Application Note

SX68200M Series: Motor Drivers with Sensorless Vector Control

A Guide to Demo Board Evaluation and Parameter Adjustment

Precautions for High Voltage

Dangerously high voltages exist inside the demonstration board.

Mishandling the demonstration board may cause the death or serious injury of a person.

Before using the demonstration board, read the following cautions carefully, and then use the demonstration board correctly.

DO NOT touch the demonstration board being energized.

Dangerously high voltages that can cause death or serious injury exist inside the demonstration board being energized.

Electrical shock may be caused even by accidental short-time contact or by putting hands close to the demonstration board.

Electrical shock can result in death or serious injury.

Before touching the demonstration board, make sure that the capacitors have been discharged.

For safety purpose, an operator familiar with electrical knowledge must handle the demonstration board.

The demonstration board is for evaluation of all the features of the SX68200M series.

The demonstration board shall not be included or used in your mass-produced products.

Before using the demonstration board, see this document and refer to the SX68200M series data sheet.

Be sure to use the demonstration board within the ranges of the ratings for input voltage, frequency, output voltage, and output current.

Be sure to strictly maintain the specified ambient environmental conditions, such as ambient temperature and humidity.

Contents

Introduction

The SX68200M series are 3-phase brushless motor drivers in which output transistors, pre-drive circuits, bootstrap diodes with current-limiting resistors are highly integrated. Employing a sinusoidal driving strategy with a sensorless vector control, the SX68200M series brings a small-sized, high-efficient, and low-noise motor controlling into your application.

The SX68200M series incorporates a microcontroller, allowing users to set individual parameters with a dedicated GUI. This application note describes how to evaluate a demo board equipped with an SX68200M series device and how to adjust parameters with the GUI. For more details, refer to the SX68200M series data sheet.

SX68200M Series Features

- Pb-free (RoHS Compliant)
- Sinusoidal Current Waveform
  (Low Noise, High Efficiency)
  Sensorless Vector Control
  (High Efficiency at Load Variation, Small Size)
- Built-in Bootstrap Diodes with Current-limiting Resistors
- EEPROM as a Control Parameter Storage
- Two Speed Control (PI Control) Modes:
  - Analog Voltage Control (VSP Pin)
  - Serial Communications Control (I^2C Compatible)
- 3-shunt Current Detection
- DIAG Pin Fault Signal to Be Output
- Protections Include:
  - V3 Pin Undervoltage Protection
  - Watchdog Timeout Detection
  - Memory Error Detection
  - Overvoltage Protection and Undervoltage Lockout for Main Power Supply (VM Pin)
  - Soft Overcurrent Protection
  - Hard Overcurrent Protection
  - Thermal Warning
  - Thermal Shutdown
  - Undervoltage Lockout for Logic Supply
  - Loss-of-Synchronization Protection

Applications

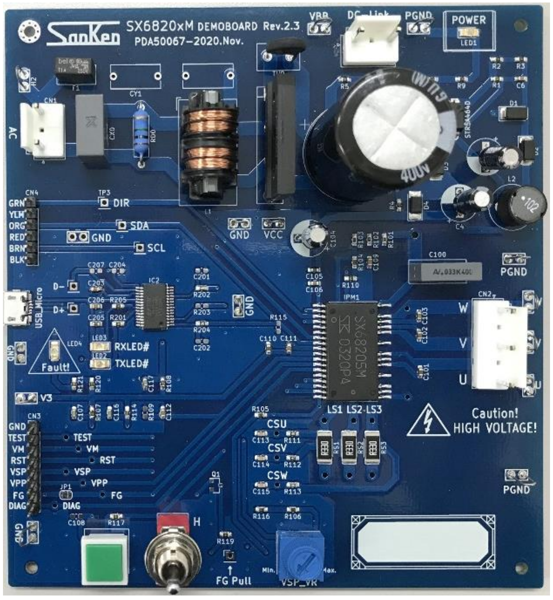
- Fan Motor for Air Conditioner
- Fan Motor for Air Purifier and Electric Fan

SX68200M Series Package

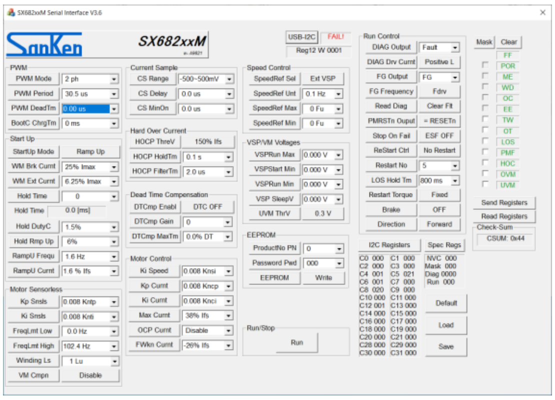
SOP36

Not to scale

SX68200M Series Demo Board



SX68200M Series GUI



1. Demo Board Overview

Table 1-1 provides the specifications of the demo boards for evaluating the SX68200M series devices. Select a demo board based on your applications and power supply specifications. The demo boards are available from the URL below.

URL: https://www.semicon.sanken-ele.co.jp/support/evalboard/hvmd.html

Table 1-1. Demo Board Specifications

No.	On-board IC (V_{DSS}, I_O)	Motor Type	Input Supply Voltage	Rectified Voltage	VCCx Pin Voltage	VSP Pin Voltage
Demo Board 1	SX68201M (250 V, 2.0 A)	100 V system	100 VAC	141 VDC	15 V	1.50 V to 5.06 V*
Demo Board 2	SX68203M (600 V, 1.5 A)	100 V system / 200 V system	100 VAC / 200 VAC	141 VDC / 282 VDC		
Demo Board 3	SX68205M (600 V, 2.0 A)	100 V system / 200 V system	100 VAC / 200 VAC	141 VDC / 282 VDC		

* Refers to when adjusting by the VSP pin voltage-adjusting resistor, VSP_VR; when using an external power supply, apply a 1.40 to 5.88 voltage to the VSP pin of the CN3 (see Figure 1-1).

Figure 1-1 is the circuit diagram of a demo board populated with an SX68200M series device.

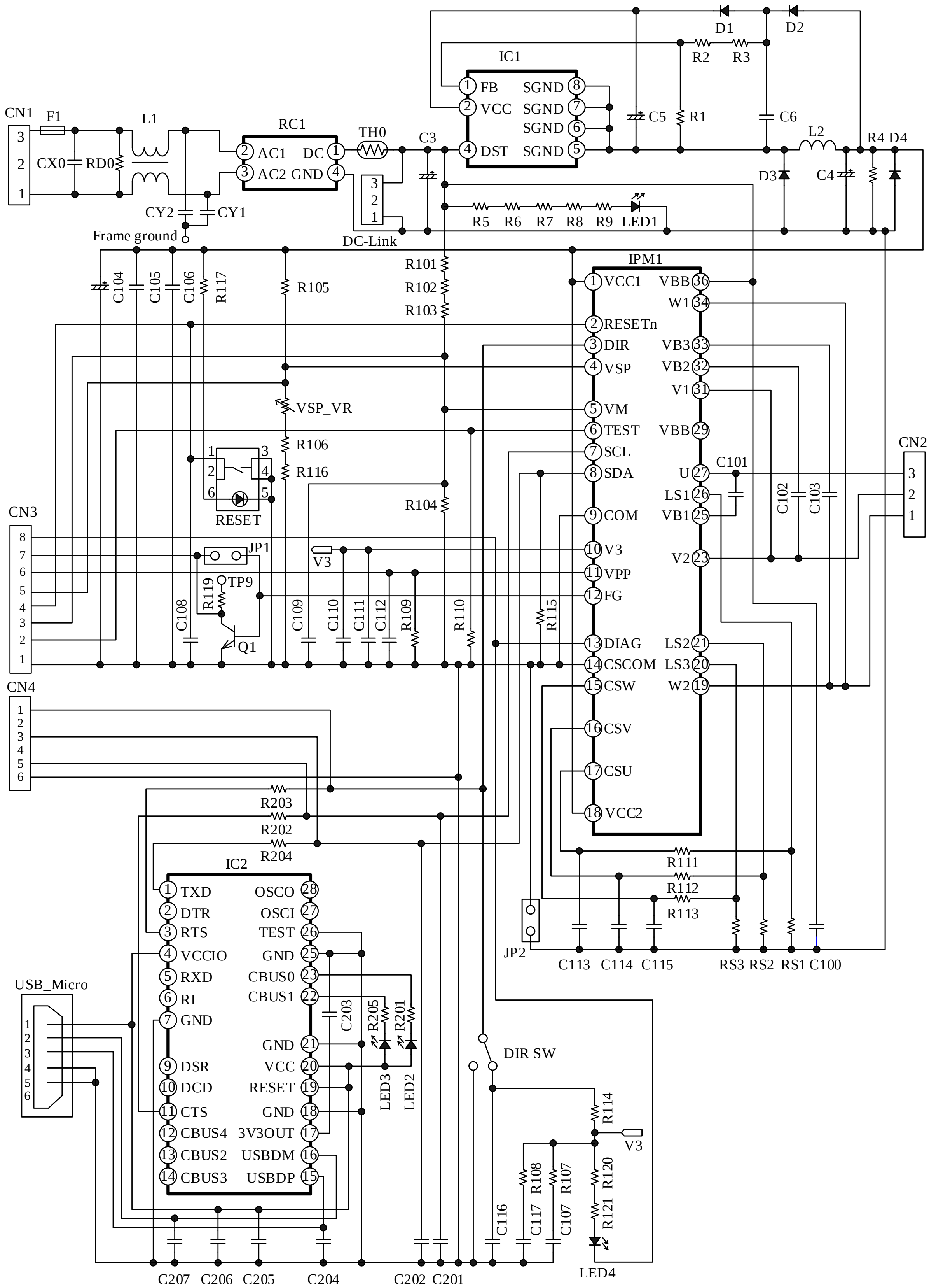


Figure 1-1. Circuit Diagram of Demo Board

- **Bill of Materials**

Symbol	Part Type	Ratings	Symbol	Part Type	Ratings
C3	Electrolytic	120 µF, 400 V	R109*	General	Open
C4	Electrolytic	100 µF, 25 V	R110	General	10 kΩ, 0.25 W
C5	Electrolytic	10 µF, 50 V	R111	General	100 Ω, 0.25 W
C6	Ceramic	0.22 µF, 50 V	R112	General	100 Ω, 0.25 W
C100	Film	0.047 µF, 400 V	R113	General	100 Ω, 0.25 W
C101	Ceramic	1 µF, 50 V	R114	General	10 kΩ, 0.25 W
C102	Ceramic	1 µF, 50 V	R115	General	10 kΩ, 0.25 W
C103	Ceramic	1 µF, 50 V	R116	General	2.2 kΩ, 0.25 W
C104	Electrolytic	100 µF, 25 V	R117	General	Open
C105	Ceramic	1 µF, 50 V	R119	General	3.3 kΩ, 0.25 W
C106	Ceramic	1 µF, 50 V	R120	General	10 kΩ, 0.25 W
C107	Ceramic	100 pF, 50 V	R121	General	10 kΩ, 0.25 W
C108*	Ceramic	Open	R201	General	1 kΩ, 0.25 W
C109	Ceramic	0.1 µF, 50 V	R202	General	100 Ω, 0.25 W
C110	Ceramic	1 µF, 50 V	R203	General	Open
C111	Ceramic	0.1 µF, 50 V	R204	General	100 Ω, 0.25 W
C112	Ceramic	0.1 µF, 50 V	R205	General	1 kΩ, 0.25 W
C113	Ceramic	1000 pF, 50 V	RS1*	Metal plate	0.36 Ω, 1 W
C114	Ceramic	1000 pF, 50 V	RS2*	Metal plate	0.36 Ω, 1 W
C115	Ceramic	1000 pF, 50 V	RS3*	Metal plate	0.36 Ω, 1 W
C116	Ceramic	100 pF, 50 V	RD0	Metal plate	1 MΩ, 1 W
C117	Ceramic	100 pF, 50 V	TH0	Thermistor	10 Ω, 1800 mW
C201*	Ceramic	Open	VSP_VR	Trimmer	20 kΩ, 0.5 W
C202*	Ceramic	Open	D1	Fast recovery	200 V, 1 A
C203	Ceramic	0.1 µF, 50 V	D2	Fast recovery	500 V, 1 A
C204	Ceramic	Open	D3	Fast recovery	500 V, 1 A
C205	Ceramic	1 µF, 50 V	D4	Zener diode	1 W, Vz = 18.8 V (min.)
C206	Ceramic	0.1 µF, 50 V	L1	Filter	74.5 mH
C207	Ceramic	Open	L2	Inductor	1 mH
CX0	Film	22 nF, 275 VAC	F1	Fuse	250 VAC, 1 A
CY1	Ceramic	4.7 nF, 250 VAC	LED1	LED	5 V, 30 mA
CY2	Ceramic	4.7 nF, 250 VAC	LED2	LED	5 V, 30 mA
R1	General	10 kΩ, 0.25 W	LED3	LED	5 V, 30 mA
R2	General	47 kΩ, 0.25 W	LED4	LED	5 V, 30 mA
R3	General	4.7 kΩ, 0.25 W	RESET	Switch	TS-AGGNH-G
R4	General	4.7 kΩ, 0.25 W	DIR SW	Switch	1MS1-T2-B1-M1-Q-N-S
R5	General	33 kΩ, 0.25 W	USB_Micro	Micro USB Type-b connector	ZX62-B-5PA
R6	General	33 kΩ, 0.25 W	CN1	Connector	Equiv. to B2P3-VH
R7	General	33 kΩ, 0.25 W	CN2	Connector	Equiv. to B3P5-VH
R8	General	33 kΩ, 0.25 W	CN3	Pin header	2.54 mm pitch
R9	General	33 kΩ, 0.25 W	CN4	Pin header	2.54 mm pitch
R101	Metal plate	1 MΩ, 0.25 W	DC-Link	Connector	Equiv. to B2P3-VH
R102	Metal plate	1 MΩ, 0.25 W	RC1	Bridge diode	D3SBA60
R103	Metal plate	1 MΩ, 0.25 W	Q1	NPN transistor	Open
R104	Metal plate	10 kΩ, 0.25 W	IPM1	IC	SX68200M series
R105	General	47 kΩ, 0.25 W	IC1	IC	STR5A464D
R106	General	5.6 kΩ, 0.25 W	IC2	IC	FT232RL
R107	General	10 kΩ, 0.25 W	JP1	Jumper	Short
R108	General	10 kΩ, 0.25 W	JP2	Jumper	Short

* Refers to a part that requires adjustment based on operation performance in an actual application.

2. Evaluating the Demo Board

This section explains the procedure until the motor starts to rotate in Int SR mode. For more details on the parameter adjustment, see Section 3.

2.1. Calculating Winding Ls

This section describes how to calculate a value to be selected from the **Winding Ls** list in the GUI, which is required when rotating a testing motor with your demo board. Note that the motor does not start to rotate unless a proper value is selected from the **Winding Ls** list.

Firstly, measure the average line inductance, L_{AVG}, of the testing motor. As Figure 2-1 shows, measure line inductances across any two phases, L_{IJ}, by an LCR meter. Measure the line inductances for multiple times since a line inductance varies according to the position of a rotor. In addition, measure the line inductances of multiple motors. After measuring the line inductances, calculate an average line inductance, L_{AVG} (see Table 2-1). The L_{AVG} is an average value from all the individual phase-to-phase inductances you measured.

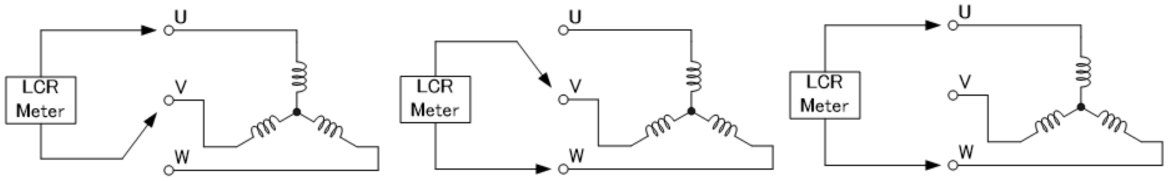


Figure 2-1. Line Inductance Measurement

Table 2-1. Example Results of Line Inductance Measurement

Motor	Number of Measurements	Line Inductance, L_{IJ} (mH)		
		L_{UV}	L_{VW}	L_{UW}
No. 1	First	81	80	79
	Second	82	82	81
	Third	80	82	81
No. 2	First	81	80	81
	Second	82	82	82
	Third	81	80	82
Average (L_{AVG})		81.1		

Secondly, calculate a value of the Winding L_S. The equations below define the Winding L_S:

$$\text{Winding } L_S = \frac{L_{AVG}}{2} \times \frac{I_{FS} \times 20 \times 10^6}{V_{DC} \times f_C \times 8.29 \times 10^{-3}}. \quad (1)$$

$$I_{FS} = \frac{\text{CS Range}}{R_{Sx}}. \quad (2)$$

$$f_C = \frac{1}{T_{PR}}. \quad (3)$$

Where:
L_{AVG} is the average line inductance (H),
V_{DC} is the main power supply voltage (V),
I_{FS} is the maximum current range of the current-sensing operational amplifiers (A),
CS Range is the maximum input voltage range of the current-sensing operational amplifiers (V),
R_{Sx} is the shunt resistance (Ω),
f_C is the PWM carrier frequency (Hz), and
T_{PR} is the PWM period (s).

When you operate the testing motor with your demo board for the very first time, the following parameters must be calculated with their default values shown in the GUI: CS Range = 0.5 V, T_{PR} (i.e., PWM period) = 58.9 µs. When L_{AVG} = 0.0811 H, V_{DC} = 282 V, CS Range = 0.5 V, R_{Sx} = 0.36 Ω, and T_{PR} = 58.9 µs, for instance, we will find the Winding L_S as follows:

$$\text{Winding } L_S = \frac{0.0811}{2} \times \frac{\frac{0.5}{0.36} \times 20 \times 10^6}{282 \times \frac{1}{58.9 \times 10^{-6}} \times 8.29 \times 10^{-3}} = 28 \text{ Lu}.$$

We also offer you Winding L_S Calculation Tool that helps you perform quick and easy calculations. Please visit the URL below to find out more:
URL: https://www.semicon.sanken-ele.co.jp/en/calc-tool/windingls_caltool_en.html

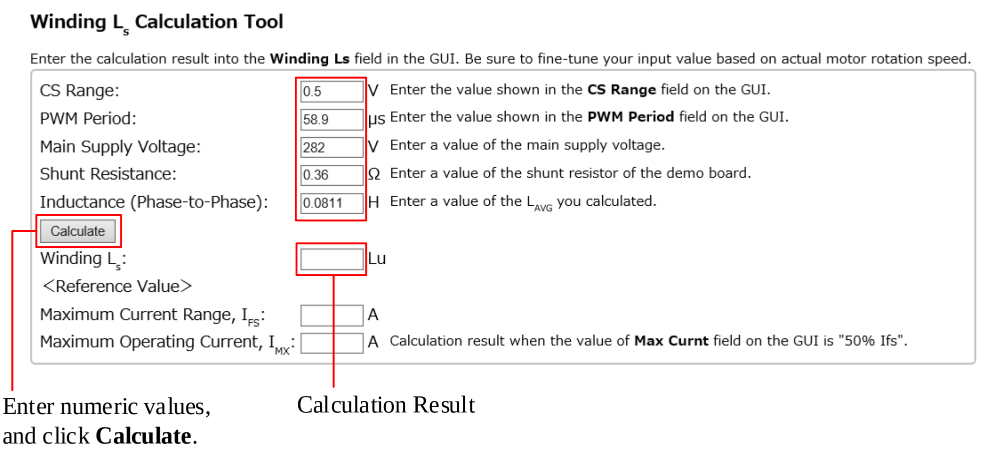


Figure 2-2. Winding L_S Calculation Tool

Section 2.4 describes how to enter a calculated value into the GUI. Note that any calculation results are reference only. When you adjust parameters, be sure to fine-tune the calculated value based on an actual motor rotation speed. For more details, see Section 3.4.1.

2.2. Preparing the Devices and Tools for Evaluations

- **Required Devices**
  Make sure that the following devices have been prepared before starting your demo board evaluation.

