# TB9M003FG Method for Tuning Motor Control Parameters in FOC

### Description

#### Purpose and Scope of this Document

This document provides an example of how to tune the parameters necessary for sensorless vector control of a brushless DC motor using the TB9M003FG. It is intended to serve as a reference for constructing control systems for brushless DC motors used in automotive applications, such as electric water pumps, electric oil pumps, electric fans, and electric blowers.

Additionally, this document assumes the use of reference software provided by our company. (Note)

#### **Intended Audience of This Document**

This document is intended for engineers developing the above-mentioned motor control systems.

(Note) For further inquiries, please contact our sales department.

# **Toshiba Electronic Devices & Storage Corporation**

Do not design your products or systems based on the information on this document. Please contact your Toshiba sales representative for updated information before designing your products.

### **Table of Contents**

Description	.1
Table of Contents	.2
1. Purpose and Intention of This Document	.6
2. Summary	.6
2.1. Parameter Tuning Procedure	. 6
2.1.1. Stage 1: Rough Tuning	6
2.1.2. Stage 2: Fine Tuning	6
2.2. Parameter List	. 8
3. Setting of Various Control Parameters	14
3.1. State Transition Diagram of Motor Control	14
3.2. Stage Transitions and Control States	15
3.3. FOC Experimental Waveforms	16
4. Parameter Settings for Current Detection	17
4.1. Summary of Parameters Related to Current Detection	17
4.1.1. Configuration when ringing occurs across the shunt resistor terminals	17
4.1.2. Current detection timing for Shift-2 PWM	17
4.2. Example of Parameter Settings for Current Detection	18
4.2.1. In case the current misdetection confirmation flag is triggered	19
5. Measurement of Various Motor Parameters	20
5.1. Summary of Parameter Measurement	20
5.2. Resistance Measurement	20
5.3. Inductance Measurement	21
5.4. Back EMF Constant Measurement	22
5.5. Pole Number Measurement	23
6. Tuning of PI Control Gains	24
6.1. Summary of PI Control Gain	24
6.2. Tuning Procedure for Each PI Control Gain	25
6.2.1. (1) Current Control Gain (Recommended to tune in the positioning stage)	25
6.2.2. (2) Position Estimation Gain (Recommended to tune in the change-up stage)	25
6.2.3. (3) Speed Control Gain (Tune in the steady stage)	25
6.3. Summary of Current Control	26
6.3.1. Method for Tuning Current Control Gain	27
6.4. Summary of Position Estimation	28
6.4.1. Tuning of Position Estimation Gain	29
6.5. Summary of Speed Control	31
6.5.1. Tuning of Speed Control Gain	32
7. Tuning by MTS	33
7.1. Summary of MTS	33
7.1.1. Explanation of MTS	33

7.1.2. Preparations Before Using MTS	34
7.1.3. Explanation of the MTS Window Layou	35
7.2. How to Use MTS	36
7.2.1. List of Parameters Required for Automatic Measurement of Motor Parameters and Automatic Calculation of PI Control Gains	36
7.2.2. Parameter Setting Window	
7.2.3. (A): Measurement of Parameters Related to PWM Mode Settings	
7.2.4. (B): Measurement of R and L and Setting of Current Control Gains	40
7.2.5. (C): Measurement of Ke and J, and setting of position estimation gain and speed control gain	43
7.2.6. (D): Motor drive using FOC with the settings of (A)-(C)	46
Notes on Contents	47
IC Usage Considerations	47
Notes on Handling of ICs	47
Points to Remember on Handling of ICs	48
RESTRICTIONS ON PRODUCT USE	49



### List of Figures

	5	
Figure 2.1	Flowchart of the Parameter Tuning Procedure	6
Figure 2.2	Flowchart of the Rough Tuning	7
Figure 2.3	Flowchart of Fine Tuning	7
Figure 3.1	State Transition Diagram of Motor Control	14
Figure 3.2	Experimental Waveforms of FOC	16
Figure 4.1	Ringing occurring in the voltage across the shunt resistor	17
Figure 4.2	Example of Current Detection Timing in Shift 2PWM	18
Figure 4.3	Experimental Waveforms of Current Detection Timing in Shift-2 PWM	18
Figure 4.4	$\label{eq:current} Current \ Detection \ Timing \ in \ Shift-2 \ PWM \ (Example \ of \ False \ Detection \ Flag \ Triggering) \ .$	19
Figure 5.1	An example of measuring the resistance between the U and V phases	20
Figure 5.2 rotated	The image of the change in inductance between the U and V lines when the test moto	or is 21
Figure 5.3	An example of measuring the inductance between the U and V phases	21
Figure 5.4	Example of measuring the back EMF constant	22
Figure 5.5	Image of the induced voltage (phase voltage) when the test motor is rotated at a certain sp	eed 22
Figure 5.6 (@1,00	Induced voltage waveforms when a test motor with 4 poles is rotated by the drive m 0rpm)	otor 22
Figure 5.7	Image of pole number measurement (motor with 4 poles)	23
Figure 5.8	Example of manual pole number measurement	23
Figure 6.1	Block diagram of PI control	24
Figure 6.2	Block Diagram of the Positioning Stage	26
Figure 6.3	Block Diagram of Current Control	26
Figure 6.4	Example of current control gain tuning	27
Figure 6.5	Block Diagram for Position Estimation Gain Tuning	28
Figure 6.6	Block Diagram of Position Estimation	28
Figure 6.7	Image of Position Estimation	29
Figure 6.8	Example of position estimation gain tuning	30
Figure 6.9	Block Diagram of FOC	31
Figure 6.10	Block Diagram of Speed Control	31
Figure 6.11	Image of Changes in Current Reference Value Due to Load Fluctuations	31
Figure 6.12	Example of tuning speed control proportional gain	32
Figure 7.1	An Example of the Window Display of the MTS Screen	33
Figure 7.2	MTS Screen (Board Information Display)	34
Figure 7.3	Enlarged View of the "Motor Tuning Support" Window	35
Figure 7.4	Enlarged View of a Part of the "Motor Tuning Support" Window	38
Figure 7.5	Screen for Measuring Parameters Related to PWM Mode Settings	39
Figure 7.6	Screen for Measuring R and L	40
Figure 7.7	Screen for Calculating Initial Values of Current Control Gain	41
Figure 7.8	Screen for Tuning Current Control Gain	42
-	-	



### Method for Tuning Motor Control Parameters in FOC TB9M003FG Application Note

Figure 7.9	Screen During Measurement of Ke and J
Figure 7.10	Screen for Calculating Initial Values of Position Estimation and Speed Control Gains 44
Figure 7.11	Screen for Setting Position Estimation and Speed Control Gains45
Figure 7.12	Screen for Position Estimation and Speed Control Gain Settings 46

### **List of Tables**

Table 2.1	List of Configuration Parameters	8
Table 3.1	Stage Transitions and Control States	15
Table 7.1	List of MTS Setting Parameters	36



### 1. Purpose and Intention of This Document

The TB9M003FG series product of the microcontroller-integrated gate driver IC "SmartMCD<sup>™</sup>" is suitable for sensorless vector control (FOC: Field-Oriented Control) of brushless DC motors.

This document introduces the method for tuning motor control parameters using FOC with the reference software provided by our company.

To implement FOC, it is necessary to tune each parameter according to the motor being used. Since appropriate parameter tuning varies depending on the system,

this document provides an example.

We hope that this document will assist you in building a better system.

#### 2. Summary

#### 2.1. Parameter Tuning Procedure

This document explains the method of tuning parameters in FOC in two stages. The tuning method provided is merely an example; please modify it according to your application and system. Figure 2.1 shows the flowchart for parameter tuning in FOC.



Figure 2.1 Flowchart of the Parameter Tuning Procedure

#### 2.1.1. Stage 1: Rough Tuning

The first stage is to achieve a state where motor control with FOC (stable control in the steady stage in the reference software) is possible. Rough tuning can be performed with a load; however, if the motor stops midway, perform the tuning without a load.

Manual acquisition of motor parameters and rough tuning are acceptable, but they may require rebuilding after the measuring instruments and the software change, which can be time-consuming. To support motor control development, we provide a PC tool called SmartMCD<sup>™</sup> MTS (Motor Tuning Support). MTS includes functions for automatic measurement of motor parameters and control gain settings. Additionally, MTS allows dynamic changes to each parameter, which is expected to improve development efficiency.

#### 2.1.2. Stage 2: Fine Tuning

Next, in the second stage, fine tuning the parameters to meet the actual system requirements. Based on the parameters from the first stage, gradually tighten the driving conditions and tune to ensure that the responsiveness and tracking meet the requirements of the target application or system. Fine tuning must be performed manually.

Figure 2.2 shows the flowchart for the rough tuning.



Figure 2.2 Flowchart of the Rough Tuning

Figure 2.3 shows the flowchart for fine tuning



Figure 2.3 Flowchart of Fine Tuning



#### 2.2. Parameter List

Table 2.1 show the list of parameters that need to be set for each motor in the reference software.

By setting these parameters, FOC can be realized.

This chapter provides an overview of the parameter tuning. Note that some parameters may not need to be changed from their default values

		For MTS, please use the parameter name listed in this column.				
Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS)	Unit	Description	Remarks	The detailed description chapter
	SPD_TARGET	_	Hz	Set the target speed (electrical angle) of the motor.	The reference speed increases aiming for the set value. The set value should be smaller than SPD_MAX.	_
Initial Setting	V_MAX	V_MAX_DEF	v	Set the maximum voltage value.	It depends on the board (voltage detection circuit) being used. In automotive applications, it is generally possible to handle up to 40V, so the default is set to 50V.	_
	A_MAX	A_MAX_DEF	A	Set the maximum current value.	It is necessary to set this value considering the board (current detection circuit) being used and the maximum current flowing through the motor. The relationship for determining A_MAX is as follows: Shunt resistance value ( $\Omega$ ) * A_MAX (A) * Current detection amplifier gain = 2.5 (V) $\Leftrightarrow$ A_MAX (A) = 2.5 (V) / Shunt resistance value ( $\Omega$ ) / Current detection amplifier gain	_
	SPD_MAX SPD_MAX_DEF H		Hz	Set the maximum motor speed (electrical angle).	Set a value larger than the maximum rotational speed (electrical angle) of the motor that will actually be used. As a guideline, set it to approximately 1.1 to 1.2 times the maximum rotational speed.	_
	A_OVC	A_OVC_DEF	А	Set the current threshold for software overcurrent protection. It is determined by the absolute value of the amplitude of the detected current in each phase.	Set a value that does not cause demagnetization according to the motor being used. Ensure that this value is always smaller than A_MAX.	_
	I_LIM	I_LIM_DEF	А	Set the current limit value.	Change from the default value as necessary.	_

