iva) > MAX_I ) {
      HZA0CTL0 |= 0x08 ;                          /* PWM output off */
      error_flag = ERR_NO1 ;                      /* Set error No. */
   }
}
```

4.4.11 Hardware initialization processing function

```
/************************************************************************** /
/*     Hardware (peripheral I/O) initialization                            */
/************************************************************************** /
void   hinit( void )
{
/* Port mode register initialization */
   PM3 = 0xfe ;
   PM4 = 0xff ;
   PMDL  = 0x0000 ;

   OUT_data( LED11, 0xff ) ;   /* LED OFF */
   OUT_data( LED12, 0xff ) ;
   OUT_data( LED13, 0xff ) ;
   OUT_data( LED14, 0xff ) ;
   OUT_data( LED21, 0xff ) ;
   OUT_data( LED22, 0xff ) ;
   OUT_data( LED31, 0xff ) ;
   OUT_data( LED32, 0xff ) ;
   OUT_data( LED41, 0xff ) ;
   OUT_data( LED42, 0xff ) ;
/* Set 10 mSEC timer TMP0 */
   TP0CTL0 = 0x05 ;           /* Select fXX/64 */
   TP0CTL1 = 0x00 ;           /* Select interval timer mode */
```

```
    TP0CCR0 = 10000 ;           /* 10 mSEC */
    TP0CTL0 |= 0x80 ;           /* Start timer */
    TP0CCIC0= 0x06;
/* Set motor control interrupt timer TMP1 */
    TP1CTL0 = 0x05 ;            /* Select fXX/64 */
    TP1CTL1 = 0x00 ;            /* Select interval timer mode */
    TP1CCR0 = TS ;              /* TS uSEC */
    TP1CTL0 |= 0x80 ;           /* Start timer */
    TP1CCIC0= 0x01;
/* Set speed measuring timer TMP2 */
    TP2CTL0 = 0x05 ;            /* Select fXX/64 */
    TP2CTL1 = 0x05 ;            /* Select free-running timer mode */
    TP2CTL0 |= 0x80 ;           /* Start timer */
/* TMQ0 initialization */
    TQ0CTL0 = 0x00;             /* fXX/2 (64 MHz/2 = 32 MHz) */
    TQ0CTL1 = 0x07;             /* Select 6-phase PWM output mode */
    TQ0IOC0 = 0x55;             /* Positive phase normal output, output enabled */
    TQ0IOC1 = 0x00;             /* TIQ00 to TIQ03, EVTQ0, and TRGQ0 pins of TMQ0 */
    TQ0IOC2 = 0x00;             /* are not used */
    TQ0OPT0 = 0x00;             /* Select comparison mode */
    TQ0CCR0 = PWM_DATA ;        /* Carrier wave cycle 20 kHz */
    TQ0CCR1 = PWM_DATA /2;      /* Set U-phase duty to 50 */
    TQ0CCR2 = PWM_DATA /2;      /* Set V-phase duty to 50 */
    TQ0CCR3 = PWM_DATA /2;      /* Set W-phase duty to 50 */
    TQ0DTC  = 180;              /* Dead time 6 uSEC */
    TQ0OPT1 = 0x00;             /* No culling, no crest and valley interrupts are used */

    TQ0OPT2 = 0x04;             /* • No culling between reloads */
                                /* • Clear and re-count dead time counter */
                                /* • Output A/D trigger output of INTTP0CC0 interrupt */
                                /*   during counting up */
                                /* • A/D trigger output of INTTP0CC0 interrupt enabled */

    TQ0IOC3 = 0xfc;             /* Negative phase inverted output, output enabled */
    PMC1 = 0x3F;                /* Alternate-function mode */
    PFCE1 = 0x00;               /* Select TOQ0T1 to TOQ0T3 or TOQ0B1 to TOQ0B3 output */
    PFC1 = 0x00;

    HZA0CTL0 = 0x00;
    HZA0CTL0 = 0xD0;            /* High-impedance operation enabled */
                                /* TOQ0OFF pin rising edge valid */
    HZA2CTL0 = 0x00;            /* High-impedance off due to analog input */
    TQ0CTL0 |= 0x80;            /* Start 6-phase PWM output mode */
/* Set A/D */
    ADA0M0 = 0x30 ;             /* ANI00, ANI01 */
    ADA0M1 = 0x01 ;
    ADA0S  = 0x01 ;
    OP0CTL0 = 0x00 ;            /* Operational amplifier invalid */
```

```
   OP0CTL1 = 0x00 ;            /* Comparator invalid */
   AD0IC  = 0x03 ;

   ADA1M0 = 0x20 ;             /* ANI10 */
   ADA1M1 = 0x01 ;
   ADA1S  = 0x00 ;
   OP1CTL0 = 0x00 ;            /* Operational amplifier invalid */
   OP1CTL1 = 0x00 ;            /* Comparator invalid */
   AD1IC  = 0x03 ;
/* Set zero-cross signal interrupt pin */
   PMC0   = 0x1c ;
   INTR0  = 0x1c ;             /* INTP2, INTP3, INTP4 both-edge interrupt */
   INTF0  = 0x1c ;
   PIC2   = 0x01 ;
   PIC3   = 0x01 ;
   PIC4   = 0x01 ;
}
```

4.4.12 Common area initialization processing function

```
/************************************************************************** /
/*     Common area initialization                                          */
/************************************************************************** /
void    ainit( void )
{
/* Initialization of flags */
   error_flag = 0 ;               /* Clear error flag */
   init_flag = OFF ;              /* Initial flag off */
   disp_co = 100 ;
   d_speed = 0 ;
/* Motor control area initialization */
   stop_flag   = ON ;             /* Stop flag on */
   object_speed = 0 ;             /* Target speed 0 */
   o_iqai = 0 ;                   /* Speed integral value 0 */
   o_trm = 0 ;
}
```

4.4.13 Revolution start initialization processing function

```
/************************************************************************** /
/*     Revolution start initialization                                     */
/************************************************************************** /
void    start_init( void )
{
   int  i;
/*  */
   for ( i = 0 ; i < 21 ; i++ ) before_posi[i][1] = 0;
   total_sa = 0 ;
```

```
    sum_speed = 0 ;
    speed_co = 100000 / TS ;
}
```

4.4.14 sin calculation processing function

