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

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1. Purpose and Intention of This Document

The TB9M003FG series product of the microcontroller-integrated gate driver IC “SmartMCD™” 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.

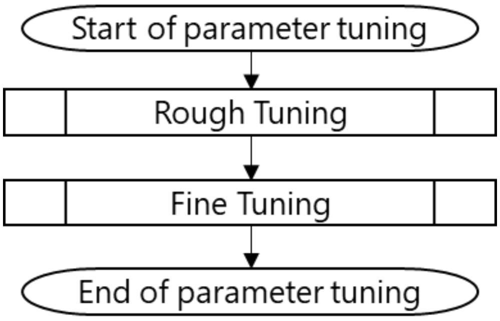

Figure 2.1 Flowchart of the Parameter Tuning Procedure

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™ 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.

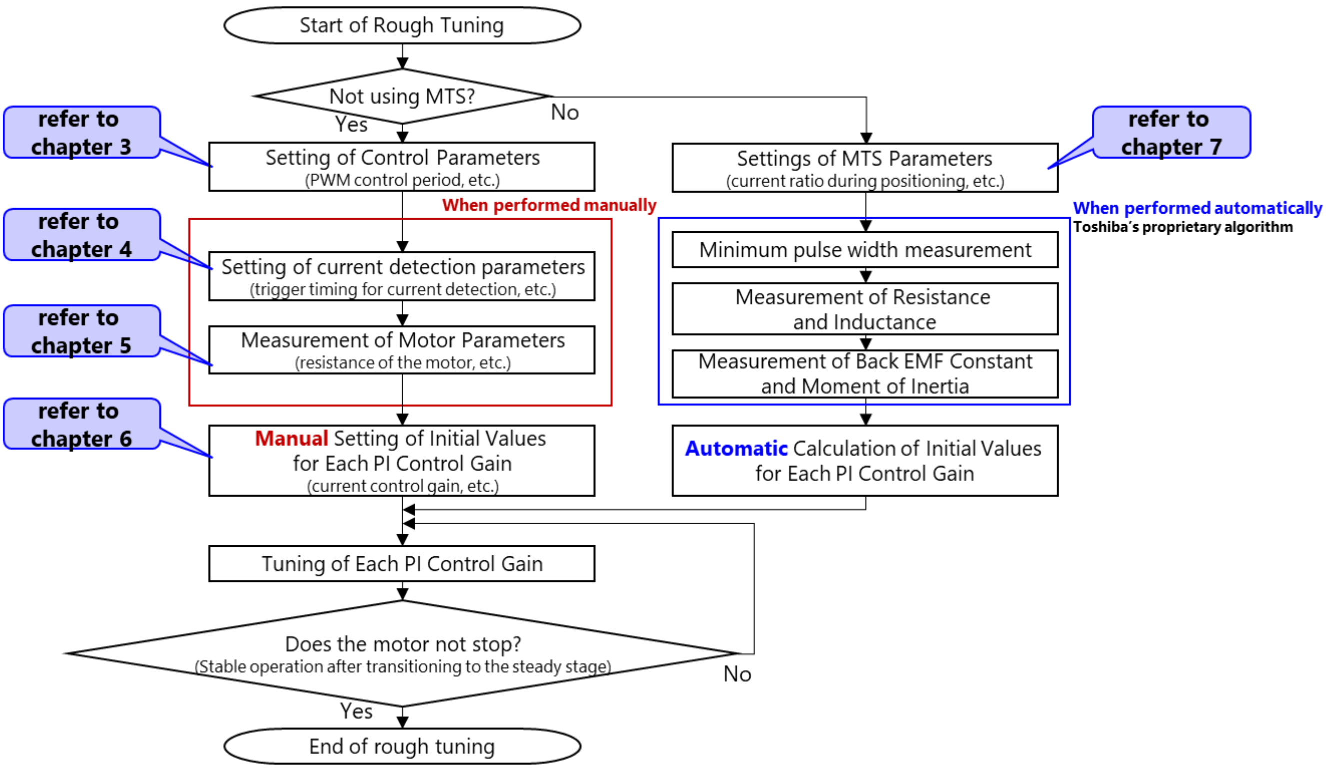

Figure 2.2 Flowchart of the Rough Tuning

Figure 2.3 shows the flowchart for fine tuning

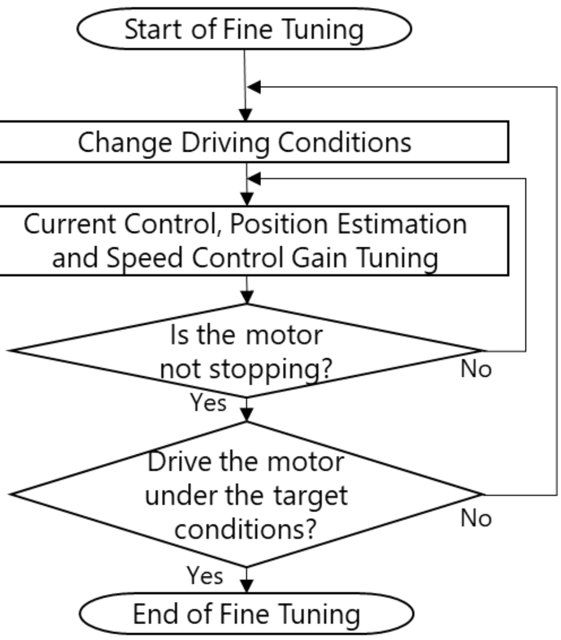

Figure 2.3 Flowchart of Fine Tuning

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

Table 2.1 List of Configuration Parameters

Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS) [For MTS, please use the parameter name listed in this column.]	Unit	Description	Remarks	The detailed description chapter
Initial Setting	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.	–
	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 (Ω) * A_MAX (A) * Current detection amplifier gain = 2.5 (V) ⇔ A_MAX (A) = 2.5 (V) / Shunt resistance value (Ω) / Current detection amplifier gain	–
	SPD_MAX	SPD_MAX_DEF	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	A	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	A	Set the current limit value.	Change from the default value as necessary.	–

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
Initial Settings	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 value per phase according to the motor being used.	5.3
	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.	
	MTR_KE	MTR_KE_DEF	V/Hz	Set the motor's back electromotive force (EMF) constant.	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	POLE_DEF	-	Set the number of poles of the motor.	Set the number of poles of the motor being used.	5.5
	PWM_PERIOD	PWM_PERIOD_DEF	μs	Set the PWM control period.	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	–	μs	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.	–
Current Detection	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
	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) For MTS, please use the parameter name listed in this column.	Unit	Description	Remarks	The detailed description chapter
Current Detection	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 = √3 * Vdq / Vdc	–
	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.	–
	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.	4.1.2 4.2.1
	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.	
	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.	
	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.	
Positioning	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. If the motor does not move, gradually increase the value.	–
	INIPOS_TIME	INIPOS_TIME_DEF	s	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_DEF	s	Set the ramp-up time.	Basically, no tuning is necessary.	3.3, 6.3.1
	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 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.	6.3
	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.	

Phase	Parameter Name (mc_config.h corresponding to the reference software)	Parameter Name (Header File for MTS) For MTS, please use the parameter name listed in this column.	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 current control proportional gain of the d-axis current.	
	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.	
Forced commutation	VD_TARGET_INI2	VD_TARGET_INI2_DEF	V	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.	–
	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, but it needs to be tuned according to the load when there is a load.	6.4.1
	WAIT_TIME_CHGUP	–	s	Set the waiting time after the change-up.	Basically, it doesn't need to be changed but 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.	6.4
	POS_KI	POS_KI_DEF	Hz/Vs	Set the position estimation integral gain.	Tune so that the d-axis induced voltage becomes zero.	
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

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_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.	–
Field weakening	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.	–
	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_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	A	Set the maximum value of the field weakening current.	Set a negative value.	–
Others (Tune as necessary)	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.	–
	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.	–
	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) For MTS, please use the parameter name listed in this column.	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 (Tune as necessary)	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.	
	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.

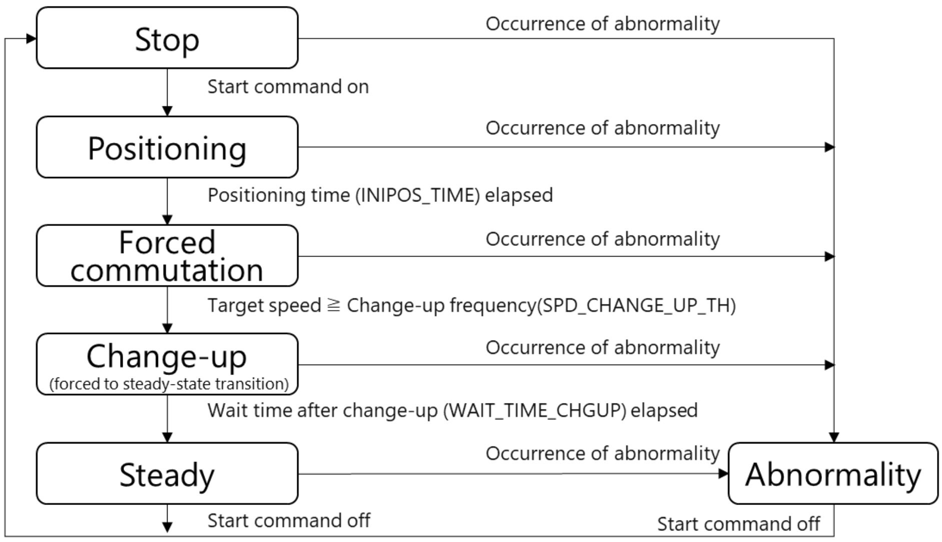

Figure 3.1 State Transition Diagram of Motor Control

3.2. Stage Transitions and Control States

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

Table 3.1 Stage Transitions and Control States

Stage		①stop	②positioning	③forced commutation (open loop control)	④change-up (Forced → Steady)	⑤steady (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)	
Current control	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) → 0	0(Note)
	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	reference speed	0	0	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)	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 + PWM control cycle * Estimated speed)	Calculated from estimated speed (Position = Previous position + PWM control cycle * Estimated speed)
	state	off	off	on	off → on	on

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.

