TB9M003FG
Sensorless Square Wave Drive Control Example

Description

Purpose and Scope of this Document

This document describes a sensorless square wave drive (120-Degree Conduction) control method for brushless motors using the TB9M003FG.
We hope that this document will serve as a useful reference when developing control systems for brushless motors used in automotive applications such as electric water pumps, electric oil pumps, electric fans, and electric blowers.
This document assumes that the reader is utilizing the reference software (SW) (Note) provided by our company.

Intended Audience of This Document

This document is intended for users who develop the above motor control system by combining the TB9M003FG with the reference software provided by our company.

(Note): Please contact our sales representative for further information.

Toshiba Electronic Devices & Storage Corporation

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1. Purpose and Intention of This Document

The TB9M003FG, a member of the “SmartMCD™” series of ICs that integrate a microcontroller and a motor driver, is well suited for sensorless control of three-phase brushless motors.
This document describes sensorless Square Wave Drive (SWD) control using the reference software (SW) provided by our company.
We hope that this document will serve as a useful reference for developing better motor control systems.

2. Overview

2.1. Overview of SWD

The characteristics of driving methods for brushless motors are shown in Table 2.1. Typical driving methods include SWD and FOC (Field-Oriented Control).
This document focuses on SWD using the TB9M003FG. For control examples of FOC, refer to the application note “Example of 1-Shunt Sensorless Vector Control”

Table 2.1 Characteristics of Brushless Motor Driving Methods

Driving Method	Merits	Demerits	Remark
SWD	· Simple processing	· High acoustic noise	· Support position sensorless · Position detection is possible at lower speeds than FOC
FOC	· Low noise · High efficiency	· Complex processing	· Support position sensorless · High-precision control in high-speed regions · Limited position detection accuracy in low-speed regions

The overall concept of the motor control system is illustrated in Fig. 2.1. An example of the circuit operation during current conduction from the V phase to the U phase in SWD is shown in Fig. 2.2.
In SWD, the motor is driven by switching the inverter conduction period every 120 electrical degrees. Therefore, this method is also referred to as “ 120-degree conduction control ”.
As shown on the next page, when the conduction pattern is changed every 60 electrical degrees and the resultant magnetic field rotates, the rotor rotates in synchronization with this rotating magnetic field.