```
/************************************************************************** /
/*     sin x                                                               */
/*          Data                                                           */
/*            Radian unit                                                  */
/*          Return value                                                   */
/*            Sign value*16384                                             */
/************************************************************************** /
int sin( int x )
{
    x = x % RAD ;
    if  ( x < 0 ) x += RAD ;
    if  ( x < (RAD/4) ){
        return sins( x ) ;
    } else if ( x < (RAD/2) ) {
        return sins( (RAD/2) - x ) ;
    } else if ( x < (RAD*3/4) ) {
        return -sins( x - (RAD/2) ) ;
    } else {
        return -sins( RAD - x ) ;
    }
}
/*************************************************************************/
int sins( int x )
{
short z1, z2, z3, z4, z5 ;
/*  */
    if  ( x <= (RAD/8) ) {
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z3 = z1 * z2 >> SGETA ;
        z5 = z2 * z3 >> SGETA ;
        return ( (12868*z1) - (1322*z3) + (40*z5) ) >> SGETA ;
    } else {
        x = (RAD/4) - x ;
        z1 = (x << SGETA) / (RAD/8) ;
        z2 = z1 * z1 >> SGETA ;
        z4 = z2 * z2 >> SGETA ;
        return ( (268432772) - (5050*z2) + (252*z4) ) >> SGETA ;
    }
}
```

4.4.15 Link directive file for V850E/IA4

```
/************************************************************************** /
/*     Link directive file for V850E/IA4                                    */
/************************************************************************** /
VECT_RESET: !LOAD ?RX V0x00000000 {
       .vect_RESET  = $PROGBITS ?AX .vect_RESET;
};
ID_NO: !LOAD ?RX V0x00000070 {
       .id_NO  = $PROGBITS ?AX .id_NO;
};
VECT_U: !LOAD ?RX V0x00000090 {
       .vect_U  = $PROGBITS ?AX .vect_U;
};
VECT_V: !LOAD ?RX V0x000000a0 {
       .vect_V  = $PROGBITS ?AX .vect_V;
};
VECT_W: !LOAD ?RX V0x000000b0 {
       .vect_W  = $PROGBITS ?AX .vect_W;
};
VECT_ETC: !LOAD ?RX V0x00000250 {
       .vect_ETC  = $PROGBITS ?AX .vect_ETC;
};
VECT_MOTOR: !LOAD ?RX V0x00000280 {
       .vect_MOTOR  = $PROGBITS ?AX .vect_MOTOR;
};
VECT_AD0: !LOAD ?RX V0x00000400 {
       .vect_AD0  = $PROGBITS ?AX .vect_AD0;
};
VECT_AD1: !LOAD ?RX V0x00000410 {
       .vect_AD1  = $PROGBITS ?AX .vect_AD1;
};

HANDLER: !LOAD ?RX V0x00001000 {
       .handler  = $PROGBITS ?AX .handler;
};
TEXT:  !LOAD ?RX {
       .text  = $PROGBITS ?AX .text;
};

CONST : !LOAD ?R {
       .const = $PROGBITS ?A .const;
};

DATA : !LOAD ?RW  V0xffffd800 {
       .data  = $PROGBITS ?AW  ;
       .sdata = $PROGBITS ?AWG ;
       .sbss  = $NOBITS   ?AWG ;
```

```
      .bss   = $NOBITS   ?AW  ;
};

_ _tp_TEXT @ %TP_SYMBOL;
_ _gp_DATA @ %GP_SYMBOL &_ _tp_TEXT{DATA};
_ _ep_DATA @ %EP_SYMBOL;
```

4.5 Program List (V850E/MA3)

4.5.1 Symbol definition

```
/************************************************************************** /
/*     Common area                                                         */
/************************************************************************** /
unsigned char   ram_start ;
unsigned char   error_flag ;         /* Error flag */
unsigned char   init_flag ;          /* Initial flag */
unsigned short  cont_time ;          /* Interrupt control time uSEC */
unsigned short  cont_time1 ;         /* Vector operation time uSEC */
unsigned short  disp_co ;            /* Interrupt control time display timer */
unsigned short  volume ;             /* Volume value */
unsigned short  timer_count ;        /* Time wait counter */
unsigned short  accel_count ;        /* Acceleration/deceleration operation time counter */
unsigned char   stop_flag ;          /* Stop flag */
signed short    before_posi[21][2] ; /* Position buffer */
signed short    total_sa ;           /* Position total difference */
signed int      sum_speed ;
signed int      speed_co ;
signed int      now_speed ;          /* Present speed rms */
signed int      object_speed ;       /* Target speed rms */
unsigned int    d_speed ;            /* Display speed rms */
unsigned char   ram_end ;

#pragma section const begin
const unsigned short led_pat[10] = { 0xfc, 0x60, 0xda, 0xf2, 0x66, 0xb6, 0xbe, 0xe0,
                                     0xfe, 0xe6 } ;
#pragma section const end
/************************************************************************** /
/*     Common flags                                                        */
/************************************************************************** /
extern unsigned char  ram_start ;
extern unsigned char  error_flag ;         /* Error flag */
extern unsigned char  init_flag ;          /* Initial flag */
extern unsigned short cont_time ;          /* Interrupt control time uSEC */
extern unsigned short cont_time1 ;         /* Vector operation time uSEC */
extern unsigned short disp_co ;            /* Interrupt control time display timer */
extern unsigned short volume ;             /* Volume value */
extern unsigned short timer_count ;        /* Time wait counter */
extern unsigned short accel_count ;        /* Acceleration/deceleration operation */
                                           /* time counter */
extern unsigned char  stop_flag ;          /* Stop flag */
extern signed short   before_posi[21][2] ; /* Position buffer */
extern signed short   total_sa ;           /* Position total difference */
extern signed int     sum_speed ;
extern signed int     speed_co ;
```

```
extern signed int     now_speed ;             /* Present speed rms */
extern signed int     object_speed ;          /* Target speed rms */
extern unsigned int   d_speed ;               /* Display speed rms */
extern unsigned char  ram_end ;