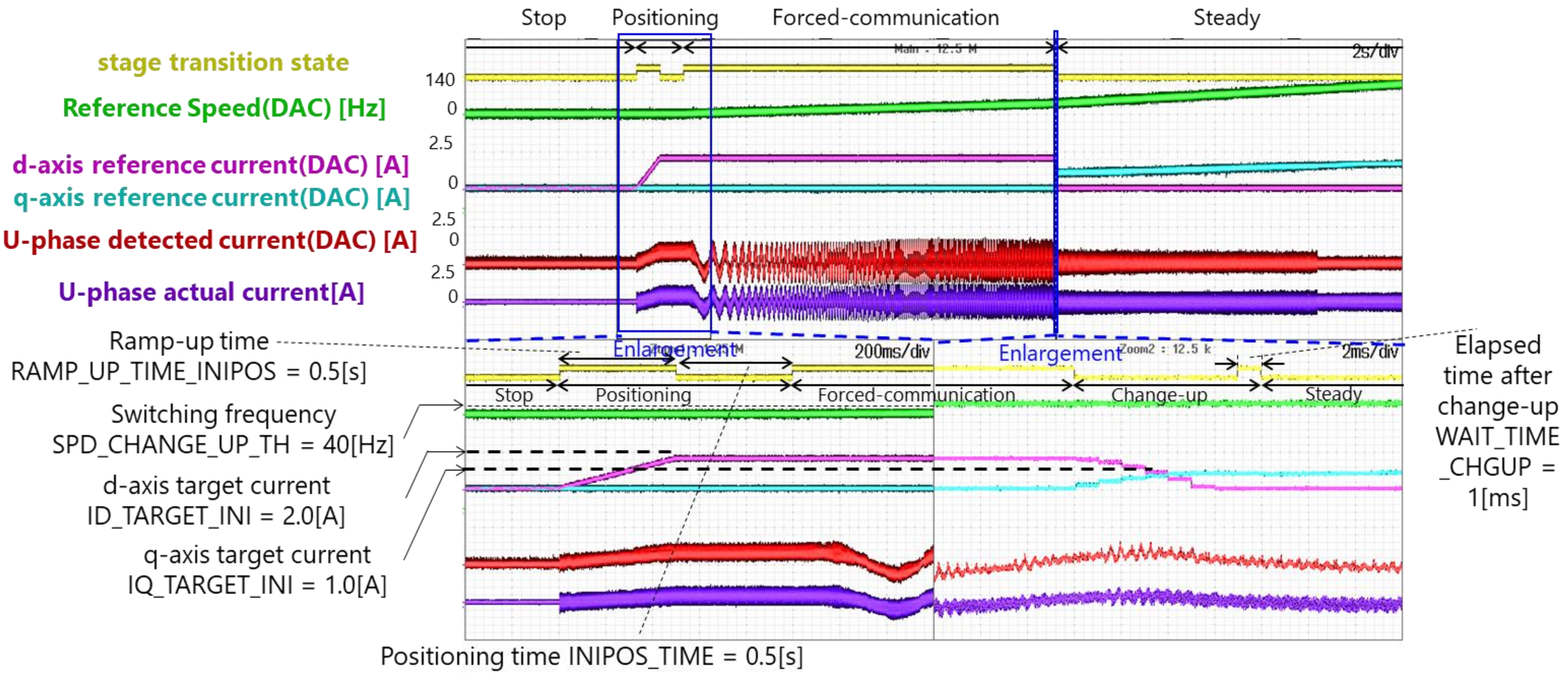

Figure 3.2 Experimental Waveforms of FOC

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 (1) for miniaturization and cost reduction. In 1-shunt 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.

(1) 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.

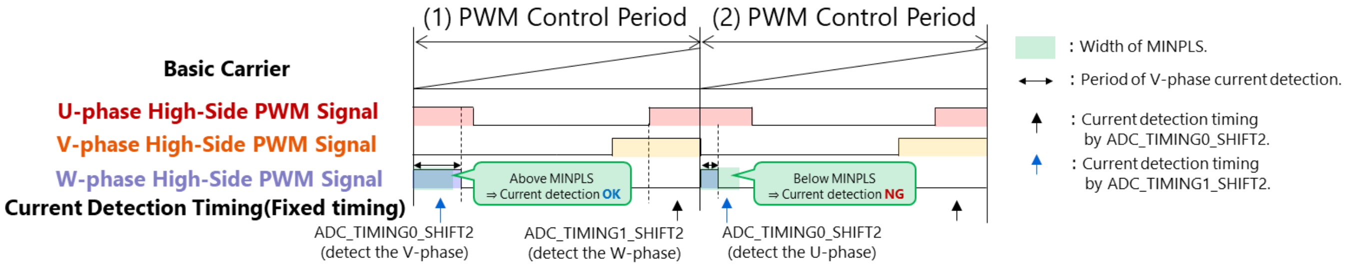

Figure 4.2 Example of Current Detection Timing in Shift 2PWM

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.

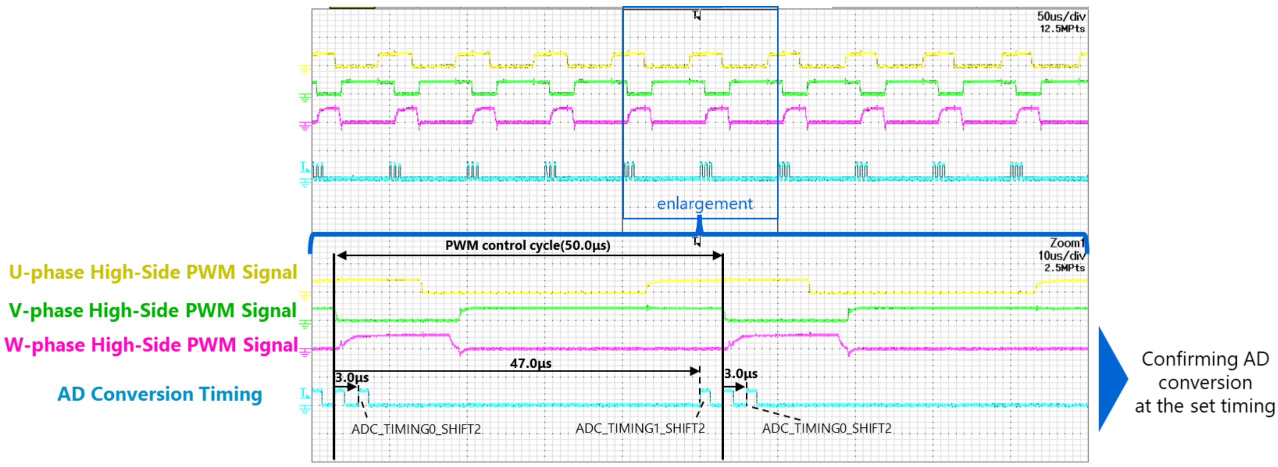

Figure 4.3 Experimental Waveforms of Current Detection Timing in Shift-2 PWM

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.

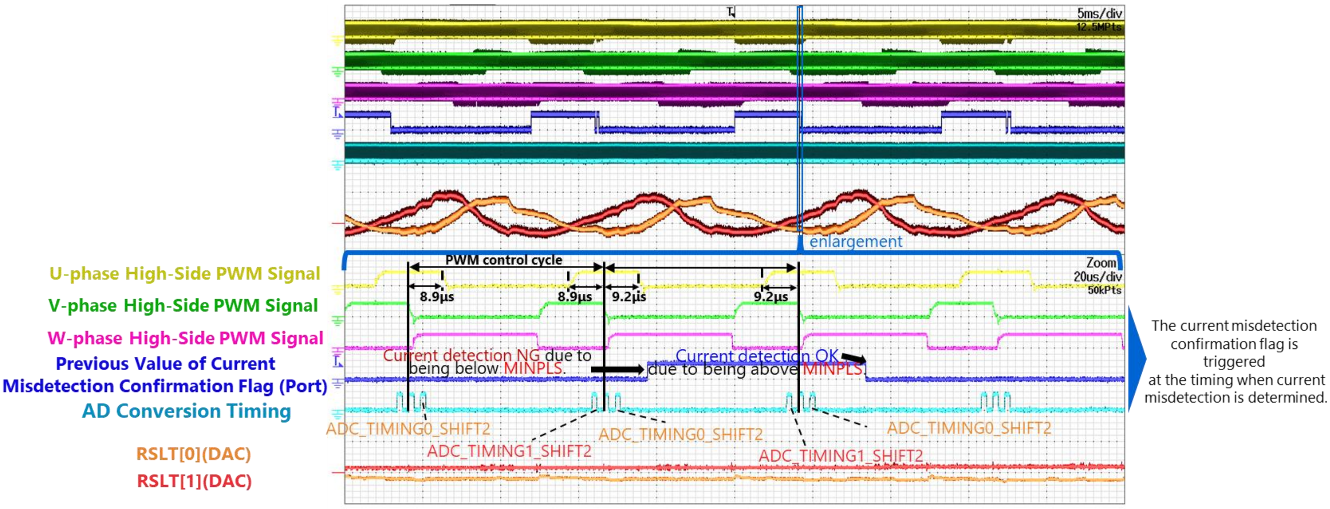

Figure 4.4 Current Detection Timing in Shift-2 PWM
(Example of False Detection Flag Triggering)

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

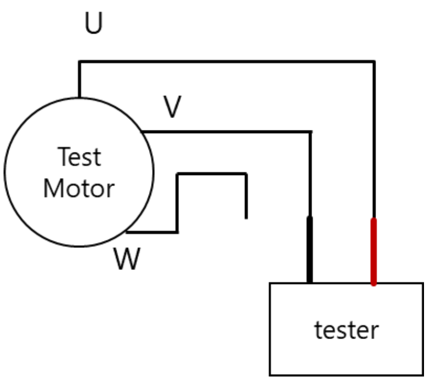

Figure 5.1 An example of measuring the resistance between the U and V phases

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.