#### Table 2.1 List of Configuration Parameters



Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS)	Unit	Description	Remarks	The detailed description chapter	
	MTR_R	MTR_R_DEF	ohm	Set the resistance value of the motor.	Set the resistance value per phase according to the motor being used.	5.2	
	MTR_LQ MTR_LQ_DEF mH Set the q-axis inductance of the motor. Set the q-axis inductance of the motor.		Set the q-axis inductance value per phase according to the motor being used.	5.2			
	MTR_LD	MTR_LD_DEF	mH	Set the d-axis inductance of the motor.	Set the d-axis inductance value per phase according to the motor being used.	5.3	
Initial Settings	MTR_KE MTR_KE_DEF V/Hz Set the motor's back electromotive force (EMF) divided accordinate		Set the induced voltage constant, which is the peak of the induced voltage (phase voltage) divided by the electrical angular frequency, according to the motor being used.	5.4			
	POLE	DLE         POLE_DEF         Set the number of poles of the motor.         Set the number of poles of the motor being used.		5.5			
	PWM_PERIOD	WM_PERIOD PWM_PERIOD_DEF $\mu$ s Set the PWM control period. If the set value is too high, it may cause of the period. If it is too low, processing may not be completed within the PWM cycle.		If the set value is too high, it may cause noise. If it is too low, processing may not be completed within the PWM cycle.	_		
	DEAD_TIME	DEAD_TIME_DEF	μs	Set the dead time.	Depends on the board (inverter) being used.	_	
	SPD_CTRL_PERIOD	PERIOD – $\mu$ s Set the speed control period. Change from the default value as needed.		_			
	MAINLOOP_USER_PERIOD	_	μs	Set the user processing period in the main loop.	Change from the default value as needed.	-	
	ADC_TIMING0_SHIFT2	ADC_TIMING0_SHIFT2_DEF	μs	Set the AD trigger timing 0 for shift 2 PWM.	In the case of Shift2-PWM with U-phase center, it is always necessary to acquire the V-phase current.	4.1.1 4.1.2 4.2	
Current Detection	ADC_TIMING1_SHIFT2	ADC_TIMING1_SHIFT2_DEF	μs	Set the AD trigger timing 1 for shift 2 PWM.	In the case of Shift2-PWM with U-phase center, it is always necessary to acquire the W-phase current. Note: AD trigger timing 1 is automatically set when the value for AD trigger timing 0 is configured.		
	NPWM_PHASE_NUM	NPWM_PHASE_NUM_DEF	-	Set the modulation method for normal PWM (2: 2-phase modulation, 3: 3-phase modulation).	Change as needed.	-	
	NPWM_TH	NPWM_TH_DEF	%	Set the threshold for switching duty to normal PWM.	Note: Duty = $\sqrt{3}$ * Vdq / Vdc (where Vdq = $\sqrt{(Vd^2 + Vq^2)}$ and Vdc is the supply voltage)	_	



Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS)	Unit	Description	Remarks	The detailed description chapter
	NPWM_HYS	NPWM_HYS_DEF	%	Set the hysteresis value of the switching duty in normal PWM.	If the modulation method switches frequently, set the hysteresis to a larger value.	-
	SPWM_TH	SPWM1_TH_DEF	%	Set the threshold for switching duty to shift PWM.	Note: Duty = $\sqrt{3}$ * Vdq / Vdc	-
Quarant	SPWM_HYS	SPWM1_HYS_DEF	%	Set the hysteresis value of the switching duty in shift PWM.	If the modulation method switches frequently, set the hysteresis to a larger value.	-
Detection	MINPLS_NPWM2	MINPLS_NPWM2_DEF	μs	Set the minimum pulse width in normal PWM 2- phase modulation.	It is necessary to set a value that prevents erroneous current detection.	
	MINPLS_NPWM3	MINPLS_NPWM3_DEF	μs	Set the minimum pulse width in normal PWM 3- phase modulation.	It is necessary to set a value that prevents erroneous current detection.	4.1.2
	MINPLS_SHIFT1	MINPLS_SHIFT1_DEF	μs	Set the minimum pulse width in shift1-PWM.	It is necessary to set a value that prevents erroneous current detection.	4.2.1
	MINPLS_SHIFT2	MINPLS_SHIFT2_DEF	μs	Set the minimum pulse width in shift2-PWM.	It is necessary to set a value that prevents erroneous current detection.	
	VD_TARGET_INI1	VD_TARGET_INI1_DEF	v	Set the reference voltage value required for positioning.	Set the initial d-axis voltage for positioning. This setting is only effective during voltage drive.	
				pooling.	If the motor does not move, gradually increase the value.	
	INIPOS_TIME INIPOS_TIME_DEF s Set the po		Set the positioning time.	Basically, no tuning is necessary. If you want to speed up the startup, reduce the value.	3.1, 3.2, 3.3	
	RAMP_UP_TIME_INIPOS	RAMP_UP_TIME_INIPOS RAMP_UP_TIME_INIPOS_DEF s Set the ramp-up time.		Set the ramp-up time.	Basically, no tuning is necessary.	3.3, 6.3.1
Positioning	POS_INIPOS_DEG	-	deg	Set the positioning angle.	Basically, 0 degrees is recommended.	3.2, 6.3, 6.3.1
	ID_TARGET_INI ID_TARGET_INI_DEF A Set the position		Set the target current value required for positioning.	If the motor does not move, gradually increase the value.	3.2, 3.3, 6.3 6.3.1 6.4.1	
	ID_KP	ID_KP_DEF	V/A	Set the current control proportional gain for the d-axis current.	Gradually increase while checking the responsiveness of the current control.	6.2
	ID_KI	ID_KI_DEF	V/As	Set the current control integral gain for the d- axis current.	Gradually increase while checking the responsiveness of the current control.	6.3
© 2025				10	20	025-07-18

Toshiba Electronic Devices & Storage Corporation



Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS)	Unit	Description	Remarks	The detailed description chapter
Positioning	IQ_KP	IQ_KP_DEF	V/A	Set the current control proportional gain for the q-axis current. Basically, set the same value as the curr control proportional gain of the d-axis cu		
. contorning	IQ_KI	IQ_KI_DEF	V/As	Set the current control integral gain for the q- axis current.	Basically, set the same value as the current control integral gain of the d-axis current.	
	VD_TARGET_INI2	VD_TARGET_INI2_DEF	v	Set the additional target voltage value required for forced commutation. Set the additional target voltage value required for forced commutation. Set the additional target voltage value required for forced commutation. Set the d-axis reference voltage value to be added to VD_TARGET_INI during forced commutation. This setting is only effective during voltage drive. If the motor current decreases and the motor stops rotating, increase the setting value.		_
Forced commutation	SPD_UP_FORCE	SPD_UP_FORCE_DEF	Hz/s	Set the acceleration of the reference speed during forced commutation. If the motor acceleration is slow, increase the setting value. If the setting value is large, the motor with high inertia may not follow.		_
	SPD_DW_FORCE	SPD_DW_FORCE_DEF	Hz/s	Set the deceleration of the reference speed during forced commutation. If the motor deceleration is slow, increase the setting value. If the setting value is large, the motor with high inertia may not follow.		_
	SPD_CHANGE_UP_TH	SPD_CHANGE_UP_TH_DEF	Hz	Set the switching frequency of the change-up.	It depends on the induced voltage of the motor being used. At the start of the tuning, set it to a higher value, and if it needs to switch to sensorless at low speed, gradually lower the setting while tuning.	6.4.1
Change-up	IQ_TARGET_INI	IQ_TARGET_INI_DEF	A	Set the initial value of the q-axis target current. It's fine to set it low when there is no load, it needs to be tuned according to the load when there is a load.		6.4.1
enange op	WAIT_TIME_CHGUP	_	s	Set the waiting time after the change-up. Basically, it doesn't need to be changed bu tune it if necessary.		6.4.1
Change-up	POS_KP	POS_KP_DEF	Hz/V	Set the position estimation proportional gain.	Tune so that the d-axis induced voltage becomes zero.	
	POS_KI	POS_KI_DEF	Hz/Vs	Set the position estimation integral gain.	Tune so that the d-axis induced voltage becomes zero.	б.4
Steady	SPD_KP_I1	SPD_KP_I1_DEF	A/Hz	Set the speed control proportional gain 1.	Tune while checking the responsiveness and tracking performance of the speed control.	6.5



Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name nc_config.h corresponding o the reference software) Parameter Name (Header File for MTS) Unit Description		Remarks	The detailed description chapter	
	SPD_KI_I1	SPD_KI_I1_DEF	A/Hzs	Set the speed control integral gain 1.	Tune while checking the responsiveness and tracking performance of the speed control.	
	SPD_KP_I2	SPD_KP_I2_DEF	A/Hz	Set the speed control proportional gain 2.	Use this parameter when control is not successful with only SPD_KP_I1.	
	SPD_KI_I2	SPD_KI_I2_DEF	A/Hzs	Set the speed control integral gain 2.	Use this parameter when control is not successful with only SPD_KP_I1.	-
	SPD_KPI_TH	SPD_KPI_TH_DEF	Hz	Set the switching speed between speed control gain 1 and 2.	When the reference speed exceeds SPD_KPI_TH, use the speed control gains SPD_KP_I2 and SPD_KI_I2.	-
	SPD_UP_STEADY	SPD_UP_STEADY_DEF	Hz/s	Set the acceleration of the reference speed during steady state.	If the motor acceleration is slow, increase the setting value. If the setting value is large, the motor with high inertia may not follow.	_
	SPD_DW_STEADY	SPD_DW_STEADY_DEF	Hz/s	Set the deceleration of the reference speed during steady state.	If the motor deceleration is slow, increase the setting value. If the setting value is large, the motor with high inertia may not follow.	-
	FLDWK_TH	FLDWK_TH_DEF	V	Set the value used for the conditions to perform field weakening control.	Set according to the motor and power supply voltage used.	-
Field weakening	FLDWK_HYS	FLDWK_HYS_DEF	V	Set the hysteresis voltage for field weakening control.	If the switching of the field weakening control on and off occurs frequently, set a larger hysteresis.	-
	FLDWK_ID_DEV	FLDWK_ID_DEV FLDWK_ID_DEV_DEF A/s		Set the change amount of the field weakening current.	Set according to the motor being used.	_
	FLDWK_ID_MAX	FLDWK_ID_MAX_DEF	А	Set the maximum value of the field weakening current.	Set a negative value.	_
	OMEGA_AVE_WINDOW	_	-	Set the coefficient for the average value calculation with respect to speed.	Basically, it doesn't need to be changed but tune it if necessary.	_
Others	VDQ_AVE_WINDOW	_	-	Set the coefficient for the average value calculation with respect to the dq-axis voltage.	Basically, it doesn't need to be changed but tune it if necessary.	_
(Tune as necessary)	IXO_AVE_WINDOW	_	-	Set the coefficient for the average value calculation with respect to zero current.	Basically, it doesn't need to be changed but tune it if necessary.	_
	VDC_SUPPLY	_	V	Set the ideal inverter voltage.	Basically, it doesn't need to be changed but tune it if necessary.	-



Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS)	Unit	Description	Remarks	The detailed description chapter
	ADC_ZERO_OFS	_	A	Set the ideal input voltage to the ADC when the current is 0A.	Basically, it doesn't need to be changed but tune it if necessary.	_
	ADC_ZERO_ERR	_	A	Set the threshold for detecting an error when the zero current offset deviates from the set value.	Basically, it doesn't need to be changed but tune it if necessary.	-
	ADC_RAW_MAX	_	-	Set the threshold for detecting an error when the ADC input is fixed at the MAX level.	Basically, it doesn't need to be changed but tune it if necessary.	_
	ADC_RAW_MIN	_	-	Set the threshold for detecting an error when the ADC input is fixed at the MIN level.	Basically, it doesn't need to be changed but tune it if necessary.	_
	VDC_MIN	VDC_MIN_DEF	V	Set the minimum DC voltage value.	Basically, it doesn't need to be changed but tune it if necessary.	-
	VDC_MAX	VDC_MAX_DEF	V	Set the maximum DC voltage value.	Basically, it doesn't need to be changed but tune it if necessary.	_
	DUTY_MAX	_	%	Set the limit for the maximum duty value.	Basically, it doesn't need to be changed but tune it if necessary.	_
	DUTY_MIN	_	%	Set the limit for the minimum duty value.	Basically, it doesn't need to be changed but tune it if necessary.	_
	SPWM_DUTY_OFS	_	%	Set the duty offset.	Basically, it doesn't need to be changed but tune it if necessary.	_
	VD_OFS	_	V	Set the d-axis voltage offset.	Basically, it doesn't need to be changed but tune it if necessary.	_
	VQ_OFS	_	V	Set the q-axis voltage offset.	Basically, it doesn't need to be changed but tune it if necessary.	_
	ADC_OFS_NPWM2	ADC_OFS_SHIFT2_DEF	μs	Set the AD conversion delay time in normal 2- phase PWM modulation.	Basically, it doesn't need to be changed but tune it if necessary.	_
Others	ADC_OFS_NPWM3	ADC_OFS_NPWM3_DEF	μs	Set the AD conversion delay time in normal 3- phase PWM modulation.	Basically, it doesn't need to be changed but tune it if necessary.	
necessary)	ADC_OFS_SHIFT1	ADC_OFS_SHIFT1_DEF	μs	Set the AD conversion delay time in shift 1 PWM.	Basically, it doesn't need to be changed but tune it if necessary.	

### 3. Setting of Various Control Parameters

#### 3.1. State Transition Diagram of Motor Control

Figure 3.1 shows the state transition diagram of motor control.

As previously mentioned, the FOC by the reference software performs position estimation to control the motor without sensors.

Since position estimation uses the induced voltage proportional to the motor speed, it is difficult to estimate the position immediately after startup or at low speeds when the induced voltage is low. Therefore, as shown in Figure 3.1, the reference software achieves FOC by transitioning from a stopped state to steady state through positioning, forced commutation, and change-up when driving the motor. If an abnormality such as overcurrent detection occurs during motor operation, it transitions to an abnormal state. The details will be explained in the following slides.



Figure 3.1 State Transition Diagram of Motor Control

#### 3.2. Stage Transitions and Control States

Table 3.1 shows the transition conditions for each stage and the state of each control

Staç	ge	(1)stop	(2)positioning	(3)forced commutation (open loop control)	(4)change-up (Forced → Steady)	(5)steady (FOC)	
Conditions for transition to the next stage		Start command	Positioning time (INIPOS_TIME) elapsed	Reference speed ≥ Change-up frequency (SPD_CHANGE_UP_TH) Elapsed time after change-up (WAIT_TIME_CHGUP)			
Gurrant	d-axis reference current Idref	0	0 → Target d-axis current (ID_TARGET_INI) However, maintain a constant value after reaching the target	Target d-axis current (ID_TARGET_INI)	Target d-axis current (ID_TARGET_INI) $\rightarrow 0$	0(Note)	
control	q-axis reference current Iqref	0	0	0	0 → Target q-axis current (IQ_TARGET_INI)	Output value of speed control	
	state	off	on	on	on	on	
Speed control	peed speed 0 0		/ No	Accelerate to target speed (ramp change). Note: Acceleration can be adjusted by the user.			
	state	off	off	off	off	on	
Position estimation	phaseθ	Initial position	Initial position → Target position(POS_INIPOS_DEG)	Calculated from reference speed (Position = Previous position + PWM control cycle * Reference speed)	Calculated from reference speed (Position = Previous position + PWM control cycle * Reference speed) Until Ed changes to < 0, it is calculated from the reference speed (Position = Previous position + PWM control cycle * reference speed) After Ed changes to < 0, it is calculated from the estimated speed (Position = Previous position		
	state	off	off	on	off $\rightarrow$ on	on	

#### Table 3.1 Stage Transitions and Control States

Note: The on/off activation in the table refers to controlling variables via the debugger to start/stop the motor.

(Note); In the steady stage, the d-axis reference current can be selected not only for Id=0 control but also for field weakening control and MTPA (Maximum Torque Per Ampere) control.

#### **3.3. FOC Experimental Waveforms**

The waveforms from the motor's stopped state to its steady state are shown in Figure 3.2. The parameters in the figure are example settings. Please refer to Table 2.1 and Table 3.1 to adjust the parameters to match the motor and system requirements you are using.



Figure 3.2 Experimental Waveforms of FOC

### 4. Parameter Settings for Current Detection

#### 4.1. Summary of Parameters Related to Current Detection

#### 4.1.1. Configuration when ringing occurs across the shunt resistor terminals

The TB9M003FG supports only 1-shunt current detection <sup>(1)</sup> for miniaturization and cost reduction. In 1shunt current detection, the three-phase motor current is detected from the voltage across the shunt resistor, which varies with the switching of the inverter. Regardless of the modulation method, ringing may occur immediately after the switch changes its state. An example is shown in Figure 4.1.

During the period when ringing occurs, the voltage across the shunt resistor fluctuates, making accurate current detection impossible.

Therefore, it is necessary to detect the current at a stable timing after the voltage fluctuations have settled.

In the TB9M003FG, two triggers, ADC\_TIMING0\_SHIFT2 and ADC\_TIMING1\_SHIFT2, are set as the timing for current detection. In Shift 2 PWM, the user sets a fixed timing, while in Shift 1 PWM and normal PWM, VE (Vector Engine) automatically sets the timing [refer to Figure 20.5.3.5.1 in the hardware UM for an Image of trigger generation position by trigger generation task].

Shift 2 PWM detects current at a fixed timing by shifting the PWM signal. Please set the timing to avoid ringing.

<sup>(1)</sup> Refer to the [Application Note] Example of 1-Shunt Sensorless Vector Control



Figure 4.1 Ringing occurring in the voltage across the shunt resistor

#### 4.1.2. Current detection timing for Shift-2 PWM

Figure 4.2 shows an example of current detection timing in Shift 2 PWM. The current detection period in the figure indicates the period during which the V-phase can be detected. During this period, the correct phase (in this case, the V-phase) current can be detected, but as mentioned earlier,

due to the influence of ringing, it is recommended to set the detection timing with a slight margin after the ringing ends (this may vary depending on the inverter and board design used).

In the (1) PWM control cycle in the figure, the setting of ADC\_TIMING0\_SHIFT2 is within the V-phase current detection period, but in the (2) PWM control cycle, it is outside the V-phase current detection period, resulting in the incorrect detection of the U-phase current. To prevent this current misdetection, the reference software allows the user to set the minimum pulse width (MINPLS) as the minimum period required for current detection.

If the period is less than MINPLS, the VE automatically determines that current detection is not possible, and the detected current at that time is not used for control, instead using the previous value. If the period during which current detection is not possible (the period using the previous value) becomes long, there is a risk of control failure, so be sure to set MINPLS to a time equivalent to the period required for current detection. In the case of Shift 2 PWM, there is basically no problem if you set the same time as the detection timing set to avoid ringing.

In Shift 1 PWM and normal PWM, the pattern of the output PWM signal changes, so the trigger is dynamically changed. Therefore, there is a possibility that the trigger will be set during the ringing that occurs when the switch is switched.

The MINPLS to be set can basically have the same values as Shift 2 PWM, but it can be individually set according to the modulation method.

Please set each parameter (MINPLS\_NPWM2, MINPLS\_NPWM3, MINPLS\_SHIFT1, MINPLS\_SHIFT2) to avoid ringing.





#### 4.2. Example of Parameter Settings for Current Detection

Figure 4.3 shows the experimental waveform during Shift 2PWM. The AD conversion timing in the figure monitors the debug output of internal signals.

The debug signal can be selected with [DBGOUTCR]<DBGMD[1: 0]>.

The parameters are as follows:

- · The PWM control period (PWM\_PERIOD) is 50.0μs
- ADC\_TIMING0\_SHIFT2 is 3.0µs
- ADC\_TIMING1\_SHIFT2 is 47.0μs.



Figure 4.3 Experimental Waveforms of Current Detection Timing in Shift-2 PWM



#### 4.2.1. In case the current misdetection confirmation flag is triggered

Figure 4.4 shows the experimental waveforms when the current misdetection confirmation flag ([MCTLF]<PLSLFM>) occurs.

In this experiment, to confirm the operation of MINPLS, MINPLS (MINPLS\_SHIFT2) is intentionally set to 9.1 µs so that the current misdetection confirmation flag is triggered.

The current detected during the high-level period of the current misdetection confirmation flag is not used for control. When the flag changes to a low level in the next PWM control cycle, the current detected in that PWM control cycle is used for control.



Figure 4.4 Current Detection Timing in Shift-2 PWM (Example of False Detection Flag Triggering)

### 5. Measurement of Various Motor Parameters

#### 5.1. Summary of Parameter Measurement

The FOC in the reference software requires the following information as motor parameters

- · resistance,
- · d-axis and q-axis inductance,
- back EMF constant,
- the number of poles

#### 5.2. Resistance Measurement

An example of measuring the resistance between U and V phases is shown in Figure 5.1.

The motor resistance is measured using a multimeter or an LCR meter.

The resistance value (MTR\_R) in the software needs to be set as the resistance per phase.

Here, the resistance values between U-V, V-W, and W-U phases are measured and the average value is calculated.

#### MTR\_R = (Resistance between U and V phases

#### + Resistance between V and W phases + Resistance between W and U phases) / 6



Figure 5.1 An example of measuring the resistance between the U and V phases



#### 5.3. Inductance Measurement

Figure 5.2 shows the variation in line-to-line inductance between U and V. The inductance changes with the rotor angle.

The maximum inductance corresponds to the q-axis inductance (MTR\_LQ) [mH], and the minimum inductance corresponds to the d-axis inductance (MTR\_LD) [mH].

On the software, the q-axis inductance (MTR\_LQ) and d-axis inductance (MTR\_LD) need to be set as the inductance values per phase.