#pragma section const begin
extern const unsigned short led_pat[] ;;
#pragma section const end
/************************************************************************** /
/*     Motor common definition                                             */
/************************************************************************** /
extern signed short    iua ;          /* U-phase current */
extern signed short    iva ;          /* V-phase current */
extern signed int      o_iqai ;       /* Speed integral value area */
extern signed int      o_trm ;        /* Target position for initialization */
extern signed int      base_position ; /* Speed estimation value reference point */
extern unsigned int    sa_time ;      /* Speed measurement value */
extern unsigned short  timer_count ;  /* Time wait counter */
extern unsigned short  accel_count ;  /* Acceleration/deceleration operation time counter */
```

4.5.2 Constant definition

```
/************************************************************************** /
/*     I/O                                                                 */
/************************************************************************** /
#define BASE_IO     0xc200000
#define LED11       3
#define LED12       2
#define LED13       1
#define LED14       0
#define LED21       5
#define LED22       4
#define LED31       7
#define LED32       6
#define LED41       9
#define LED42       8

#define DIPSW       0x10
#define SW          0x20
#define DA1         0x30
#define DA2         0x40
#define DA3         0x50
#define WRESET      0x60
#define MODE        0x70
/************************************************************************** /
/*     Constant                                                            */
/************************************************************************** /
#define ON          1
```

```
#define OFF         0
#define CW          1                   /* CW operation mode */
#define CCW         2                   /* CCW operation mode */
#define STOP        0                   /* Operation stop mode */
#define ERR_NO1     1                   /* Overcurrent error */
#define ERR_NO2     2                   /* Speed difference error  */
/************************************************************************** /
/*     Motor constant                                                      */
/************************************************************************** /
#define PAI           3.14159265            /* π */
#define TH_U          1000                  /* Radian value  jack-up constant */
#define RAD           (int)(2*PAI*TH_U)     /* Radian value of one revolution */
#define OFFSET        1945                  /* Original point OFFSET */
#define RPM_RADS      (int)((2*PAI*TH_U)/60)/* rpm -> radian conversion constant */
/* Motor constant */
#define KSP           500                   /* Speed proportion constant */
#define KSI           50                    /* Speed integral constant */
#define KI            1                     /* Current conversion constant */
#define P             2                     /* Number of poles */

#define KSPGETA       0                     /* KSP jack-up constant */
#define KSIGETA       9                     /* KSI jack-up constant */
#define KIGETA        9                     /* KI jack-up constant */
#define SGETA         14                    /* sin jack-up constant */

#define PWM_TS        50                    /* PWM cycle */
#define PWM_DATA      (PWM_TS/0.05)         /* PWM set value */
#define SPEED_MAX     3000                  /* Maximum speed rpm */
#define SPEED_MINI    600                   /* Minimum speed rpm */
#define SA_SPEED_MAX  800                   /* Maximum speed difference rpm */
#define IQAMAX        40000000              /* Maximum speed integral value */
#define MAX_I         800                   /* Maximum current value */
#define TS            200                   /* Motor control time interval uSEC */
#define WATCH_START   500                   /* Speed monitor start time 10 mSEC */
#define ACCEL_VAL_1ST 50                    /* Initial acceleration/deceleration */
                                            /* time constant */
#define ACCEL_VAL     3                     /* Acceleration/deceleration time constant */
#define ACCEL_SPD     50                    /* Acceleration/deceleration constant */
/************************************************************************** /
/*     Function constant                                                   */
/************************************************************************** /
void            fcalcu( signed int *wrm, signed int *trm );
void            OUT_data( unsigned short reg, unsigned short data );
unsigned short  IN_data( int reg );
void            led_num( int no, long data ) ;
/************************************************************************** /
/*     Motor-related common area                                           */
/************************************************************************** /
```

```
signed short    iua ;           /* U-phase current */
signed short    iva ;           /* V-phase current */
signed int      o_iqai ;        /* Speed integral value area */
signed int      o_trm ;         /* Target position for initialization */
signed int      base_position ; /* Speed estimation value reference point */
unsigned int    sa_time ;       /* Speed measurement value */
unsigned short  timer_count ;   /* Time wait counter */
unsigned short  accel_count ;   /* Acceleration/deceleration operation time counter */
```

4.5.3 Interrupt handler setting

```
/************************************************************************** /
/*     Interrupt symbol table                                              */
/************************************************************************** /
       .extern _ _start
       .extern _int_MOTOR
       .extern _int_U
       .extern _int_V
       .extern _int_W
       .extern _int_AD0
       .extern _int_AD1
       .extern _int_ETC

       .globl V_RESET
       .globl V_U
       .globl V_V
       .globl V_W
       .globl V_ETC
       .globl V_MOTOR
       .globl V_AD0
#************************************************************************
       .section ".handler",text
V_RESET:
       Jr     _ _start
V_U:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_U                  -- INTP130
V_V:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_V                  -- INTP131
V_W:
       ld.w   [sp],r1
       add    4,sp
       jr     _int_W                  -- INTP132
V_ETC:
       ld.w   [sp],r1
```

```
        add    4,sp
        jr     _int_ETC                  -- Other timers
V_MOTOR:
        ld.w   [sp],r1
        add    4,sp
        jr     _int_MOTOR                -- Speed control timer
V_AD0:
        ld.w   [sp],r1
        add    4,sp
        jr     _int_AD0                  -- A/D converter CH0

        .extern V_RESET
        .extern V_U
        .extern V_V
        .extern V_W
        .extern V_ETC
        .extern V_MOTOR
        .extern V_AD0
/************************************************************************** /
/*     Interrupt jump table                                                */
/************************************************************************** /
        .section ".vect_RESET",text
        mov    #V_RESET,r1
        jmp    [r1]

        .section ".id_NO",text
        .byte  0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff

        .section ".vect_U",text
        add    -4,sp
        st.w   r1,[r3]
        mov    #V_U,r1
        jmp    [r1]

        .section ".vect_V",text
        Add    -4,sp
        st.w   r1,[r3]
        mov    #V_V,r1
        jmp    [r1]

        .section ".vect_W",text
        Add    -4,sp
        st.w   r1,[r3]
        mov    #V_W,r1
        jmp    [r1]

        .section ".vect_ETC",text
        Add    -4,sp
```

```
       st.w   r1,[r3]
       mov    #V_ETC,r1
       jmp    [r1]

       .section ".vect_MOTOR",text
       Add    -4,sp
       st.w   r1,[r3]
       mov    #V_MOTOR,r1
       jmp    [r1]

       .section ".vect_AD0",text
       Add    -4,sp
       st.w   r1,[r3]
       mov    #V_AD0,r1
       jmp    [r1]
```

4.5.4 Startup routine setting