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

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

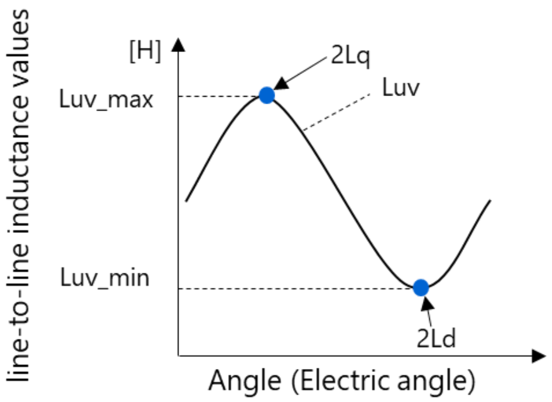

Figure 5.2 The image of the change in inductance between the U and V lines when the test motor is rotated

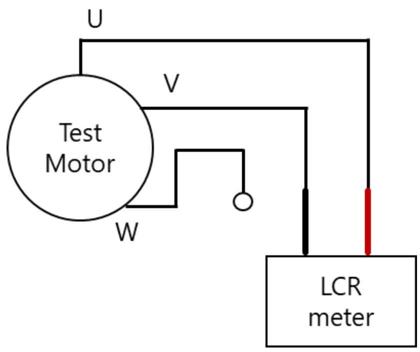

Figure 5.3 An example of measuring the inductance between the U and V phases

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 √ (3) to convert it to the peak value Vpeak of the phase voltage before calculating the back EMF constant.

MTR_KE = Vpeak / f

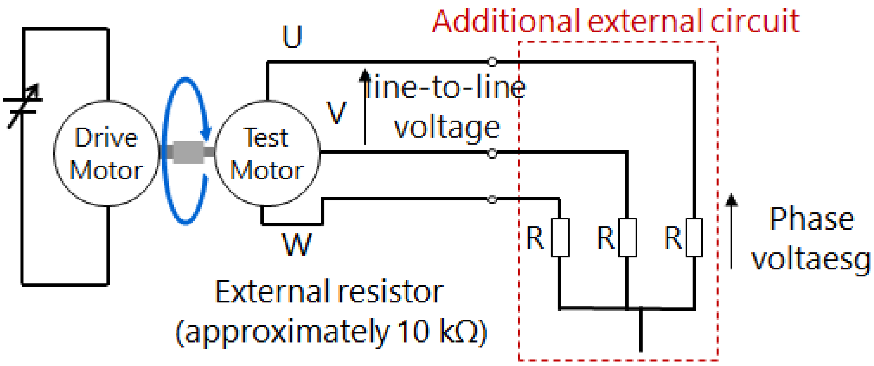

Figure 5.4 Example of measuring the back EMF constant
(Dashed line area is only necessary when measuring phase voltage)

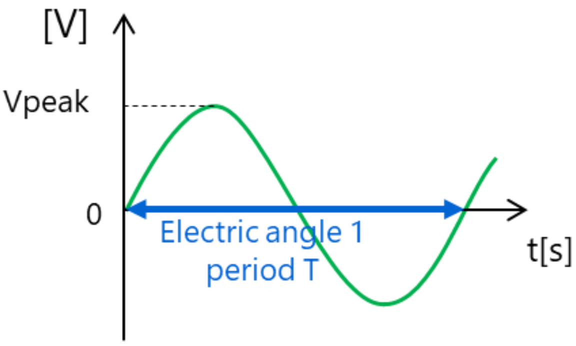

Figure 5.5 Image of the induced voltage (phase voltage) when the test motor is rotated at a certain speed

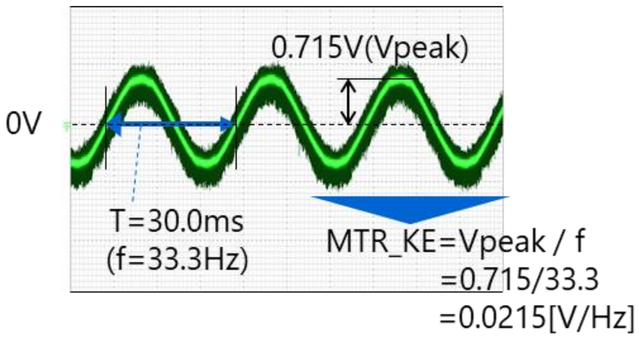

Figure 5.6 Induced voltage waveforms when a test motor with 4 poles is rotated by the drive motor (@1,000rpm)

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)

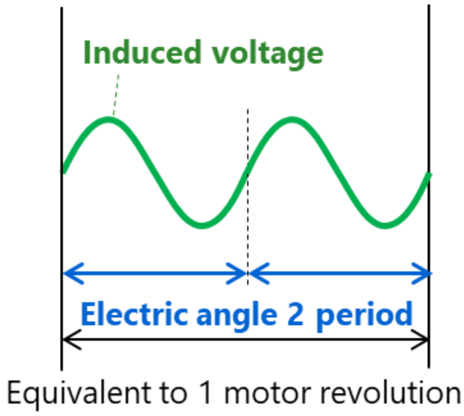

Figure 5.7 Image of pole number measurement (motor with 4 poles)

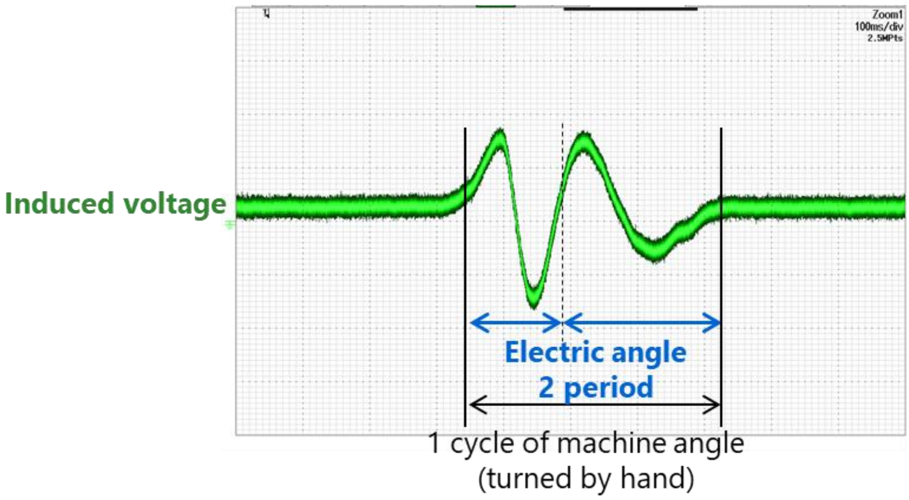

Figure 5.8 Example of manual pole number measurement
(motor with 4 poles)

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)

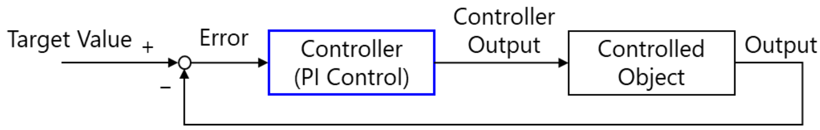

Figure 6.1 Block diagram of PI control

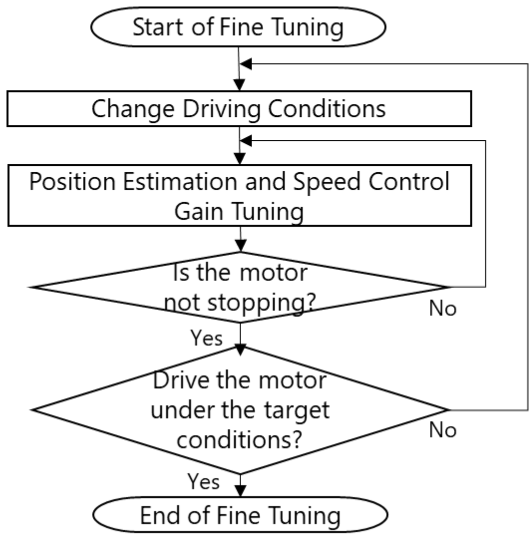

Figure 2.3 Flowchart of Fine Tuning (reprinted)

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 (Idref) with the d-axis current (Id).

Similarly, for q-axis current control, the q-axis voltage (Vq) is controlled to match the q-axis reference current (Iqref) with the q-axis current (Iq). In the positioning and forced commutation stages, the q-axis reference current (Iqref) 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.