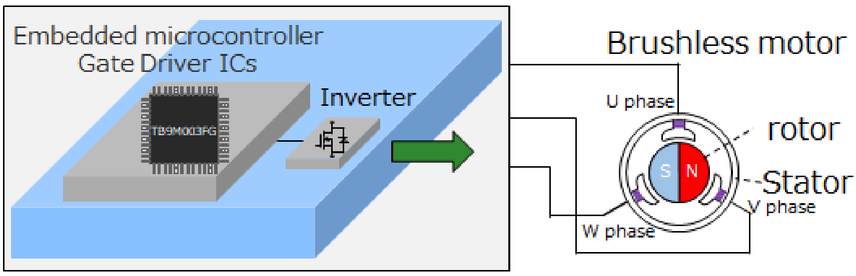


Figure 2.1 Image of the motor control system

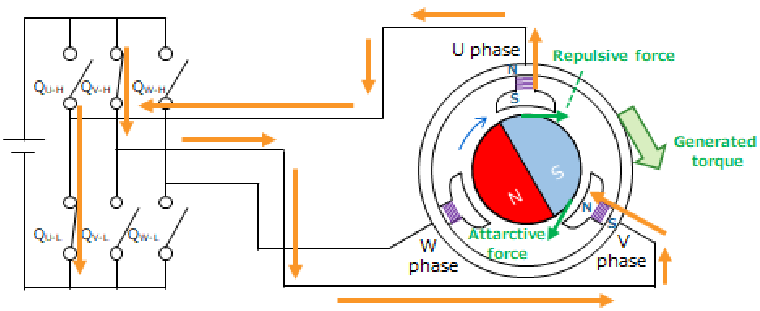
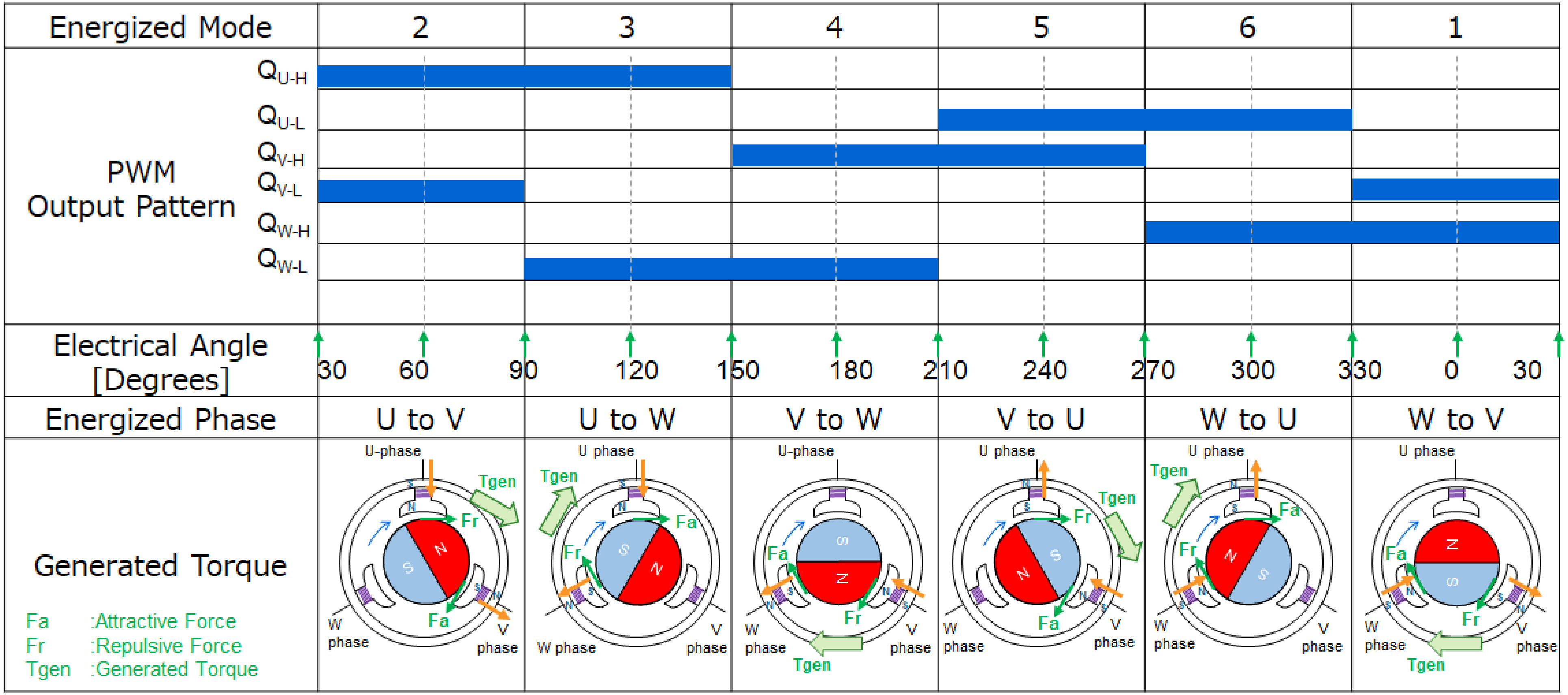


Figure 2.2 Example of circuit operation in SWD (During Conduction from V to U phase)

The relationship between the conduction modes and the resultant magnetic field is shown in Table 2.2.

Table 2.2 Relationship between the conduction modes and the resultant magnetic field



2.2. Parameter List

The parameters that need to be set in the reference software are listed in Table 2.3. By properly setting each parameter, SWD can be implemented. Note that some parameters may not need to be changed from their default values.