```
#===============================================================================
# DESCRIPTIONS:
#      This assembly program is a sample of start-up module for ca850.
#    If you modified this program, you must assemble this file, and
#    locate a given directory.
#
#    Unless -G is specified, sections are located as the following.
#
#                |       :       |
#                |       :       |
#          tp -> -+-------------- + _ _start   _ _tp_TEXT
#                 | start up      |
#                 |-------------- |
# text section    |               |
#                 | user program  |
#                 |               |
#                 |-------------- |
#                 | library       |
#                -+-------------- +
#                 |               |
# sdata section   |               |
#                 |               |
#          gp -> -+-------------- +           _ _ssbss
#                 |               |
# sbss section    |               |
#                 |               |
#                 +-------------- + _ _stack   _ _esbss     _ _sbss
#                 | stack area    |
# bss section     |               |
#                 | 0x400 bytes   |
```

```
#          sp->  -+-------------- + _ _stack + STACKSIZE    _ _ebss
#                 |       :       |
#                 |       :       |
#                 |       :       |
#          ep -> -+-------------- + _ _ep_DATA
# tidata section  |               |
#                -+-------------- +
# sidata section  |               |
#                -+-------------- +
#                 |       :       |
#                 |       :       |
#
#===============================================================================
#-------------------------------------------------------------------------------
#     special symbols
#-------------------------------------------------------------------------------
      .extern _ _tp_TEXT, 4
      .extern _ _gp_DATA, 4
      .extern _ _ep_DATA, 4
      .extern _ _ssbss, 4
      .extern _ _esbss, 4
      .extern _ _sbss, 4
      .extern _ _ebss, 4


#-------------------------------------------------------------------------------
#     C program main function
#-------------------------------------------------------------------------------
      .extern _main


#-------------------------------------------------------------------------------
#     dummy data declaration for creating sbss section
#-------------------------------------------------------------------------------
      .sbss
      .lcomm _ _sbss_dummy, 0, 0


#-------------------------------------------------------------------------------
#     system stack
#-------------------------------------------------------------------------------
      .set   STACKSIZE, 0x400
      .bss
      .lcomm _ _stack, STACKSIZE, 4

#-------------------------------------------------------------------------------
#     start up
#          pointers:  tp - text pointer
```

```
#                       gp - global pointer
#                       sp - stack pointer
#                       ep - element pointer
#      exit status is set to r10
#------------------------------------------------------------------------------
        .text
        .align 4
        .globl _ _start
        .globl _exit
        .globl _ _exit
_ _start:
        mov     0x26,r10
        st.b    r10,VSWC[r0]                -- Set peripheral I/O wait

        mov     0x07,r10                    -- ×10
        st.b    r10,PRCMD[r0]
        st.b    r10,CKC[r0]                 -- PLL xx multiplication
        nop
        nop
        nop
        nop
        nop

        mov     #_ _tp_TEXT, tp             -- set tp register
        mov     #_ _gp_DATA, gp             -- set gp register offset
        add     tp, gp                      -- set gp register
        mov     #_ _stack+STACKSIZE, sp     -- set sp register
        mov     #_ _ep_DATA, ep             -- set ep register
#
        mov     #_ _ssbss, r13              -- clear sbss section
        mov     #_ _esbss, r12
        cmp     r12, r13
        jnl     .L11
.L12:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
        jl      .L12
.L11:
#
        mov     #_ _sbss, r13               -- clear bss section
        mov     #_ _ebss, r12
        cmp     r12, r13
        nl      .L14
.L15:
        st.w    r0, [r13]
        add     4, r13
        cmp     r12, r13
```

```
        jl      .L15
.L14:
#
        jarl    _main, lp                   -- call main function
_ _exit:
        halt                                -- end of program
_ _startend:
        nop
#                                                                              #
#------------------------- end of start up module ----------------------------#
#                                                                              #
```

4.5.5 Main processing function

```
#include    "Common.h"
#include    "Motor.h"
#pragma     ioreg                       /* Peripheral I/O register definition */

static int save_psw;
/****************************************************************************** /
/*     3-phase motor control program                                           */
/****************************************************************************** /
void   main()
{
unsigned char    proc_no ;                  /* Present processing number */
signed int       speed ;                    /* Indication speed rms */
signed int       accel_spd ;
int              sw, sw_mode ;
/* */
   hinit() ;                                /* Hardware initialization */
   ainit() ;                                /* Initialization of area used */
   proc_no = 0 ;
   _ _EI();
   while( 1 ) {
          accel_spd = ( SPEED_MAX - SPEED_MINI ) / 100;
          speed  = ( ( SPEED_MAX - SPEED_MINI ) * volume  / 1024 )
                   + SPEED_MINI ;           /* Indication speed calculation by */
                                            /* volume */
      sw =  ~IN_data( SW ) & 0x07 ;         /* Read operation button */
      if  ( sw == 1 ) {
          sw_mode = CW ;
      } else if  ( sw == 2 ) {
          sw_mode = CCW ;
      } else if  ( sw == 4 ) {
          sw_mode = STOP ;
      }
      switch( proc_no ) {
/* STOP processing */
```

```
          case 0 :
             if  ( sw_mode == CW ) {
                _ _DI() ;
                object_speed  = SPEED_MINI ;  /* Set target speed to minimum value */
                stop_flag = OFF ;
                timer_count = WATCH_START ;   /* Set speed monitor start time to 5 SEC */
                accel_count = ACCEL_VAL_1ST ; /* Set acceleration/deceleration counter */
                init_flag = 2 ;               /* CCW initial request */
                start_init() ;                /* Initialize revolution start */
                _ _EI() ;
                proc_no = 1 ;                 /* Set next processing number */
             } else if  ( sw_mode == CCW ) {
                _ _DI() ;
                stop_flag = OFF ;             /* Stop flag off */
                object_speed = -SPEED_MINI ;  /* Set target speed to minimum value */
                timer_count = WATCH_START ;   /* Set speed monitor start time to 5 SEC */
                accel_count = ACCEL_VAL_1ST ; /* Set acceleration/deceleration counter */
                init_flag = 3 ;               /* CCW initial request */
                start_init() ;                /* Initialize revolution start */
                _ _EI() ;
                proc_no = 4 ;                 /* Set CCW processing number */
             }
             break ;
/* CW processing, acceleration */
          case 1 :
             if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;     /* Set acceleration/deceleration counter */
                if  ( object_speed  < speed ) {
                   object_speed += accel_spd ;
                   if  ( object_speed > speed ) object_speed = speed;
                   timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else if ( object_speed  > speed ) {
                   object_speed -= accel_spd ;
                   if  ( object_speed < speed ) object_speed = speed;
                   timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
                } else {
                   proc_no = 2 ;              /* Constant-speed processing */
                }
             }
             if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
                proc_no = 3 ;                 /* Deceleration, set processing number */
             }
             break ;
/* CW processing, constant-speed */
          case 2 :
             object_speed = speed ;
             if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
                proc_no = 3 ;                 /* Deceleration, set processing number */
```