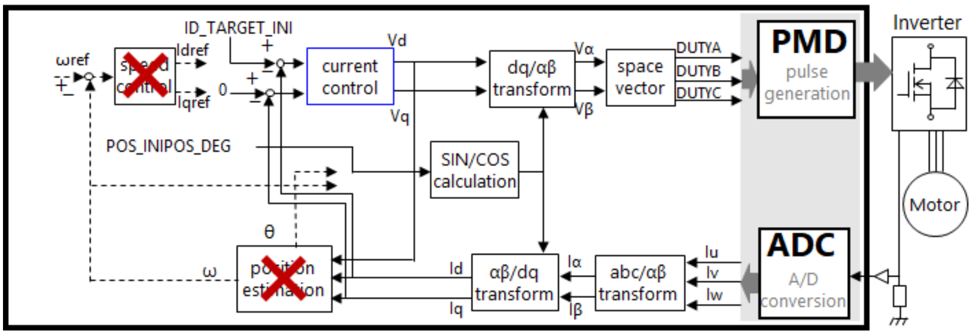

Figure 6.2 Block Diagram of the Positioning Stage

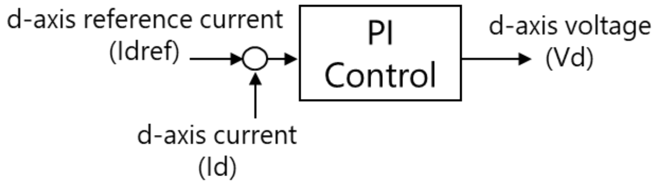

Figure 6.3 Block Diagram of Current Control

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.

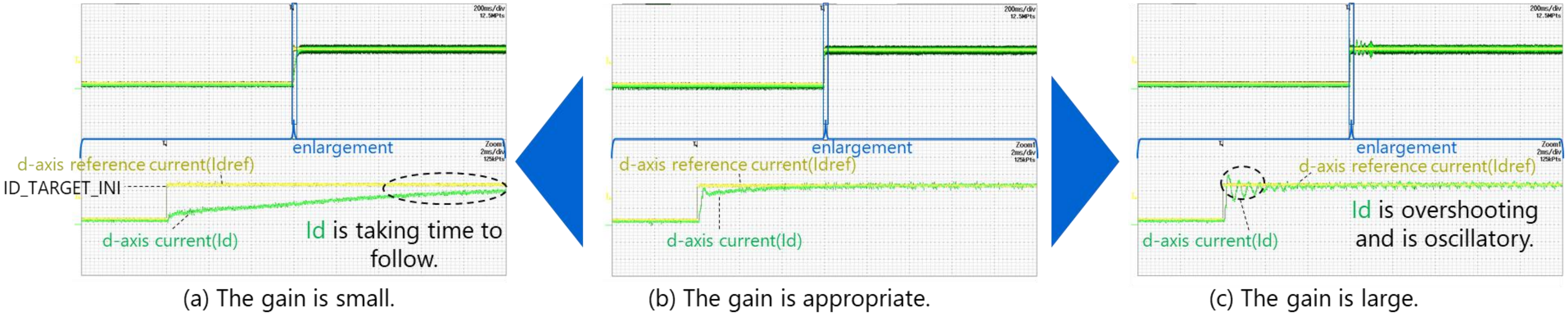

Figure 6.4 Example of current control gain tuning

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 ω is determined so that the d-axis induced voltage Ed becomes zero, and the estimated position θ is calculated from this result.
In the change-up stage, after Ed changes to less than 0, the previous value of ω is used to calculate Ed. However, until Ed changes to less than 0, ωref is substituted into ω to calculate Ed.

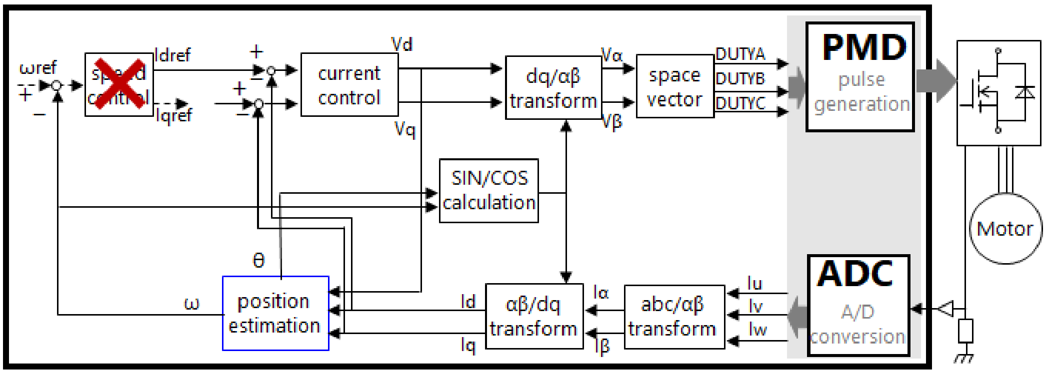

Figure 6.5 Block Diagram for Position Estimation Gain Tuning

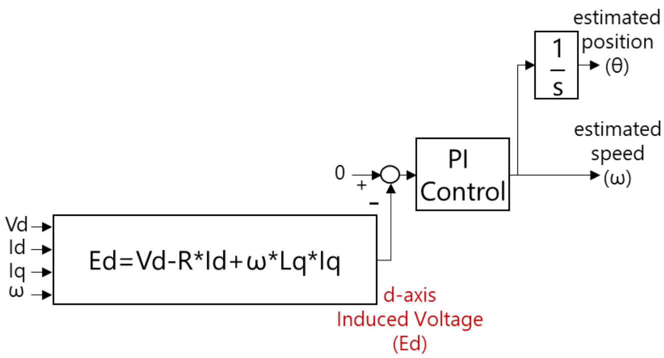

Figure 6.6 Block Diagram of Position Estimation

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 ω is determined so that Ed becomes zero, and the position Δθ 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.

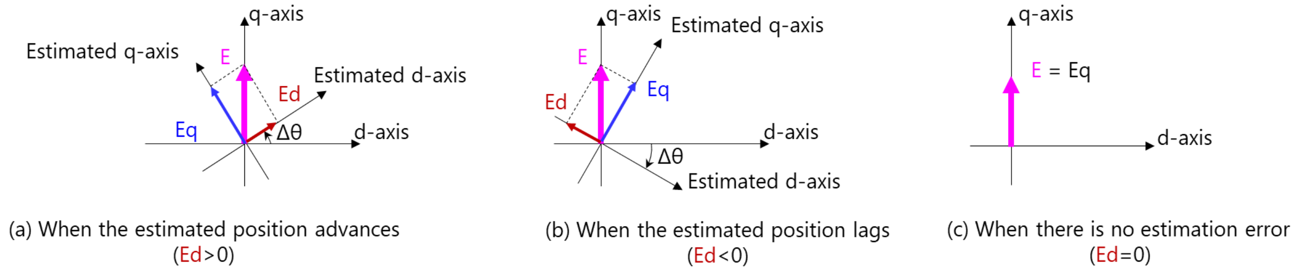

Figure 6.7　Image of Position Estimation

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.

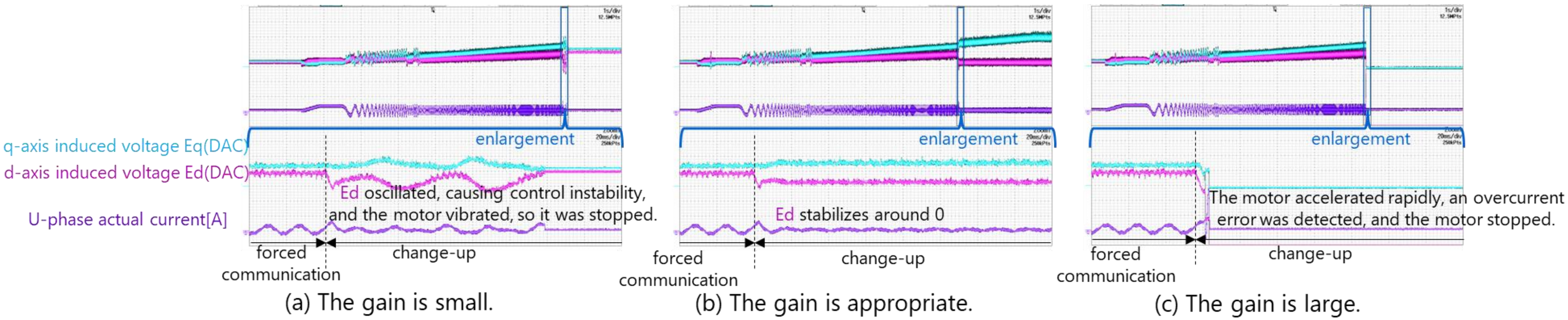

Figure 6.8 Example of position estimation gain tuning

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 (ωref). 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 (Iqref) to match the reference speed (ωref) with the estimated speed (ω).
For example, if the load increases and ω decreases, the speed error increases, and Iqref is increased to raise ω.
Similarly, if ωref increases, the speed error also increases, and Iqref is increased to raise ω.
Speed control tunes by monitoring ωref, ω, Iqref, and other parameters to ensure responsiveness and tracking performance.