Figure 5.3 shows an example of measuring the line-to-line inductance between U and V. The inductance can be measured using an LCR meter.

For the measurement, manually rotate the rotor of the test motor gradually for one full rotation and obtain the maximum values of line-to-line inductance (Luv\_max, Lvw\_max, Lwu\_max) and the minimum values (Luv\_min, Lvw\_min, Lwu\_min). Here, the average values of the q-axis inductance and d-axis inductance are calculated from the line-to-line inductances between U-V, V-W, and W-U.

MTR\_LQ = (Luv\_max + Lvw\_max + Lwu\_max) / 6 MTR\_LD = (Luv\_min + Lvw\_min + Lwu\_min) / 6







Figure 5.3 An example of measuring the inductance between the U and V phases



#### 5.4. Back EMF Constant Measurement

An example of measuring the back EMF constant is shown in Figure 5.4. The back EMF constant (MTR\_KE) [V/Hz] can be measured by rotating the test motor externally using a drive motor. If measuring the phase voltage instead of the line voltage, it is necessary to connect an external circuit as enclosed by the dashed lines.

Figure 5.5 shows an image of the induced voltage (phase voltage) generated in the external resistor when the test motor is rotated at a certain speed.

As an example of an actual waveform, Figure 5.6 shows the waveform of the induced voltage (phase voltage) when a test motor with 4 poles is rotated at approximately 1,000 rpm by the drive motor. Here, the electrical angular frequency f [Hz] is the reciprocal of the electrical angle period T [s] (f = 1/T[Hz]). The back EMF constant is calculated from the peak value Vpeak of the measured phase voltage. However, if measuring the line voltage, divide the peak value of the measured line voltage by  $\sqrt{3}$  to convert it to the peak value Vpeak of the phase voltage before calculating the back EMF constant.



MTR\_KE = Vpeak / f







Figure 5.6 Induced voltage waveforms when a test motor with 4 poles is rotated by the drive motor (@1,000rpm)



#### 5.5. Pole Number Measurement

There are cases where the pole number (POLE) is not listed in the datasheet. For motors with an unknown pole number, you can determine the pole number by driving the test motor at a constant speed using another motor, or by observing the change in induced voltage when the motor is rotated once.

Figure 5.7 shows an example of pole number measurement for a motor with 4 poles.

Figure 5.8 illustrates the change in induced voltage when a motor with 4 poles is manually rotated once. From the figure, it can be confirmed that the electrical angle period is 2 cycles, indicating that the pole number is 4.

POLE = 2 \* (Number of electrical cycles during one motor revolution)



Equivalent to 1 motor revolution

Figure 5.7 Image of pole number measurement (motor with 4 poles)



### 6. Tuning of PI Control Gains

#### 6.1. Summary of PI Control Gain

PI (Proportional Integral) control is a type of feedback control. PI control adjusts the manipulated variable so that the error between the setpoint (Target Value) and the controlled variable (Output) becomes zero. Figure 6.1 shows the block diagram of PI control.

With P control alone, the target value can be approached, but the error cannot be eliminated. I control operates to eliminate this error.

In general, when the control gain is large, the response improves but becomes unstable. Conversely, when the control gain is small, the stability of the control increases, but the responsiveness deteriorates. The stable operating range of the PI control gain varies depending on the conditions. Figure 2.3 is shown again below.

**Basics of PI Control** 

```
Controller Output = Proportional term + Integral term
Proportional term = Proportional gain * Error
Integral term = Integral gain * Error * PWM control cycle + (previous integral term)
```



Figure 6.1 Block diagram of PI control



Figure 2.3 Flowchart of Fine Tuning (reprinted)



#### 6.2. Tuning Procedure for Each PI Control Gain

To implement FOC, it is necessary to appropriately tune the PI control gains according to the motor being used. The FOC provided by our reference software includes three PI control gains: current control gain, position estimation gain, and speed control gain.

This document explains how to tune these PI control gains in the following order:

- 1. Current control gain
- 2. Position estimation gain
- 3. Speed control gain

Please note that the procedures for rough tuning and fine tuning are the same, but fine adjustment should be performed to meet actual system requirements, such as load fluctuations and changes in speed commands. Using MTS, you can automatically calculate the initial values for gain adjustment.

#### 6.2.1. (1) Current Control Gain (Recommended to tune in the positioning stage)

In the positioning stage, the motor is not rotating, and position estimation and speed control are not functioning. Therefore, it is possible to tune only the current control gain without being affected by the position estimation gain or speed control gain.

#### 6.2.2. (2) Position Estimation Gain (Recommended to tune in the change-up stage)

In the change-up stage, the estimated position from position estimation is used. At this time, speed control is not functioning, so it is possible to adjust the position estimation gain without being affected by the speed control gain.

#### 6.2.3. (3) Speed Control Gain (Tune in the steady stage)

In the steady stage, the speed control function operates. Tune the speed control gain while checking the responsiveness and tracking performance according to the actual system.



#### 6.3. Summary of Current Control

As for the tuning of the current control gain (ID\_KP, ID\_KI, IQ\_KP, IQ\_KI), the tuning method in the positioning stage is explained. Figure 6.2 shows the block diagram of the positioning stage. In the positioning stage, the motor is not rotating.

Therefore, it is possible to tune only the current control gain independently of the position estimation gain and speed control gain.

Figure 6.3 shows the block diagram of current control. In current control, the control is performed to match the reference current with the detected current. Figure 6.3, the d-axis voltage (Vd) is controlled to match the d-axis reference current (ldref) with the d-axis current (ld).

Similarly, for q-axis current control, the q-axis voltage (Vq) is controlled to match the q-axis reference current (lqref) with the q-axis current (lq). In the positioning and forced commutation stages, the q-axis reference current (lqref) is controlled to be zero. The setting of the current control gain can generally be the same value for both the d-axis and q-axis.



Figure 6.2 Block Diagram of the Positioning Stage



Figure 6.3 Block Diagram of Current Control



#### 6.3.1. Method for Tuning Current Control Gain

An example of tuning the current control gain is shown in Figure 6.4.

Set the ramp-up time (RAMP UP TIME INIPOS) to 0 and set the value of the d-axis target current (ID TARGET INI).

Monitor the d-axis reference current (Idref) and the d-axis current (Id) to tune the current control gain. The key points for gain tuning are tracking performance and responsiveness. Change the current control gain while checking the waveform.

To avoid waveform distortion caused by motor movement during positioning, restart the positioning operation from the beginning if the motor moves even slightly. If the motor does not move, gradually increase the value of ID TARGET INI until the motor starts moving.

Figure 6.4(a) shows an example where the gain is too low, resulting in poor responsiveness.

Figure 6.4(b) shows an example where the gain is appropriate, resulting in good responsiveness and tracking performance.

Figure 6.4(c) shows an example where the gain is too high, causing vibration and poor tracking performance.

Tune the parameters to achieve a result like in (b). The concept of PI control is the same for position estimation gain and speed control gain.

Note: If the rotor of the motor moves when transitioning to the stop stage by stopping the power supply to the motor, please change the value of POS INIPOS DEG to another value.



Figure 6.4 Example of current control gain tuning



#### 6.4. Summary of Position Estimation

As an example of adjusting the position estimation gain (POS\_KP, POS\_KI), the adjustment method in the change-up stage is explained.

Figure 6.5 shows the block diagram during position estimation gain tuning. In the change-up stage, speed control is not functioning.

Therefore, it is possible to adjust the position estimation gain independently of the speed control gain. Figure 6.6 shows the block diagram of position estimation. In PI control, the estimated speed  $\omega$  is determined so that the d-axis induced voltage Ed becomes zero, and the estimated position  $\theta$  is calculated from this result.

In the change-up stage, after Ed changes to less than 0, the previous value of  $\omega$  is used to calculate Ed. However, until Ed changes to less than 0,  $\omega$ ref is substituted into  $\omega$  to calculate Ed.



Figure 6.5 Block Diagram for Position Estimation Gain Tuning



Figure 6.6 Block Diagram of Position Estimation



In the reference software, position estimation utilizes the fact that d-axis induced voltage Ed is generated when the estimated position deviates from the actual position. When Ed is zero, the position estimation error is zero. Therefore, in PI control, the estimated speed  $\omega$  is determined so that Ed becomes zero, and the position  $\Delta\theta$  is calculated. The relationship between Ed and q-axis induced voltage Eq is illustrated in Figure 6.7.

If the estimated d-axis advances relative to the actual d-axis, Ed > 0. Conversely, if the estimated d-axis lags, Ed < 0.



Figure 6.7 Image of Position Estimation

#### 6.4.1. Tuning of Position Estimation Gain

To tune the position estimation gain in the change-up stage, please make the following settings:

Set the change-up switching frequency (SPD\_CHANGE\_UP\_TH) and the target speed (SPD\_TARGET) to the same value and set the waiting time after the change-up (WAIT\_TIME\_CHGUP) to a few seconds. Here, SPD\_CHANGE\_UP\_TH needs to be set to a speed at which sufficient induced voltage for position estimation is generated. With these settings, the estimated position from position estimation is used for control without enabling speed control. This allows for the tuning of the position estimation gain without the influence of speed control.

Note that the change-up stage is the stage where the motor drive, which was previously driven by the d-axis starting current (ID\_TARGET\_INI),

is switched to the q-axis starting current (IQ\_TARGET\_INI).

If the position estimation error after switching to the change-up stage is large, it may cause step-out or overcurrent due to shock.

If the motor accelerates rapidly during the switch, decrease the value of IQ\_TARGET\_INI. If it stops, increase the value.

Additionally, after the WAIT\_TIME\_CHGUP elapses, the system switches to the steady stage and speed control operates, so be sure to stop

the motor before the switch. If the motor does not operate stably, change the start command to off and stop the motor.



Examples of position estimation gain tuning are shown in Figure 6.8. Monitor Ed and tune the position estimation gain accordingly.

Figure 6.8(a) shows an example where the gain is too low, resulting in poor responsiveness and stability. The motor vibrates and loses synchronization midway.

Figure 6.8(b) shows an example where the gain is appropriate, allowing Ed to be controlled around zero, and the operation can continue.

Figure 6.8 (c) shows an example where the gain is too high, causing significant vibrations and unstable control. Adjust the settings to achieve a state like (b).

Additionally, the purpose of the rough tuning is to use the position estimation result (estimated position) for control and ensure that the motor can drive without losing synchronization. If the operation can continue, there is no problem. Fine adjustments need to be made in the steady stage, gradually increasing the load while adjusting.

Note: If the operation stops immediately after switching to the steady stage despite adjusting each parameter, set SPD\_CHANGE\_UP\_TH to a value larger than the desired setting. Confirm that the steady stage switches stably, then gradually lower SPD\_CHANGE\_UP\_TH and test again.