```
            }
            break ;
/* CW stop processing */
         case 3 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;     /* Set acceleration/deceleration counter */
               if  ( object_speed  > SPEED_MINI ) {
                  object_speed -= accel_spd ;
                  if  ( object_speed < SPEED_MINI ) object_speed = SPEED_MINI;
                  timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
               } else {
                  stop_flag = ON ;           /* Stop flag on */
                  proc_no = 0 ;              /* Set stop processing number */
               }
            }
            break ;
/* CCW processing, acceleration */
         case 4 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;     /* Set acceleration/deceleration counter */
               if  ( object_speed  < -speed ) {
                  object_speed += accel_spd ;
                  if  ( object_speed > -speed ) object_speed = -speed;
                  timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
               } else if ( object_speed  > -speed ) {
                  object_speed -= accel_spd ;
                  if  ( object_speed < -speed ) object_speed = -speed;
                  timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
               } else {
                  proc_no = 5 ;              /* Constant-speed processing */
               }
            }
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
               proc_no = 6 ;                 /* Deceleration, set processing number */
            }
            break ;
/* CCW processing, constant-speed */
         case 5 :
            object_speed = -speed ;
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
               proc_no = 6 ;                 /* Deceleration, set processing number */
            }
            break ;
/* CCW stop processing */
         case 6 :
            if  ( accel_count == 0 ) {
               accel_count = ACCEL_VAL ;     /* Set acceleration/deceleration counter */
               if  ( object_speed  < -SPEED_MINI ) {
```

```
                object_speed += accel_spd ;
                if  ( object_speed > -SPEED_MINI ) object_speed = -SPEED_MINI;
                timer_count = WATCH_START ;/* Set speed monitor start time to 5 SEC */
            } else {
                stop_flag = ON ;          /* Stop flag on */
                proc_no = 0 ;             /* Set stop processing number */
            }
        }
        break ;
}

if  ( ( proc_no == 2 ) || ( proc_no == 5 ) ) {
    if  (  timer_count == 0 ) {
        if  ( abs( object_speed - now_speed ) > SA_SPEED_MAX ) {
            error_flag = ERR_NO2 ;        /* Set error No. */
        }
    }
}

    if  ( disp_co == 0 ) {
        led_num(1, d_speed / 100 );       /* Number of revolutions */
        d_speed = 0 ;
        disp_co = 100 ;
        if  ( abs(now_speed) == 0 ) {
            disp_co = 0;
        }
        led_num(2, 1000/PWM_TS );         /* Carrier frequency */
        led_num(3, cont_time );           /* Overall processing time */
        led_num(4, cont_time1 );          /* Vector operation processing time */
    }
    if  ( error_flag ) {
        while( 1 ) {
            OUT_data( LED41, ~0x00 ) ;    /* LED display off */
            OUT_data( LED42, ~0x00 ) ;
            timer_count = 50 ;
            while( timer_count ) ;
            if  ( error_flag == ERR_NO1 ) {
                OUT_data( LED41, ~0x9e ) ;    /* E1 display */
                OUT_data( LED42, ~0x60 ) ;
            } else if ( error_flag == ERR_NO2 ) {
                OUT_data( LED41, ~0x9e ) ;    /* E2 display */
                OUT_data( LED42, ~0xda ) ;
            } else {
                OUT_data( LED41, ~0x9e ) ;    /* E3 display */
                OUT_data( LED42, ~0xf2 ) ;
            }
            timer_count = 50 ;
            while( timer_count ) ;
```

```
          }
       }
   }
}
```

4.5.6 LED display function

```
/************************************************************************** /
/*     LED value display subroutine                                        */
/*              no   : Display area number (1 to 4)                        */
/*              data : Display data (0 to 99)                              */
/************************************************************************** /
void led_num( int no, long data )
{
   if  ( no == 1 ) {
       data = data % 10000;
       OUT_data( LED11, ~led_pat[data/1000]&0xff ) ;
       OUT_data( LED12, ~led_pat[(data%1000)/100]&0xff ) ;
       OUT_data( LED13, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED14, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 2 ) {
       OUT_data( LED21, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED22, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 3 ) {
       OUT_data( LED31, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED32, ~led_pat[data%10]&0xff ) ;
   } else {
       OUT_data( LED41, ~led_pat[(data%100)/10]&0xff ) ;
       OUT_data( LED42, ~led_pat[data%10]&0xff ) ;
   }
}
/************************************************************************** /
/*     External I/O output subroutine                                      */
/*             reg  : Output register number                              */
/*             data : Output data                                         */
/************************************************************************** /
void   OUT_data( unsigned short reg, unsigned short data )
{
       if  ( reg == WRESET ) {
              P4.3 = 0;
              data = 1;                    /* Dummy step */
              P4.3 = 1;
       } else {
              PDL = data | ( reg << 8 );
              PDL = reg | ( reg << 8 ) | 0x8000;
       }
}
/************************************************************************** /
```

```
/*     External I/O input subroutine                                          */
/*              reg  : Input register number                                  */
/************************************************************************** /
unsigned short  IN_data( int reg )
{
unsigned char *po;
/*  */
       if    ( reg == SW ) {
              return P4;
       } else {
              return 0;
       }
}
```

4.5.7 Motor control interrupt processing function