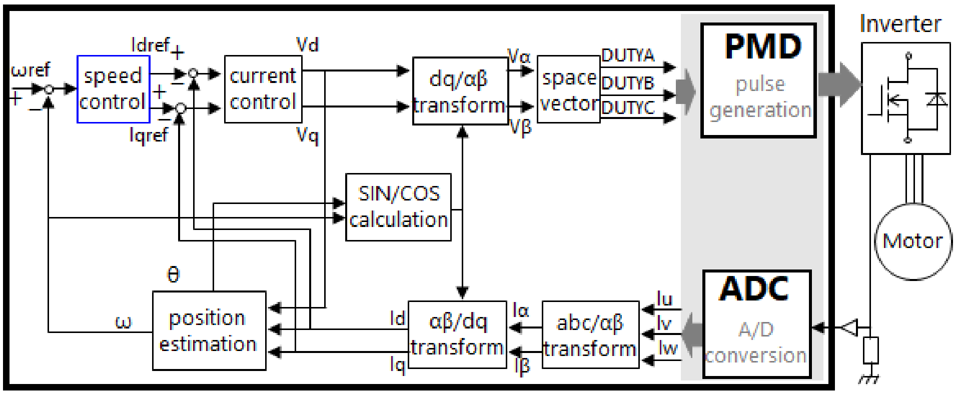

Figure 6.9 Block Diagram of FOC

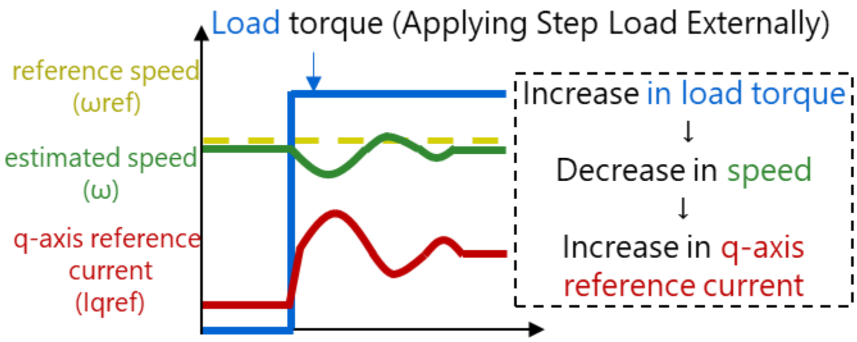

Figure 6.10 Image of Changes in Current Reference Value Due to Load Fluctuations

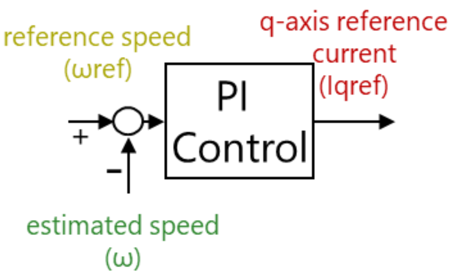

Figure 6.11 Block Diagram of Speed Control

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.

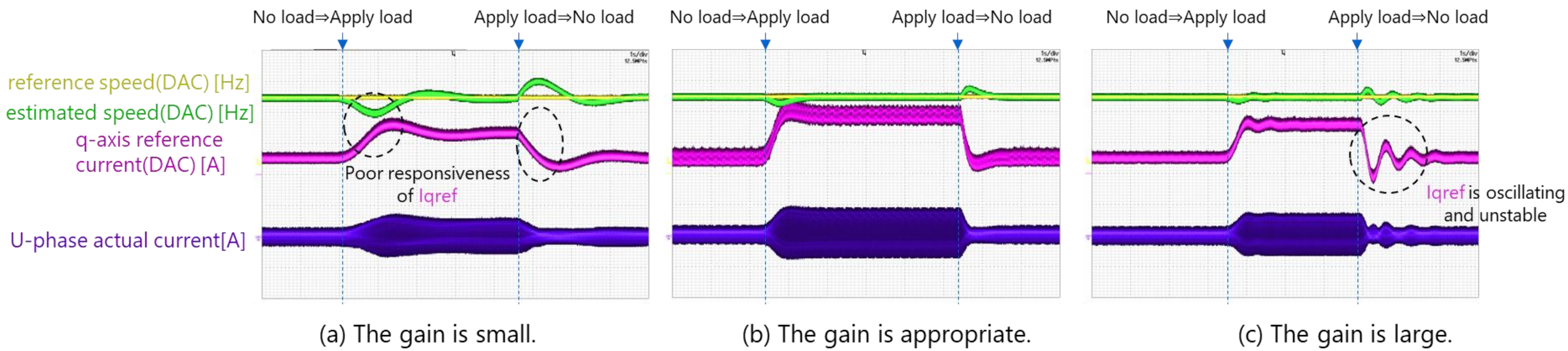

Figure 6.12 Example of tuning speed control proportional gain

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.

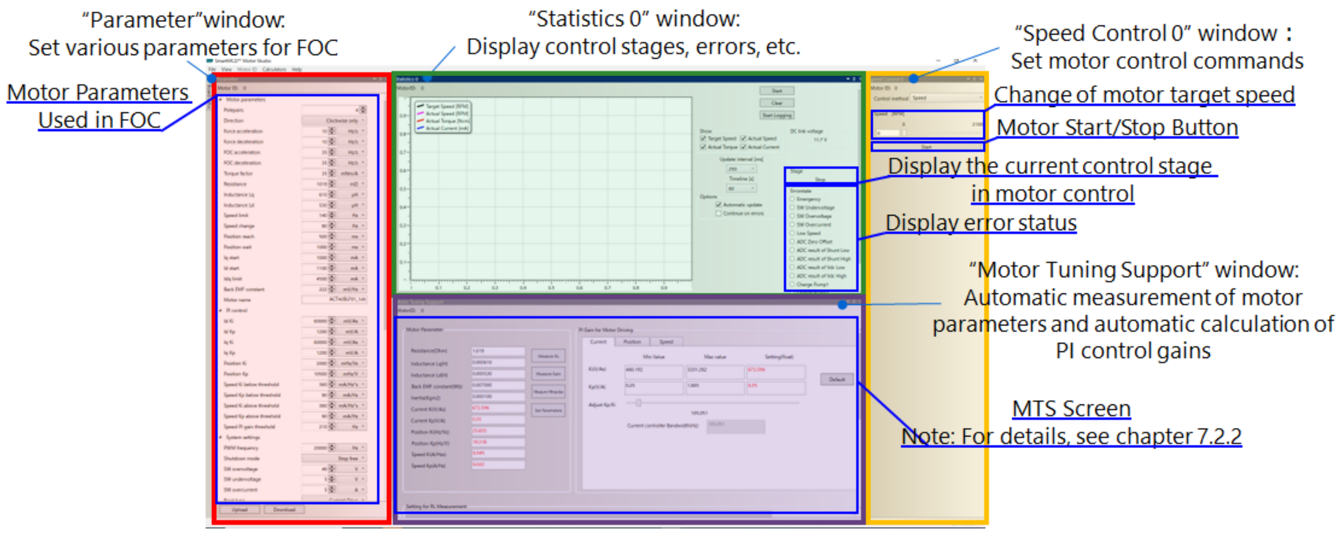

Figure 7.1 An Example of the Window Display of the MTS Screen

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.

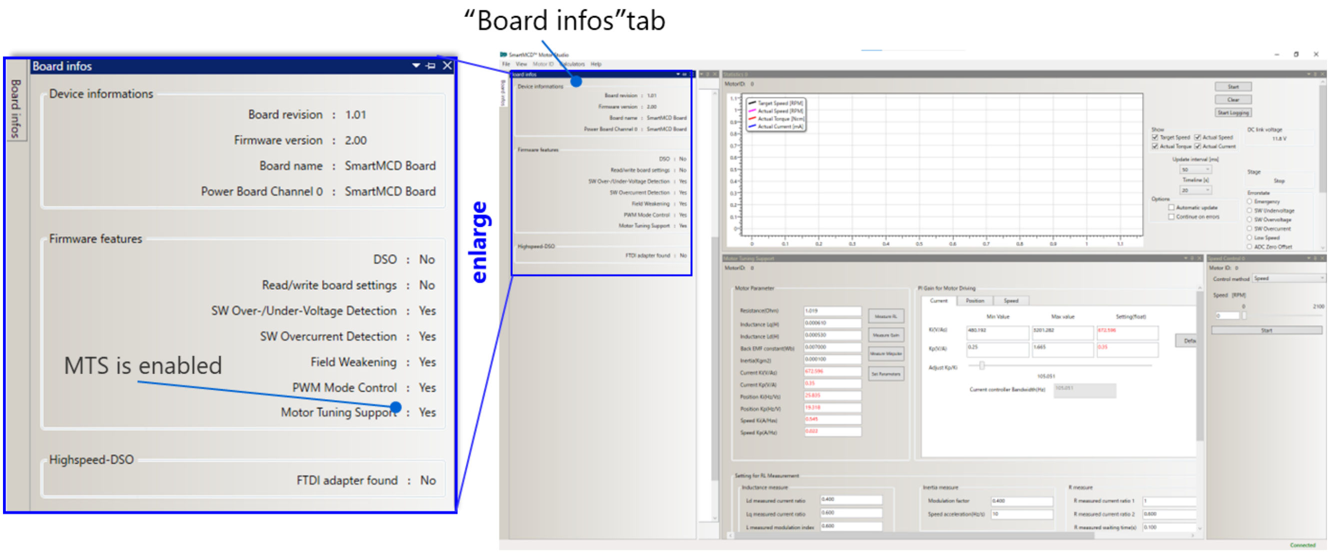

Figure 7.2 MTS Screen (Board Information Display)

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.