Table 2-2. Required Devices

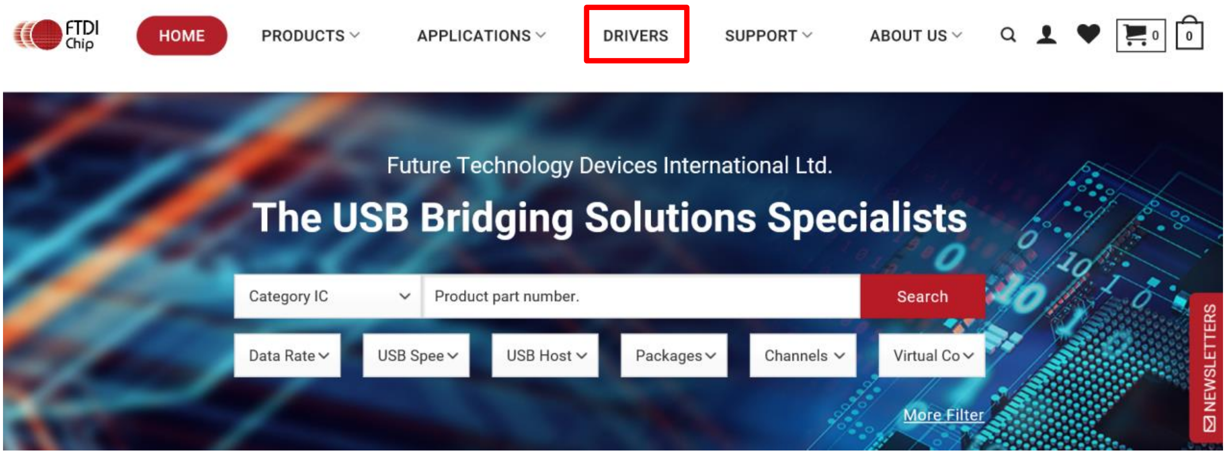
Device	Description	Remarks
AC Power Supply	Constant voltage power supply or SLIDAC	Required
USB Cable	USB A－USB micro B cable	Required
FTDI Cable	Model name: TTL-232R-5V	Recommended
USB Isolator	Model name: 114991949 Manufacturer: Seeed Studio URL: https://www.mouser.jp/ProductDetail/Seeed-Studio/114991949?qs=P1JMDcb91o6Z7ld6yCt%2FVQ==	Required (The items at left are examples; you can use any USB isolator.)
	Model name: USB Isolator USB-ISO Manufacturer: OLIMEX URL: https://strawberry-linux.com/catalog/items?code=15043	
Motor		Required
Load		Required in parameter adjustment
Control PC	OS: Windows 7 or later	Required
Logic Power Supply	Power supply for EEPROM write or external VSP mode evaluation	Not used in Int SR mode; only used for operating the motor in stand-alone mode.

- **GUI Executable File**
  The GUI for setting parameters is available.
  From the URL below, download the **SX682xxM_Serial_Interface_V3p6.exe** file.
  URL: https://www.semicon.sanken-ele.co.jp/en/support/documentsfordesign/hvmdtools/sx68200m.html#tool

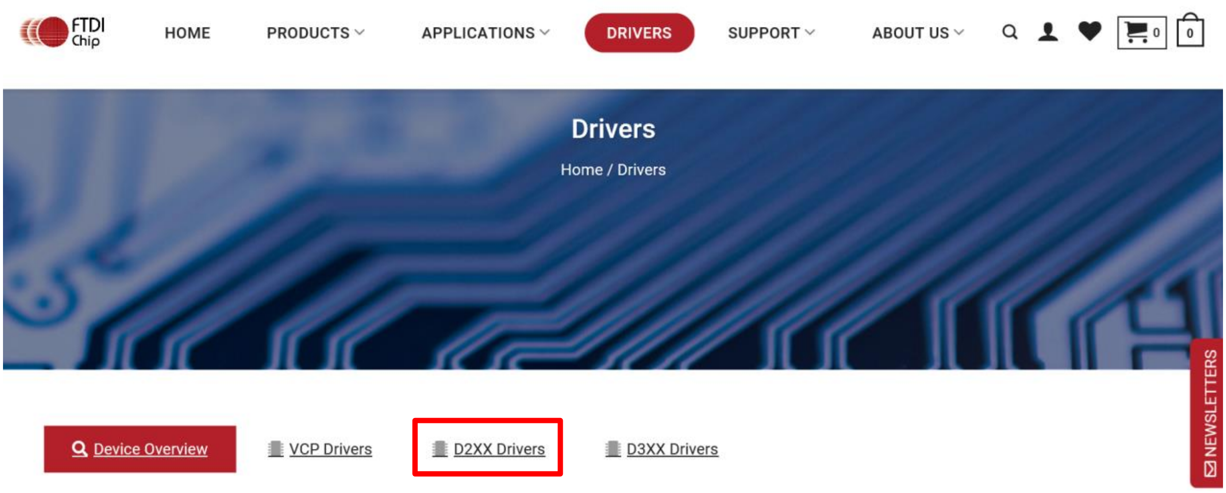
● **Downloading an FTDI Driver**

An FTDI driver is required for executing the GUI. When any FTDI driver has not been installed in your control PC, follow the steps below to download a proper driver (as of February 4, 2021). The following steps exemplify a procedure to download the driver that supports Windows® 64-bit operating systems.

1) Go to the FTDI's website.
   URL: https://ftdichip.com/
2) Click **DRIVERS**.



3) Click **D2XX Drivers**.



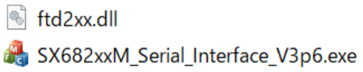
4) Click **2.12.28**.

Currently Supported D2XX Drivers:

		Processor Architecture					
Operating System	Release Date	X86 (32-Bit)	X64 (64-Bit)	ARM	MIPS	SH4	Comments
Windows*	2017 −08-30	2.12.28	2.12.28	–	–	–	WHQL Certified.Includes VCP and D2XX. Available as a setup executable Please read the Release Notes and Installation Guides.

Select an appropriate processor architecture that supports your PC envronment from the table.

5) Download and unzip the .zip file you selected.
6) Place the **ftd2xx.dll** and **SX682xxM_Serial_Interface_V3p6.exe** files in the same hierarchy.



Note that the file name and file location of a .dill file will depend on which file you downloaded.
Your .dll file downloaded through the steps above should be stored as follows:

CDM v2.12.28 WHQL Certified > i386 > ftd2xx.dll

2.3. Connecting the Devices

The following steps describe how to connect your demo board and control PC. DO NOT connect any AC power supply at this stage.

1) Connect the USB isolator to the control PC.
   To protect the control PC from any damage, be sure to use the USB isolator you have chosen.

2) Connect the USB isolator and the demo board by using a USB cable (Figure 2-3) or FTDI cable (Figure 2-4). Using an FTDI cable enables I^{2}C-compatible communications control. Pay attention to the connector orientation so that the cable color and the silkscreen indicator are matched.

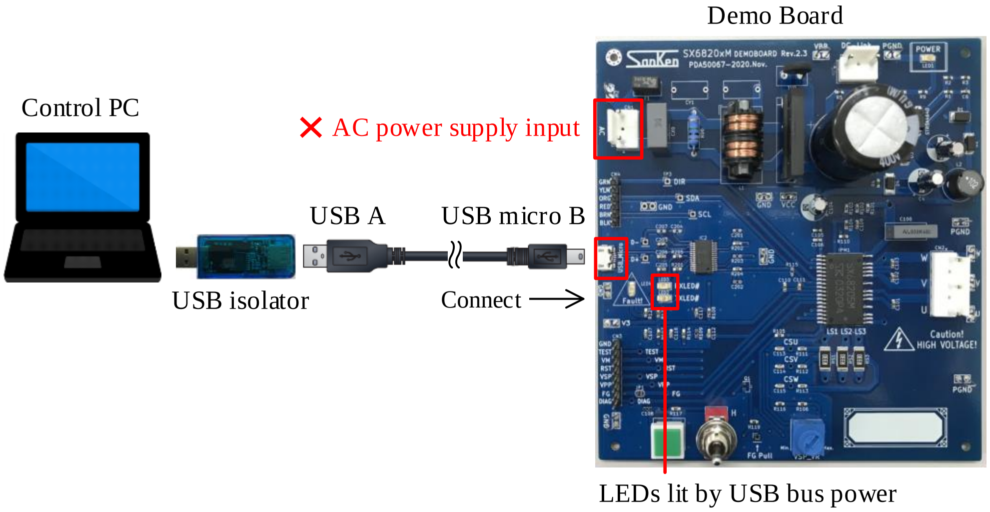


Figure 2-3. Connection by USB Cable

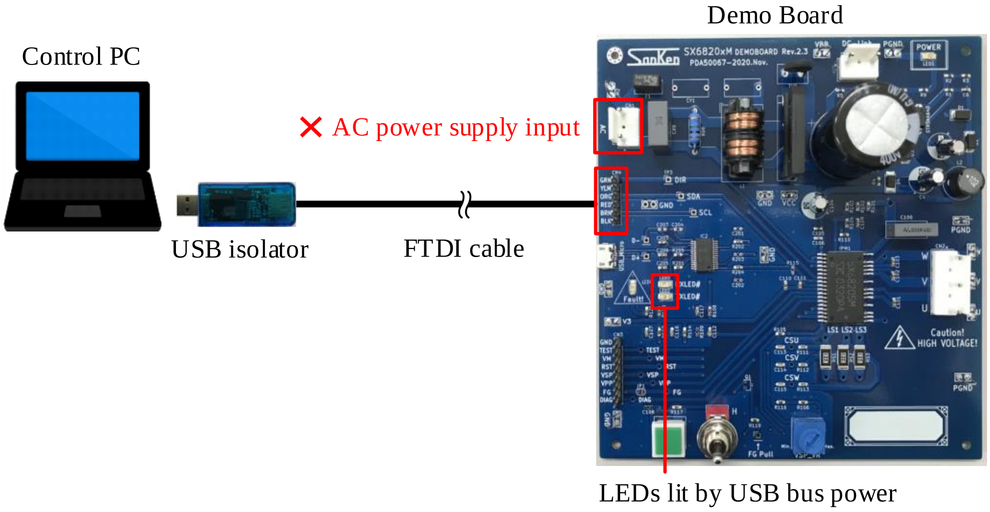
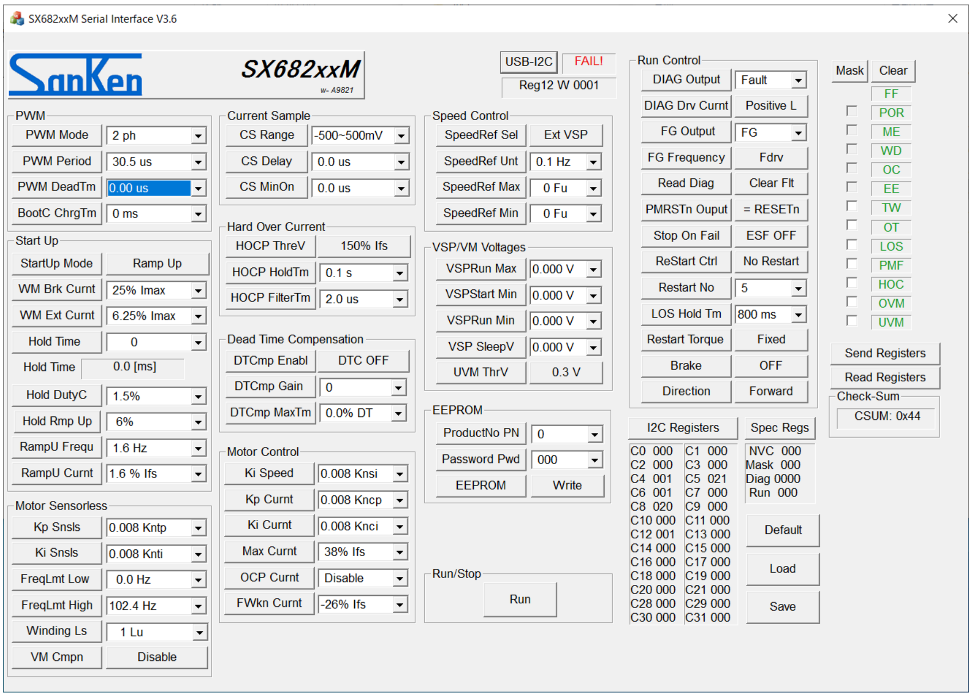


Figure 2-4. Connection by FTDI Cable

3) To launch the GUI, double-click the **SX682xxM_Serial_Interface_V3p6.exe** file.
Section 4 gives detailed descriptions on the GUI.



Once the communications between the control PC and the IC become available, the **USB-I2C** indicator displays "OKAY!", changed from its default "FAIL!".

Communications Disabled	Communications Enabled
USB-I2C FAIL!	USB-I2C OKAY!

If the error message appears during GUI launch, the following may be possible causes:

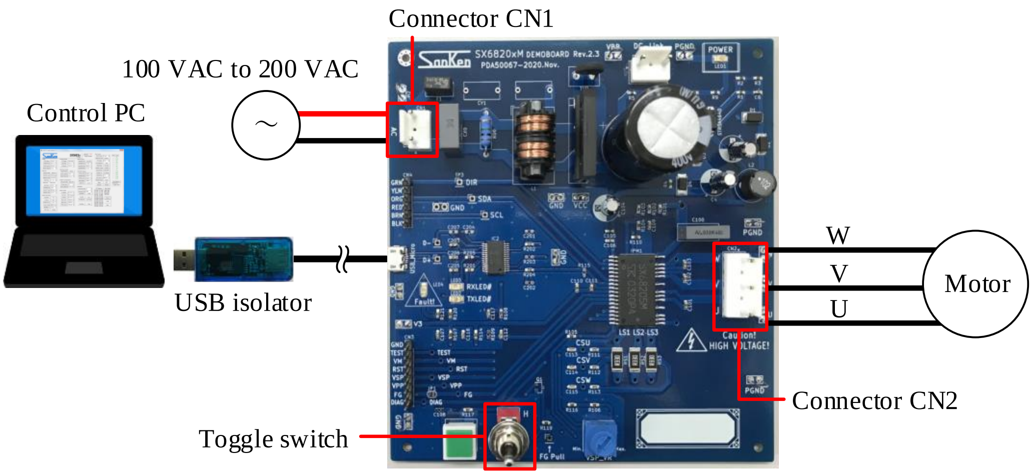
- The FT232 driver, an essential interface between the control PC and the IC, have not been downloaded.
- The .dll file and the **SX682xxM_Serial_Interface_V3p6.exe** file are not placed in the same hierarchy.

Go back to *Downloading an FTDI Driver* to check if you have taken all the necessary steps, and then retry to execute the **SX682xxM_Serial_Interface_V3p6.exe** file.

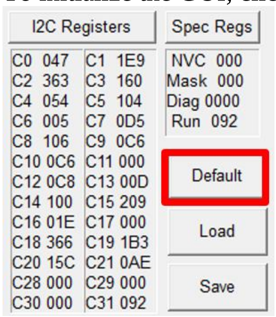
2.4. Setting Up the Motor

The following steps explain how to connect the devices, to initialize the GUI settings, and to check the motor operation.

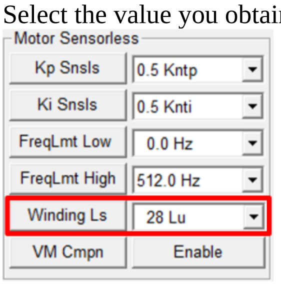
1) Connect the motor to the connector CN2.
2) Connect the AC power supply to the connector CN1.
3) Flip the toggle switch to “L” (i.e., push the switch lever toward the demo board edge).



4) Connect the current and voltage probes of your oscilloscope.
   To measure the U-phase waveform, connect the current probe to the U-phase.
   To measure the FG waveform, connect the voltage probe to the FG pin of the connector CN3.
   To measure the DIAG waveform, connect the voltage probe to the DIAG pin of the connector CN3.
5) To initialize the GUI, click the **Default** button.



6) In the **Motor Sensorless** group box, select a value from the **Winding Ls** list.
   Select the value you obtained by the calculations in Section 2.1.



7) Turn on the AC power supply.
High voltages are then applied to the demo board. Therefore, extreme care must be taken during the AC power-on.
After the first AC power-on, the GUI displays error statuses in red, e.g., POR (power-on reset), on the status column.

8) Click the **Send Registers** button.

9) Click the **Clear** button, or press the RST_SW on the demo board (see Figure 1-1).
Then the IC is reset and all the error statuses in red will turn green.
10) To start the motor rotation, click the **Run** button in the **Run/Stop** field.
Once you click the **Run** button, the button label switches to “Stop”.
11) To stop the motor rotation, click the **Stop** button in the **Run/Stop** field.
Once you click the **Stop** button, the button label switches to “Run”.

3. Parameter Tuning

This section provides the guide for parameter adjustment using the GUI. For proper parameter tuning, use the devices, tools, and measuring instruments listed in Table 2-2 and Table 3-1. The following must be taken into account in tuning parameters:

- Tune parameters after AC power-on.
- Tune parameters while measuring IC case temperatures, which should be <100 °C.
- Tune parameters while measuring and checking operational waveforms.
- DO NOT change parameter values drastically (e.g., from a minimum to maximum value). Tune parameters by small increments.

In case of contingency events, click the **Stop** button in the **Run/Stop** field to stop the motor operation or turn off the AC power supply.

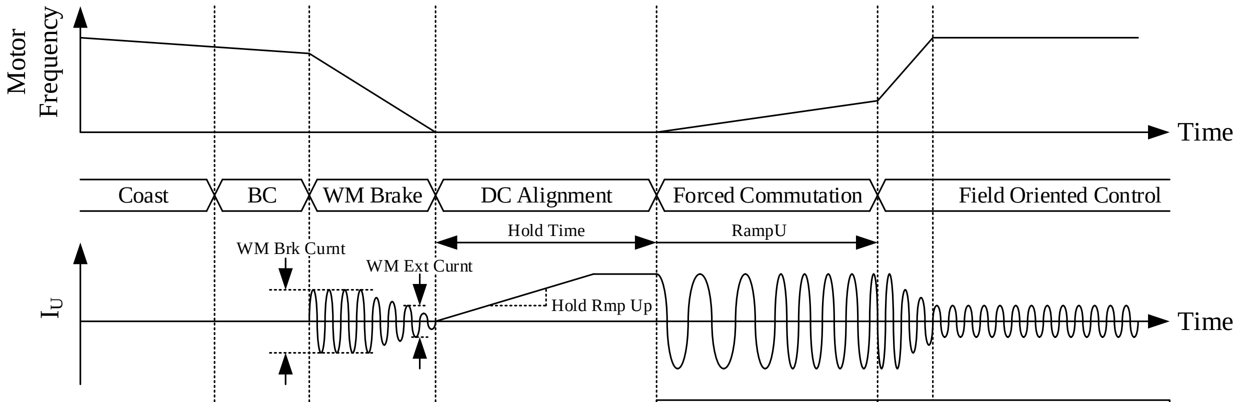
Table 3-1. Required Measuring Instruments

No.	Measuring Instrument	Target Parameter	Remarks
1	Rotational speed meter	Rotation speeds	
2	Encoder	Mechanical angles	
3	Torque meter	Torques	
4	Oscilloscope	Current waves etc.	Required
5	Power meter	Electric power, losses, etc.	
6	Thermometer/data logger	Temperatures on and around the IC	Required
7	Digital multimeter	Voltages etc.	

Figure 3-1 shows the relation between the motor operation sequences and parameter tuning.

Note that individual parameters have mutual impacts on the motor operations. Therefore, thoroughly check the motor operations, from startup to stable operations, every time you change the parameters.

Parameter setting values differ according to conditions including loads, power supplies, motors, and specifications.



	Coast	BC	WM Brake	DC Alignment	Forced Commutation	Field Oriented Control
Start Up				Required	Recommended	
Kp Curnt				Recommended	Required	
Ki Curnt				Recommended	Required	
Kp Snsls						Required
Ki Snsls						Required
Ki Speed						Required
Winding Ls				Recommended		Required

"Required" refers to tuning is required; the motor will never rotate unless optimal values are set.
"Recommended" refers to tuning is recommended; setting optimal values will reduce power consumption (Section 3.4.1).

Figure 3-1. Motor Operation Sequences vs. Parameter Tuning

3.1. Setting the Conditions

3.1.1. Setting Operating Conditions

This section explains how to set operating conditions. Table 3-2 provides the example setting of operating conditions.

Table 3-2. Example Setting of Operating Conditions

Parameter	Operating Condition	Related Items	
		GUI Parameter	Demo Board
PWM Carrier Frequency	17 kHz	PWM Period	
Motor Speed	500 rpm to 1200 rpm	SpeedRef Unt, SpeedRef Drv, SpeedRef Min	
Motor Direction	CW (Forward)	Direction	DIR SW
Startup Time(1)	Within 7 seconds	RampU Frequ, RampU Curnt, Hold Time	
Maximum Phase Current(2)	Up to 0.4 A	CS Range, Max Curnt	Shunt resistors, R_{Sx}
IC Case Temperature	T_C < 100 °C		IC

(1) Refers to a time from when the motor accelerates until when it reaches its command speed.
(2) Refers to a value estimated from load.

3.1.2. Shunt Resistance and Reference Current

A reference current value is determined by the shunt resistance, R_{Sx}, and a GUI parameter. Table 3-3 lists the reference current values by default parameter values for each demo board.

Care should be taken when you change the parameters so that output currents and applied CSx pin voltages do not exceed their absolute maximum ratings. This also applies to when you change the shunt resistance values.