Table 2.3 Configuration Parameters

No.	Item	Parameter Name	Unit	Description	Remarks
1	Initial Settings	V_MAX	V	Set the maximum voltage	Depends on the board used (voltage detection circuit). In automotive applications, since voltages up to 40 V may typically be handled, the default value is set to 50 V.
2		SPD_MAX	Hz	Set the maximum motor speed (electrical angle)	Set a value higher than the maximum motor speed (electrical angle) of the actual motor used. As a guideline, it is recommended to set this value to approximately 1.1 to 1.2 times the maximum motor speed.
3	Positioning	RAMP_UP_TIME_INIPOS	s	Set the ramp-up time	Set the ramp-up time until the duty reaches V_INIPOS.
4		INIPOS_TIME1	s	Set positioning time 1	Set the duration of current conduction from the U phase to the V phase. To shorten the startup time, decrease this value.
5		INIPOS_TIME2	s	Set positioning time 2	Set the duration of current conduction from the U phase to the W phase. To shorten the startup time, decrease this value.
6		V_INIPOS	V	Set the voltage command during positioning	Set the voltage command during positioning. If the motor does not start, gradually increase the command value.
7	Forced Commutation	V_FORCE	V	Set the voltage command during forced commutation	Set the voltage command during forced commutation. If the motor does not start, gradually increase the command value.
8		SPD_FORCE_INI	Hz	Set the target frequency during forced commutation	If the setting value is too low, zero-cross detection may fail.
9		RAMP_UP_TIME_FORCE	s	Set the ramp-up time	Set the time required for the configured duty to reach V_FORCE from V_INIPOS. In general, this parameter does not need to be changed; however, it can be adjusted if necessary.
10	Steady State	SPD_KP_V	V/Hz	Set the proportional gain for speed control	Adjust this parameter while evaluating the responsiveness and tracking performance of the speed control.

No.	Item	Parameter Name	Unit	Description	Remarks
11		SPD_KI_V	V/Hzs	Set the integral gain for speed control	Adjust this parameter while evaluating the responsiveness and tracking performance of the speed control.
12		SPD_UP_STEADYL	Hz/s	Set the acceleration limit of the speed command (electrical angle)	If motor acceleration is too slow, increase the setting value. If the setting value is too high, the motor may fail to follow the command, especially for motors with high inertia.
13		SPD_DW_STEADYL	Hz/s	Set the deceleration limit of the speed command (electrical angle)	If motor acceleration is too slow, increase the setting value. If the setting value is too high, the motor may fail to follow the command, especially for motors with high inertia.
14	Others	DEAD_TIME	μs	Set the dead time	Depends on the board used (inverter).
15		SPD_TARGET	Hz	Set the target motor speed (electrical angle)	The speed command ramps up toward the setting value. This value must be set lower than SPD_MAX.
16		VDC_MAX	V	Set the maximum DC voltage	Adjust this parameter as necessary.
17		BEMF_STABLE_CNT	-	Set the number of consecutive stable zero-cross detections	In general, this parameter does not need to be changed; however, it can be adjusted as necessary.
18		BEMF_TRIAL_CNT	-	Set the maximum number of conduction attempts at startup	Stable zero-cross detection must be achieved within the setting number of attempts. If the system fails to transition to sensorless control, stable sensorless operation cannot be achieved at this frequency.
19		BEMF_TIMEOUT	s	Set the timeout duration for position detection	In general, this parameter does not need to be changed; however, it can be adjusted as necessary.
20		OMEGA_AVE_WINDOW	-	Set the coefficient for averaging calculation	In general, this parameter does not need to be changed; however, it can be adjusted as necessary.
21		PWM_PERIOD_BOOT	μs	Set the PWM period from startup to the forced commutation stage	In general, this parameter does not need to be changed; however, it can be adjusted as necessary.
22		PWM_PERIOD_SWD	μs	Set the PWM period during sensorless operation	In general, this parameter does not need to be changed; however, it can be adjusted as necessary.
23		SPD_CTRL_PERIOD	s	Set the speed control period	In general, this parameter does not need to be changed; however, it can be adjusted as necessary.