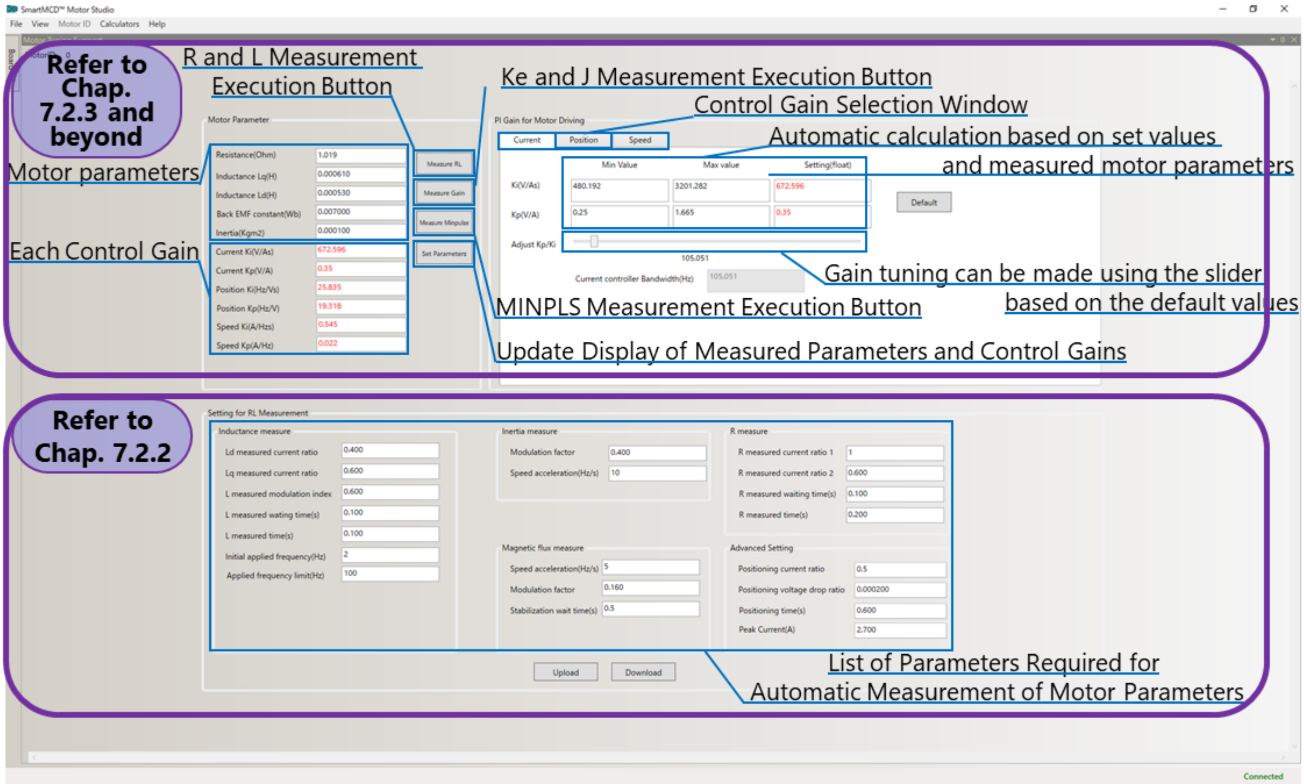

Figure 7.3 Enlarged View of the "Motor Tuning Support" Window

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.

Table 7.1 List of MTS Setting Parameters

	Parameter names on the MTS screen	Parameter names in the header file for MTS	unit	Description	Remarks
Advanced Setting	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.
	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	A	Set the peak current value of the motor.	Please tune according to the motor in use.
R measure	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 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.
	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.
Inductance measure	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.
	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.
	L measured waiting time(s)	L_MEASURE_WAIT_LEN	s	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))

	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 flux measure	Speed acceleration (Hz/s)	FORCE_SPEED_INC	Hz/s	Set the acceleration and deceleration limits.	The acceleration during back EMF constant measurement varies.
	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.
	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.
Other	Back EMF constant	MAGNETIC_FLUX	Wb	Set the back EMF constant.	-
	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)

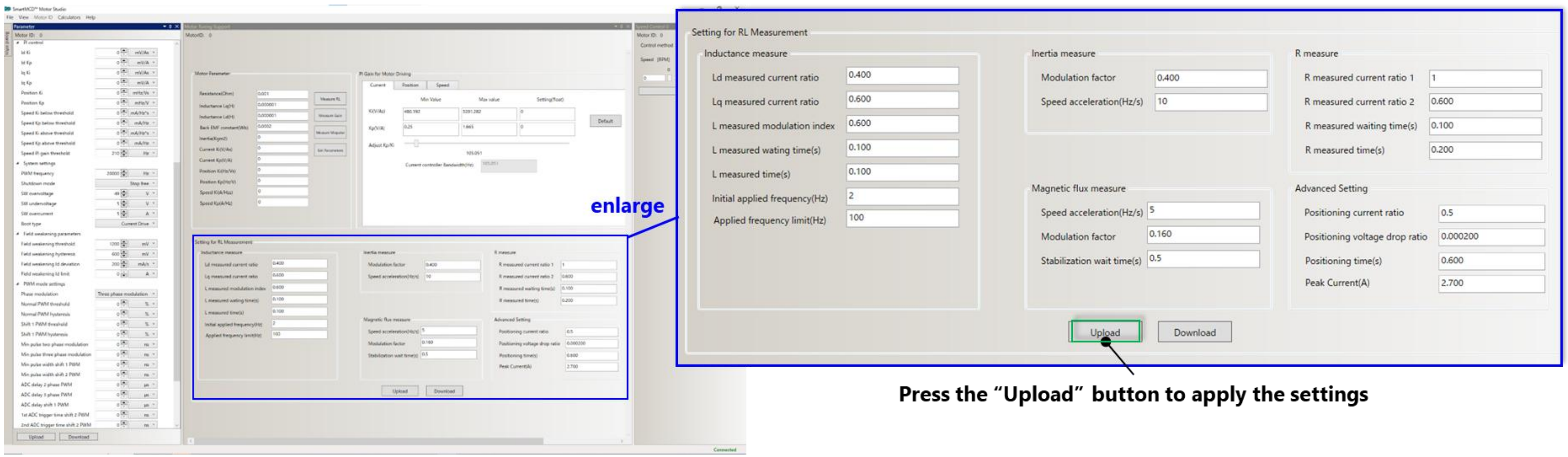

Figure 7.4 Enlarged View of a Part of the “Motor Tuning Support” Window

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.

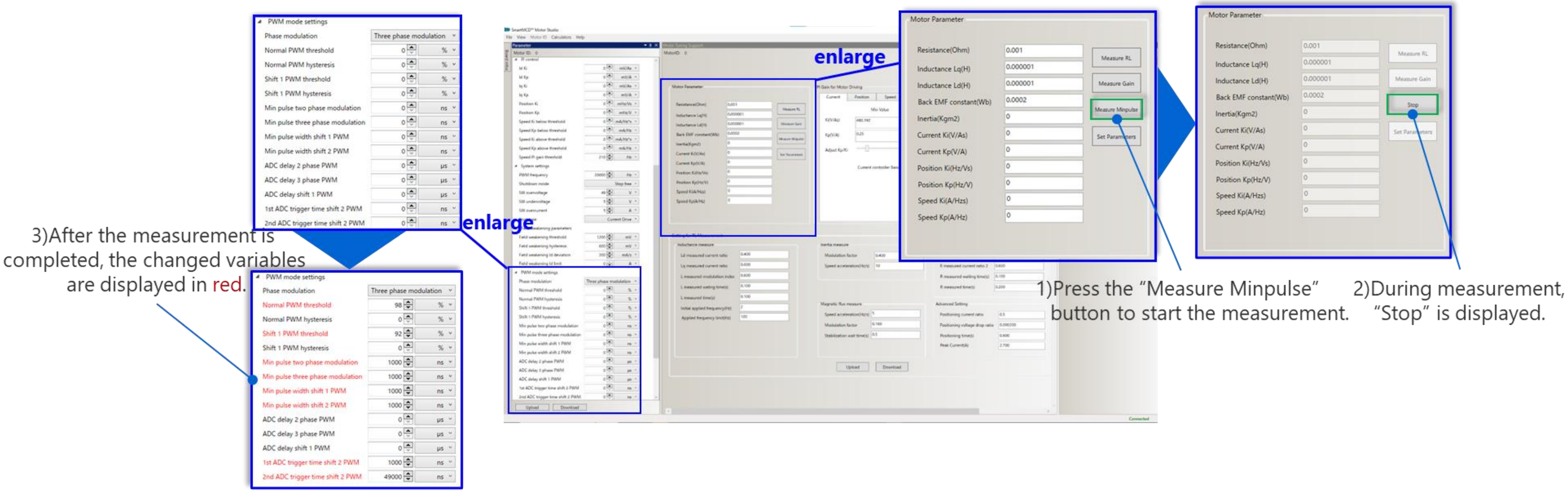

Figure 7.5 Screen for Measuring Parameters Related to PWM Mode Settings

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.