```
#include   "Common.h"
#include   "Motor.h"
#pragma    ioreg                          /* Peripheral I/O register definition */
/************************************************************************** /
/*     Motor control timer interrupt processing                               */
/************************************************************************** /
_ _interrupt
void   int_MOTOR(void)
{
    // A/D is started automatically.
}
/************************************************************************** /
/*     Motor control processing                                               */
/************************************************************************** /
void   Motor_CONT(void)
{
signed int    wrm, wre, trm, tre ;
signed int    o_wre, we, o_iqap, o_iqa ;
signed int    ida, iqa, o_vda1, o_vqa1 ;
signed int    o_vd0, o_vq0, o_vda, o_vqa ;
signed int    o_vua, o_vva, o_vwa, wiua, wiva ;
signed int    s_time, wk ;
/* */
/************************************************************************** /
/*     Calculation processing of speed and rotor position                     */
/************************************************************************** /
   fcalcu( &wrm, &trm ) ;
   sum_speed += ( wrm * TH_U / RPM_RADS ) ; /* Radian -> rpm */
   if  ( --speed_co == 0 ) {
      speed_co = 100000 / TS ;             /* Set 100 mSEC counter value */
      now_speed = sum_speed / speed_co ;
      sum_speed = 0 ;
```

```
   }
   wre = wrm * P ;
   tre = ( trm * P + OFFSET ) % RAD ;
/************************************************************************** */
/*     Speed control processing                                             */
/************************************************************************** */
   if  ( ( stop_flag == OFF ) && ( error_flag == 0 ) ) {
      s_time = TMD0 ;
      o_wre = object_speed * RPM_RADS * P / TH_U ;      /* rpm -> radian conversion */
      we = o_wre - wre ;
      o_iqap = ( ( wre * KSP ) + ( we * KSP ) ) >> KSPGETA ;
      o_iqa = o_iqap + ( o_iqai >> KSIGETA ) ;

      if  ( o_iqai > IQAMAX ) {
         o_iqai = IQAMAX ;
      } else if ( o_iqai < -IQAMAX ) {
         o_iqai = -IQAMAX ;
      } else {
         o_iqai += ( KSI * we ) ;
      }
/************************************************************************** */
/*     Current control processing                                           */
/************************************************************************** */
      ida = ( ( ( iva * sin( tre ) ) - ( iua * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      iqa = ( ( ( iva * sin( tre + RAD/4 ) ) - ( iua * sin( tre + 11*RAD/12 ) ) ) ) >> SGETA ;

      o_vda = ( KI * -ida ) >> KIGETA ;
      o_vqa = ( KI * ( o_iqa  - iqa )  ) >> KIGETA ;
/************************************************************************** */
/*     3-phase voltage conversion processing                                */
/************************************************************************** */
      if ( init_flag == 2 ) {                          /* CW initial processing */
         o_trm += ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm > ( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else if ( init_flag == 3 ) {                  /* CCW initial processing */
         o_trm -= ( SPEED_MINI * TS / 20000 ) ;
         tre = ( o_trm * P ) % RAD ;
         o_vda = 0 ;
         o_vqa = 100 ;
         if  ( o_trm < -( 2 * RAD ) ) {
            init_flag = 0;
         }
      } else {
```

```
         o_trm = 0 ;
      }
      o_vua  = ( ( ( o_vda * sin( tre + RAD/4 ) ) - ( o_vqa * sin( tre ) ) ) ) >> SGETA ;
      o_vva  = ( ( ( o_vda * sin( tre + 11*RAD/12 ) ) - ( o_vqa * sin( tre + 2*RAD/3 ) ) ) ) >> SGETA ;
      o_vwa  = -o_vua - o_vva ;

      cont_time1 = ( TMD0 - s_time ) * 10 / 32; /* Convert to uSEC */
/************************************************************************** /
/*     PWM conversion output processing                                    */
/************************************************************************** /
      OUT_data( WRESET, 0 ) ;                  /* Reset watchdog timer */
      HZA0CTL1 |= 0x04;                        /* PWM output on */
/* PWM counter value calculation output */
      o_vua += ( PWM_DATA  / 2 ) ;
      o_vva += ( PWM_DATA  / 2 ) ;
      o_vwa += ( PWM_DATA  / 2 ) ;

      if  ( o_vua <= 0 ) {
         o_vua = 1 ;
      } else if  ( o_vua >= PWM_DATA  ) {
         o_vua = PWM_DATA  - 1 ;
      }
      if  ( o_vva <= 0 ) {
         o_vva = 1 ;
      } else if  ( o_vva >= PWM_DATA  ) {
         o_vva = PWM_DATA  - 1 ;
      }
      if  ( o_vwa <= 0 ) {
         o_vwa = 1 ;
      } else if  ( o_vwa >= PWM_DATA  ) {
         o_vwa = PWM_DATA  - 1 ;
      }

      TQ0CCR1 = o_vua ;
      TQ0CCR2 = o_vva ;
      TQ0CCR3 = o_vwa ;
   } else {
      HZA0CTL1 |= 0x08;               /* PWM output off */
      now_speed = 0;
      cont_time1 = 0;
   }
}
/************************************************************************** /
/*     Calculation processing of speed, etc.                               */
/************************************************************************** /
void    fcalcu( signed int *wrm, signed int *trm )
{
signed short   es_trm, cur_time, delta, i ;
```

```
signed int     wwrm, wk, *p1, *p2;
//
//      Speed and position calculation from zero-cross point
//
   cur_time = TMENC10 ;
   delta = ( (RAD/6/P) * cur_time ) / sa_time ;  /* Calculation of rotor position */
                                                 /* difference from reference */
                                                 /* position (radian) */
   if  ( object_speed >= 0 ) {
      es_trm = base_position + delta;
   } else {
      es_trm = base_position - delta;
      if  ( es_trm < 0 ) es_trm += (RAD/P);
   }

   total_sa -= before_posi[20][1] ;

   p1 = (int *)before_posi[19] ;
   p2 = (int *)before_posi[20] ;
   for ( i = 0; i <= 19 ; i++ ) {
      *p2-- = *p1-- ;
   }
   before_posi[0][0] = *trm = es_trm % (RAD/P) ;

   wk = before_posi[0][0] - before_posi[1][0] ;
   if  ( abs(wk) > (RAD/2/P) ) {
      if  ( wk < 0 ) {
         wk = (RAD/P) + wk ;
      } else {
         wk = wk - (RAD/P) ;
      }
   }

   before_posi[1][1] = wk ;
   total_sa += wk ;                          /* Total difference in average buffer */

   wwrm = ( total_sa * ( 1000000 / 20 / TH_U ) / TS );
   *wrm = wwrm ;                             /* Speed  radian/second */
}
```

4.5.8 Zero-cross interrupt processing function