Figure 6.8 Example of position estimation gain tuning

#### 6.5. Summary of Speed Control

The block diagram of FOC is shown in Figure 6.9. In the FOC (steady stage), current control, position estimation, and speed control are functional. The block diagram of speed control is shown in Figure 6.10. It operates based on factors such as load variations that cause a difference from the reference speed ( $\omega$ ref). Therefore, the speed control gain (SPD\_KP\_I1, SPD\_KI\_I1, SPD\_KP\_I2, SPD\_KI\_I2) does not require much tuning when the motor is standalone, but it has a significant impact when incorporated into the system.

Figure 6.11 shows an image of the changes in the current reference value due to load variations.

Speed control tunes the q-axis current reference value (lqref) to match the reference speed ( $\omega$ ref) with the estimated speed ( $\omega$ ).

For example, if the load increases and  $\omega$  decreases, the speed error increases, and lqref is increased to raise  $\omega$ .

Similarly, if  $\omega$ ref increases, the speed error also increases, and lqref is increased to raise  $\omega$ .

Speed control tunes by monitoring  $\omega$ ref,  $\omega$ , lqref, and other parameters to ensure responsiveness and tracking performance.



Figure 6.9 Block Diagram of FOC







Figure 6.11 Block Diagram of Speed Control

#### 6.5.1. Tuning of Speed Control Gain

The example of speed control gain tuning is shown in Figure 6.12.

Load fluctuations make it easier for the motor to lose synchronization under more severe driving conditions. Gain tuning should be performed by gradually increasing the load or by applying a step load externally. If there is no load device, it is acceptable to change the target speed in steps.

Here, an example of applying a step load is explained.

Figure 6.12(a) shows an example where the gain is too low, resulting in poor responsiveness of the q-axis reference current, which is the output of speed control, and causing significant oscillations in the estimated speed.

Figure 6.12(b) shows an example where the gain is appropriate, resulting in good responsiveness and good tracking performance.

Figure 6.12(c) shows an example where the gain is too high, causing oscillations and poor tracking performance. Please tune the gain to achieve a result like in (b).

At the initial stage of tuning, it is recommended to tune the gain so that the operation can continue with no load or light load, and then gradually make the motor driving conditions more severe.



Figure 6.12 Example of tuning speed control proportional gain

### 7. Tuning by MTS

#### 7.1. Summary of MTS

The main features of our PC tool, MTS, which supports motor control development, are as follows. As mentioned earlier, the following motor parameter measurements and PI control gain settings can also be performed manually without any issues.

Feature 1: The following motor parameters can be measured automatically:

- Resistance (R)
- q-axis inductance (Lq)
- d-axis inductance (Ld)
- Back EMF constant (Ke)
- Moment of inertia (J)
- Minimum pulse width (MINPLS)

Feature 2: The following PI control gains can be calculated automatically:

- Current control gain
- Position estimation gain
- Speed control gain

#### 7.1.1. Explanation of MTS

Figure 7.1 shows an example of the window display on the MTS screen. Please note that this is just one example of the MTS screen window display, and the screen display configuration can be changed by the user.

This document focuses on the automatic measurement of motor parameters and the automatic calculation of PI control gains.

For detailed manuals on MTS, please refer to the separate document (MTS User Manual).

Note: To display the "Motor Tuning Support" window, the preparations shown in the next slide are required.



Figure 7.1 An Example of the Window Display of the MTS Screen



#### 7.1.2. Preparations Before Using MTS

To use MTS, please install the necessary software and set up the MTS environment. Figure 7.2 shows the MTS screen. When you hover over the "Board infos" tab, various information will be displayed.

If "Motor Tuning Support" is set to No, automatic motor parameter measurements and PI control gain calculations will be disabled.

Note: If "Motor Tuning Support" is set to No, the following reasons may be considered:

- •The software is not installed correctly.
- "Motor Tuning Support" is not enabled in the firmware.



Figure 7.2 MTS Screen (Board Information Display)



#### 7.1.3. Explanation of the MTS Window Layou

Figure 7.3 shows an enlarged view of the "Motor Tuning Support" window and provides descriptions of each block.

As mentioned earlier, you can use the automatic parameter acquisition algorithm built into MTS to automatically measure motor parameters (resistance R, inductance L, back EMF constant Ke, moment of inertia J, and minimum pulse width MINPLS).

Based on the measured motor parameters, the initial values of the PI control gains for current control, position estimation, and speed control can be automatically calculated. Please refer to chapter 7.2 for usage instructions.

File View Motor ID Calculators Help		- σ ×
Refer to Chap. 7.2.3 and beyond	and L Measurement Execution Button Moter Parameter	Ke and J Measurement Execution Button           Control Gain Selection Window           R Gain for Meter Daving           Corrett         Paster           Automatic calculation based on set values
Motor parameters	Inductance Lq(H)         0.000610         Measure I           Inductance Lq(H)         0.00530         Measure I           Back EMF constant(Wb)         0.007000         Interfail(Kgm2)         Measure I	L         Mir Value         Max value         Setting/float         and measured motor parameters           in         K(V/A)         5201.282         672.596         Default           in         K(V/A)         0.55         0.55
Each Control Gain	Current Kp(V/A)         072.596         Set Pursue           Current Kp(V/A)         0.35         Set Pursue           Position Kp(Hz/V)         25.085         Position Kp(Hz/V)           Position Kp(Hz/V)         19.318         Speed Ki(A/Hz)           Speed Ki(A/Hz)         0.545         Speed Kp(A/Hz)	Agent for 60     Comment control for 60     Comment contro     Comment contro     Comment control for 60     Comment control
Refer to Chap. 7.2.2	Setting for RL Measurement I dimensured current ratio Lid measured current ratio Lid measured current ratio Limeasured current ratio Limeasured setting inne(s) Initial applied frequency/http 2 Applied frequency limit(Ng) 100	Mediation fistor       0.400         Speed acceleration(h(y))       10         Reasure       0.600         Reasure       0.600         Magnetic flux measure       0.600         Magnetic flux measure       Advanced Setting         Speed acceleration(h(y))       5         Postioning current ratio       0.6         Postioning current ratio       0.600         Postioning time(s)       0.200         Postioning time(s)       0.200         Postioning time(s)       0.200         Postioning time(s)       0.200
		Automatic Measurement of Motor Parameters

Figure 7.3 Enlarged View of the "Motor Tuning Support" Window

#### 7.2. How to Use MTS

#### 7.2.1. List of Parameters Required for Automatic Measurement of Motor Parameters and Automatic Calculation of PI Control Gains

Chapter 7.2 explains how to use MTS for the automatic measurement of motor parameters and the automatic calculation of PI control gains. Table7.1 lists the parameters that need to be set.

Note: If the motor parameters are already known, you can skip the measurement steps and enter the values manually. Please perform the gain tuning calculations and tuning based on the manually entered values.

	Parameter names on the MTS screen	Parameter names in the header file for MTS	unit	Description	Remarks				
	Positioning current ratio	MEASURE_CURRENT_RATE		Set the current ratio during positioning.	If the motor vibrates during positioning, increase the setting value. If overcurrent protection occurs, decrease the setting value.				
Advanced Setting	Positioning voltage drop ratio	INC_VOLT_RATE		Set the positioning voltage increase rate.	If the setting value is too high, the applied voltage will increase rapidly, potentially triggering overcurrent protection. If the setting value is too low, the applied voltage will increase slowly, which may result in longer measurement times.				
	Positioning time(s)	MEASURE_INIT_POS_LEN	s	Set the positioning time.	Generally, no changes are necessary. If you want to speed up the startup, reduce the setting.				
	Peak Current(A)	MOTOR_RATED_CURRENT	А	Set the peak current value of the motor.	Please tune according to the motor in use.				
	R measured current ratio 1	R_MEASURE_CURRENT_RATE1		Set the resistance measurement current ratio 1.	If the setting value is too low, the error may increase. If overcurrent protection occurs, reduce the setting value.				
R measure	R measured current ratio 2	R_MEASURE_CURRENT_RATE2	-	Set the resistance measurement current ratio 2.	If the setting value is too low, the error may increase. If overcurrent protection occurs, reduce the setting value.				
it modeure	R measured waiting time(s)	R_MEASURE_WAIT_LEN	s	Set the resistance measurement waiting time.	Generally, no changes are necessary.				
	R measured time(s)	R_MEASURE_LEN	s	Set the resistance measurement time.	Generally, no changes are necessary.				
	Ld measured current ratio	L_MEASURE_CURRENT_D_RATE	-	Set the d-axis inductance measurement current ratio.	If the setting value is too low, the error may increase. If overcurrent protection occurs, reduce the setting value.				
	Lq measured current ratio	L_MEASURE_CURRENT_Q_RATE	-	Set the q-axis inductance measurement current ratio.	If the setting value is too low, the error may increase. If overcurrent protection occurs, reduce the setting value.				
Inductance	L measured modulation index	L_MEASURE_VOLT_RATE	-	Set the applied voltage ratio during inductance measurement.	If the setting value is too low, the error may increase. If overcurrent protection occurs, reduce the setting value.				
measure	L measured waiting time(s)	L_MEASURE_WAIT_LEN		Set the waiting time for inductance measurement.	Generally, no changes are necessary.				
	L measured time(s)	L_MEASURE_LEN	s	Set the time for inductance measurement.	Generally, no changes are necessary.				
	Initial applied frequency (Hz)	INIT_FRQ	-	Set the counter used for calculating the initial applied frequency.	Generally, no changes are necessary. Initial value of the applied voltage frequency = (1 / PWM control frequency / (INIT_FRQ * 4))				

#### Table 7.1 List of MTS Setting Parameters

© 2025



### Method for Tuning Motor Control Parameters in FOC TB9M003FG Application Note

	Parameter names on the MTS screen	Parameter names in the header file for MTS	unit	Description	Remarks				
	Applied frequency limit (Hz)	MIN_FRQ	-	Set the counter used for the lower limit of the applied frequency.	Generally, no changes are necessary. Lower limit of the applied voltage frequency = (1 / PWM control frequency / (MIN_FRQ * 4))				
Magnetic	Speed acceleration (Hz/s)	FORCE_SPEED_INC	Hz/s	Set the acceleration and deceleration limits.	The acceleration during back EMF constant measurement varies.				
flux	Modulation factor	PHI_F_MEASURE_VDQ_RATE	-	Set the modulation rate during back EMF constant measurement.	If it is too low, the measurement accuracy of the back EMF constant decreases.				
medoure	Stabilization wait time(s)	PHI_F_MEASURE_WAIT_LEN	s	Set the stabilization waiting time for back EMF constant measurement.	Generally, no changes are necessary.				
Inertia measure	Modulation factor	J_MEASURE_VDQ_RATE	-	Set the modulation rate during moment of inertia measurement.	If it is increased, the reached rotational speed increases.				
	Speed acceleration (Hz/s)	J_MEASURE_ACC_MUL	Hz/s	Set the acceleration during moment of inertia measurement.	The acceleration during moment of inertia measurement varies.				
	Back EMF constant	MAGNETIC_FLUX	Wb	Set the back EMF constant.	-				
Other	Inertia (Kgm2)	INERTIA	kg∙ m^2	Set the moment of inertia.	-				
	Direction	CW_CCW	-	Set the rotation direction.	Positive Rotation: Clockwise only (0) Negative Rotation: Counterclockwise only (1)				

#### 7.2.2. Parameter Setting Window

Figure 7.4 shows an enlarged view of a part of the "Motor Tuning Support" window. A list of the necessary parameters shown in Table 7.1 is displayed. These need to be set for each motor used, so please refer to Table 7.1 for the settings.