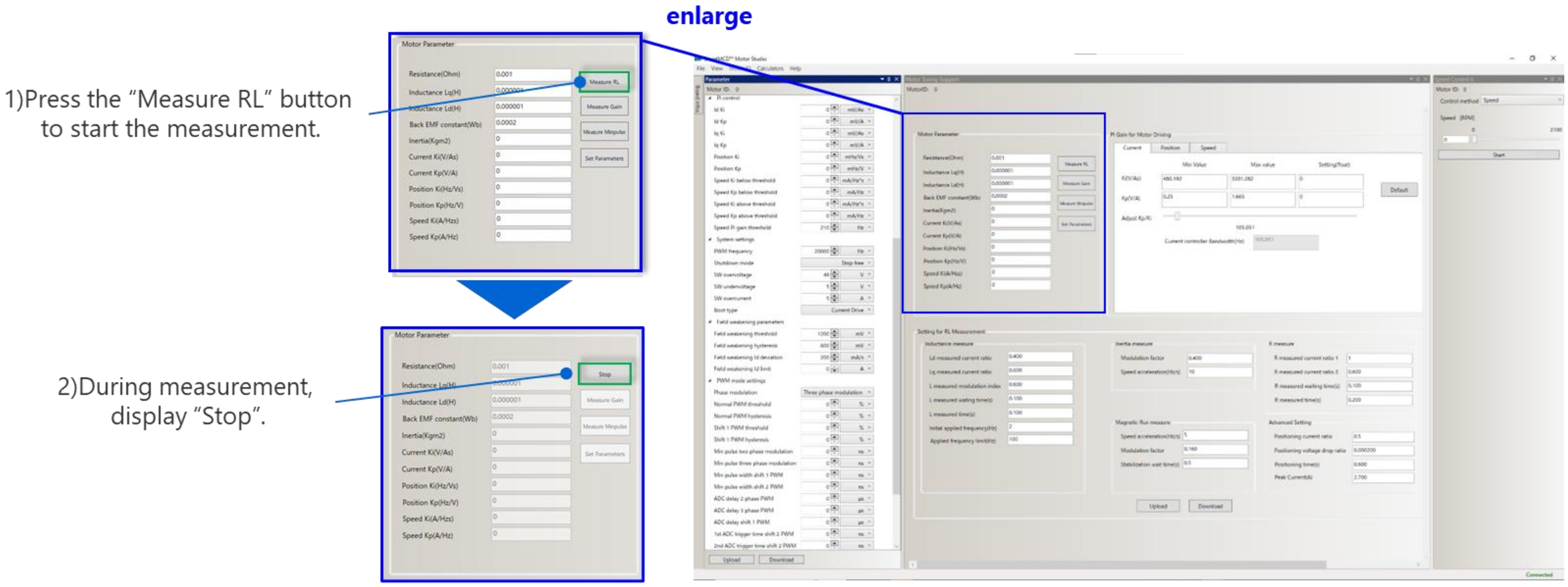

Figure 7.6 Screen for Measuring R and L

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.

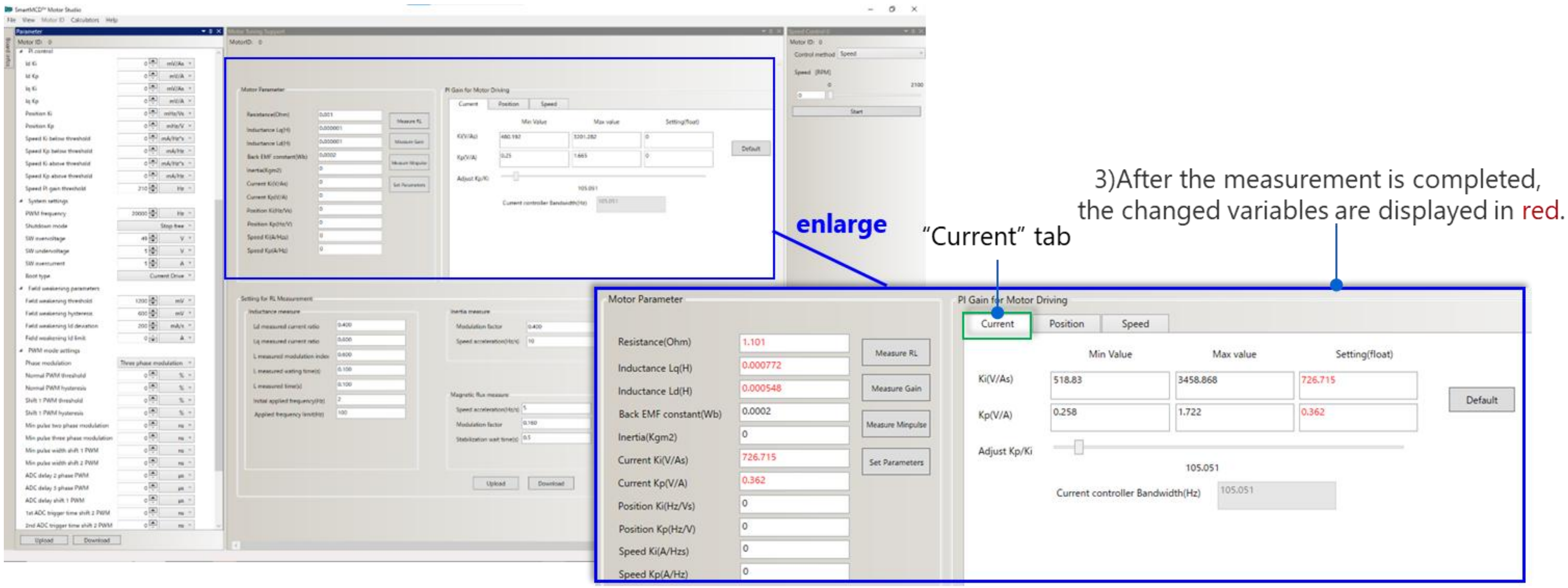

Figure 7.7 Screen for Calculating Initial Values of Current Control Gain

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.

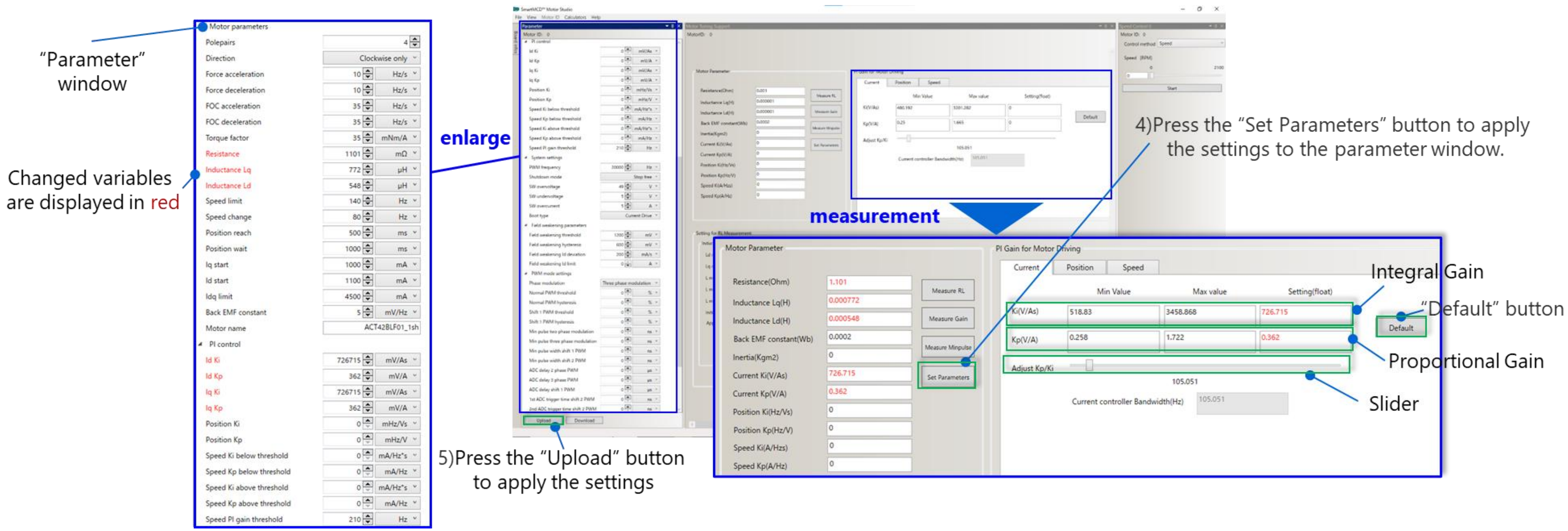

Figure 7.8 Screen for Tuning Current Control Gain

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.