Table 3-3. Reference Current Values by Default Parameter Values

Description	GUI Parameter	Default Parameter Value	Reference Current Values		
			R_{Sx} Setting Example 1 R_{Sx} = 560 mΩ (I_{FS} = 0.89 A)[1]	R_{Sx} Setting Example 2 R_{Sx} = 470 mΩ (I_{FS} = 1.06 A)[3]	R_{Sx} Setting Example 3 R_{Sx} = 360 mΩ (I_{FS} = 1.39 A)[3]
Maximum Input Voltage Range for Current-sensing Ope-amp	CS Range	−500 mV to 500 mV	—	—	—
Maximum Operating Current, I_{MX}	Max Curnt	50% Ifs	0.45 A[2]	0.53 A[4]	0.69 A[4]
SOCP Threshold Current, I_{LIM}	OCP Curnt	80% Ifs	0.71 A[3]	0.85 A[5]	1.11 A[5]
Field Weakening Current, I_{FW}	FWkn Curnt	0% Ifs	0 A[4]	0 A[4]	0 A[6]
Braking Current, I_{WM}	WM Brk Curnt	25% Imax	0.11 A[5]	0.13 A[5]	0.17 A[7]
Minimum Braking Current Threshold, $I_{WM(MIN)}$	WM Ext Curnt	6.25% Imax	0.03 A[6]	0.03 A[6]	0.04 A[8]
HOCP Threshold Current, I_{HOCP}	HOCP ThreV	150% Ifs	1.34 A[7]	1.6 A[7]	2.08 A[9]

(1) Determined by the following equation:

$$I_{FS}(A) = \frac{\text{CS Range (mV)}}{R_{Sx}\ (\text{m}\Omega)}.$$

(2) $I_{MX} = I_{FS} \times 0.5$.
(3) $I_{LIM} = I_{FS} \times 0.8$.
(4) $I_{FW} = I_{FS} \times 0$.
(5) $I_{WM} = I_{max} \times 0.25$.
(6) $I_{WM(MIN)} = I_{max} \times 0.0625$.
(7) $I_{HOCP} = I_{FS} \times 1.5$.

3.2. Setting the Start Up Group Box (Startup)

This section describes how to set the parameters in the **Start Up** group box on the GUI. Table 3-4 lists the setting parameters related to the startup operations (motor startup/restart). Be sure to set these parameters after the motor is stopped. During the startup operations, IC temperatures have high tendencies to increase; therefore, care should be taken not to raise case temperatures up to 100 °C.

Table 3-4. Setting Description: Startup (Startup/Restart)

Setting Description	GUI Parameter	Information Required for Setting
Coefficient of Startup Hold Time	Hold Time	A time that the rotor is aligned to its initial position.
Duty Cycle of Startup Hold Current	Hold DutyC	A current that the rotor can be fixed to its initial position.
Ramp-up Time of Hold Current	Hold Rmp Up	With or without hunting
Ramp-up Frequency	RampU Frequ	A motor speed that allows the motor to start running.
Ramp-up Current	RampU Curnt	A torque (current) that allows the motor to start running.

Figure 3-2 shows the sequence related to the startup operations (start/restart); Figure 3-3 shows the block diagram of the corresponding components.

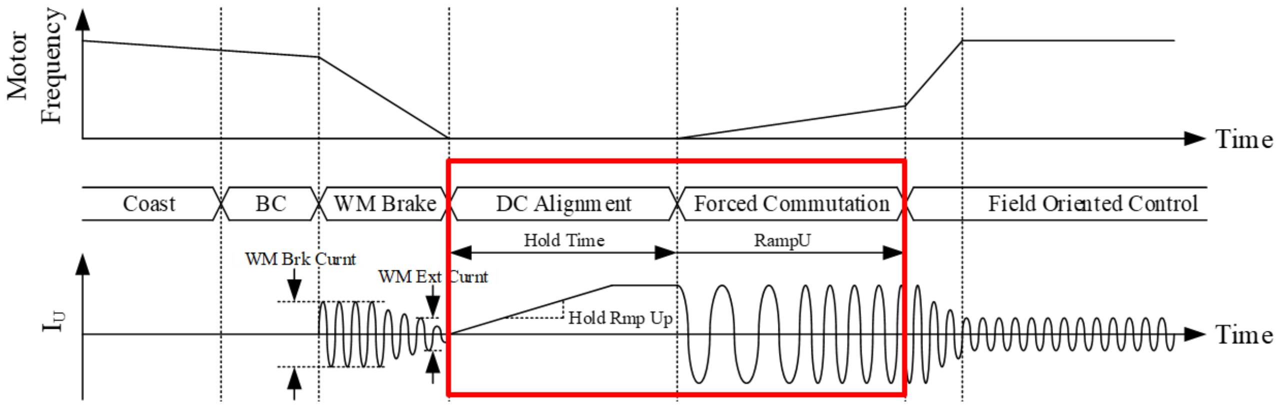


Figure 3-2. Sequence: Startup (Startup/Restart)

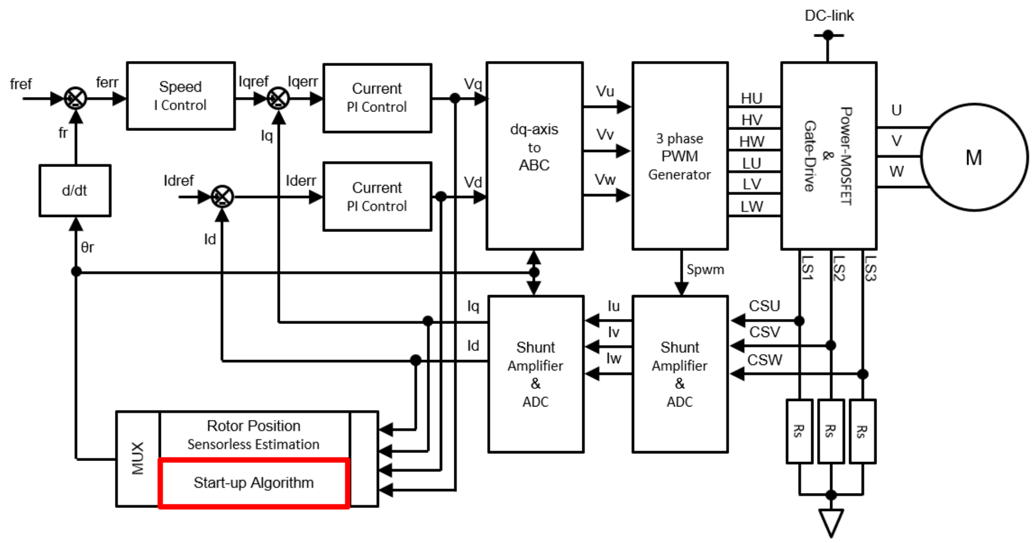


Figure 3-3. Block Diagram: Startup (Startup/Restart)

3.2.1. Hold Time (Startup Hold Time)

From the **Hold Time** list in the **Start Up** group box, select a value of a startup hold time (i.e., a hold time the motor rotor starts to rotate). Adjust the value so that the rotor can be aligned to its initial position within the time you have set. As Figure 3-4 shows, adjust the value so that the rotor will not be aligned to an unstable position.

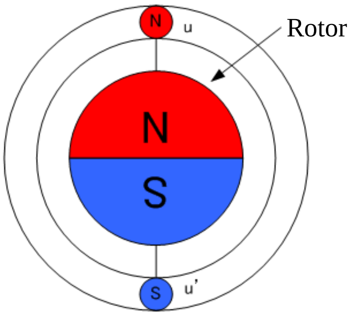


Figure 3-4. Example of Rotor Fixed to Unstable Position

Table 3-5 provides the overview of the **Hold Time** parameters. Figure 3-5 and Figure 3-6 show the corresponding operational waveforms.

Table 3-5. Parameter Overview: Hold Time

Setting Description	GUI Parameter	Parameter Settings		
		GUI Default	Setting Range	Step
Coefficient of Startup Hold Time	Hold Time	5	0 to 63	1
Startup Hold Time (Automatic Calculation)	Hold Time [ms]*	544.8 ms	0 ms to 6295.0 ms	—

* Automatically calculated based on the value set in the **PWM Period** field under the **PWM** group box.

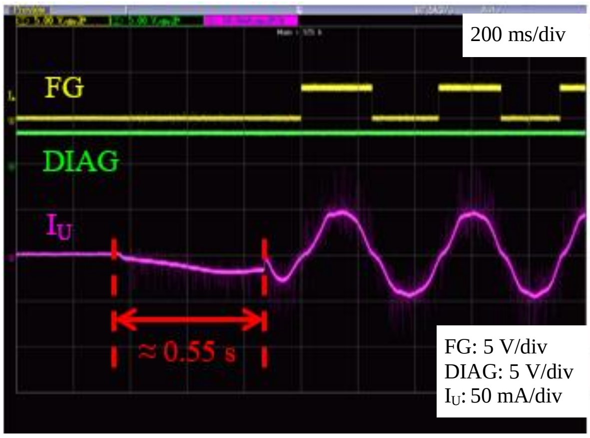


Figure 3-5. Operational Waveforms (Default: Hold Time = 10)

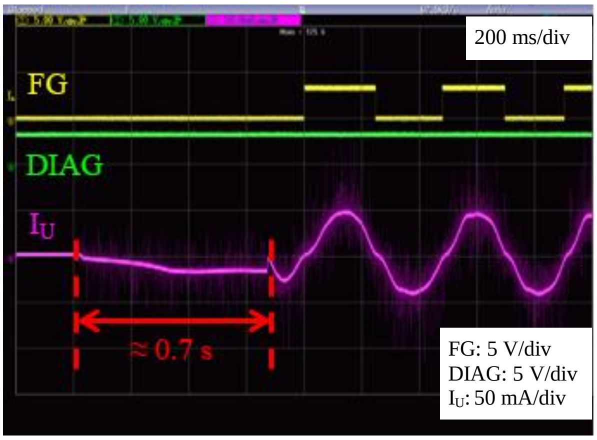


Figure 3-6. Operational Waveforms (Hold Time = 13)

3.2.2. Hold DutyC (Startup Hold Current)

From the **Hold DutyC** list in the **Start Up** group box, select a value of a startup hold current during startup hold time. A startup hold current is excited with a constant PWM duty cycle regardless of DC link voltages. When you adjust the **Hold DutyC** parameter, the following must be taken into account:

- Adjust a setting value so that the rotor will be aligned to its initial position.
- When selecting a higher value from the **Hold DutyC** list, set a value so that an IC case temperature does not exceed 100 °C. (NOTE: The higher the cogging torque, the higher the current.)
- Rotor rotations may affect the FG waveform and phase current waveform.

Table 3-6 lists the overview of the **Hold DutyC** parameter. Figure 3-7 and Figure 3-8 show the corresponding operational waveforms.

Table 3-6. Parameter Overview: Hold DutyC

Setting Description	GUI Parameter	Parameter Settings		
		GUI Default	Setting Range	Step
Duty Cycle of Startup Hold Current	Hold DutyC	6.1%	1.5% to 22.9%	1.5

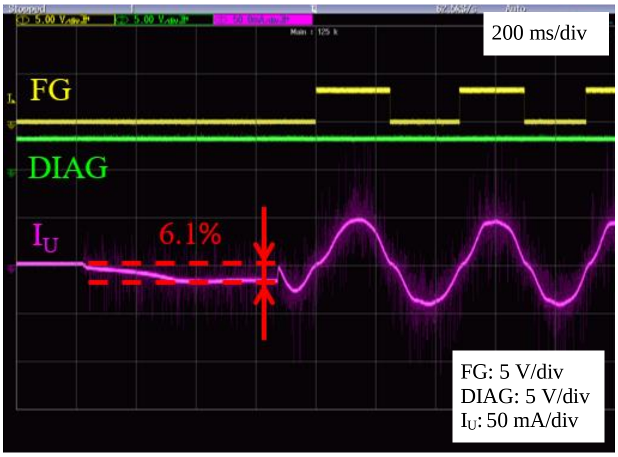


Figure 3-7. Operational Waveforms (Default: Hold DutyC = 6.1%)

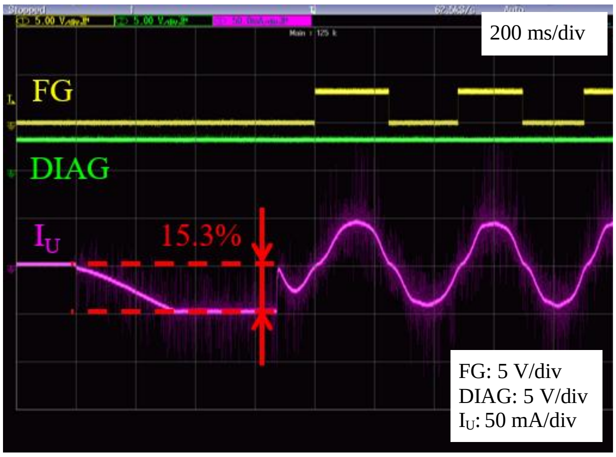


Figure 3-8. Operational Waveforms (Hold DutyC = 15.3%)

The equation below defines the startup hold current:

$$I_{SHC} = \frac{V_{BB}}{R_L} \times \text{Hold DutyC} \times 2\,. \tag{4}$$

Where:
I_{SHC} is the startup hold current (A),
V_{BB} is the main power supply voltage (V),
R_L is the inter-phase resistance of the load (Ω), and
Hold DutyC is the value selected from the **Hold DutyC** list.

3.2.3. Hold Rmp Up (Ramp-up Time of Startup Hold Current)

From the **Hold Rmp Up** list in the **Start Up** group box, select a value of a startup hold current slope. Allowing a startup hold current to have a slope prevents load-induced hunting, thus ensuring smooth rotor positioning. The lower the **Hold Rmp Up** setting value, the shorter the startup time. The following must be taken into account in adjusting the parameter: load movements, FG waveform, and phase waveform.

Table 3-7 lists the overview of the **Hold Rmp Up** parameter. Figure 3-9 and Figure 3-10 show the corresponding operational waveforms.

Table 3-7. Parameter Overview: Hold Rmp Up

Setting Description	GUI Parameter	Parameter Settings		
		GUI Default	Setting Range	Step
Ramp-up Time of Hold Current	Hold Rmp Up	50%	6% to 94%	6

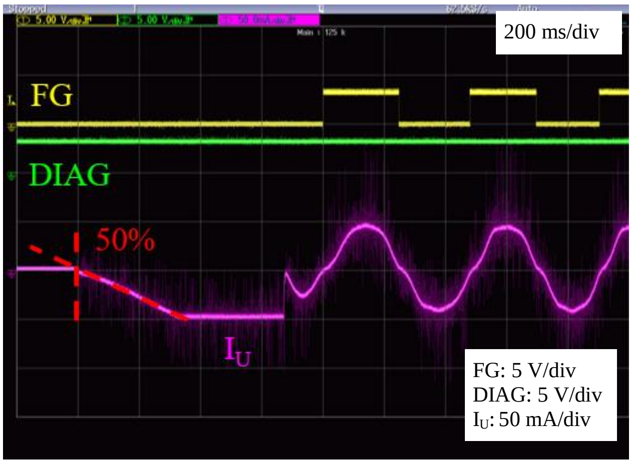


Figure 3-9. Operational Waveforms
(Default: Hold Rmp Up = 50%)

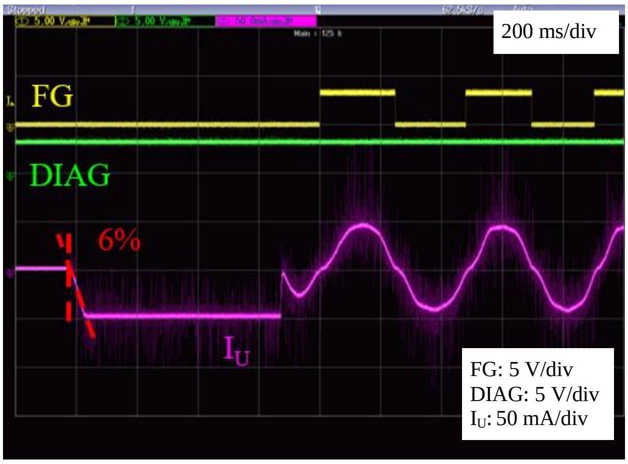


Figure 3-10. Operational Waveforms
(Hold Rmp Up = 6%)

3.2.4. RampU Frequ (Ramp-up Frequency)

From the **RampU Frequ** list in the **Start Up** group box, select a value of a ramp-up frequency when it changes from open-loop to closed-loop frequency control. Increase the **RampU Frequ** setting value gradually, from low to high, according to load conditions. This approach prevents a loss-of-synchronization condition at open-to-closed loop frequency control changeover. Also, thoroughly check the **RampU Curnt** setting value, FG waveform, phase current waveform, and rotor operation when adjusting the parameter. In case of the following conditions, a loss-of-synchronization condition at open-to-closed loop frequency control changeover is more likely to occur:

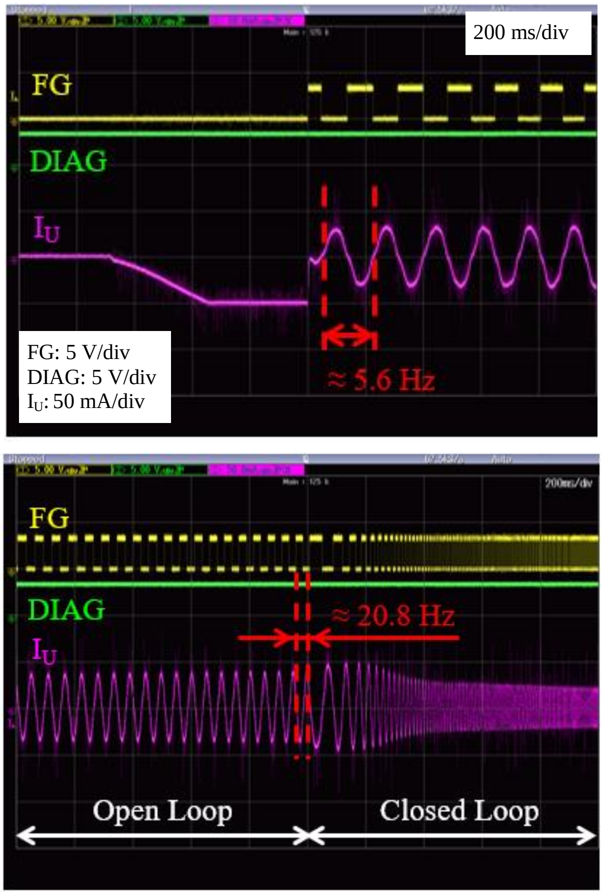
- A higher **RampU Frequ** setting value and heavy load
  (This may cause a startup failure because the **RampU Frequ** setting value becomes unfollowable.)
- A lower **RampU Frequ** setting value and inadequate motor rotation

Once the motor starts to rotate, a phase current frequency automatically increases (accelerates) until it reaches the predetermined ramp-up frequency, set by the **RampU Frequ** list. After the phase current frequency reaches the ramp-up frequency set by the **RampU Frequ** list, the frequency control is changed to closed-loop frequency control.

Table 3-8 lists the overview of the **RampU Frequ** parameter. Figure 3-11 and Figure 3-12 show the corresponding operational waveforms.

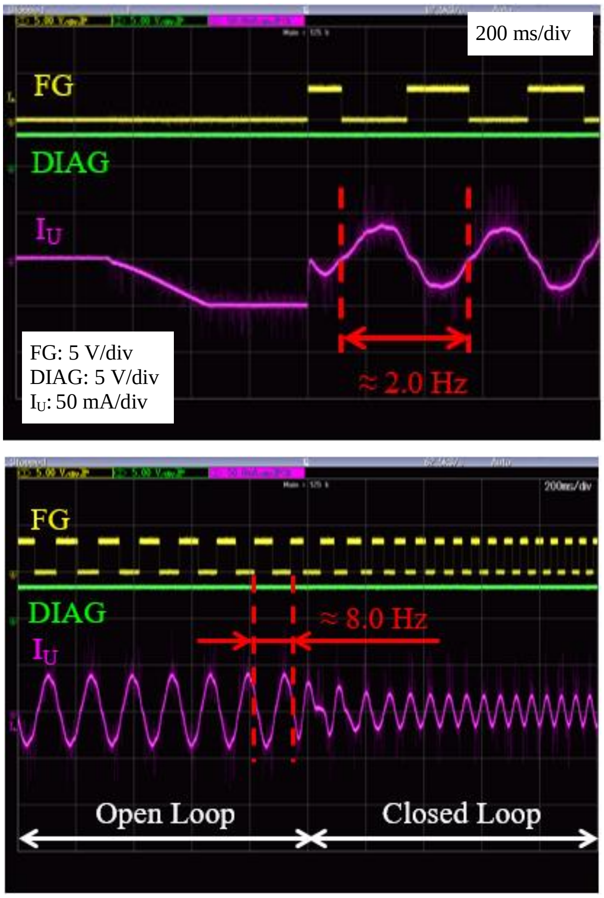
Table 3-8. Parameter Overview: RampU Frequ

Setting Description	GUI Parameter	Parameter Settings		
		GUI Default	Setting Range	Step
Ramp-up Frequency	RampU Frequ	20.8 Hz	1.6 Hz to 49.6 Hz	1.6



Accelerated from 5.6 Hz to 20.8 Hz

Figure 3-11. Operational Waveforms
(Default: RampU Frequ = 20.8 Hz)



Accelerated from 2.0 Hz to 8.0 Hz

Figure 3-12. Operational Waveforms
(RampU Frequ = 8.0 Hz)

3.2.5. RampU Curnt (Ramp-up Current)

From the **RampU Curnt** list in the **Start Up** group box, select a value of a phase current during forced commutation. Increase the **RampU Curnt** setting value gradually, from low to high, while checking the rotor condition. Also, thoroughly check the **RampU Frequ** setting value, FG waveform, and phase current waveform when adjusting the parameter. Note that the higher the **RampU Curnt** setting value, the higher the starting torque, thus resulting in an increased loss.