Note that simply changing the values in the text boxes will not apply the changes. If there are variables displayed in red, please press the "Upload" button.

The following slides explain the operation methods for (A), (B), (C), and (D) below:

- (A): Measurement of parameters related to PWM mode settings
- (B): Measurement of R and L and setting of current control gains
- (C): Measurement of Ke and J and setting of position estimation gain and speed control gain
- (D): Motor drive using FOC with the settings of (A)-(C)

The Vee Motor Columbon Hep		
Parader + 1.3 Not Standard St		
Wards a March a Setting for RL Measurement		
A Roster Contra method		
👔 🗰 👘 👘 🗰 👘 👘 👘 👘 👘 👘 👘 👘 👘 👘	neasure	
NG 0 MIA -		
16 0 <sup>12</sup> mile - Manharen Rank Har Gala	T	
Ld measured current ratio Modulation factor 0.400 R	R measured current ratio 1	1
the set of	8 measured current ratio 2	0.600
	theosored content to bo z	01000
See		
liper ( ) bits the set bit method 000 ( ) bits the set bit method 0000 ( ) bits the set bits method 0000 ( ) bits the set bits method 0000 ( ) bits the set bits method 0000 ( ) bits method	R measured waiting time(s)	0.100
Spell destrated	and the second sec	
Specify alore the balance the balance of the second s	D	0.000
Typed If gas thinked 210 to 100 to 10	x measured time(s)	0.200
A System withing Content Capital Content control in Content control in Content control in Content content in		
PM/tegany 2000/0 In - Poeter 60/00 P		
Durban mode Stag Nam - Prestan Egitty) 0		
Magnetic flux measure Adviz	vanced Setting	
Initial applied frequency(Hz)		
Speed acceleration(H7/s) 5 Pr	Positioning current ratio	0.5
Applied frequency limit(Hz) 100	ostroning current toto	015
Modulation factor 0.100 Pc	Positioning voltage drop ratio	0.000200
Infrastrug young and a Market autor and a M	Desitioning time(s)	0.600
Lind waterweigt die weter 20 🙀 mAy * Urstannel career sale 0.00 Valuation letter 1.40 Freezond career sale 1.1	ostuoning time(s)	0.000
Followatering U link 0 (give A * (givestand generated 5000 Speed Evolution(b)) (0 Eventue of generated 2 500		Former 1
PMInulating	Peak Current(A)	2.700
Page mobilition Three plage mobilition 1		
Name PM Novi Al 0 S v		
Numer 2007 North Contract Contra		
Dui 1200 mund di L. Marci la near Assentition		
Data 200 Series 40 Series 10 Series 10 Series Series 10 Series Series 10 Series Series 10		
Nach dar weiter and weiter and weiter and		
No you account i time of the new		
Bit pairs with the 2 PWV 0 77 M *		
Press the Upload putton to apply the set	attinas	
AC close with 1988. 1979		
to ACC higher line with 2 MMA O		
Ded AlC bigger free Ark 2 PMA U R 1 MA		
Tatisf Develop		

Figure 7.4 Enlarged View of a Part of the "Motor Tuning Support" Window



#### 7.2.3. (A): Measurement of Parameters Related to PWM Mode Settings

Figure 7.5 shows the screen for measuring parameters related to PWM mode settings.

- 1. Press the "Measure Minpulse" button.
- 2. While the measurement is in progress, the button will turn gray and a "Stop" button will appear. If you want to interrupt the measurement, press the "Stop" button.
- 3. Once the measurement is completed, the changed text boxes will be displayed in red. To apply the measured values, press the "Set Parameters" button.

Note: If the hysteresis for switching between Shift 2 PWM and Shift 1 PWM (Shift 1 PWM hysteresis) or the hysteresis for switching between Shift 1 PWM and Normal PWM (Normal PWM hysteresis) is set to 0, frequent switching of modulation methods may occur. This can lead to unstable control, so it is recommended to input a value other than 0.



Figure 7.5 Screen for Measuring Parameters Related to PWM Mode Settings



#### 7.2.4. (B): Measurement of R and L and Setting of Current Control Gains

Figure 7.6 shows the screen for measuring R and L.

- 1. Press the "Measure RL" button.
- 2. While the measurement is in progress, the button will turn gray and a "Stop" button will appear. If you want to interrupt the measurement, press the "Stop" button.



Figure 7.6 Screen for Measuring R and L



Figure 7.7 shows the screen for calculating the initial values of the current control gain.

3. Once the measurements of R and L are completed, the initial values of the current control gain are automatically calculated. These values are entered as default values in the "Current Gain" tab.

Note: If the measurement or transmission fails, a failure message will be displayed in the log window.

In case of failure, the values have not been measured correctly, so re-measurement is necessary. Please change the parameters used for measuring R and L and re-measure.