3. System Configuration and Operating Principle

3.1. Configuration of Motor Control System

The configuration of the motor control system is shown in Fig. 3.1.
This section describes an overview of the SWD control method. For detailed descriptions of the PMD (Programmable Motor Driver), ENC (Encoder), and other hardware modules, refer to the hardware user manual, "TB9M003FG_UM_J."
In SWD, the BEMF (Back Electromotive Force) of each phase is compared with the virtual neutral-point voltage, VN, to detect six BEMF zero crossings per electrical cycle. Based on these detections, BEMF zero-cross detection signals, BEMFX (where X represents U, V, or W), are generated.
Figure 3.2 on the following page shows an example of the corresponding waveforms.
In the ENC, the edge pulse count value, CNT, is calculated from the interval between the edges of the detected BEMF zero-cross detection signals.
The square-wave control block calculates the rotational speed, ω, from the edge pulse count value CNT.
The speed control block performs PI control so that the speed command, ωref, matches the rotational speed, ω, and calculates the duty cycle, Duty, to be applied to the PWM output during SWD operation.
In the PMD, the PWM output configuration of each phase is changed according to the rotor position by setting the PMD conduction control register [MDOUT].

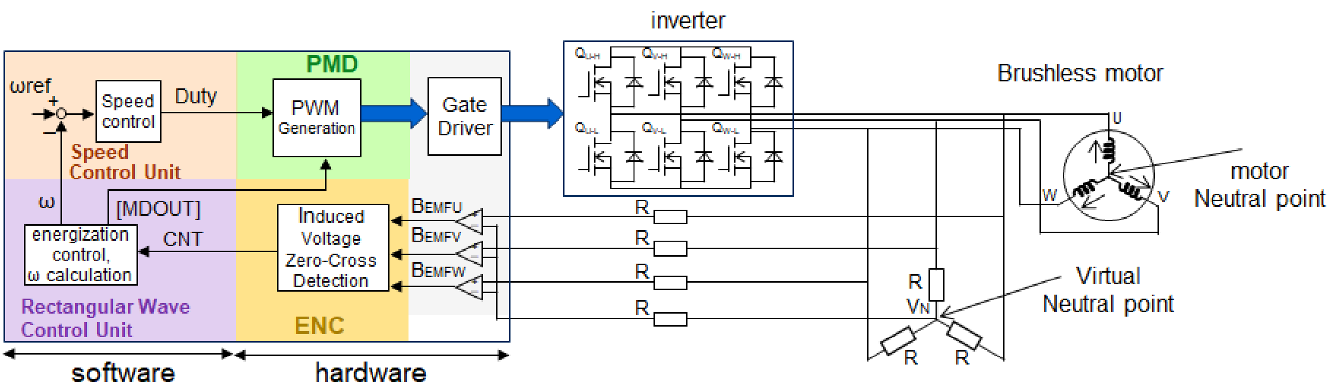


Figure 3.1 Configuration of the motor control system

3.2. Principle of Position Detection (Induced-Voltage Zero-Cross Detection)

Figure 3.2 illustrates the waveforms in SWD. In SWD, two of the three motor phases are energized, while the remaining phase is left open.
When the switching devices are operating and voltage is being applied to the motor, the BEMF of the energized phases cannot be observed. However, the open phase exhibits the BEMF, and the rotor position can be detected by detecting the zero crossing of this BEMF.
Figure 3.2 illustrates the waveforms in SWD. For example, by comparing the BEMF of the U-phase with the virtual neutral-point voltage, which serves as the threshold voltage, two zero crossings can be detected during one electrical cycle. These zero-cross detections provide the rotor position information required for motor control.
Although Fig. 3.2 shows only the case of detecting zero crossings of the U phase, the same principle applies to the V and W phases. As a result, a total of six zero crossings can be detected during one electrical cycle, corresponding to rotor position updates every 60 electrical degrees.