Table 3-9 provides the overview of the **RampU Curnt** parameter. Figure 3-13 and Figure 3-14 show the corresponding operational waveforms.

Table 3-9. Parameter Overview: RampU Curnt

Setting Description	GUI Parameter	Parameter Settings		
		GUI Default	Setting Range	Step
Ramp-up Current	RampU Curnt	6.3% Ifs	1.6% Ifs to 48.4% Ifs	1.6

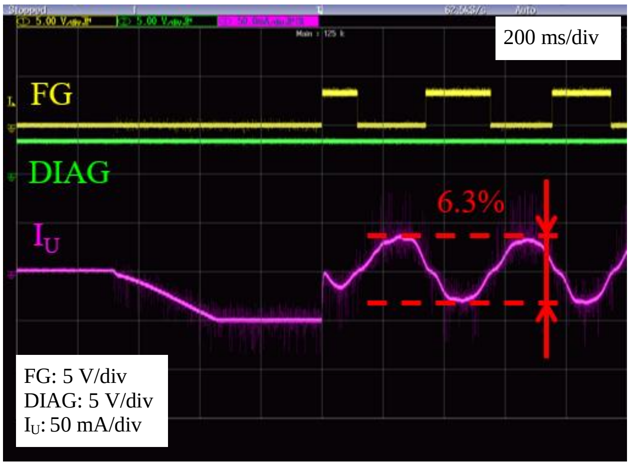


Figure 3-13. Operational Waveforms (Default: RampU Curnt = 6.3% Ifs)

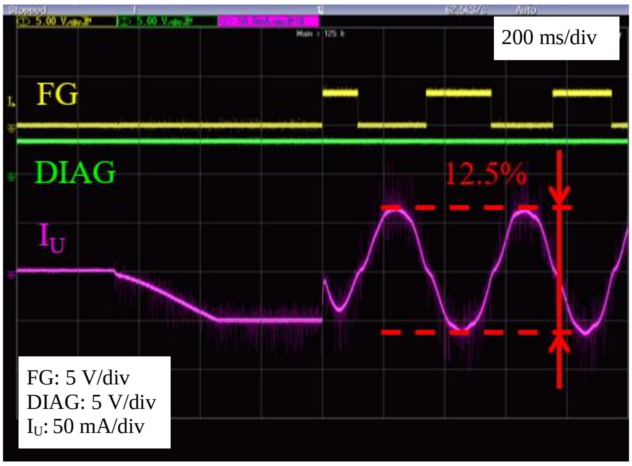


Figure 3-14. Operational Waveforms (RampU Curnt = 12.5% Ifs)

3.3. Setting the Motor Control Group Box (Motor Control)

3.3.1. Kp Curnt and Ki Curnt (Current Control Gains)

After the startup sequence ends, the forced commutation sequence starts. The current control during the forced commutation sequence is determined by the following parameters in the **Motor Control** group box: the **Kp Curnt** for proportional gain setting; the **Ki Curnt** for integral gain setting. Gain design methods include phase margin designing, simulations, and so on. This section describes how to adjust the current control gain parameters by using current waveforms as criteria samples.

The following must be taken into account when you adjust the gain parameters:

- The lower the gain, the slower the response; hence, steady-state deviation increases.
- The higher the gain, the faster the response; hence, steady-state deviation decreases.
- A higher gain causes the motor response to be vibrational. An extremely high gain destabilizes motor operations.

Figure 3-15 illustrates the sequence related to the current control gains; Figure 3-16 illustrates the block diagram of the corresponding components.

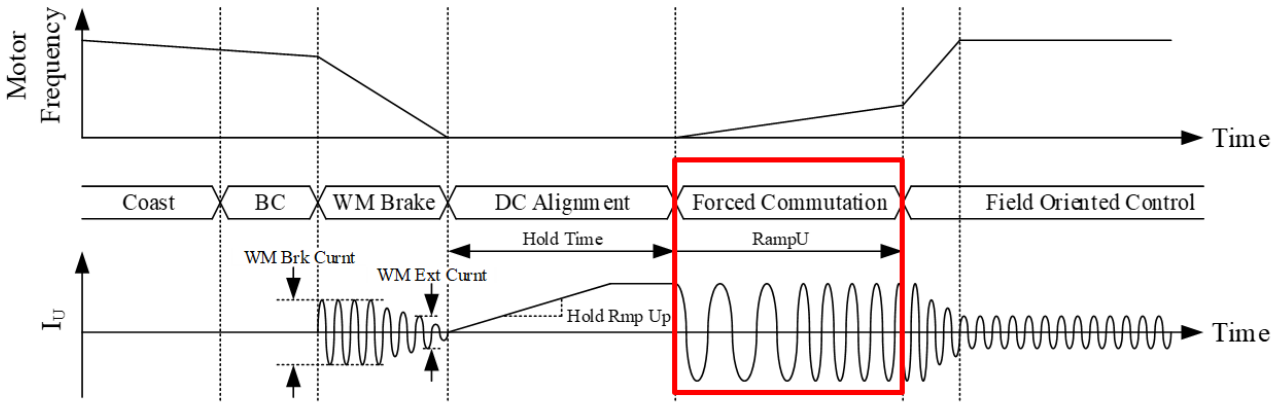


Figure 3-15. Sequence: Current Control Gain

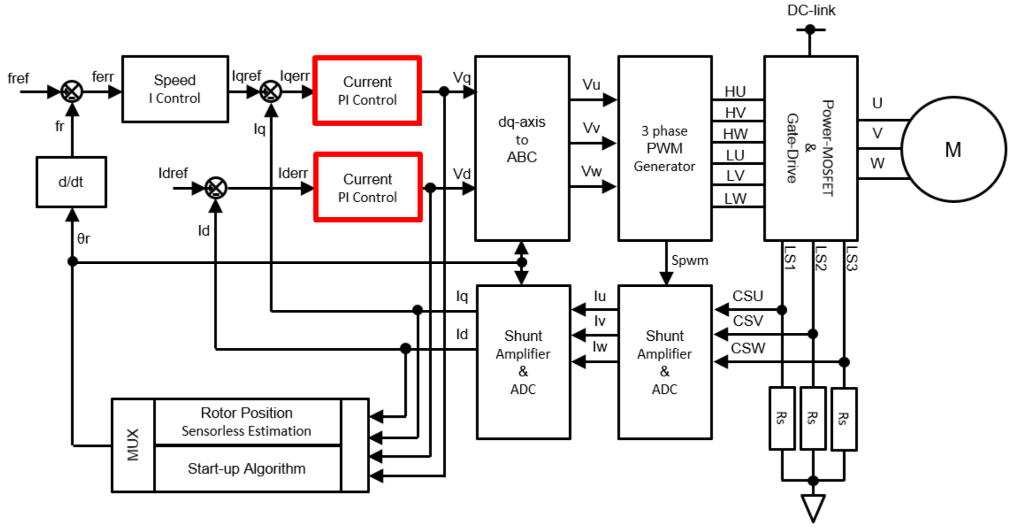


Figure 3-16. Block Diagram: Current Control Gains

Table 3-10 provides the overviews of the **Kp Curnt** and **Ki Curnt** parameters.

Table 3-10. Parameter Overview: Kp Curnt, Ki Curnt

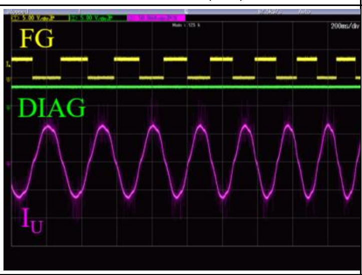
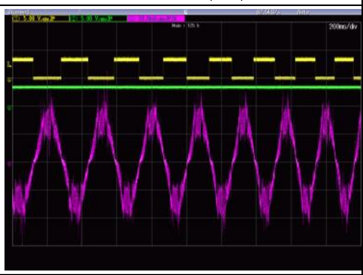
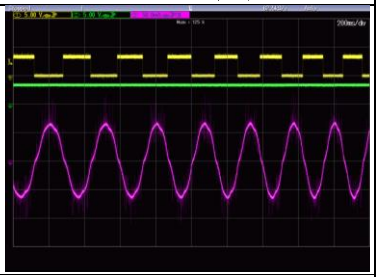
Setting Description	GUI Parameter	Parameter Settings			
		GUI Default	Setting Range	Step	# of Options
Proportional Gain for Current Control	Kp Curnt	0.5 Kncp (2^{-1})	0.008 Kncp (2^{-7}) to 256 Kncp (2^{8})	(2^{X})	16
Integral Gain for Current Control	Ki Curnt	0.5 Knci (2^{-1})	0.008 Knci (2^{-7}) to 256 Knci (2^{8})	(2^{X})	16

This section contains the tuning examples of the **Kp Curnt** and **Ki Curnt** parameters. The setting values for yielding ideal current waveforms depend on motor conditions. Based on the tuning examples, set optimal values while checking motor conditions and phase current waveforms.

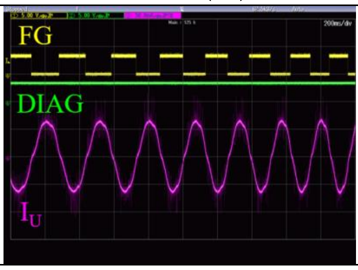
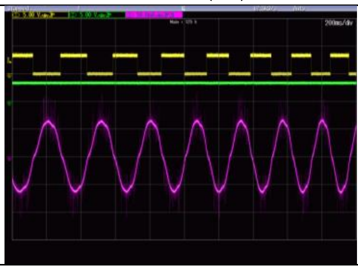
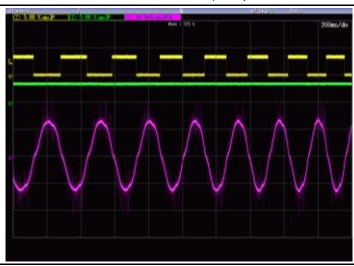
- **Tuning Example 1: Tune Kp Curnt with fixed Ki Curnt**

Setting Example 1: Selected 0.5 from the **Ki Curnt** list, and changed the **Kp Curnt** setting value from 0.5 to 64. The result shows overdamping, i.e., the current waveform, I_U, vibrated and the motor produced an audible noise.

Setting Example 2: Selected 16 from the **Kp Curnt** list, 2 levels down from the previously selected option 64. This tuning yielded no audible noise.

	GUI Default	Setting Example 1	Setting Example 2
Kp Curnt	0.5 Kncp (2^{-1})	64 Kncp (2^{6})	16 Kncp (2^{4})
Ki Curnt	0.5 Knci (2^{-1})	0.5 Knci (2^{-1})	0.5 Knci (2^{-1})
Operational Waveform			
Result	No problem found	Overdamped (audible noise)	No problem found

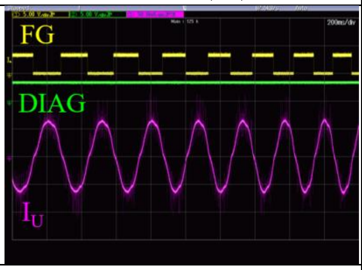
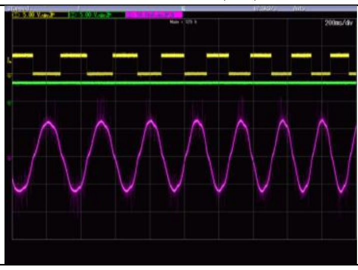
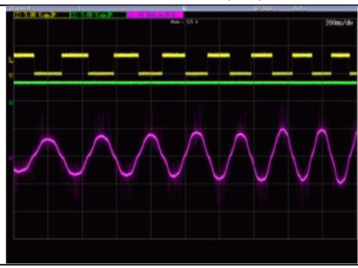
Setting Examples 3 and 4: Selected 0.5 from the **Ki Curnt** list, and decreased the **Kp Curnt** setting value from 0.5 to 0.008. This tuning yielded stable current waveforms and motor operations.

	GUI Default	Setting Example 3	Setting Example 4
Kp Curnt	0.5 Kncp (2^{-1})	0.031 Kncp (2^{-5})	0.008 Kncp (2^{-7})
Ki Curnt	0.5 Knci (2^{-1})	0.5 Knci (2^{-1})	0.5 Knci (2^{-1})
Operational Waveform			
Result	No problem found	No problem found	No problem found

According to the results of Tuning Example 1, the optimal **Kp Curnt** setting values when **Ki Curnt** = 0.5 will range from 0.008 to 16.

- **Tuning Example 2: Tune Ki Curnt with Kp Curnt = 0.5**

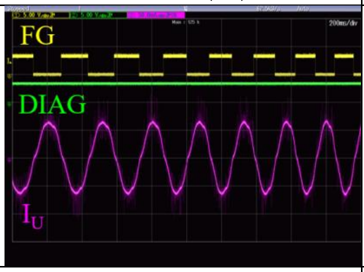
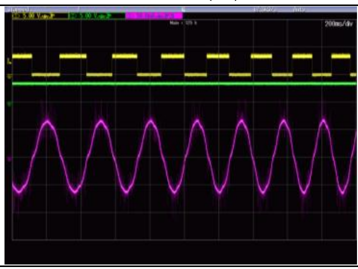
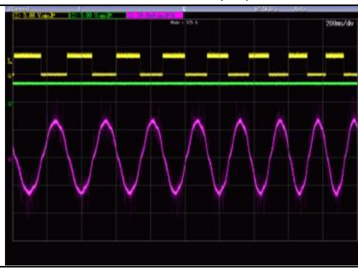
With 0.5 set in the **Kp Curnt** list, the **Ki Curnt** setting value was decreased from 0.5 to 0.125. This tuning yielded stable current waveforms and motor operations. However, as Setting Example 5 presents, when the **Ki Curnt** setting value was further decreased to 0.063, the motor produced an abnormal noise even though the current waveform remained followable. And then, Setting Example 6 shows that when the **Ki Curnt** setting value was further decreased to 0.008, the motor caused a loss-of-synchronization condition due to underdamped control.

	GUI Default	Setting Example 5	Setting Example 6
Kp Curnt	0.5 Kncp (2^{-1})	0.5 Kncp (2^{-1})	0.5 Kncp (2^{-1})
Ki Curnt	0.5 Knci (2^{-1})	0.063 Knci (2^{-4})	0.008 Knci (2^{-7})
Operational Waveform			
Result	No problem found	Abnormal noise	Underdamped (LOS)

According to the results of Tuning Example 2, the optimal **Ki Curnt** setting values when **Kp Curnt** = 0.5 will range from 0.125 to 0.5.

- **Tuning Example 3: Tune Ki Curnt with Kp Curnt = 16**

Setting Examples 7 and 8: Selected 16 from the **Kp Curnt** list, and increased the **Ki Curnt** setting value from 0.5 to its maximum value. This tuning yielded stable current waveforms and motor operations.

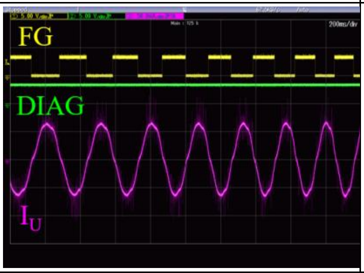
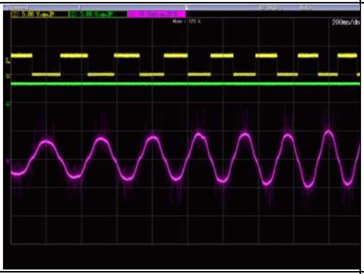
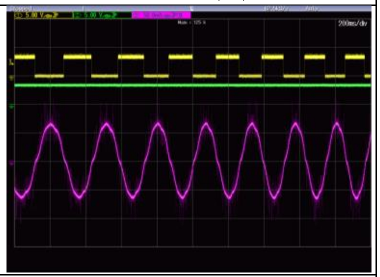
	GUI Default	Setting Example 7	Setting Example 8
Kp Curnt	0.5 Kncp (2^{-1})	16 Kncp (2^{4})	16 Kncp (2^{4})
Ki Curnt	0.5 Knci (2^{-1})	16 Knci (2^{4})	256 Knci (2^{7})
Operational Waveform			
Result	No problem found	No problem found	No problem found

According to the results of Tuning Example 3, the optimal **Ki Curnt** setting values when **Kp Curnt** = 0.5 will range from 0.5 to 256.

- **Tuning Example 4: Tune Kp Curnt Ki Curnt both**

Setting Example 9: Selected minimum values form the **Kp Curnt** and **Ki Curnt** lists. The motor caused a loss-of-synchronization condition due to underdamped control.

Setting Example 10: Selected 16 from the **Kp Curnt** and Ki **Curnt** lists. This tuning yielded stable motor operations.

	GUI Default	Setting Example 9	Setting Example 10
Kp Curnt	0.5 Kncp (2^{-1})	0.008 Kncp (2^{-7})	16 Kncp (2^{4})
Ki Curnt	0.5 Knci (2^{-1})	0.008 Knci (2^{-7})	16 Knci (2^{4})
Operational Waveform			
Result	No problem found	Underdamped (LOS)	No problem found

The Tuning Example 4 results found that both of the GUI default and Setting Example 10 had stable waveforms. Therefore, employing the setting values used in both cases will cause no problem.

Setting lower values in the **Kp Curnt** and **Ki Curnt** lists allows the motor to have better damping and slower responsiveness.

Setting higher values in the **Kp Curnt** and **Ki Curnt** lists allows the motor to have worse damping and faster responsiveness.

3.3.2. Ki Speed (Speed Control Gain)

From the **Ki Speed** list in the **Motor Control** group box, select a value of an integral gain for speed control.

Figure 3-17 shows the sequence related to the speed control gain; Figure 3-18 shows the block diagram of the corresponding component.

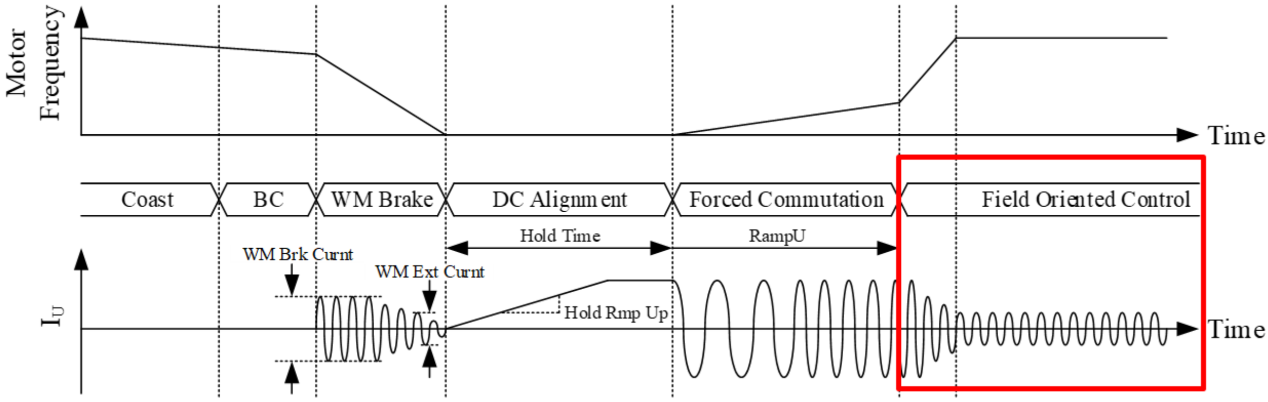


Figure 3-17. Sequence: Speed Control Gain

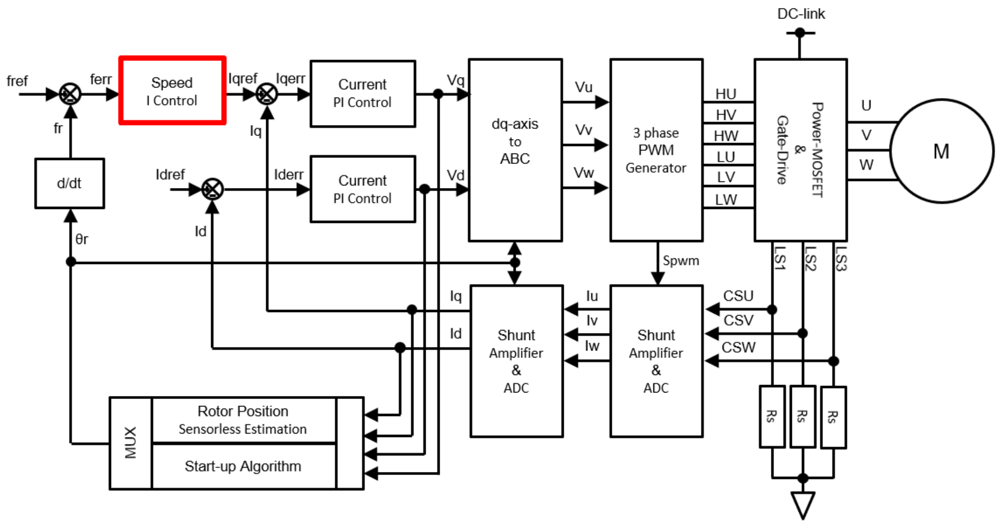


Figure 3-18. Block Diagram: Speed Control Gain

3.4. Setting the Motor Sensorless Group Box (Sensorless Control)

After tuning the current control gains, adjust the values for rotor position estimation and followability gains. This section describes how to set the parameters in the **Motor Sensorless** group box on the GUI.