neter										
		× Weter Turing Turport			• I X See Case I • I X					
10.0		MotoriD: 0			Motor ID: 0					
cantral					Control method Speed *					
6	o 👘 👘 mV/Aa 🔹				the state					
*	0 101 mil/A =				Want Land					
	o ter envitan +	Matter Paramatar	Pl Gain for Motor Driving		0 2100					
	o Aldre		Current Position Speed							
an Si	o the mitte/Ve +	Residunce(Otm) 0.001		28 40 Youth 2605	Start					
tan Kp	< Water (\$10	Industance Laphi 0.000001	Mervpue	Max value Setting(hoat)						
of Ki beine threshold	o (#) mA/He's -	Industance Left 0.000001 Munute Left	#AVV/Ap3 #400.1932 1201	0 0						
d Kg: beine threshold	o 🕐 mA/hte -	And Dationant and Dates	0.5 1.6		Default					
d K-above threshold	o the mainten -	Manual States	a thora							
d Kp above threshold	o (th) mA/Hz -	(setal(gm2)	Advection -				2) A ft/	ar tha maa	surament is	romnlat
Propert threehold	310 D He -	Current K(K)A() 2 Set Parameter	101	L09 Y			3/710	ei the mea	Surementis	Joinpier
en settings		Current KpD//A)	Current controller Banduidt/Otr	WESD'S					1.1 12	
Inequency.	20000-@- His -	Reation Kithis/Vol 0			and a second		the cha	anded varia	ables are disi	plaved ir
itum mode	Stop two -	Poster (p01n/0)			enlarge			angea ran		
envoltage	49 (\$) V Y	Speed Kilk-Host U			Cinarge "(	Current" t	ah			
viennitane	10 V -	Speed Katk/Hz) 0				current t	ab			
and a rest of the	10 4.1					1				
	Current Drue *	and the second se								
undering parameters				10						
undering threshold	1200 (0) en// =	Setting for FL Measurement		Motor Parameter		Pl Gain for Motor D	riving			
mediators hateress			The state of the s							
territer and the second	625C HERE 1 100 T	Inductory measure	and the statement of th							
undianing Lf developer	200 (10) mA/n =	Ed measured current ratio 0.400	Machine Iron			Current	Position Speed			
I weakening 1d deviation	600 (m) * 200 (m) mA/4 *	Ed measured current ratio	Modulation Sector 0.400			Current	Position Speed			
Eventioning LG deviation Eventioning LG Binit	000 (12) mil/ 1 200 (12) mil/16 ~ 0 (12) A 1	Gi messurel carect ratio 0.400 Gg messurel carect ratio 0.400	Modulation Sactor 0.400 Speed acreteration/http://10	Resistance(Ohm)	1.101	Current	Position Speed		27020200	
t weakening lid devation I weakening lid Emit M mode artifings 	000 00 mV * 200 00 mA/s * 0 0 0 A *	Laf measured carrent ratio 0.400 Laf measured carrent ratio 0.400 La measured ratinett ratio 0.400 L measured modulation index 0.400	Modulation Sector 0.400 Speed acceleration(10)(1)	Resistance(Ohm)	1.101 Measure RL	Current	Position Speed Min Value	Max value	Setting(float)	
I weeklening lid devlation I weeklening lid Britk M mode artilings et modufation	000 (1) mV * 2000 (1) mV * 200	L measured anticipation index	Mathalation factor 0.400 Speed acceleration/fact( 10	Resistance(Ohm) Inductance Lq(H)	1.101 Measure RL 0.000772	Current	Position Speed Min Value	Max value	Setting(float)	
rweekierung tid devaation rweekierung tid Einik Mimoude arttings er moderlaktion nul PRM/ threshold	600 gr         mV *           200 [gr         mA/e *           0 [gr         mA/e *           Three phase modulation *         *           0 [gr         % *	Indextruct measure         0.450           Edit measured covert rolo         0.600           Eq. measured modulation index         0.600           E. measured modulation index         0.600           E. measured modulation index         0.600           E. measured modulation index         0.500           E. measured modulation index         0.500	Madulation Bactor 0.400 Speed acceleration(http://10	Resistance(Ohm) Inductance Lq(H)	1.101 Measure RL	Current Ki(V/As)	Position Speed Min Value	Max value	Setting(float)	
weatering 16 deviation resultationg 18 Emit. Mi mode antiings er medvlattion nal PAMM threshold nal PAMM hysteriais	GOD (W)         MM (V)           200 (W)         mA(V)           0 (W)         A. V           7 Inversion structures         -           0 (A)         S. V           0 (B)         S. V           0 (B)         S. V           0 (B)         S. V	Molecterior mediane     Molecterior mediane     Molecterior     Molecteri     Molecteri	Mandudaian Entre Speed ansierantopitiput 0 Magnetii Rus maaawe	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H)	1.101 Measure RL 0.000772 Measure Gain	Current Ki(V/As)	Position Speed Min Value	Max value	Setting(float)	Defents
weakening tid devation waakening tid limit; If mode antiings it mode/antificing nal PWM (threahold) nal PWM (threahold) T PWM (threahold)	col (g)         m/s           col (g)         m/s           0 (g)         m/s	Ide Research and an end of the second s	Maddation Solar (2000) Speed antivestophistic (2000) Magnetic Rus measure Speed Sciences (2000) (5	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H)	1.101 0.000772 0.000548 Measure Gain 0.0002	Current Ki(V/As)	Position Speed Min Value	Max value	Setting(float)	Default
weekening til devation weekening til Ewik di mode artilings i modelaföion nal 79054 Overähold al 29054 hysteresis 1 29054 hysteresis	$\begin{array}{c} & & & & & & & & \\ \hline & & & & & \\ \hline & & & &$	Advances	Maddatist Schor 0.400 Speed antivestoologing 0 Magnetic Reviewsone Speed antivestoologing 5	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Total Measure Gain	Current Ki(V/As) Kp(V/A)	Position         Speed           Min Value         518.83           0.258	Max value 3458.868 1.722	Setting(float) 726.715 0.362	Default
uwelening tid devation Insulaning tid Enik Mi modie antilegs er noduktion nal PAMA (Insulad mal PAMA (Insulad INMA (Insulanis) 1 PAMA (Insulanis) pulse two phase moduletion	$\begin{array}{c} 00^{-1} \frac{100}{100} & mV^{-1} \\ 00^{-1} \frac{100}{100} & \frac{100}{100} & \frac{100}{100} \\ 0^{-1} \frac{100}{100} & \frac{100}{100} & \frac{100}{100} \\ 0^{-1} \frac{100}{100} & \frac{100}{100} \\ 0^{-1} 10$	Kall Research Landsong         ALRO           Kall Research Landsong Landsong         ALRO           Kall Research Landsong Landsong         ALRO           Landsong Landsong Landsong         ALRO           Landsong Landsong Landsong         ALRO           Landsong Landsong Landsong Landsong         ALRO           Landsong Land	Maduation Sector 0.400 Speed anotextrophoty 01 Magnetic Run masaw Speed anotextrophoty 010 (	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb)	1.101 D.000772 D.000548 Measure Gain D.0002 Measure Mirpulse D	Current Ki(V/As) Kp(V/A)	Position         Speed           Min Value         518.83           0.258	Max value 3458.868 1.722	Setting(float) 726.715 0.362	Default
weakening til devation weakening til Emit M mode artilings er modulasion nal PAMA Usreihold nal PAMA Usreihold al PAMA Usreihold 1 PAMA Usreihold 1 PAMA Usreihold 1 PAMA Usreihold public two phase modulation public three phase modulation	$\begin{array}{c} & & & & & & & & & & & \\ \hline & & & & & & &$	Generative resolution     Generative re	Madulation Status Speed amsteadcolyboxy Magnetic Rus reasoner Speed amsteadcolyboxy Statustication and theory Statustication and theories	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2)	1.101         Measure RL           0.000772         Measure Gain           0.000548         Measure Gain           0.0002         Measure Mepulse	Current Ki(V/As) Kp(V/A)	Position         Speed           Min Value         518.83           0.258	Max value 3458.868 1.722	Setting(float) 726.715 0.362	Default
weakering til deviation weakering til Ensit 41 mode settings er modviation ul PAM tystenesis 12 PAM ty	$\begin{array}{c c} & & & & & & & & & & & & & \\ \hline & & & & &$	Generation readout     Generation     Generati	Maddadlar Sicher Speed ansetwation/bining Magnetiit, Rai massaw Speed antineenkon/bining Maddadlare Sicher Stebilization waht tweeto	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Mirpulse           0         Measure Mirpulse	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258	Max value 3458.868 1.722	Setting(float) 726.715 0.362	Default
weakening til deviation weakening til Enrit M rocke antlings rocke antlings rocke til som al PAMM threahold al PAMM threahold 1 PAMM threahold 1 PAMM threahold 1 PAMM threahold 1 PAMM threahold 1 PAMM threahold weaken threahold pake modulation rocke threa place modulation rocke threa place	$\begin{array}{c} 000 \ \mbox{[20]} & mn^{-1} \\ 000 \ \mbox{[20]} & mAA = \\ 000 \ \mbox{[20]} & mAA = \\ 000 \ \mbox{[20]} & mAA = \\ 0000 \ \mbox{[20]} & mA = \\ 0000 \ [2$	Germannen erweisen     Germannen diveren solle     Germannen diveren di diveren diveren diveren diveren di diveren diveren diveren divere	Maddation Solar Speed analiseston/bioly Speed analiseston/bioly Speed analiseston/bioly Maddation Solar Stelekization and thereit	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Micpulse           0         Measure Micpulse           726.715         Set Parameters	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258	Max value 3458.868 1.722 105.051	Setting(float) 726.715 0.362	Default
transforming to devantion. Transforming to limit, the mode antitype an implementation and PAMM transforming in PAMM transforming in PAMM transforming in PAMM transforming packet they phase incoductions packet they phase incoductions phase incoductions phase incoductions phase incoductions phase incoductions phase incoductions phase incoductions phase incoductions phase incoductions phas	$\begin{array}{c} \cos(2\theta) & \sin^{-1} \\ \sin(2\theta) & \sin^{-1} \\ 0 & 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$	Ide International Control State     Ide International Control	Maladata Satur Bado Speed anatomicrofitig 9 Magantis Ran masser Speed antinentino(big) 5 Maladatan Satur Stabilization and Imagi 03	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Minpulse           726.715         Set Parameters           0.562         Set Parameters	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258	Max value 3458.868 1.722 105.051	Setting(float) 726.715 0.362	Default
sentiering Li decation meakening Li Dek Mi mode arthropi en oblakion and PAM Hystenesia in PAM Hystenesia 1 PAM Hystenesia 1 PAM Hystenesia pular waith ahr 1 PAM pular waith ahr 1 PAM pular waith ahr 1 PAM pular waith ahr 1 PAM dalay 2 phase PAM	$\begin{array}{c} \cos(2) & \sin^{-1} \\ \sin(2) & \sin^{-1} \\ \cos(2) & \sin^{-1} \\ \sin^{-1} \\ \cos(2) & \sin^{-1} \\ $	Grinnanskov     Grinnansk	Maddation State: 0.400 Speed analisedicrobiologi 10 Magnetic Ran masses Speed analisedicrobiologi 10 Maddation Rock: 0.10 Statebilization and threads 0.5 Update: Desertioned	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Ki(V/As)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Mepulse           726.715         Set Parameters           0.362         Set Parameters	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default
d undersong Ld devation of medicine og Ll dev Min onder artifisje om moduliker and PMM hysterskin in PMM forsenheld and PMM hysterskin is 1 PMM forsenheld is 1 PMM forsenheld is 1 PMM forsenheld is 1 PMM forsenheld gabet meng hanse moduliker gabet meng hanse moduliker gabet meng hanse moduliker gabet meng hanse PMM Calety 2 sphane PMM Calety 2 sphane PMM	$\begin{array}{c} \cos \left( 2 \right) & \sin x \\ \sin \left( 2 \right) & \sin x \\ \cos \left( 2 \right) & \sin x \\ 0 & \cos x \\ 0 & \sin x \\ 0 & \sin$	Generative resource     Generative     Generat	Maduata Satur Buto Speed antivesticolything 9 Magnetic Bas masses Speed antidepticolything 5 Maduatation Satur 9 Stabilization and throug 95 Uptical Description	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Ki(V/As) Current Kp(V/A)	1.101         Measure Ri           0.000772         Measure Ri           0.000548         Measure Gain           0.0002         Measure Mirpulse           726.715         Set Parameters           0.362         O	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258 Current controller Ban	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default
d anation of 16 devation of anatorio (s) 4 line; Min order artistica and PAM Instancia and PAM Instancia and PAM Instancia and PAM Instancia and PAM Instancia and PAM Instancia (s) PAM Instanc	$\begin{array}{c} \cos(2) & \sin^{-1} \\ \sin(2) & \sin^{-1} \\ \cos(2) & \sin^{-1} \\ $	Grimmanne energiese and an	Madukatu fasiri 840 Seed antirestorotojoji 9 Magneti Ran mazen Seed antirestorotojoji 1 Madukatu Ran Markov Setolataria sad tineto 65 Upitali Deseitat	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Ki(V/As) Position Ki(Hz/Vs)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Mirpulse           726.715         Set Parameters           0.562         0	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258 Current controller Ban	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default
Exercision of Lifescenton analization of Lifesce Min order attributes are modulation and PAMA distancial and PAMA distancial and PAMA distancial and PAMA distancial and PAMA hypotensis and pAMA hypotensis a	$\begin{array}{c} \cos 2 & \sin x \\ \sin x \\ \sin 2 & \sin x \\ \cos 2 & \sin x \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\$	def mensande over role 0400     de mensande over role 0400     equinassande over role 0400     executed modelates hole     executed model	Madulation State Speed antivestication(bits) Magnetic Ran masses Speed antivestication(bits) Madulation State Statebistation and Strategi Update	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Ki(V/As) Position Ki(Hz/Vs) Position Ki(Hz/Vs)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Megulse           726,715         Set Parameters           0.362         Set Parameters           0         0	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258 Current controller Ban	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default
d mattering (d devation d mattering (d devation d mattering) or mobilitation main PAM threahuld and PAM threahuld and PAM threahuld in 1 PAM threahuld apice within which it PAM apice within which it PAM apice within which it PAM apice within which it PAM ADC trapper time with 2 PAM ADC trapper time with 2 PAM	000         001         001           000         001         001         001           000         001         001         001         001           000         001         001         001         001         001           000         001	Gir maximal and print table and table     Gir maximal and print table and table     Gir maximal and print table     Gir m	Maddatia fasiri 840 Seend anatestatoribiti 9 Magneti An mazer Seend anatestatoribiti 1 Madata Anatoribiti 1 Madata Anatoribiti 1 Madata Marka 1 Matata Marka 1 Matata Marka 1 Matata Marka 1 Matata Marka 1 Matata	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Ki(V/As) Current Kp(V/A) Position Ki(Hz/Vs) Position Kp(Hz/V)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Mispulse           726.715         Set Parameters           0.362         0           0         0	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258 Current controller Ban	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default
Inensience (s) di devatione Franchistering (s) di devit Min order attribuis en reduktioni and PMM Insolutioni and PMM Insolutioni and PMM Insolutioni 1 PMM In	000         001         001           010         001         001         001           010         001         001         001         001           010         001         001         001         001         001           010         001	Grimmanne energie	Madukatur Sator Speed aminestorofotoji Magastri, Ruo mazave Speed Aminestorofotoji Madukatur Sator Stabilantur wat timoji Stabilantur wat timoji St	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Ki(V/As) Position Ki(Hz/Vs) Position Kp(Hz/V) Speed Ki(A/Hzs)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure RL           0.0002         Measure Mirpulse           726.715         Set Parameters           0.362         Set Parameters           0         0           0         0	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258 Current controller Ban	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default
Invaliancy (al devalues Invaliancy) (al Gen), Mi order antises an endelation and PAM Invaliancy and PAM Invaliancy (al PAM Invaliancy) (al PAM Inv	000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000           000         000         000	Gri manuarda unertirologia antoni Gri manuarda unertirologia antoni Gri manuarda unertirologia antoni Erenaurudi montolitario Indiano Mareaurudi Integlio Mareaurudi I	Madukatu fasiri Sgend anatestatoribiti Magashi, Nan mazara Sgend anatestatoribiti Mada Sala Salakitatina wati kwela (1) (gatashi	Resistance(Ohm) Inductance Lq(H) Inductance Ld(H) Back EMF constant(Wb) Inertia(Kgm2) Current Ki(V/As) Current Kp(V/A) Position Ki(Hz/Vs) Position Kp(Hz/V) Speed Ki(A/Hzs)	1.101         Measure RL           0.000772         Measure RL           0.000548         Measure Gain           0.0002         Measure Mispulse           726.715         Set Parameters           0.362         Set Parameters           0         0           0         O	Current Ki(V/As) Kp(V/A) Adjust Kp/Ki	Position Speed Min Value 518.83 0.258 Current controller Ban	Max value 3458.868 1.722 105.051 dwidth(Hz) 105.051	Setting(float) 726.715 0.362	Default

Figure 7.7 Screen for Calculating Initial Values of Current Control Gain



Figure 7.8 shows the screen for tuning the current control gain.