```
/************************************************************************** /
/*     U zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void    int_U(void)
{
```

```
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time = TMENC10 ;
        TMENC10 = 0 ;                       /* Restart timer */

        if  ( ~P3 & 0x04 ) {                /* Check W phase */
            base_position = 0 ;
        } else {
            base_position = RAD/2/P ;
        }
    }
}
/************************************************************************** /
/*     V zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void   int_V(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time = TMENC10 ;
        TMENC10 = 0 ;                       /* Restart timer */

        if  ( ~P3 & 0x01 ) {
            base_position = RAD/3/P ;
        } else {
            base_position = RAD*5/6/P ;
        }
    }
}
/************************************************************************** /
/*     W zero-cross point interrupt                                        */
/************************************************************************** /
_ _interrupt
void    int_W(void)
{
    if  ( ( init_flag == 0 ) && ( stop_flag == OFF) ) {
        sa_time = TMENC10 ;
        TMENC10 = 0 ;                       /* Restart timer */

        if  ( ~P3 & 0x02 ) {
            base_position = RAD*2/3/P ;
        } else {
            base_position = RAD/6/P ;
        }
    }
}
```

4.5.9 10 mSEC interval interrupt processing function

```
/************************************************************************** /
/*     Other timer interrupt processing (10 mSEC interval)                 */
/************************************************************************** /
_ _multi_interrupt
void    int_ETC(void)
{
/* Wait timer processing */
   if  ( timer_count != 0 ) {
       timer_count -= 1 ;
   }
/* Acceleration/deceleration timer processing */
   if  ( accel_count != 0 ) {
       accel_count -= 1 ;
   }
/* */
   if  ( disp_co != 0 ) {
       d_speed += abs( now_speed ) ;
       disp_co -= 1 ;
   }
}
```

4.5.10 A/D converter interrupt processing function

```
/************************************************************************** /
/*     A/D converter interrupt processing                                  */
/************************************************************************** /
_ _multi_interrupt
void   int_AD0(void)
{
   iua = (( ADCR0 & 0x3ff ) - 0x200) ;
   if  ( abs(iua) > MAX_I ) {
       HZA0CTL1 |= 0x08;                    /* PWM output off */
       error_flag = ERR_NO1 ;               /* Set error No. */
   }
   iva = (( ADCR1 & 0x3ff ) - 0x200) ;
   if  ( abs(iva) > MAX_I ) {
       HZA0CTL1 |= 0x08;                    /* PWM output off */
       error_flag = ERR_NO1 ;               /* Set error No. */
   }
   volume = 1023 - ( ADCR3 & 0x3ff ) ;      /* Set volume value */
   Motor_CONT() ;
   cont_time = TMD0 * 10 / 32;              /* Convert to uSEC */
}
```

4.5.11 Hardware initialization processing function

```
/************************************************************************** /
/*     Hardware (peripheral I/O) initialization                            */
/************************************************************************** /
void    hinit( void )
{
/* Port mode register initialization */
    PM4 = 0xf7 ;
    PMDL = 0x0000 ;

    OUT_data( LED11, 0xff ) ;     /* LED OFF */
    OUT_data( LED12, 0xff ) ;
    OUT_data( LED13, 0xff ) ;
    OUT_data( LED14, 0xff ) ;
    OUT_data( LED21, 0xff ) ;
    OUT_data( LED22, 0xff ) ;
    OUT_data( LED31, 0xff ) ;
    OUT_data( LED32, 0xff ) ;
    OUT_data( LED41, 0xff ) ;
    OUT_data( LED42, 0xff ) ;
/* Set 10 mSEC timer TMD0 */
    TMCD0 = 0x00;                 /* Stop (reset) timer D0 */
    TMCD0 = 0x01;                 /* Supply clock to timer D0 */
    TMCD0 |= 0x70;                /* Select fXX/512 (3.2 uSEC) */
    CMD0  = 10000 / 32;           /* 10 mSEC */
    TMCD0 |= 0x02;                /* Start timer */
    CMICD0 = 0x06;
/* Set motor control interrupt timer TMD1 */
    TMCD1 = 0x00;                 /* Stop (reset) timer D1 */
    TMCD1 = 0x01;                 /* Supply clock to timer D1 */
    TMCD1 |= 0x70;                /* Select fXX/512 (3.2 uSEC) */
    CMD1 = TS * 10 / 32 ;         /* 0.5 mSEC */
    TMCD1 |= 0x02;                /* Start timer */
    CMICD1 = 0x02;
/* Set speed measuring timer TMENC10 */
    TUM10 = 0x00;
    TMC10 = 0x03;
    PRM10 = 0x07;                 /* fXX (8 MHz*10/2)/256 (6.4 uSEC) */
    TMC10 = 0x43;                 /* Start timer */
/* TMP2 initialization */
    TP2CTL0 = 0x01;
    TQ0CTL0 = 0x01;
    TP2CTL1 = 0x85;               /* Select tuning operation slave mode */
    TP2IOC0 = 0x00;               /* Not used */
    TP2IOC1 = 0x00;               /* Not used */
    TP2IOC2 = 0x00;               /* Not used */
    TP2OPT0 = 0x00;               /* Select comparison register */
```

```
    TP2CCR0 = 100;                /* Set A/D timing */
/* TMQ0 initialization */
    TQ0CTL1 = 0x07;               /* Select 6-phase PWM output mode */
    TQ0IOC0 = 0x55;               /* Positive phase normal output, output enabled */
    TQ0IOC1 = 0x00;               /* INTPQ0 to INTPQ3, EVTQ, and TIQ pins of */
    TQ0IOC2 = 0x00;               /* TMQ0 are not used */
    TQ0OPT0 = 0x00;               /* Select comparison mode */
    TQ0CCR0 = PWM_DATA ;          /* Carrier wave cycle 20 kHz */
    TQ0CCR1 = PWM_DATA /2;        /* Set U-phase duty to 50 */
    TQ0CCR2 = PWM_DATA /2;        /* Set V-phase duty to 50 */
    TQ0CCR3 = PWM_DATA /2;        /* Set W-phase duty to 50 */
    TQ0DTC  = 120;                /* Dead time 6 uSEC */
    TQ0OPT1 = 0x00;               /* No culling, no crest and valley interrupts */
                                  /* are used */