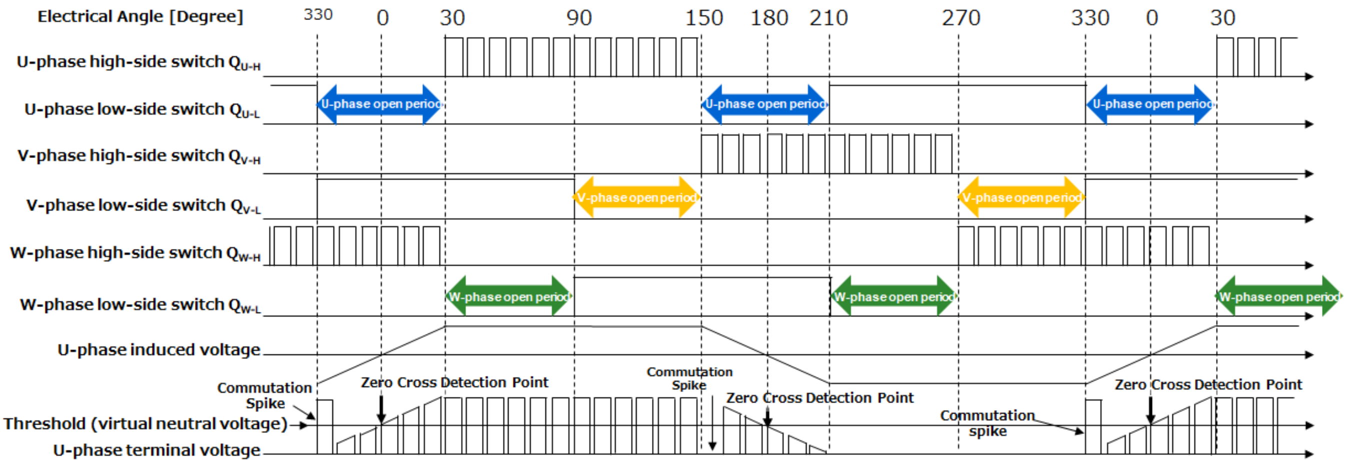


Figure 3.2 Image of each waveform in SWD

4. Overview of Motor Control Using SWD (Square Wave Drive)

4.1. SWD State Transition

Figure 4.1 shows the state transition diagram of the motor control system.
As described previously, SWD is realized by detecting six BEMF (back electromotive force) zero-cross signals generated during each electrical cycle. Since the BEMF is proportional to the motor speed, its amplitude is very small immediately after startup and during low-speed operation, making rotor position detection difficult.
To start the motor from a standstill condition, the reference software operates through the sequence of "Positioning → Forced Commutation," as shown in Fig. 4.1.
As the motor speed increases and the BEMF reaches a level sufficiently large for reliable detection, the control transitions to the steady-state operation mode. In this way, SWD is achieved. Figure 4.2 on the following page shows the corresponding operating waveforms.