- 4. To apply the measured values to the "Parameter" window, press the "Set Parameters" button. Note: The current control gain may work without changes from the initial values, but if you want to tune it, you can use the slider within the range from the minimum to the maximum value. If you want to reset to the initial values, press the "Default" button.
- 4. Press the "Upload" button to apply the settings, which will be used for motor control.



Figure 7.8 Screen for Tuning Current Control Gain



#### 7.2.5. (C): Measurement of Ke and J, and setting of position estimation gain and speed control gain

Figure 7.9 shows the screen during the measurement of Ke, J.

- 1. Press the "Measure Gain" button.
- 2. While the measurement is in progress, the button will turn gray and a "Stop" button will appear. If you want to interrupt the measurement, press the "Stop" button.



Figure 7.9 Screen During Measurement of Ke and J



Figure 7.10 shows the screen for calculating the initial values of position estimation and speed control gains.

- 3. Once the measurements of Ke and J are completed, the initial values of the position estimation gain and speed control gain is automatically calculated. These values are entered as default values in the "Position" tab and "Speed" tab.
  - Note: If the measurement or transmission fails, a failure message will be displayed in the log window. In case of failure, the values have not been measured correctly, so re-measurement is necessary. Please change the parameters used for measuring Ke and J and re-measure.



Figure 7.10 Screen for Calculating Initial Values of Position Estimation and Speed Control Gains



Figure 7.11 shows the screen for setting position estimation and speed control gains.

- 4. To apply the measured values to the "Parameter" window, press the "Set Parameters" button in the "Position" tab and the "Speed" tab, respectively.
  - Note: Particularly, If the position estimation gain and speed control gain remain at their initial values, errors may occur, and the system may stop after switching to the steady stage. In this case, you can tune the slider within the range from the minimum to the maximum value. If you want to reset to the initial values, press the "Default" button.
- 5. Press the "Upload" button to apply the settings, which will be used for motor control.

4	Motor parameters		<b>B</b> 3	SewettinCD** Matter Statio						Makes Paramates			Di Guin Ine Materi	Decision			_
	Polepairs	4 🗮	7 m	Pere Motor D. Catolators He Recentled		A Martin Court Report		*11	-	NIGHT Parameter			Current	Decition Sneed			
"Parameter" /	Direction	Clockwise only ~	ball	Mater D: 0		Manado e			Mater ID: 0 Control meth	Resistance(Ohm)	1.101	( and the second	content	- spece			
window	Force acceleration	10 🖨 Hz/s 👻	8	ie G Ie fa	- AKSH= 1400 - AKSH= 1400				Speed (1994	Inductance Lo(H)	0.000772	Measure RL		Min Value	Max value	Setting(float)	
window	Force deceleration	10 🜩 Hz/s 👻		14.6 14.6a	e =	Marter Faustration	the second second		-	Inductance Ld(H)	0.000548	Measure Gain	Ki(Hz/Vs)	0.238	95.013	24.743	
	FOC acceleration	35 😴 Hz/s *		Realizer G	0 <sup>(1)</sup> ==00000 =	Researching 2021	Min Value - Min Value	er benahus		Back EMF constant(Wb)	0.00731		Kp(Hz/V)	1.813	36,256	16.502	Default
	FOC deceleration	35 😧 Hz/s 👻		Speed & being threehold	· *****	Inductions La(20) 5.00001 Inductions La(20) 5.00001 Inductions La(20) 5.00001 Induction La(20)	50/241 482.987 5001.282	*		Inertia(Kgm2)	0.00068	Measure Merpular	Adverter		Adduct Kords		
	Torque factor	35 🚔 mNm/A ×	enlarg	Speed Kp below Breefield	official states -	Back Diff provident/bbg Addoor	Fg(5(4) 0.23 1465	a Difeit		Current Ki(V/As)	726.715	Set Parameters	wolvor.cb	0.9989899	Aufust Karki	2,351515	
	Resistance	1101 🔹 mΩ *	emarg	Speed Kp above Resoluted	0 <sup>(8)</sup> m4/10 - 7-0 <sup>(8)</sup> He -	Correct 6008d P	Adust Name -0			Current Kp(V/A)	0.362						
	Inductance Lq	772 😴 µH *		<ul> <li>System settings</li> </ul>		Current RyV(A)	Connect controller Bandwatth/http:///	53.0		Position Ki(Hz/Vs)	24.743		N	Damping Ratio	0.9989899		
	Inductance Ld	548 💭 🛛 µH 🗡		Shutdown mode	Ship tee *	Paskes Sp(1)(1)				Position Kp(Hz/V)	18.502						
	Speed limit	140 🚭 Hz 👻		SH sumships SH underschape	- (1) V - (1)	Speed Rick Hut				Speed Ki(A/Hzs)	0.064						
	Speed change	80 🗣 Hz 👻		107 contained	* (d) A *					Speed Kp(A/Hz)	0.022						
	Position reach	500 🖨 ms 👻		· Fahl underling parameters		- Territori da El Management											
	Position wait	1000 🜩 ms 👻		Faid analisming hyderece	ant (2) and -	Industance manage	Instantiant Engine			ntor Parameter 51 G.			Pl Gain for Mator Driven				
	lq start	1000 🖨 🛛 mA 👻		Fahit analors y 16 decates Fahit analors of 18 Mil	200 🔄 mA/1 * 0 (g) A *	Lat measured current ratio 0.420 Lat measured current ratio 0.420	Medulation factor (1400)	Rimssand over tals 1 1 Einessand over tals 1 1.000					Current	Position Sored			
	ld start	1100 🗢 mA 👻		<ul> <li>PWM multi-artitinga</li> <li>Page multidation</li> </ul>	Tree chair mobilities *	a manufacture index 0.900		Emanand waiting time(g) 0.100		Resistance(Ohm)	1.101			in the second			
	Idq limit	4500 🖨 mA 👻		Normal PAIM threaksaid	4 <sup>(2)</sup> 5. 4	L measured and the first A 100		Energian (1996)		Inductance Lq(H)	0.000772	Measure RL	1	Min Value	Max value	Setting(float)	
Changed variables	Back EMF constant	184 🜩 mV/Hz 👻		Suit 1 PBNI sveehold	- 10 x -	total applied test-sources	Magnetic Rue manage	Advanced Setting		Inductance Ld(H)	0.000548	Measure Gain	Ki(A/Hzs)	°	20.251	0.084	0.6.4
	Motor name	ACT428LF01_1sh		Shift 1 PBM hysteresis Nin pulsa tere phase readulation	·** · · ·	Applied Requests (Institute 199	Madulation factor 0.100	Pastoring volage drag rate 0.00000		Back EMF constant(Wb)	0.00731	[How we have been been been been been been been be	Kp(A/Hz)	4	0.343	0.022	Delaur
are displayed in red	<ul> <li>Pl control</li> </ul>			Min pulse three phase modulation Min pulse with and 1 2007	·** **		Stabilization and tenetic (41	Pastoong Searcy 0.400		Inertia(Kgm2)	0.00068	New York Residuate	Adjust Ko		Advert York		
	ld Ki	sz characters max. mV/As ~		Min pulse width and a Politi	• <sup>[8]</sup> •• •			Pear Carentina 2.50		Current Ki(V/As)	726.715	Set Parameters	endow ub	0.1	Helen de la	0.00009798	
\	ld Kp	362 😴 mV/A 👻		ADC delay 2 phase PMM ADC delay 2 phase PMM	- 10 M		Uplant Deveload			Current Kp(V/A)	0.362					22	
\	lq Ki	726715 🔷 mV/As ~		ADC delay sick 1 PMM Tet ADC trigger fore shift 2 PMM	ана (19) 1900 — 1911 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1912 — 1					Position Ki(Hz/Vs)	24,743		Omega Or	separa Tuning	o Dar	nping ratio	
\	lq Kp	362 💼 mV/A ~		and ASS suggestions with 2 PMM	- m -	H				Position Kp(Hz/V)	18,502				Gai	n adjustment 10206.16	
\	Position Ki	24743 🔹 mHz/Vs 👻		these desires				5 K.		Speed Ki(A/Hzs)	0.004			//	131.6566		_
N	Position Kp	18502 🚔 mHz/V ~								Speed Kp(A/Hz)		E					
	Speed Ki below threshold	84 🖨 mA/Hz*s *	5)Dra	acc tha '	'I Inload	" button to apply	the settings							_			
	Speed Kp below threshold	22 🖨 mA/Hz ×	SJEIG	ess the	opioau	button to apply	the settings				4)F	ress the	e "Set	Paramet	ters" butt	on to app	ly
	Speed Ki above threshold	84 💭 mA/Hz*s 🗡									,	the cot	tinge	to tho n	aramatar	window	
	Speed Kp above threshold	22 🖨 mA/Hz 🗡										the set	ungs	to the p	arameter	window	
	Speed Pl gain threshold	210 🖶 Hz *															

Figure 7.11 Screen for Setting Position Estimation and Speed Control Gains

# TOSHIBA

#### 7.2.6. (D): Motor drive using FOC with the settings of (A)-(C)

Figure 7.12 shows the screen for position estimation and speed control gain tuning.

- 1. In FOC, use the values on the "Parameter" window, and refer to Table 2.1 (List of Configuration Parameters), Table 3.1 and Chapter 3. If there are variables in red, it means the settings have not been applied, so please press the "Upload" button.
- 2. In the "Speed Control 0" window, set the motor control commands. Target speed and start/stop can be executed during operation.
- 3. If necessary, tune the motor control parameters in the "Parameter" window or the PI control gains in the "Motor Tuning Support" window.



Figure 7.12 Screen for Position Estimation and Speed Control Gain Settings

#### 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.
- (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.



#### 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.
- (2) Thermal Shutdown Circuit

Thermal shutdown circuits do not necessarily protect ICs under all circumstances. If the thermal shutdown circuits operate against the over temperature clears the heat generation status immediately.

### **RESTRICTIONS ON PRODUCT USE**

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA". Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.
- PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE"). Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT. For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please
  use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including
  without limitation, the EU RoHS Directive. TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT
  OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.

# **Toshiba Electronic Devices & Storage Corporation**

https://toshiba.semicon-storage.com/