    TQ0OPT2 = 0x04;               /* • No culling between reloads */
                                  /* • Clear and re-count dead time counter */
                                  /* • Output A/D trigger output of INTCCP20 */
                                  /*   interrupt during counting up */
                                  /* • A/D trigger output of INTCCP20 interrupt */
                                  /*   enabled */
    TQ0IOC3 = 0xfc;               /* Negative phase inverted output, output enabled */
    PMC1 = 0x3F;                  /* Alternate-function mode */
    PFCE1 = 0x00;                 /* Select TOQT1 to TOQT3 or TOQB1 to TOQB3 output */
    PFC1 = 0x3F;
    HZA0CTL1 = 0x00;
    HZA0CTL1 = 0xD0;              /* High-impedance operation enabled */
                                  /* INTP000 pin rising edge valid */
    TP2CTL0 |= 0x80;
    TQ0CTL0 |= 0x80;              /* Start 6-phase PWM output mode */
/* Set A/D */
    ADM2 = 0x00;                  /* Stop (reset) A/D clock */
    ADM2 = 0x01;                  /* Supply A/D clock */
    ADM0 = 0x03;
    ADM1 = 0x24;                  /* Select timer trigger mode */
    ADTS = 0x01;                  /* Use timer trigger selected with TQ0OPT2 of */
                                  /* motor control function */
    ADM0 |= 0x80;                 /* A/D operation enabled */
    ADIC = 0x03 ;
/* Set zero-cross signal interrupt pin */
    INTR3 = 0x07;                 /* INTP130/INTP131/INTP132 both-edge interrupt */
    INTF3 = 0x07;
    P13IC0 = 0x01;
    P13IC1 = 0x01;
    P13IC2 = 0x01;
}
```

4.5.12 Common area initialization processing function

```
/************************************************************************** /
/*     Common area initialization                                          */
/************************************************************************** /
void    ainit( void )
{
/* Initialization of flags */
   error_flag = 0 ;                    /* Clear error flag */
   init_flag = OFF ;                   /* Initial flag off */
   disp_co = 100 ;
   d_speed = 0 ;
/* Motor control area initialization */
   stop_flag   = ON ;                  /* Stop flag on */
   object_speed = 0 ;                  /* Target speed 0 */
   o_iqai = 0 ;                        /* Speed integral value 0 */
   o_trm = 0 ;
}
```

4.5.13 Revolution start initialization processing function

```
/************************************************************************** /
/*     Revolution start initialization                                     */
/************************************************************************** /
void    start_init( void )
{
   int  i;
/*  */
   for ( i = 0 ; i < 21 ; i++ ) before_posi[i][1] = 0;
   total_sa = 0 ;
   sum_speed = 0 ;
   speed_co = 100000 / TS ;
}
```

4.5.14 sin calculation processing function

```
/************************************************************************** /
/*     sin x                                                               */
/*          Data                                                           */
/*            Radian unit                                                  */
/*          Return value                                                   */
/*            Sign value*16384                                             */
/************************************************************************** /
int sin( int x )
{
   x = x % RAD ;
   if  ( x < 0 ) x += RAD ;
   if  ( x < (RAD/4) ){
```

```
      return sins( x ) ;
   } else if ( x < (RAD/2) ) {
      return sins( (RAD/2) - x ) ;
   } else if ( x < (RAD*3/4) ) {
      return -sins( x - (RAD/2) ) ;
   } else {
      return -sins( RAD - x ) ;
   }
}
/*****************************************************************************/
int sins( int x )
{
short z1, z2, z3, z4, z5 ;
/*  */
   if  ( x <= (RAD/8) ) {
      z1 = (x << SGETA) / (RAD/8) ;
      z2 = z1 * z1 >> SGETA ;
      z3 = z1 * z2 >> SGETA ;
      z5 = z2 * z3 >> SGETA ;
      return ( (12868*z1) - (1322*z3) + (40*z5) ) >> SGETA ;
   } else {
      x = (RAD/4) - x ;
      z1 = (x << SGETA) / (RAD/8) ;
      z2 = z1 * z1 >> SGETA ;
      z4 = z2 * z2 >> SGETA ;
      return ( (268432772) - (5050*z2) + (252*z4) ) >> SGETA ;
   }
}
```

4.5.15 Link directive file for V850E/MA3

```
/************************************************************************** /
/*     Link directive file for V850E/MA3                                    */
/************************************************************************** /
VECT_RESET: !LOAD ?RX V0x0000000 {
        .vect_RESET  = $PROGBITS ?AX .vect_RESET;
};
ID_NO: !LOAD ?RX V0x0000070 {
        .id_NO  = $PROGBITS ?AX .id_NO;
};
VECT_U: !LOAD ?RX V0x00001a0 {
        .vect_U  = $PROGBITS ?AX .vect_U;
};
VECT_V: !LOAD ?RX V0x00001b0 {
        .vect_V  = $PROGBITS ?AX .vect_V;
};
VECT_W: !LOAD ?RX V0x00001c0 {
        .vect_W  = $PROGBITS ?AX .vect_W;
```

```
};
VECT_ETC: !LOAD ?RX V0x0000220 {
        .vect_ETC  = $PROGBITS ?AX .vect_ETC;
};
VECT_MOTOR: !LOAD ?RX V0x0000240 {
        .vect_MOTOR  = $PROGBITS ?AX .vect_MOTOR;
};
VECT_AD0: !LOAD ?RX V0x00003c0 {
        .vect_AD0  = $PROGBITS ?AX .vect_AD0;
};

HANDLER: !LOAD ?RX V0x00001000 {
        .handler  = $PROGBITS ?AX .handler;
};
TEXT:  !LOAD ?RX {
        .text  = $PROGBITS ?AX .text;
};

CONST : !LOAD ?R {
        .const = $PROGBITS ?A .const;
};

DATA : !LOAD ?RW V0x0fff0000 {
        .data  = $PROGBITS ?AW  ;
        .sdata = $PROGBITS ?AWG ;
        .sbss  = $NOBITS   ?AWG ;
        .bss   = $NOBITS   ?AW  ;
};

_ _tp_TEXT @ %TP_SYMBOL;
_ _gp_DATA @ %GP_SYMBOL &_ _tp_TEXT{DATA};
_ _ep_DATA @ %EP_SYMBOL;
```