- Set the **Winding Ls** value to define an estimated rotor position (i.e., define the V_{BEMF} phase).
- Set the **Kp Snsls** and **Ki Snsls** values to adjust the responsiveness to any deviation in the estimated rotor position defined by the **Winding Ls** setting value.

These parameters affect not only steady-state motor operations but also motor startup and other operating conditions. Therefore, thoroughly check the motor operations, from startup to stable operations, every time you change the parameters.

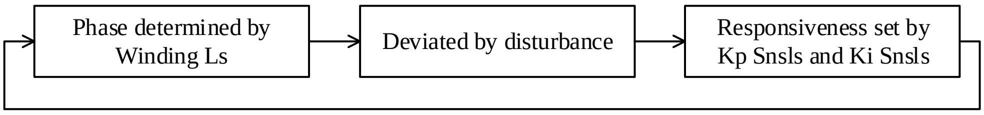


Figure 3-19 illustrates the sequence related to the rotor position estimation; Figure 3-20 illustrates the block diagram of the corresponding component.

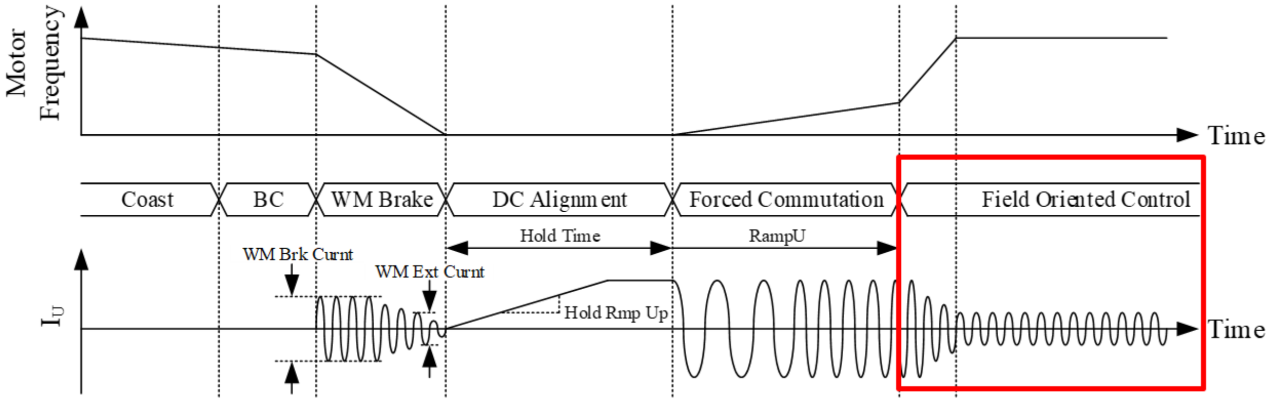
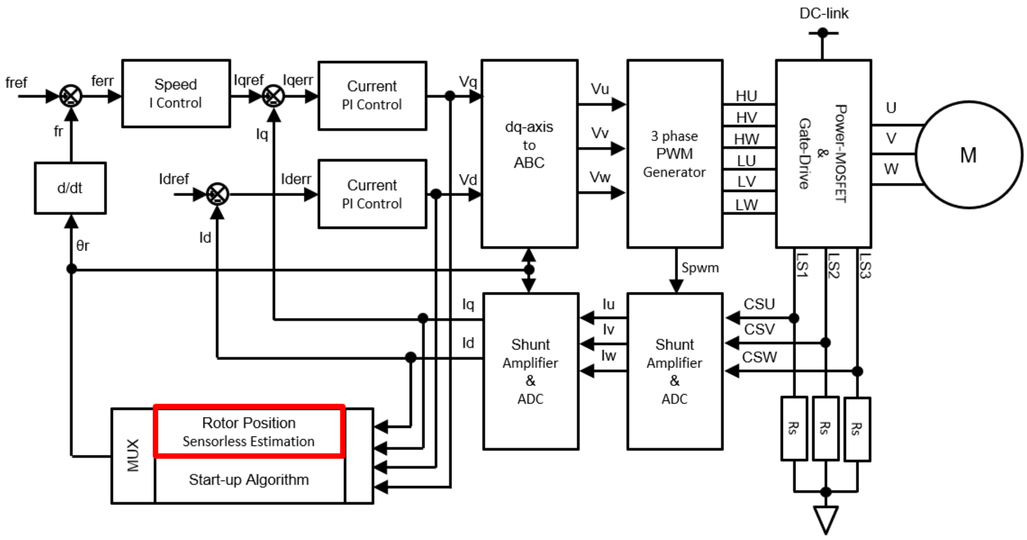


Figure 3-19. Sequence: Rotor Position Estimation



- Only Iq is controlled when Id = 0 (default).
- Deviation (Iqerr) = q-axis Current Command (Iqref) − q-axis Current (Iq)

Figure 3-20. Block Diagram: Rotor Position Estimation

3.4.1. Winding Ls (Motor Constant)

The IC has the function that estimates a rotor position (d-q axis) from the motor's back EMF (BEMF: Back Electromotive Force). The back EMF, V_{BEMF}, depends on the following motor-related factors: materials, structures, windings, rotation speeds, power supply voltages, etc.

Figure 3-21 exemplifies the V_{BEMF} phases when the motor load is rapidly changed from light to heavy. In heavy load, the phase current has a delay in the followability to the phase voltage, V_{BRG}. The motor rotor also causes a mechanical delay; consequently, the V_{BEMF} shifts into a transient state. As a result, the difference between the phase voltage and the back EFM widens, thus increasing the phase current. The higher the phase current the higher the torque, hence an increase in the motor rotation speed.

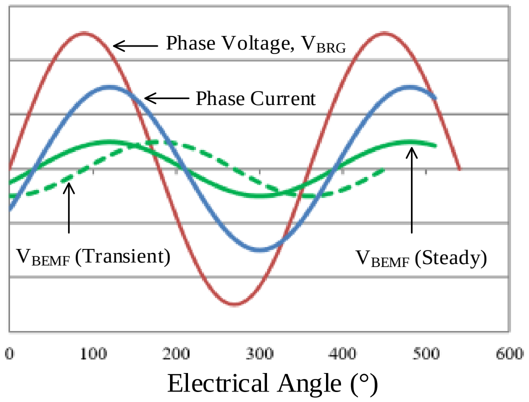


Figure 3-21. Example V_{BEMF} Phase

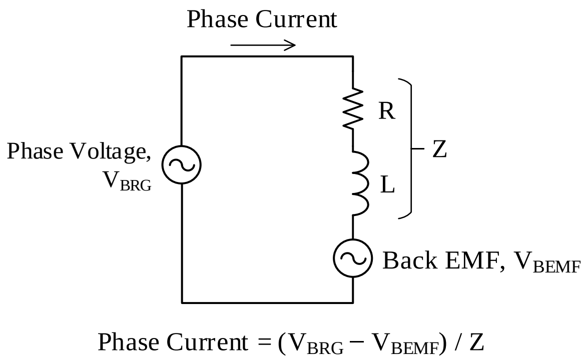


Figure 3-22. Schematic Diagram of Phase Current

Circuit efficiency reaches its highest level when the phase current and V_{BEMF} phases are matched. Select an optimal value from the **Winding Ls** list in the **Motor Sensorless** group box to adjust the estimated rotor position (d-q axis) so that the phase current and V_{BEMF} phases can match depending on motor specifications, power conditions, loads, etc.

Figure 3-23 illustrates a phase relation between the phase current and V_{BEMF}. As Figure 3-24 plots, the value calculated in Section 2.1 slightly varies (i.e., causes phase shifts in the phase current). Therefore, be sure to fine-tune the calculated value based on an actual motor rotation speed.

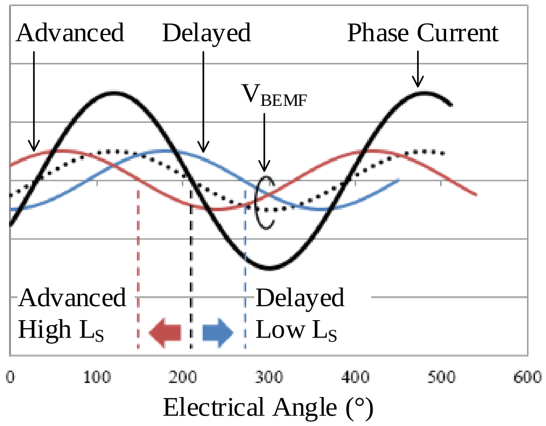


Figure 3-23. Phase Current vs. V_{BEMF}

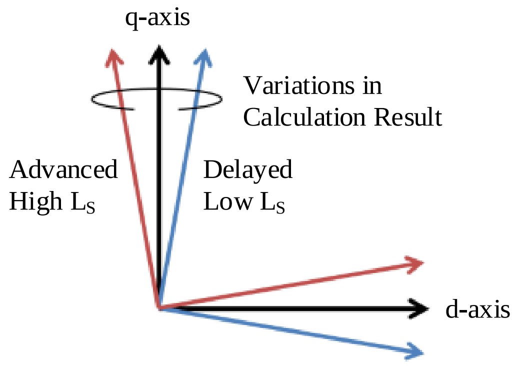


Figure 3-24. Relationship of d-q Axis Coordinate (Phasor Diagram)

Table 3-11 lists the overview of the **Winding Ls** parameter.

Table 3-11. Parameter Overview: Winding Ls

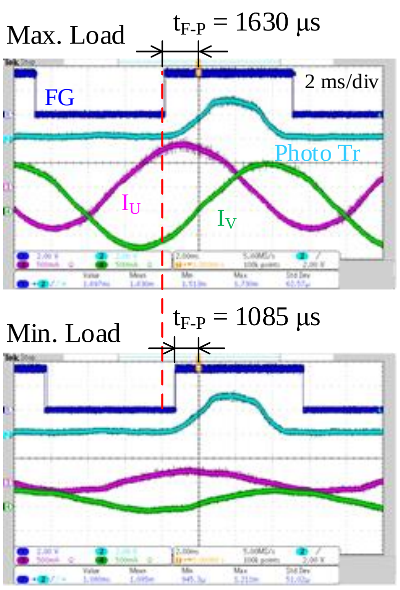
Setting Description	GUI Parameter	Parameter Settings			
		GUI Default	Setting Range	Step	# of Options
Motor Constant	Winding Ls	200 Lu	1 Lu to 1023 Lu	1	1023

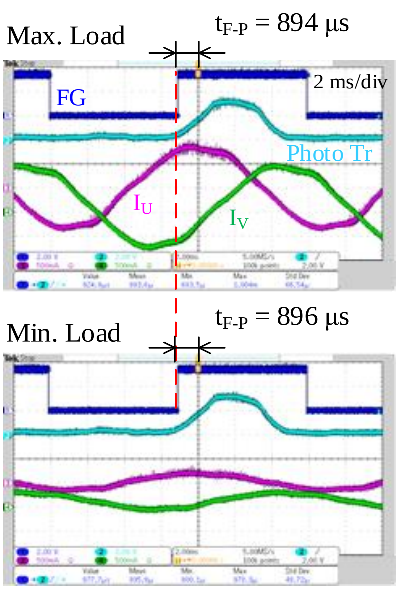
The following are the tuning examples of the **Winding Ls** parameter. Among the waveform of the tuning examples listed below, "Photo Tr" represents the rotor's mechanical angle (an actual rotor position). "FG" represents the FG pin voltage (an estimated rotor position determined by the IC).

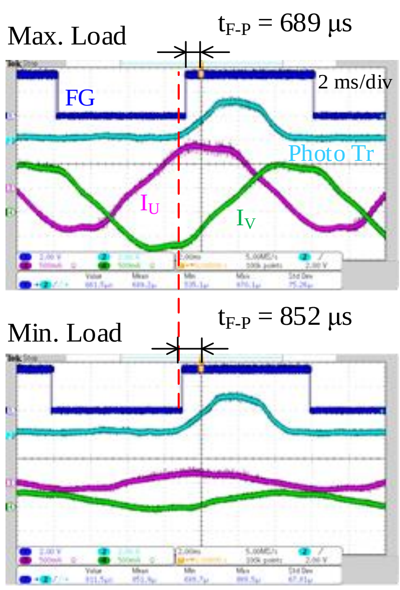
These tuning examples employed Photo Tr as an oscilloscope trigger to measure $t_{F\text{-}P}$, a time from the rising edge of an FG signal to the Photo Tr triggering point, under different load conditions. The load conditions are a maximum value (high phase current) and a minimum value (low phase current) under assumed operating conditions. As the Example 2 results indicate, the **Winding Ls** setting value was adjusted so that the $t_{F\text{-}P}$ values can be equalized under each load condition.

- **Tuning Examples**

Conditions: Air purifier; VCC = 15 V, VBB = 150 V, T_A = 25 °C

<table>
<tr><td>Example 1 (Winding Ls = 160 Lu)</td><td>Example 2 (Winding Ls = 208 Lu)</td><td>Example 3 (Winding Ls = 220 Lu)</td></tr>
<tr><td>

I_U: 500 mA/div FG: 2 V/div
I_V: 500 mA/div Photo Tr: 2 V/div</td><td>

I_U: 500 mA/div FG: 2 V/div
I_V: 500 mA/div Photo Tr: 2 V/div</td><td>

I_U: 500 mA/div FG: 2 V/div
I_V: 500 mA/div Photo Tr: 2 V/div</td></tr>
<tr><td>1630 − 1085 = 545 µs (Delayed)</td><td>894 − 896 = −2 µs (Matched)</td><td>689 − 852 = −163 µs (Advanced)</td></tr>
</table>

3.4.2. Kp Snsls and Ki Snsls (Followablitiy Gains)

From the **Kp Snsls** and **Ki Snsls** lists in the **Motor Sensorless** group box, select values of followability gains. The followability gains refer to the responsiveness when an estimated rotor position, which is determined by the **Winding Ls** setting value, becomes deviated due to a rapid change in load.

Each GUI parameter serves as follows: the **Kp Snsls** for setting a proportional gain; the **Ki Snsls** for setting an integer gain. The following must be taken into account in tuning the followability gain parameters:

- The lower the gain, the slower the response; hence, steady-state deviation increases.
- The higher the gain, the faster the response; hence, steady-state deviation decreases.
- A higher gain causes the motor response to be vibrational. An extremely high gain destabilizes motor operations.

Table 3-12 provides the overviews of the **Kp Snsls** and **Ki Snsls** parameters.

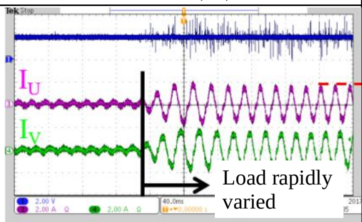
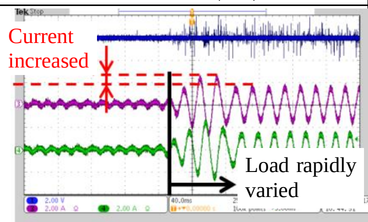
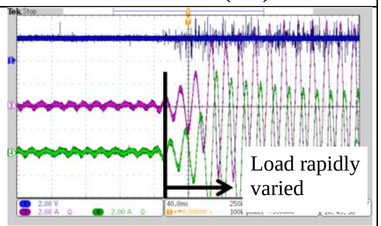
Table 3-12. Parameter Overview: Kp Snsls, Ki Snsls

GUI Parameter	Parameter Settings			
	GUI Default	Setting Range	Step	# of Options
Kp Snsls	0.5 Kntp (2^{-1})	0.008 Kntp (2^{-7}) to 256 Kntp (2^{8})	(2^{X})	16
Ki Snsls	0.5 Knti (2^{-1})	0.008 Knti (2^{-7}) to 256 Knti (2^{8})	(2^{X})	16

Be sure to adjust the **Kp Snsls** and **Ki Snsls** setting values while thoroughly checking the responsiveness to any deviation in an estimated position caused by rapid load changes or other disturbing factors. The tuning examples are listed below.

- **Tuning Examples**

Conditions: Torque bench; VCC = 15 V, VBB = 12 V, T_A = 25 °C

Parameter	Tuning Example 1	Tuning Example 2	Tuning Example 3
Kp Snsls	8 Kntp (2^{3})	1 Kntp (2^{0})	0.5 Kntp (2^{-1})
Ki Snsls	2 Knti (2^{1})	0.25 Knti (2^{-2})	0.125 Knti (2^{-3})
Operational Waveform			
Result	Followed	Followed but current increased at transient	Loss-of-synchronization

3.5. Setting the PWM Group Box (PWM Control)

This section explains how to set the PWM control parameters in the **PWM** group box, listed in Table 3-13.

Table 3-13. Setting Description: PWM Control

Setting Description	GUI Parameter	Parameter Settings	
		GUI Default	Setting Range
PWM Switching Mode	PWM Mode	2/3 ph Hyst	2 ph, 3 ph, 2/3 ph Hyst
PWM Period	PWM Period	58.9 µs	30.5 µs to 132.5 µs
Dead Time	PWM DeadTm	1.50 µs	0 µs to 3.15 µs
Charging Time of Bootstrap Capacitors	BootC ChegTm	10 ms	0 ms to 100 ms

3.5.1. PWM Mode (PWM Switching Mode)

From the **PWM Mode** list in the **PWM** group box, select a value to determine the PWM switching mode. Table 3-14 provides the overview of the **PWM Mode** parameter.

Table 3-14. Parameter Overview: PWM Mode

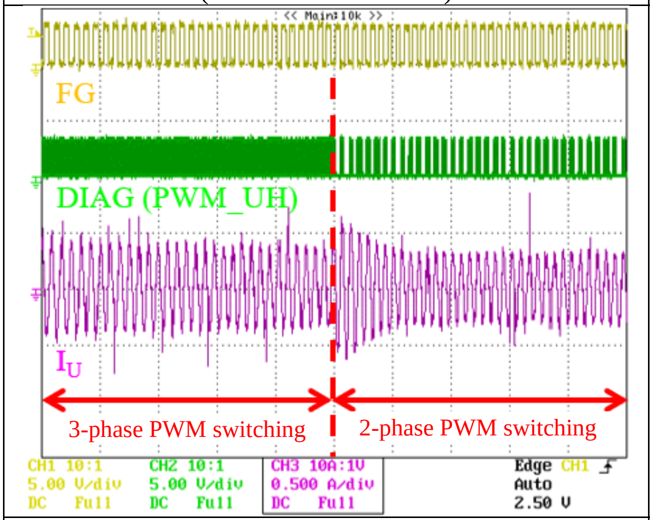
Setting Description	GUI Parameter	Parameter Setting	Function	Remarks
PWM Switching Mode	PWM Mode	2 ph	2-phase PWM switching	Low loss
		3 ph	3-phase PWM switching	Low noise
		2/3 ph Hyst	Auto-shifting between 2-/3-phase PWM switching modes	With Hysteresis

The following are the operational waveforms when “2/3 ph Hyst” is selected.

- **Tuning Examples**

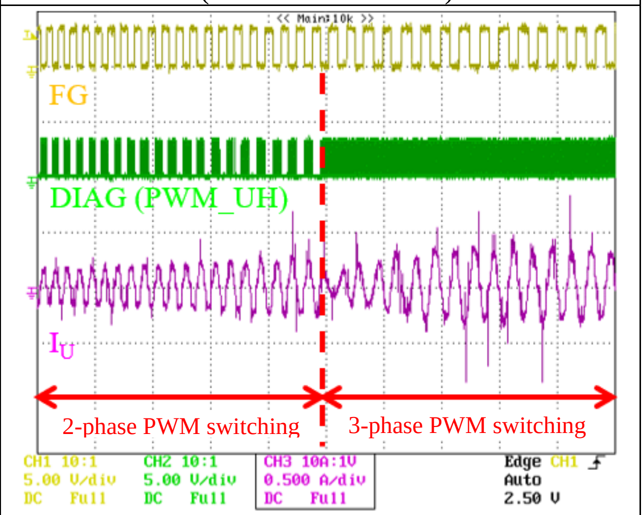
Conditions: Motor torque bench; VCC = 15 V, VBB = 12 V, T_A = 25 °C

3-phase PWM → 2-phase PWM (at Motor Acceleration)



Switched at modulation index ≈ 50%

2-phase PWM → 3-phase PWM (at Motor Deceleration)



Switched at modulation index ≈ 25%

3.5.2. PWM Period

From the **PWM Period** list in the **PWM** group box, select a value for the PWM period, T_{PR}. Table 3-15 provides the overview of the **PWM Period** parameter.