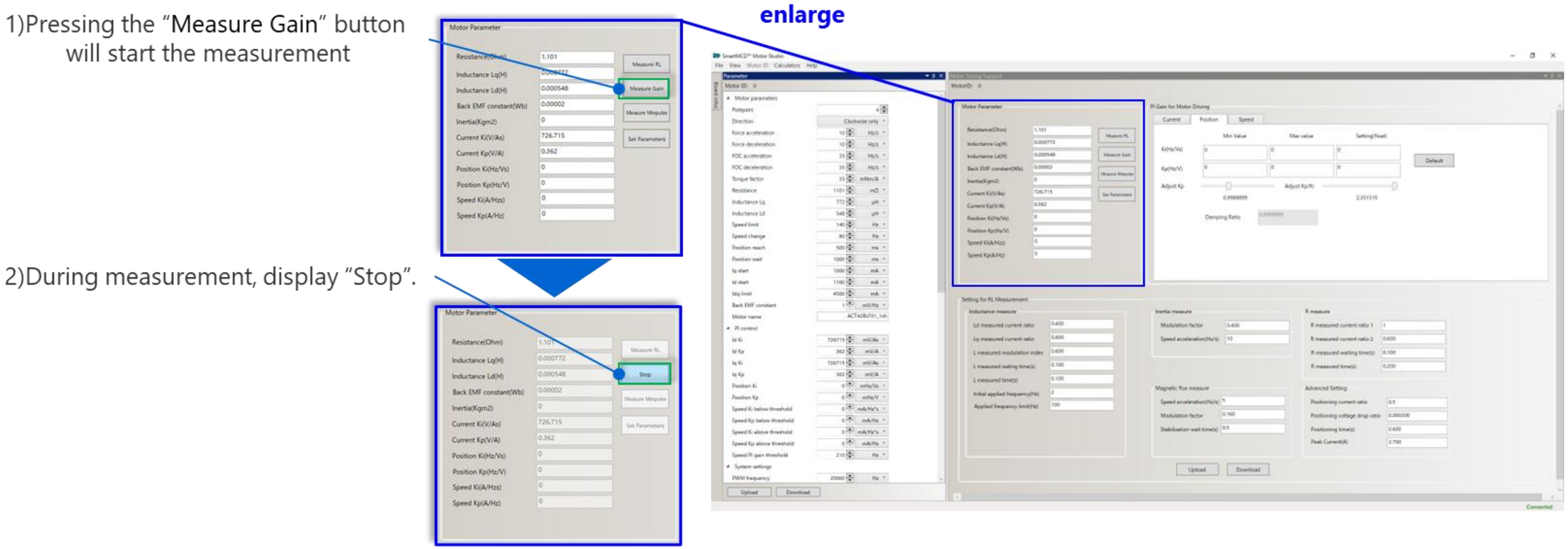

Figure 7.9 Screen During Measurement of Ke and J

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.

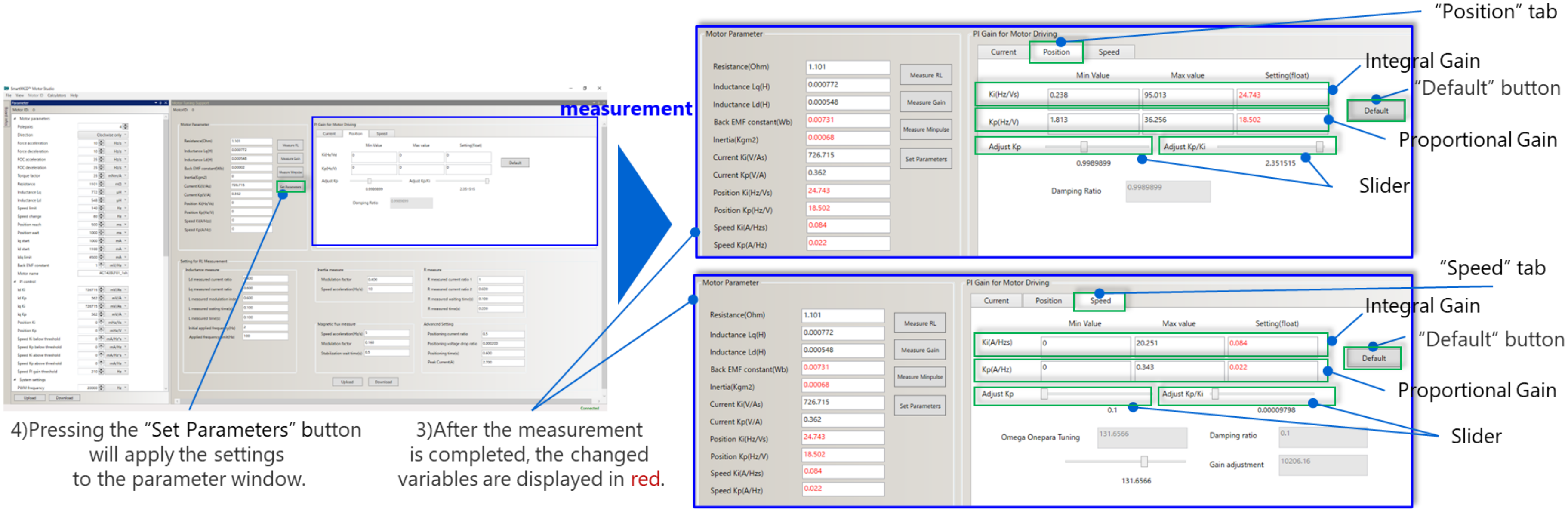

Figure 7.10 Screen for Calculating Initial Values of Position Estimation and Speed Control Gains

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.

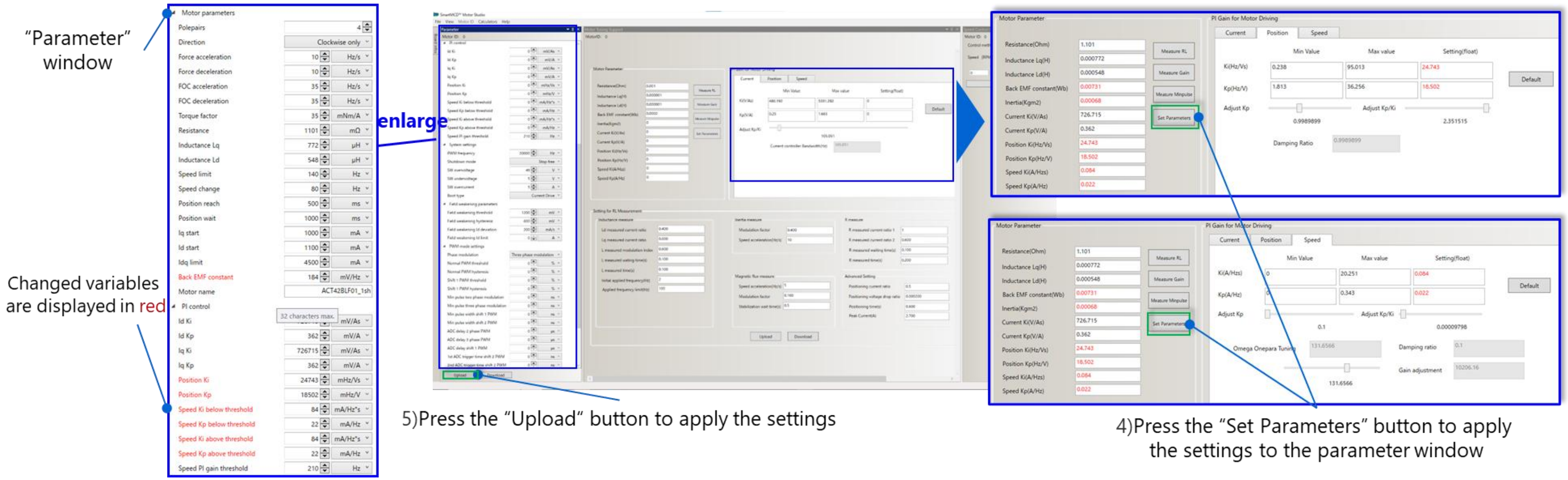

Figure 7.11 Screen for Setting Position Estimation and Speed Control Gains

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.

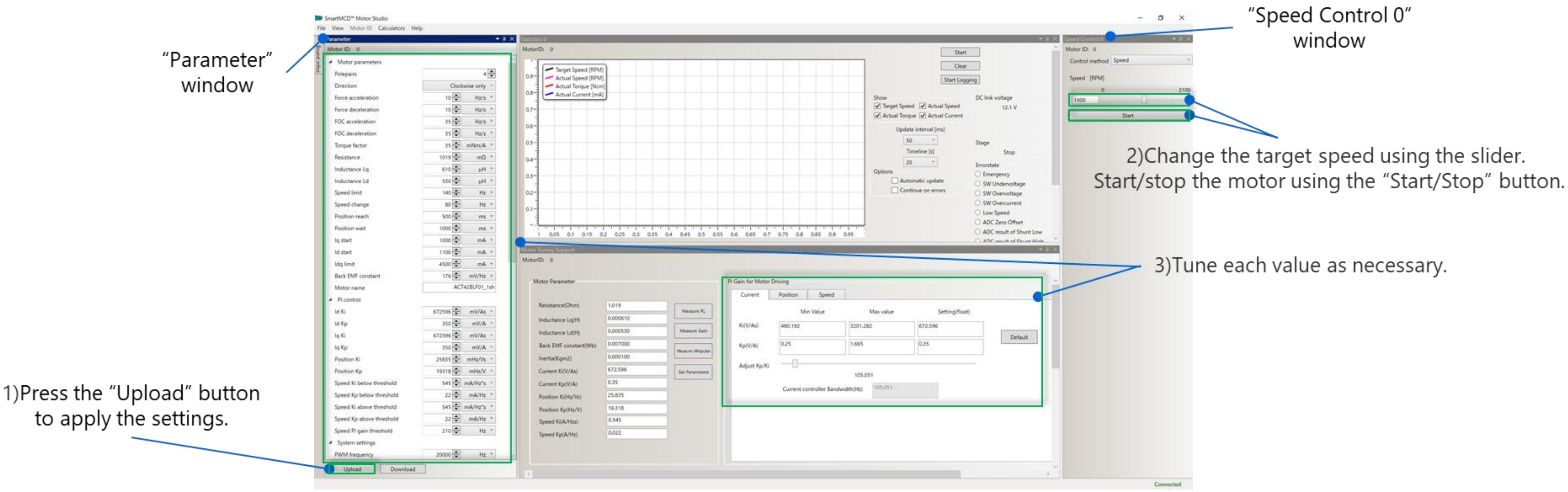

Figure 7.12 Screen for Position Estimation and Speed Control Gain Settings

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.

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