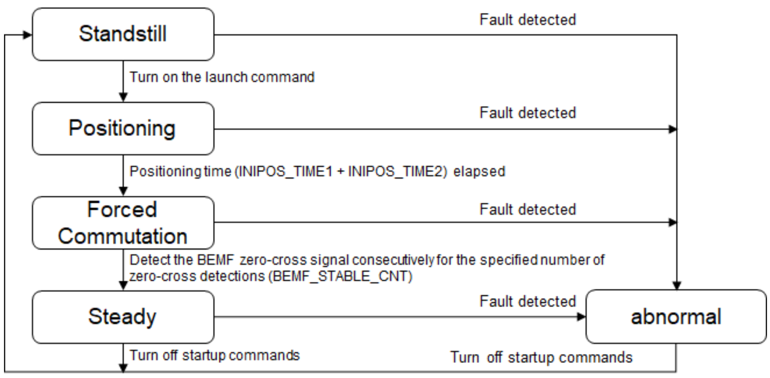
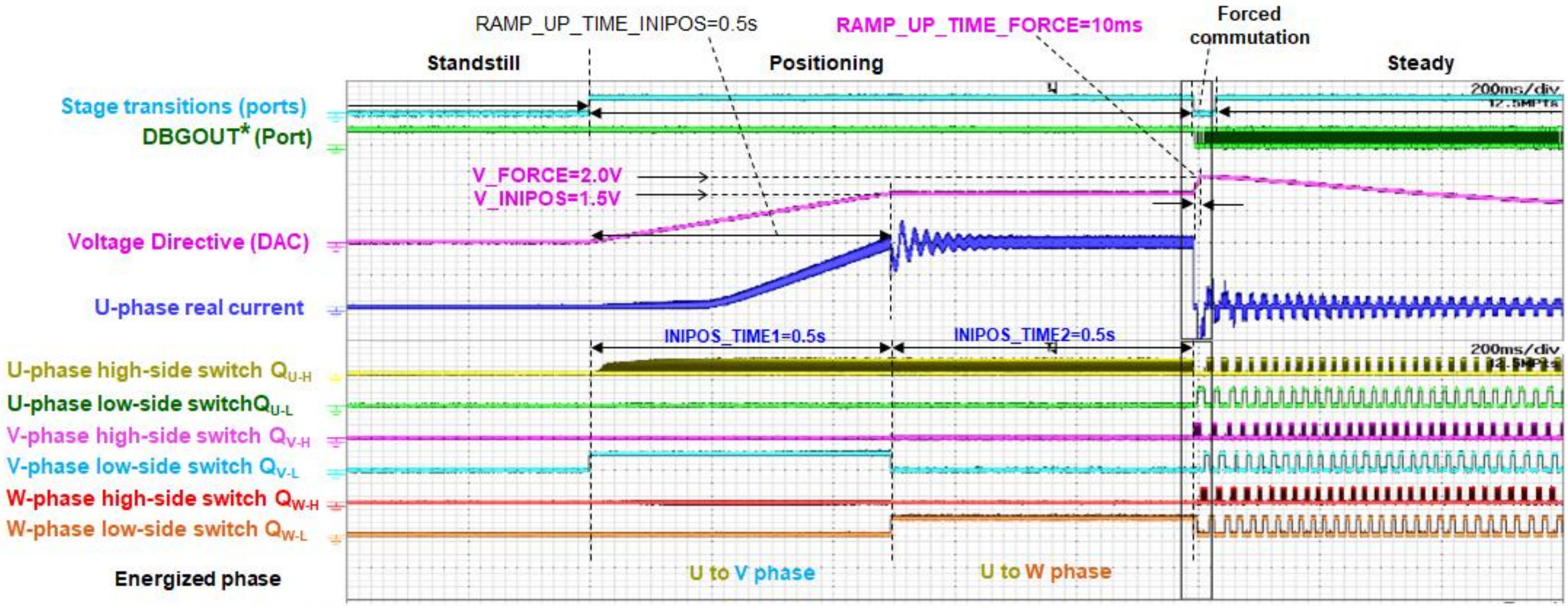


Figure 4.1 State transition diagram of motor control

4.2. Example Operating Waveforms

Figure 4.2 shows the waveforms during the transition from motor standstill to steady-state operation.
The parameters shown in the figure are example settings used during startup and transition to steady-state operation.
Adjust each parameter according to the motor characteristics and system requirements, referring to Table 2.3.



*For checking internal control signals

Figure 4.2 Example of SWD Operating Waveforms

5. Overview of PI (Proportional-Integral) Control

5.1. Principle of PI (Proportional-Integral) Control

PI (Proportional-Integral) control is a type of feedback control. In PI control, the control input is adjusted so that the deviation between the target value (reference command) and the controlled variable (output) becomes zero. Figure 5.1 shows the block diagram of PI control.
Although P control alone can bring the controlled variable close to the target value, it cannot completely eliminate the deviation. I control is used to eliminate this remaining deviation.
In general, increasing the control gain improves the response performance; however, it also tends to make the system more unstable. Conversely, reducing the control gain improves stability, but degrades the response performance.
The stable operating range of the PI control gains varies depending on the operating conditions and system characteristics.