Table 3-15. Parameter Overview: PWM Period

Setting Description	GUI Parameter	Parameter Settings			
		GUI Default	Setting Range	Step	# of Options
PWM Period	PWM Period	58.9 µs (17.0 kHz)	30.5 µs to 132.5 µs (32.8 kHz to 7.5 kHz)	0.4	256

The equation below defines the relationship between the PWM period and carrier frequency:

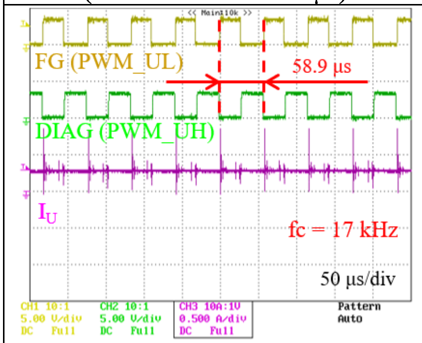
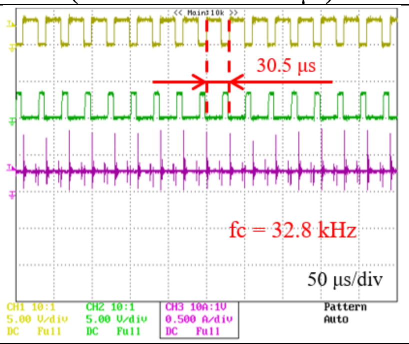
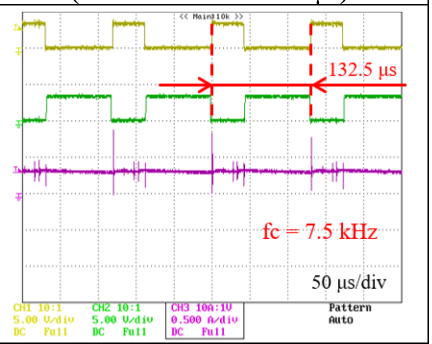
$$f_C = \frac{1}{T_{PR}} \times 1000\,. \qquad (5)$$

Where:
f_C is the motor PWM carrier frequency (kHz), and
T_{PR} is the period (µs).

The smaller the T_{PR}, the higher the f_C and thus an increase in switching loss. Therefore, adjust the **PWM Period** setting value so that an IC case temperature maintain at <100 °C. The following are the examples of PWM period tuning.

- **Tuning Examples**

Conditions: VBB = 100 V, VCC = 15 V, TA = 25 °C; general-purpose motor

Example 1 / GUI Default (PWM Period = 58.9 µs)	Example 2 (PWM Period = 30.5 µs)	Example 3 (PWM Period = 132.5 µs)
		

3.5.3. PWM DeadTm (Dead Time)

From the **PWM DeadTm** list in the **PWM** group box, select a value for a dead time. A shorter dead time results in a current waveform more approximated to a sine wave. However, in case any high-side power MOSFET of the three phases and its corresponding low-side power MOSFET both turn on at once, a short-circuit condition may occur. Therefore, be sure to set a dead time within the recommended operational range (≥1.5 µs). For more details, refer to the SX68200M series data sheet.

Table 3-16 lists the overview of the **PWM DeadTm** parameter.

Table 3-16. Parameter Overview: PWM DeadTm

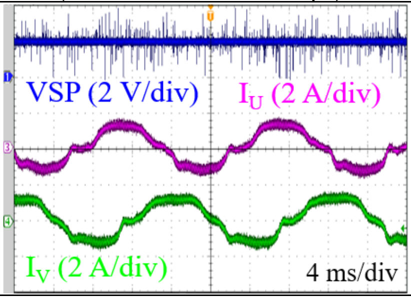
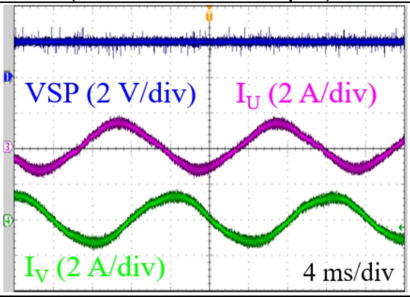
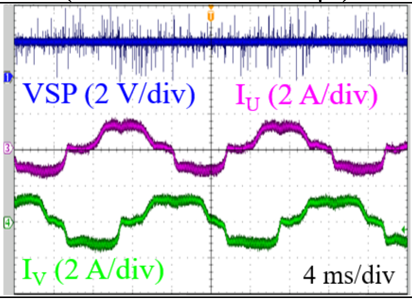
Setting Description	GUI Parameter	Parameter Settings			
		GUI Default	Setting Range	Step	# of Options
Dead Time	PWM DeadTm	1.50 µs	0 µs* to 3.15 µs	0.05	64

* Any value out of the recommended operational range is selectable but prohibited. Be sure to set a value within the range.

The following are the examples of dead time tuning.

- **Tuning Examples**

Conditions: VBB = 12 V, VCC = 15 V, T_A = 25 °C; low-voltage motor for general purpose

Example 1 / GUI Default (PWM DeadTm = 1.50 µs)	Example 2 (PWM DeadTm = 0 µs*)	Example 3 (PWM DeadTm = 3.15 µs)
		

* Temporarily set as an experimental value; be sure to set a value within the recommended operating range.

3.5.4. BootC ChrgTm (Charging Time of Bootstrap Capacitor)

From the **BootC ChrgTm** list in the **PWM** group box, select a value to determine the charging time of bootstrap capacitors. A charging time depends on the capacitance of the bootstrap capacitor, C_{Bx}. Select a value to have an adequate charging time even when C_{Bx} is electrically uncharged, e.g., the first startup.

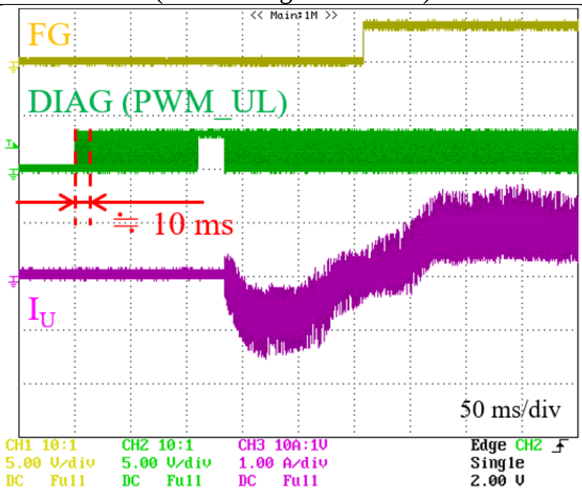
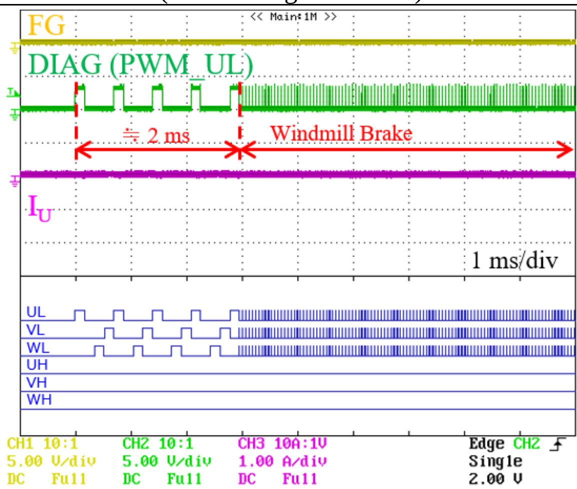
Table 3-17 provides the overview of the **BootC ChrgTm** parameter.

Table 3-17. Parameter Overview: BootC ChrgTm

Setting Description	GUI Parameter	Parameter Settings		Remarks
		GUI Default	Setting Range	
Charging Time of Bootstrap Capacitors	BootC ChrgTm	10 ms	0 ms to 100 ms	Select from the following options in the list: 1 ms, 2 ms, 5 ms, 10 ms, 20 ms, 50 ms, 100 ms.

The following are the examples of bootstrap charging time tuning. Example 1 shows that the adequate charging time resulted in a successful motor startup. In Example 2, on the other hand, the inadequate charging time resulted in a motor startup failure. Adjust the **BootC ChrgTm** setting value so that the motor can start successfully.

- **Tuning Examples**

Example 1 / GUI Default (BootC ChrgTm = 10 ms)	Example 2 (BootC ChrgTm = 2 ms)
	
Startup succeeded	Startup failed

3.6. Setting the Speed Control and VSP/VM Voltages Group Boxes (Rotation Speed)

This section explains how to set the parameters pertaining to the motor rotation speed control, as listed in Table 3-18 and Table 3-19. In the **SpeedRef Sel** field under the **Speed Control** group box, select the motor speed control ("Int SR" or "Ext VSP") by clicking the button.

- When "Int SR" is selected:
  Adjust the following parameter in the **Speed Control** group box: SpeedRef Unt; SpeedRef Drv.
  No adjustment is required for the parameters in the **VSP/VM Voltages** group box.
  For more details, see Section 3.6.1.
- When "Ext VSP" is selected:
  Adjust the following parameter in the **Speed Control** group box: SpeedRef Unt; SpeedRef Max; SpeedRef Min.
  Adjust the following parameter in the **VSP/VM Voltages** group box: VSPRun Max; VSPStart Min; VSPRun Min; VSP SleepV.
  For more details, see Section 3.6.2.

Table 3-18. Parameter Overview: Speed Control

Setting Description	GUI Parameter	Parameter Settings	
		GUI Default	Setting Range
Speed Control Mode	SpeedRef Sel	Int SR	Int SR: controlled by internal register settings Ext VSP: controlled by the VSP pin voltage
Multiplier of Reference Speed	SpeedRef Unt	1.0 Hz	0 Hz to 1.6 Hz
Reference Speed	SpeedRef Drv[(1)]	30 f_U	0 f_U to 1023 f_U
Maximum Reference Speed	SpeedRef Max[(2)]	250 f_U	0 f_U to 1023 f_U
Minimum Reference Speed	SpeedRef Min	0 f_U	0 f_U to 1023 f_U

(1) When "Int SR" is selected in the **SpeedRef Sel** field.
(2) When "Ext VSP" is selected in the **SpeedRef Sel** field.

Table 3-19. Parameter Overview: VSP/VM Voltages

Setting Description	GUI Parameter	Parameter Settings	
		GUI Default	Setting Range
Maximum Speed Voltage (V_{SMX})	VSPRun Max	5.000 V	0 V to 5.879 V
Excitation Start Voltage (V_{SST})	VSPStart Min	2.500 V	0 V to 5.879 V
Minimum Speed Voltage (V_{SMN})	VSPRun Min	2.000 V	0 V to 5.879 V
Low Power Consumption Mode Transition Voltage (V_{SSN})	VSP SleepV	1.000 V	0 V to 5.879 V

3.6.1. Int SR (Internal Control Mode)

In Int SR mode, the motor rotation speed is controlled by the internal register settings. Which means that you can control the motor rotation speed directly through the GUI. This mode does not support the motor rotation speed control by the VSP pin voltage. Adjust the parameters to yield your ideal motor control.

The equation below defines a motor rotation speed:

$$S = \frac{60 \times \mathrm{SpeedRef\ Unt} \times \mathrm{SpeedRef\ Drv}}{N_{PP}} . \quad (6)$$

Where:
S is the motor rotation speed (rpm),
SpeedRef Unt is the multiplier of the reference speed (Hz),
SpeedRef Drv is the positive integer that determines the reference speed, and
N_{PP} is the number of magnetic pole pairs.

For example, when N_{PP} = 4 (8 poles), SpeedRef Unt = 1.0 Hz, SpeedRef Drv = 30 f_U, the motor rotation speed can be defined as follows:

$$S = \frac{60 \times 30 \times 1.0}{4} = 450\ \mathrm{rpm} .$$

3.6.2. Ext VSP (External Control Mode)

In Ext VSP mode, the motor rotation speed is controlled by the VSP pin voltage (see Figure 3-25). Adjust the parameters to yield your ideal motor control. However, the VSP pin startup voltage (V_{SSX} = 1.26 V) cannot be changed.

Writing the adjusted parameters to the EEPROM enables the motor to be controlled in stand-alone mode (see Section 4.4).

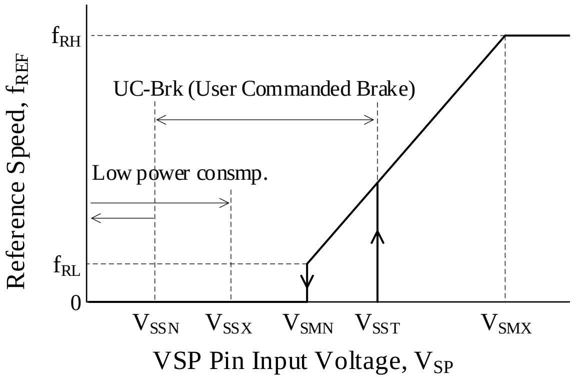


Figure 3-25. VSP Pin Input Voltage vs. Reference Motor Rotation Speed

The equations below define motor rotation speeds:

$$f_{RH} = \text{SpeedRef Unt} \times \text{SpeedRef Max}\,. \tag{7}$$

$$f_{RL} = \text{SpeedRef Unt} \times \text{SpeedRef Min}\,. \tag{8}$$

Where:
- f_{RH} is the maximum reference speed (Hz),
- f_{RL} is the minimum reference speed (Hz),
- SpeedRef Unt is the multiplier of the reference speed (Hz),
- SpeedRef Max is the positive integer that defines the maximum reference speed, and
- SpeedRef Min is the positive integer that defines the minimum reference speed.

$$S_{MAX} = \frac{f_{RH} \times 60}{N_{PP}}\,. \tag{9}$$

$$S_{MIN} = \frac{f_{RL} \times 60}{N_{PP}}\,. \tag{10}$$

Where:
- S_{MAX} is the maximum rotation speed (rpm),
- S_{MIN} is the minimum rotation speed (rpm), and
- N_{PP} is the number of magnetic pole pairs.

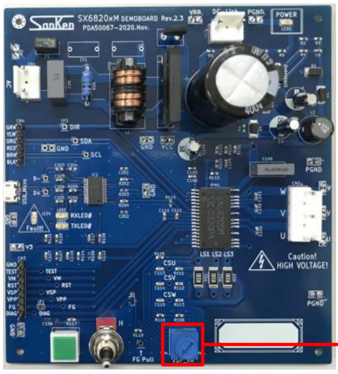
For example, when N_{PP} = 4 (8 poles), SpeedRef Unt = 1.0 Hz, SpeedRef Max = 250 f_U, SpeedRef Min = 0 f_U, S_{MAX} and S_{MIN} can be defined as follows:

$$S_{MAX} = \frac{250 \times 1.0 \times 60}{4} = 3750 \text{ rpm} \text{ , and}$$

$$S_{MIN} = \frac{0 \times 1.0 \times 60}{4} = 0 \text{ rpm} \text{ .}$$

- **Notes on Powering On the AC Power Supply**

In Ext VSP mode, before you power on the AC power supply, be sure to twist the VSP pin voltage-adjusting resistor, VSP_VR, fully counterclockwise. This is to protect the motor to start suddenly.

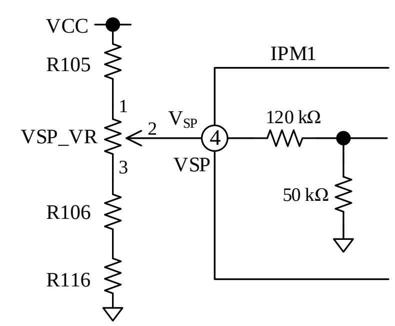


Twist the VSP_VR fully counterclockwise.

When you twist the VSP_VR fully counterclockwise, the VSP pin input voltage, V_{SP}, is 1.50 V at AC power-on. Adjust VSP_VR so that V_{SP} is maintained below the excitation start voltage, V_{SST}. On the GUI, the V_{SST} value (i.e., the **VSPStart Min** list) is set to 2.5 V by default.

Table 3-20 provides the VSP_VR vs. V_{SP} relationship.

Table 3-20. VSP Pin Voltage-adjusting Resistor, VSP_VR vs. VSP Pin Input Voltage, V_{SP}

<table>
<tr><td rowspan="7">
</td><td rowspan="2">VCC</td><td rowspan="2">R105</td><td rowspan="2">R106</td><td rowspan="2">R116</td><td colspan="2">VSP_VR</td><td rowspan="2">V_{SP}</td></tr>
<tr><td>Between 1 and 2</td><td>Between 2 and 3</td></tr>
<tr><td rowspan="5">15 V</td><td rowspan="5">47 kΩ</td><td rowspan="5">5.6 kΩ</td><td rowspan="5">2.2 kΩ</td><td>0 kΩ(1)</td><td>20 kΩ(1)</td><td>5.06 V</td></tr>
<tr><td>5 kΩ</td><td>15 kΩ</td><td>4.18 V</td></tr>
<tr><td>10 kΩ</td><td>10 kΩ</td><td>3.31 V</td></tr>
<tr><td>15 kΩ</td><td>5 kΩ</td><td>2.42 V</td></tr>
<tr><td>0 kΩ(2)</td><td>0 kΩ(2)</td><td>1.50 V</td></tr>
</table>

(1) Refers to the value when twisted fully clockwise.
(2) Refers to the value when twisted fully counterclockwise.

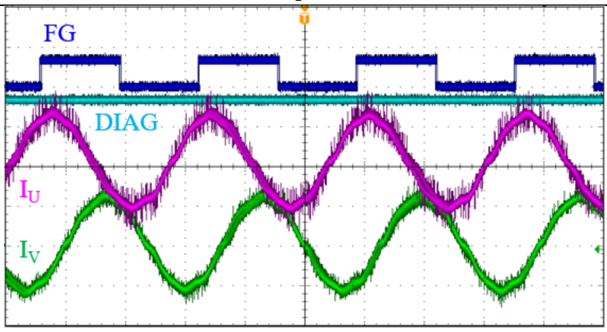
3.7. Setting the Dead Time Compensation Group Box

In case any of the high-side power MOSFETs and its corresponding low-side power MOSFET turn on at the same time, a short-circuit condition may occur. For protecting the power MOSFETs of the three phases from such short-circuit condition, a dead time must be set between a turn-off of each high- or low-side power MOSFET and the next turn-on of its paring low- or high-side power MOSFET. However, setting the dead time, t_{DEAD}, will cause disturbance in waveforms due to errors for a command voltage. The dead time compensation is the function to correct such disturbance in current waveforms. The following are the positive effects obtained by setting the dead time compensation:

- Reduction in audible noise
- Suppression in mechanical oscillation by current waveform becoming more sinusoidal (but ineffective depending on load)

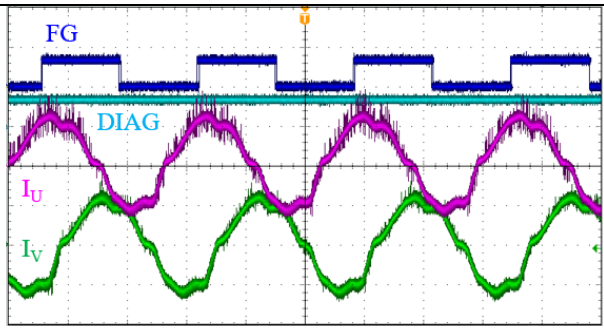
For comparison, we also show the operational waveform when the dead time compensation is enabled and those which the function is disabled.

Dead Time Compensation Enabled



Waveforms Not Disturbed

Dead Time Compensation Disabled



Waveforms Disturbed

This section describes how to set the dead time compensation parameters in the **Dead Time Compensation** group box, as listed in Table 3-21.

Table 3-21. Setting Description: Dead Time Compensation Parameters

Setting Description	GUI Parameter	Parameter Settings	
		GUI Default	Setting Range
Enable/Disable of Dead Time Compensation	DTCmp Enabl	DTC OFF	DTC OFF, DTC ON
Dead Time Compensation Voltage Slope	DTCmp Gain	0	0 to 15
Maximum Value of Dead Time Compensation Voltage Amplitude	DTCmp MaxTm	0.0% DT	0.0% DT to 93.8% DT

3.7.1. DTCmp Enabl (Enable/Disable of Dead Time Compensation)

By clicking the button in the **DTCmp Enabl** field under the D**ead Time Compensation** group box, you can select the dead time compensation to be enabled or disabled. Table 3-22 lists the overview of the **DTCmp Enabl** parameters.

Table 3-22. Parameter Overview: DTCmp Enabl

Setting Description	GUI Parameter	Parameter Setting	Function
Enable/Disable of Dead Time Compensation	DTCmp Enabl	DTC OFF	Disables the dead time compensation.
		DTC ON	Enables the dead time compensation.

At the timing when the polarity of a phase current undergoes a positive-to-negative transition (and vice versa), a dead time causes disturbance in the current waveform. Selecting "DTC ON" enables the dead time compensation and thus corrects the disturbed current waveform with its dead time compensation voltage being applied regardless of a command voltage (see Figure 3-26).

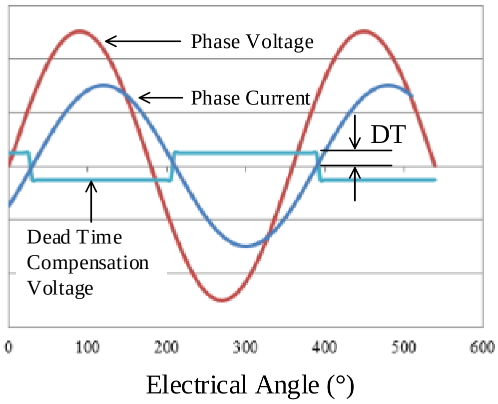


Figure 3-26. Dead Time Compensation Voltage

Section 3.7.2 explains how to adjust the dead time compensation voltage slope.
Section 3.7.3 describes how to adjust a maximum value of the dead time compensation voltage amplitude.