PI Control Basics

Manipulated Variable	= Proportional Term + Integral Term
Proportional Term	= Proportional Gain × Deviation
Integral Term	= Integral Gain × Deviation × PWM Control Period + (previous Integral Term)

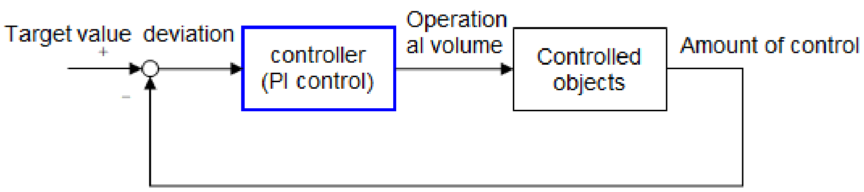


Figure 5.1 PI control block diagram

5.2. Overview of Speed Control

Implementation of SWD requires appropriate adjustment of the PI control gains. In the reference software provided by our company, speed control is implemented using the block diagram shown in Fig. 5.2.
This PI controller adjusts its output so that the commanded speed, **ωref**, set by the user matches the detected average speed, **ωave**.
Note that the output of the PI controller is the voltage reference, Vref. The duty cycle is calculated as **Duty = Vref / Vdc_ave**, where **Vdc_ave** is the detected average DC voltage. The calculated duty cycle is then used to set the PWM pulse width.
The speed control tuning procedure is essentially same as that of FOC speed control. Refer to the application note "FOC Motor Parameter Tuning Method" for guidance on parameter tuning.

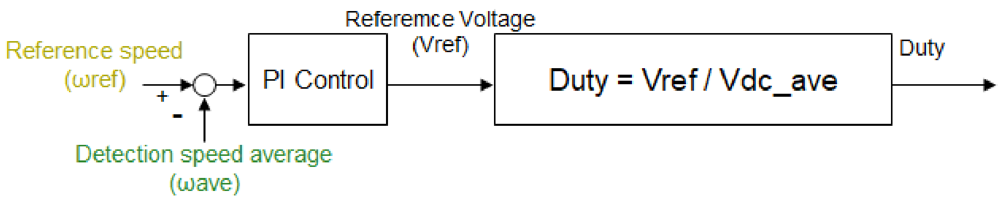


Figure 5.2 Block diagram of speed control

Notes on Contents

1. **Block Diagrams**
   Some of the functional blocks, circuits, or constants in the block diagram may be omitted or simplified for explanatory purposes.

2. **Equivalent Circuits**
   The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

IC Usage Considerations

Notes on Handling of ICs

(1) The absolute maximum ratings of a semiconductor device are a set of ratings that must not be exceeded, even for a moment.
Exceeding the Absolute Maximum Ratings may cause destruction, damage, or degradation of the device, and may result in injury due to rupture or combustion.

(2) Use an appropriate power supply fuse to ensure that a large current does not continuously flow in case of over current and/or IC failure.
The IC may be destroyed due to operation beyond the Absolute Maximum Ratings, incorrect wiring, or abnormal pulse noise induced from wiring or loads. As a result, a large current may continue to flow through the IC, potentially leading to smoke generation or fire. Therefore, it is necessary to properly design protective measures, including fuse rating, blowing time, and circuit insertion location, assuming the possibility of large current inflow or outflow caused by IC failure, in order to minimize the impact of such failures.

Points to Remember on Handling of ICs

(1) Over current Protection Circuit

Over current protection circuits (referred to as current limiter circuits) do not necessarily protect ICs under all circumstances. If the Over current protection circuits operate against the over current, clear the over current status immediately.

Depending on the operating conditions and application, the overcurrent protection circuit may not operate correctly, or the IC may be damaged before the overcurrent protection circuit becomes active, for example, when the Absolute Maximum Ratings are exceeded.

In addition, if an overcurrent continues to flow for an extended period after the protection circuit has operated, the IC may be damaged due to heat generation or other factors, depending on the operating conditions and application.

(2) Thermal Shutdown Circuit

Thermal shutdown circuits do not necessarily protect ICs under all circumstances. After the protection circuit has operated, promptly eliminate the condition causing excessive heat generation.

When the Absolute Maximum Ratings are exceeded, depending on the operating conditions and application, the thermal shutdown circuit may not operate properly, or the IC may be damaged before the thermal shutdown circuit is activated.

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