3.7.2. DTCmp Gain (Dead Time Compensation Voltage Slope)

From the **DTCmp Gain** list in the **Dead Time Compensation** group box, select a value to adjust a slope (i.e., gain) of the dead time compensation voltage. Table 3-23 lists the overview of the **DTCmp Gain** parameter.

Table 3-23. Parameter Overview: DTCmp Gain

Setting Description	GUI Parameter	Parameter Settings			
		GUI Default	Setting Range	Step	# of Options
Dead Time Compensation Voltage Slope	DTCmp Gain	0	0 to 15	1	16

The higher the **DTCmp Gain** setting value, the steeper the slope of the dead time compensation voltage becomes. When the **DTCmp Gain** parameter is set to 15 (at maximum), the dead time compensation voltage will have a slope of about 90° (see Figure 3-27).

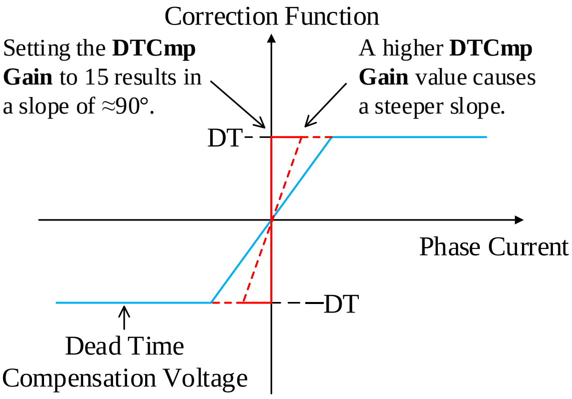


Figure 3-27. Dead Time Compensation Voltage vs. DTCmp Gain

3.7.3. DTCmp MaxTm (Maximum Value of Dead Time Compensation Voltage Amplitude)

From the **DTCmp MaxTm** list in the **Dead Time Compensation** group box, select a value to adjust a maximum value of the dead time compensation voltage amplitude. Table 3-24 provides the overview of the **DTCmp MaxTm** parameter.

Table 3-24. Parameter Overview: DTCmp MaxTm

Setting Description	GUI Parameter	Parameter Settings			
		GUI Default	Setting Range	Step	# of Options
Maximum Value of Dead Time Compensation Voltage Amplitude	DTCmp MaxTm	0.0% DT	0.0% DT to 93.8% DT	6.3% DT	16

Figure 3-28 shows a relationship between the dead time compensation voltage and the **DTCmp MaxTm** parameter.

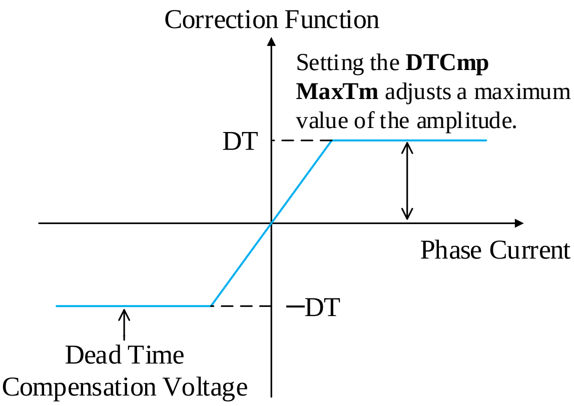


Figure 3-28. Dead Time Compensation Voltage vs. DTCmp MaxTm

The equation below defines the dead time compensation voltage amplitude, DT:

$$DT = V_{DC} \times t_{DEAD} \times f_C \,.$$

Where:
- DT is the dead time compensation voltage amplitude (V),
- V_{DC} is the DC-link voltage (V),
- t_{DEAD} is the dead time (s), and
- f_C is the PWM carrier frequency (Hz).

For example, when V_{DC} = 280 V, t_{DEAD} = 1.5 µs, and f_C = 20 kHz, the dead time compensation voltage amplitude can be obtained as follows:

$$DT = 280 \times 1.5 \times 10^{-6} \times 20 \times 10^{3} = 8.4\text{ V}\,.$$

At this time, if the **DTCmp MaxTm** parameter is set to 93.8% DT, the maximum value of the dead time compensation voltage amplitude will be: 8.4 × 0.938 = 7.88 V.

3.8. Setting the Braking Operations

There are two braking methods you can choose from: the WM-Brk (Windmill Brake) operation and the manual braking operation. These braking operations are carried out by turning on the low-side power MOSFETs at once.
Table 3-25 provides the overviews of the braking operation parameters.

Table 3-25. Parameter Overview: Startup (Braking Operation)

Setting Description	GUI Parameter	Parameter Settings		
		GUI Default	Setting Range	Step
Braking Current	WM Brk Curnt	25% Imax	25% Imax to 100% Imax	25% Imax
Minimum Braking Current Threshold	WM Ext Curnt	6.25% Imax	6.25% Imax to 25% Imax	6.25% Imax

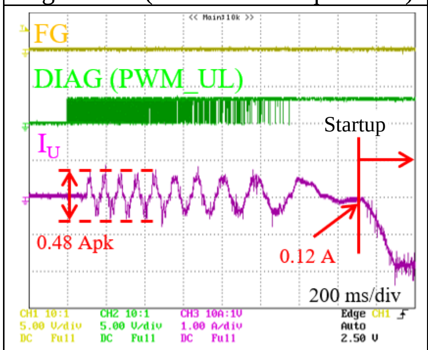
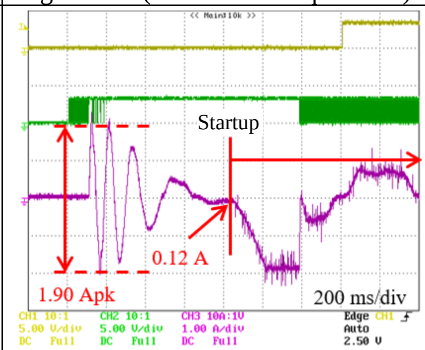
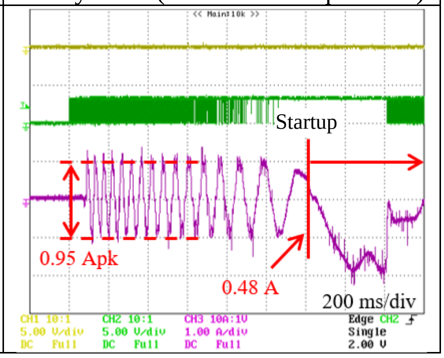
3.8.1. WM Brk Curnt and WM Ext Curnt (WM-Brk Operation)

When you need to start the motor from an idle state, perform the braking operation, i.e., WM-Brk (Windmill Brake), prior to the startup sequence to bring the motor to a standstill.
If a huge load inertial, such as a fan motor, brings a motor to a sudden stop, noise will occur. To reduce such noise, adjust each parameter in the **Start Up** group box: the **WM Brk Curnt** list for setting a braking current; the **WM Ext Curnt** list for setting a minimum braking current threshold.

The following are the operational waveforms according to the **WM Brk Curnt** and **WM Ext Curnt** setting values.

- **Setting Examples**

Conditions: Fan motor; DC-link = 100 V, VCC = 15 V,
R_{SX} = 100 mΩ, CS Range = 500 mV, Max Curnt = 38% Ifs (Imax = 1.9 A)

Setting Example 1	Setting Example 2	Setting Example 3
WM Brk Curnt = 25% Imax WM Ext Curnt = 6.25% Imax Light Load (Rotational Freq.: 15 Hz)	WM Brk Curnt = 100% Imax WM Ext Curnt = 6.25% Imax Light Load (Rotational Freq.: 15 Hz)	WM Brk Curnt = 50% Imax WM Ext Curnt = 25% Imax Heavy Load (Rotational Freq.: 30 Hz)
		

3.8.2. Run/Stop and Brake (Manual Braking Operation)

When the motor is running (i.e., when the switching button in the **Run/Stop** field indicates "Stop"), the motor can be stopped manually. To perform the manual braking operation, click the switching button in the **Brake** filed under the **Run Control** group box. Note that the switching button contains the label indicating a current braking operation state (see Table 3-26).

Once you click the **OFF** button in the **Brake** field, the motor stops running and the button label switches to "ON".

Once you click the **ON** button in the **Brake** field, the motor restarts to run and the button label switches to "OFF".

A braking current during the manual braking operation is the maximum operating current (Imax). Table 3-26 lists the overview of the manual braking operation settings.

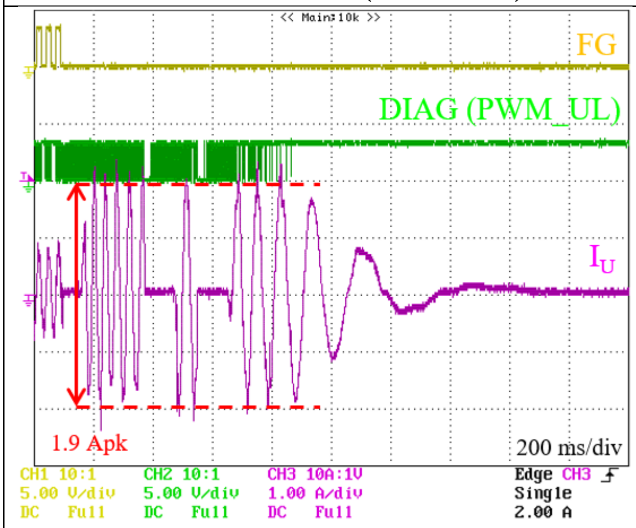
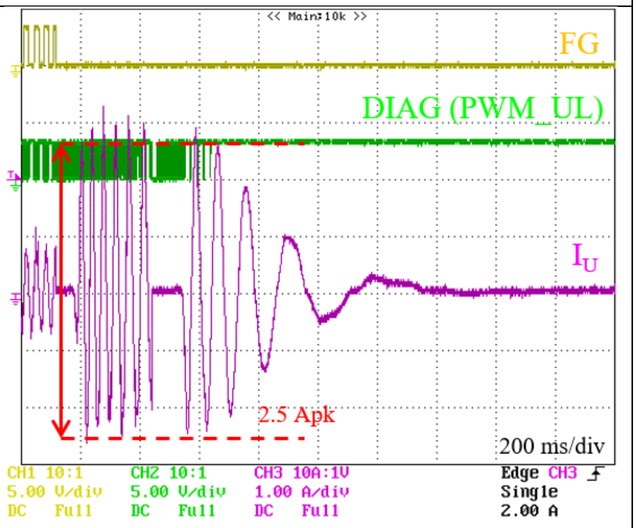
Table 3-26. Setting Description: Manual Braking Operation

Setting Description	GUI Parameter	Parameter Settings	
		GUI Default	Button Label and Braking State
Manual Braking Operation	Brake	OFF	OFF: Normal operation (brake off) ON: Braking operation (brake on)

The following are the operational waveforms of setting examples according to the maximum operating current (Imax).

- **Setting Examples**

Conditions: Fan motor; DC-link = 100 V, VCC = 15 V, rotational frequency = 30 Hz,
R_{Sx} = 100 mΩ, CS Range = 500 mV

<table>
<tr><td>Setting Example 1</td><td>Setting Example 2</td></tr>
<tr><td>Max Curnt = 38% Ifs (Imax = 1.9 A)</td><td>Max Curnt = 50% Ifs (Imax = 2.5 A)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Braking Time ≈ 1 s</td><td>Braking Time ≈ 0.8 s</td></tr>
</table>

3.9. Setting the Restart Operation

This section gives details on how to set the motor's restart operation.
The following subsections contain the overviews of each parameter for the restart operation.

3.9.1. ReStart Ctrl (Enable/Disable of Restart)

This parameter sets whether to enable or disable the motor's restart operation upon loss-of-synchronization detection.
"No Restart" — The restart operation is disabled.
"Restart" — The restart operation is enabled.

When you select "Restart", be sure to set the following related parameters as instructed below. Otherwise, the motor will not restart properly.

- In the **Read Diag** field, select "No Clear". If you select "Clear Fit", the number of restarts is reset each time the motor restarts and the motor's first startup operation is repeated infinitely (see Sections 3.9.2 and 3.9.3).
- In the **Stop On Fail** field, select "ESF ON". If you select "ESF OFF", the motor does not restart but will keep running even after a loss-of-synchronization condition is detected.

3.9.2. Restart No (Number of Restarts)

This parameter determines how many times the motor to be restarted. Select from the following options in the list: 5, 10, 20, Infinite. Note that each numeric value includes the first startup.

3.9.3. Restart Torque

This parameter sets whether to fix or vary the ramp-up current at restart.
"Fixed" — The ramp-up current is fixed to the value selected in the **RampU Curnt** list.
"Spread" — The ramp-up current is variable. Table 3-27 lists the overview of the variable ramp-up current setting.

Table 3-27. Overview: Variable Ramp-up Current

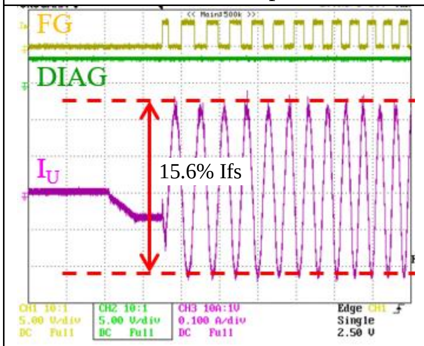
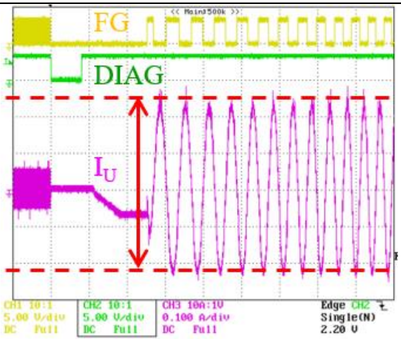
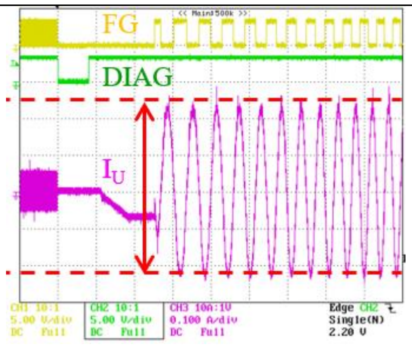
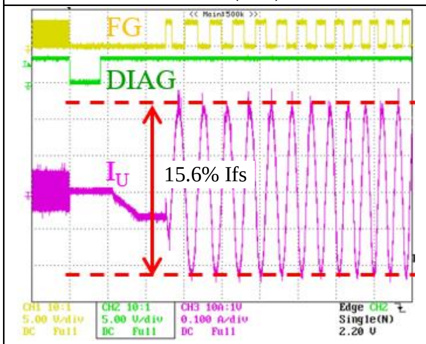
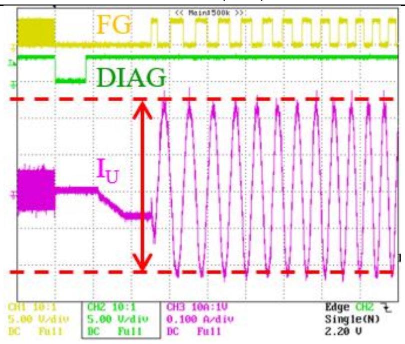
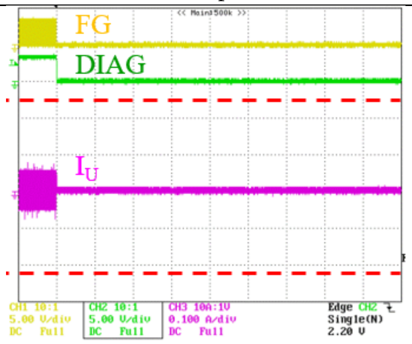
Number of Restarts	Ramp-up Current Value*	Example: RampU Curnt = 15.6% Ifs
First Startup	RampU Curnt setting value	15.6% Ifs
Restart (1st)	RampU Curnt setting value	15.6% Ifs
Restart (2nd)	RampU Curnt setting value + 1 step	17.2% Ifs
Restart (3rd)	RampU Curnt setting value − 1 step	14.1% Ifs
Restart (4th)	RampU Curnt setting value + 2 steps	18.8% Ifs
Restart (5th)	RampU Curnt setting value – 2 steps	12.5% Ifs
…	…	…

* 1 step = 1.6%

For more details on the ramp-up current, see Section 3.2.5.
The following are the operational waveforms when "Fixed" is selected and those which "Spread" is selected, respectively, in the **Restart Torque** field.

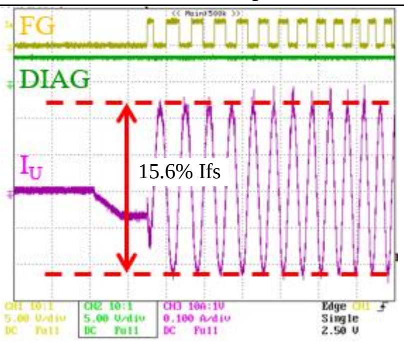
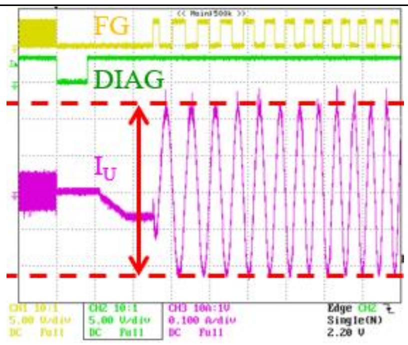
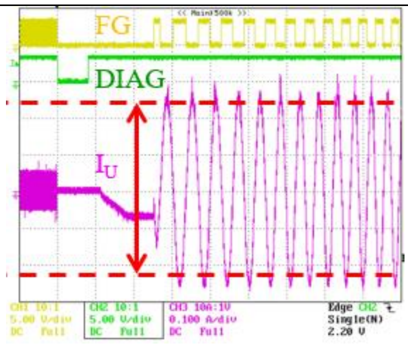
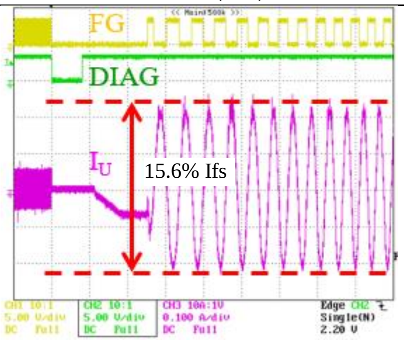
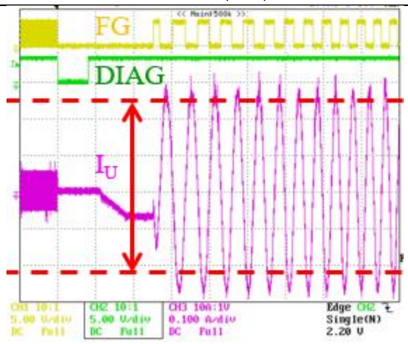
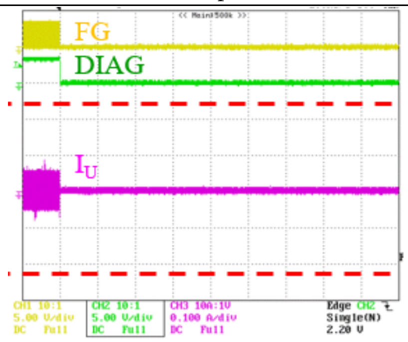
● Operational Waveforms at Restart with Fixed Ramp-up Current

Setting values: ReStart Ctrl = Restart, Restart No = 5, Restart Torque = Fixed, RampU Curnt = 15.6% Ifs.

<table>
<tr><td>First Startup</td><td>Restart (1st)</td><td>Restart (2nd)</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Current Value: 15.6% Ifs</td><td>Current Value: 15.6% Ifs</td><td>Current Value: 15.6% Ifs</td></tr>
<tr><td>Restart (3rd)</td><td>Restart (4th)</td><td>Stop</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Current Value: 15.6% Ifs</td><td>Current Value: 15.6% Ifs</td><td></td></tr>
</table>

● Operational Waveforms at Restart with Variable Ramp-up Current

Setting values: ReStart Ctrl = Restart, Restart No = 5, Restart Torque = Spread, RampU Curnt = 15.6% Ifs.

First Startup	Restart (1st)	Restart (2nd)
		
Current Value: 15.6% Ifs	Current Value: 15.6% Ifs	Current Value: 17.2% Ifs
Restart (3rd)	Restart (4th)	Stop
		
Current Value: 14.1% Ifs	Current Value: 18.8% Ifs	

3.10. Setting the Run Control Group Box (DIAG/FG Pin Output Signals)

The **Run Control** group box helps you determine which pin should output which signal: the **DIAG Output** list for setting the DIAG pin output signal; the **FG Output** list for setting the FG pin output signal.

- **DIAG Output**

DIAG[4:0]	Parameter	DIAG Pin Output Signal
0	Fault(1)	General fault flag (FF)
1	LOS	Loss of synchronization (LOS)
2	Temperature	Temperature output of control MIC
3	Clock	Clock
4	PWMDIR	PWMDIR(2)
5	SHTRIG	SHTRIG(2)
6	ADDONE	ADDONE(2)
7	CLFLK_SYN	CLFLK_SYN(2)
8	CLFLK_ASYN	CLFLK_ASYN(2)
9	UH	PWM output (HIN1)
10	UL	PWM output (LIN1)
11	VH	PWM output (HIN2)
12	VL	PWM output (LIN2)
13	WH	PWM output (HIN3)
14	WL	PWM output (LIN3)
15	WDTMO	Watchdog timeout
16	WDACT	Watchdog active
17	PMFLTn	Power module fault (PMF)
18	PMRSTn	Power module fault (PMF) reset
19	HOCP	Hard overcurrent (HOC)
20	VAR1	q-axis current
21	VAR2	—
22	VAR3	—
23	VAR4	—
24–31	Reserved	Reserved

- **FG Output**

FG[4:0]	Parameter	FG Pin Output Signal
0	FG(1)	Motor speed
1	FG(1)	Motor speed
2	FG(1)	Motor speed
3	FG(1)	Motor speed
4	PWMDIR	PWMDIR(2)
5	SHTRIG	SHTRIG(2)
6	ADDONE	ADDONE(2)
7	CLFLK_SYN	CLFLK_SYN(2)
8	CLFLK_ASYN	CLFLK_ASYN(2)
9	UH	PWM output (HIN1)
10	UL	PWM output (LIN1)
11	VH	PWM output (HIN2)
12	VL	PWM output (LIN2)
13	WH	PWM output (HIN3)
14	WL	PWM output (LIN3)
15	WDTMO	Watchdog timeout
16	WDACT	Watchdog active
17	PMFLTn	Power module fault (PMF)
18	PMRSTn	Power module fault (PMF) reset
19	HOCP	Hard overcurrent (HOC)
20	VAR1	q-axis current
21	VAR2	—
22	VAR3	—
23	VAR4	—
24–31	Reserved	Reserved

(1) Set as the GUI default.
(2) Not used in motor designing.

4. GUI

4.1. Settings Window Overview

Figure 4-1 explains the window of the GUI (Graphic User Interface); Table 4-1 provides the functional descriptions of the individual GUI elements such as parameters and indications.

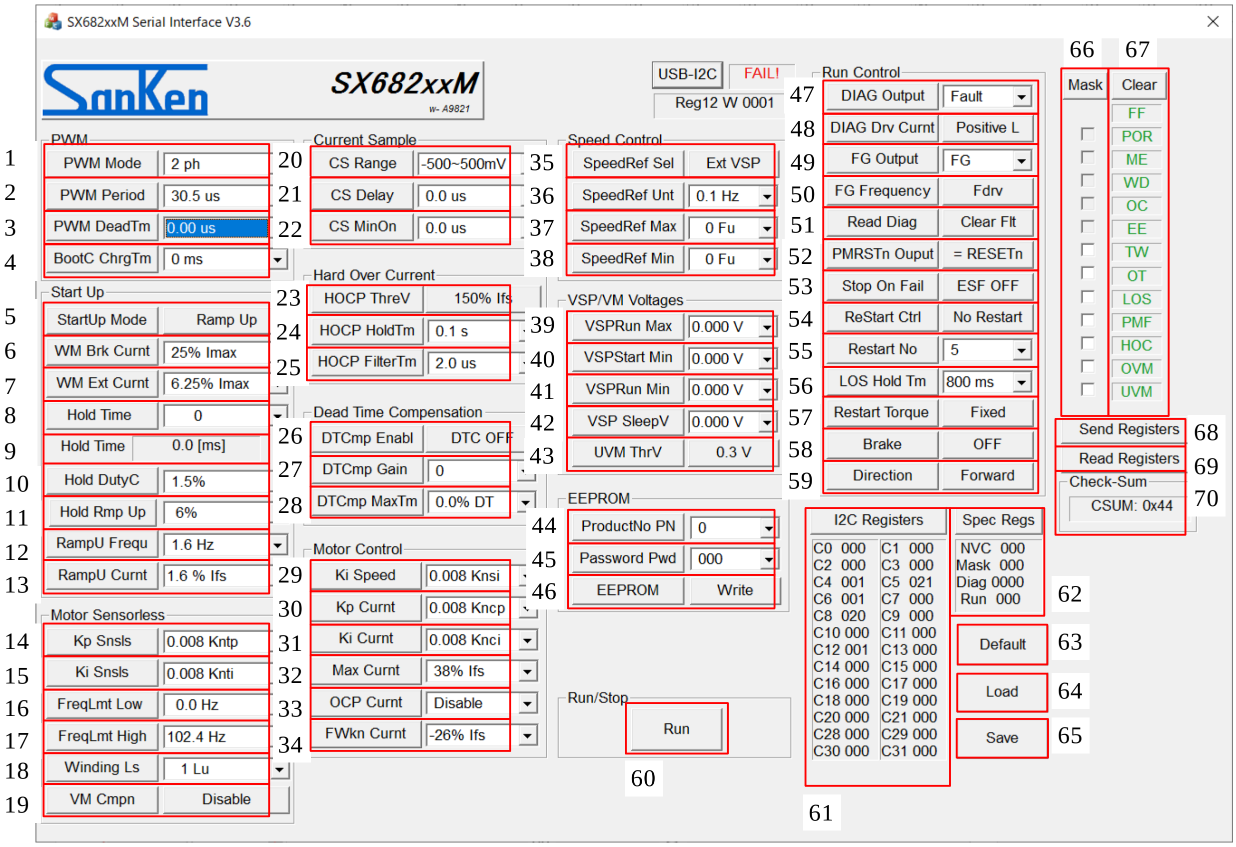


Figure 4-1. GUI Settings Window

Table 4-1. GUI Settings Window: Elements and Functions

No.	Group Box/ GUI Parameter	Description
PWM		
1	PWM Mode	The drop-down list to select the PWM switching mode.
2	PWM Period	The drop-down list to set the PWM period.
3	PWM DeadTm	The drop-down list to set the dead time.
4	BootC ChrgTm	The drop-down list to set the charging time of bootstrap capacitors.
Start Up		
5	StartUp Mode	The toggle button to select the startup mode.
6	WM Brk Curnt	The drop-down list to set the braking current.
7	WM Ext Curnt	The drop-down list to set the minimum braking current threshold.
8	Hold Time	The drop-down list to set the coefficient of a startup hold time.
9	Hold Time [ms]	The non-editable text field that indicates the startup hold time automatically calculated.
10	Hold DutyC	The drop-down list to set the duty cycle of startup hold current.
11	Hold Rmp Up	The drop-down list to set the ramp-up time of hold current.
12	RampU Frequ	The drop-down list to set the ramp-up frequency.
13	RampU Curnt	The drop-down list to set the ramp-up current.
Moror Sensorless		
14	Kp Snsls	The drop-down list to set the proportional gain for adjusting an estimated rotor position.
15	Ki Snsls	The drop-down list to set the integral gain for adjusting an estimated rotor position.
16	FreqLmt Low	The drop-down list to set the lower limit of an electrical angle.
17	FreqLmt High	The drop-down list to set the upper limit of an electrical angle.
18	Winding Ls	The drop-down list to set the motor constant.
19	VM Cmpn	The toggle button to enable or disable the compensation of DC link voltage fluctuations.
Current Sample		
20	CS Range	The drop-down list to set the maximum input voltage range of current-sensing ope-amps.
21	CS Delay	The drop-down list to set the delay time of current detection.
22	CS MinOn	The drop-down list to set the minimum on-time for current detection.
Hard Over Current		
23	HOCP ThreV	The toggle button to select the HOCP threshold current.
24	HOCP HoldTm	The drop-down list to set the HOCP hold time.
25	HOCP FilterTm	The drop-down list to set the HOCP filtering time.
Dead Time Compensation		
26	DTCmp Enabl	The toggle button to enable or disable the dead time compensation.
27	DTCmp Gain	The drop-down list to set the slope of the dead time compensation voltage.
28	DTCmp MaxTm	The drop-down list to set the maximum value of the dead time compensation voltage amplitude.
Motor Control		
29	Ki Speed	The drop-down list to set the integral gain for motor speed control.
30	Kp Curnt	The drop-down list to set the proportional gain for current control.
31	Ki Curnt	The drop-down list to set the integral gain for current control.
32	Max Curnt	The drop-down list to set the maximum operating current.
33	OCP Curnt	The drop-down list to set the SOCP threshold current.
34	FWkn Curnt	The drop-down list to set the field weakening current.

No.	Group Box/ GUI Parameter	Description
Speed Control		
35	SpeedRef Sel	The toggle button to select the speed control mode.
36	SpeedRef Unt	The drop-down list to set the multiplier of a reference speed.
37	SpeedRef Drv(1) / SpeedRef Max(2)	The drop-down list to set the reference speed(1) or the maximum reference speed(2).
38	SpeedRef Min	The drop-down list to set the minimum reference speed.
VSP/VM Voltages		
39	VSPRun Max	The drop-down list to set the maximum speed voltage (V_{SMX}).
40	VSPStart Min	The drop-down list to set the excitation start voltage (V_{SST}).
41	VSPRun Min	The drop-down list to set the minimum speed voltage (V_{SMN}).
42	VSP SleepV	The drop-down list to set the low power consumption mode transition voltage (V_{SSN}).
43	UVM ThrV	The toggle button to select the VM pin UVP threshold voltage (“0.3 V” or “0.6 V”).
EEPROM		
44	ProductNo PN	The drop-down list to assign the identification number of the EEPROM.
45	Password Pwd	The command button and drop-down list to set the password to the EEPROM.
46	EEPROM	The command button to execute a write to the EEPROM.
Run Control		
47	DIAG Output	The drop-down list to set the DIAG pin output signal.
48	DIAG Drv Curnt	Executable only when “Drv Curnt” is selected in the **DIAG Output** list. The toggle button to select the DIAG output logic (“Positive L” or “Negative L”).
49	FG Output	The drop-down list to set the FG pin output signal.
50	FG Frequency	The toggle button to select the FG pin output pulse frequency: “Fdrv” — 1 pulse per 360° electrical angle “3*Fdrv” — 3 pulses per 360° electrical angle
51	Read Diag	The toggle button to select whether to clear the DIAG pin status after the GUI reads it.
52	PMRSTn Ouput	The toggle button to select whether to put the gate-drive MIC into a standby state at the reset operation by the RESETn pin.
53	Stop On Fail	The toggle button to select whether to stop the motor run at fault detection, i.e., power module fault, loss of synchronization, or thermal shutdown.
54	ReStart Ctrl	The toggle button to select whether to restart motor operations when a loss-of-synchronization (LOS) condition is detected.
55	Restart No	The drop-down list to set the number of restarts allowed after a startup failure.
56	LOS Hold Tm	The drop-down list to set the hold time after an LOS (loss of synchronization) fault occurs.
57	Restart Torque	The toggle button to select the ramp-up current for motor restart (“Fixed” or “Spread”).
58	Brake	The toggle button to turn on or off the manual braking operation.
59	Direction	The toggle button to select the direction of motor rotation (“Forward” or “Reverse”).

(1) When “Int SR” is selected in the **SpeedRef Sel** field.
(2) When “Ext VSP” is selected in the **SpeedRef Sel** field.

No.	Group Box/ GUI Parameter	Description
Other		
60	Run/Stop	The field that contains the toggle button to start or stop the motor run (“Run” or “Stop”).
61	I2C Registers	The pane containing the non-editable text field that displays the register values (parameters).
62	Spec Regs	The pane containing the non-editable text field that displays the status register values.
63	Default	The command button to read the default parameters (i.e., to initialize the GUI).
64	Load	The command button to import a parameter file (.rst format).
65	Save	The command button to save a parameter file (.rst format).
66	Mask	The column of check boxes to disable the corresponding diagnostic function (by selecting the check box).
67	Clear	The command button to reset the status indicators displaying error statuses in red. ● FF: General fault flag ● POR: V3 pin undervoltage (power-on reset) ● ME: Memory error ● WD: Watchdog timeout ● OC: SOCP operation ● EE: EEPROM overwrite limit ● TW: Thermal warning for control MIC ● OT: Thermal shutdown for control MIC ● LOS: Loss of synchronization ● PMF: Power module fault ● HOC: Hard overcurrent ● OVM: VM pin overvoltage ● UVM: VM pin undervoltage
68	Send Registers	The command button to transmit the register values displayed on the GUI.
69	Read Registers	The command button to read the register values of the EEPROM.
70	Check-Sum	The group box containing the non-editable text field that indicates the sum of all the register values.

4.2. Locking by Password

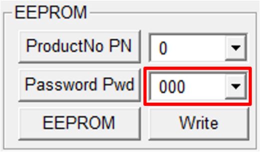
The IC has the function to enable the password-locked mode that protects the EEPROM from overwrite or read operations. For more details, refer to the SX68200M series data sheet.

For GUI-assisted password locking and unlocking procedures, a logic power supply is required to apply voltages to the VCCx and VPP pins. When using both of an AC power supply and a logic power supply in these procedures, make sure that the logic power supply has a floating connection. In case both supplies are connected to the same ground, your demo board may have an overcurrent and thus permanent damage.

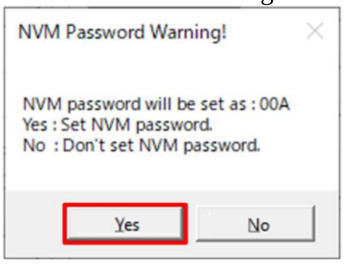
The following subsections contain the procedure using both an AC power supply (as the VCCx pin voltage supply) and a logic power supply (for the VPP pin voltage application).

4.2.1. Locking Procedure: Setting a Password

1) Power on the AC power supply.
   A voltage of VCC =15 V is applied.
2) Apply 24 V to the VPP pin.
   Before applying the voltage, make sure that the logic power supply has a floating connection.
3) From the **Password Pwd** list in the **EEPROM** group box, select a password you want to set.



4) Click the **Password Pwd** button.
5) Click the **Write** button in the **EEPROM** field.
   The confirmation message below then appears.

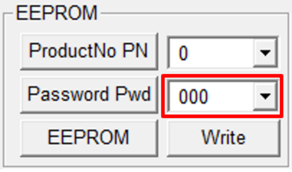


6) After acknowledging the message content, click **Yes**.
7) Turn off the logic power supply.
8) Turn off the AC power supply.
   You have enabled the locked mode.

During the locked mode setting, if you click the **Read Registers** button, the GUI displays random numbers in the **I2C Registers** field where the register values appear. The identification number is the value set in the **ProductNo P**N list, which will also be reflected in the register value display. By setting the identification number, you can recognize the parameters even while setting the locked mode.

4.2.2. Unlocking Procedure: Cancelling the Password

1) Power on the AC power supply.
   A voltage of VCC =15 V is applied.
2) Apply 24 V to the VPP pin.
   Before applying the voltage, make sure that the logic power supply has a floating connection.
3) From the **Password Pwd** list in the **EEPROM** group box, select the password you have set.



4) Click the **Password Pwd** button.
5) Wait for about 15 seconds.
   You have disabled the locked mode.
6) Turn off the logic power supply.
7) Turn off the AC power supply.
   If you click the **Read Registers** button without turning off the AC power supply, the GUI displays random numbers in the **I2C Registers** field where the register values appear. To read proper register values, turn on the AC power supply again, and then click the **Read Registers** button.

4.3. Generating a Parameter File

To save a parameter file (.rst), which contains the tuned parameter values, to your computer, click the **Save** button at the bottom right of the GUI. The saved parameter file is editable, i.e., it can be opened in a general text editor. To import an edited parameter file into the GUI, click the **Load** button.

You can also use a programmer to import a parameter file and to write a parameter to the IC. Section 4.4.2 gives detailed explanations on the parameter writing.

Figure 4-2 shows the parameter file containing the GUI default values. The configuration register 11 (hereafter "Config[11]") is the register for setting a security password to the EEPROM. When you set a value other than "0" to the Config[11], reading from the EEPROM via the serial communications will cause the IC to output random numbers (except for specified registers). Therefore, performing a verify operation results in an error. Care must be taken when you make a change to the Config[11].

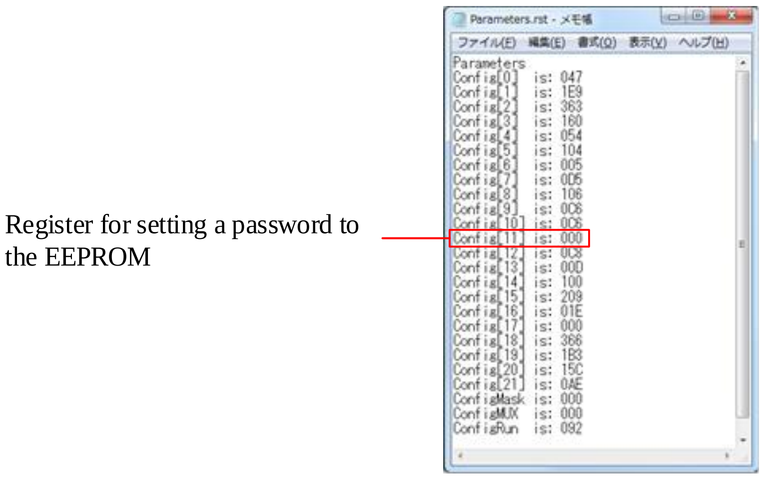


Figure 4-2. Default Parameter File

4.4. Writing Parameters

You can write (save) parameters to the EEPROM embedded in the IC. Writing parameters to the EEPROM allows the motor to be controlled in stand-alone mode, not via the serial communications but via analog voltage applied to the VSP pin.

There are two ways to perform write operations: using the GUI or using a programmer from Elnec s.r.o.

4.4.1. Writing Parameters with the GUI

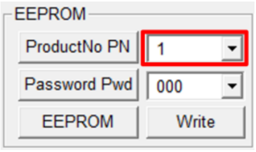
Writing the GUI parameter values to the EEPROM requires a logic power supply, which is used for applying voltages to the VCCx, VSP, and VPP pins.

This section explains the writing procedure using the GUI.

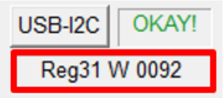
1) Connect the demo boad and the control PC.
   See Steps 1) to 2) in Section 2.3.
2) Twist the VSP pin voltage-adjusting resistor, VSP_VR, fully counterclockwise.
   With this setting, applying a 1.5 V voltage to the VCCx pin allows a 1.5 V voltage to be applied to the VSP pin as well. For more details, see Table 3-20.
3) In the **VSP/VM Voltages** group box, set the **VSP SleepV** and **VSPRun Min** parameters.
   Be sure to set the parameters to fall within the range below (see Section 3.6):
   VSP SleepV < VSP pin voltage (1.5 V) < VSPRun Min.
4) Apply 15 V to the VCCx pin.
   Voltages are applied respectively as follows: VCC = 15 V, V_{SP} = 1.5 V.
5) Apply 24 V to the VPP pin as the EEPROM write supply voltage, V_{PP}.
6) To launch the GUI, double-click the **SX682xxM_Serial_Interface_V3p6.exe** file.
   Once the communications between the control PC and the IC become available, the USB-I2C indicator displays “OKAY!”, changed from its default “FAIL!”.

Communications Disabled	Communications Enabled
	

7) Check the **SpeedRef Sel** field setting in the **Speed Control** group box.
   When “Ext VSP” is selected, go to Step 8).
   When “Int SR” is selected, go to Step 9).
8) In the **Run/Stop** field, click the **Run** button.
9) From the **ProductNo PN** list in the **EEPROM** group box, select a value to be assigned as the EEPROM identification number.



10) Under the **EEPROM** group box, click the **Write** button in the **EEPROM** field.
    A parameter writing process then starts. DO NOT operate the GUI until the writing process ends. As in the image below, the status indicator right under the **USB-I2C** indicator starts to display the registers currently being written, one after another. As a sign of completion, the status indicator stops switching and changes the letter in its display from “W” to “R”.



After the writing process completes, the NVC counter value (i.e., the number of writes) is incremented.

4.4.2. Writing Parameters with a Programmer

This section describes how to write parameters with the programmer from Elnec. To write parameters to the IC, import the parameter file (.rst) into your programmer.

The procedure we introduce in this section is one example of writing parameters, which has been confirmed as of February 4, 2021. For more details, refer to the corresponding user manuals provided by Elnec.

Preparing the Hardware and Software

1) Prepare the devices listed in Table 4-2, below.

Table 4-2. Required Devices

Device	Description	Remarks
Universal Programmer	 Model name: BeeProg2 Manufacturer: Elnec s.r.o. URL: https://www.elnec.com/en/products/universal-programmers/beeprog2/	For mass production, the production programmer BeeHive204 is also available.
Adopter	 Model name: DIL48/SOIC36-1.01 ZIF-CS SX6-1 Manufacturer: Elnec s.r.o. URL: https://www.elnec.com/en/products/programming-adapters/DIL48_SOIC36-1.01_ZIF-CS_SX6-1/	

2) From the URL below, download and install the software (Reglar SW).
URL: https://www.elnec.com/en/

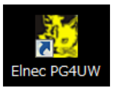
Click here

3) Connect the adaptor to the universal programmer.

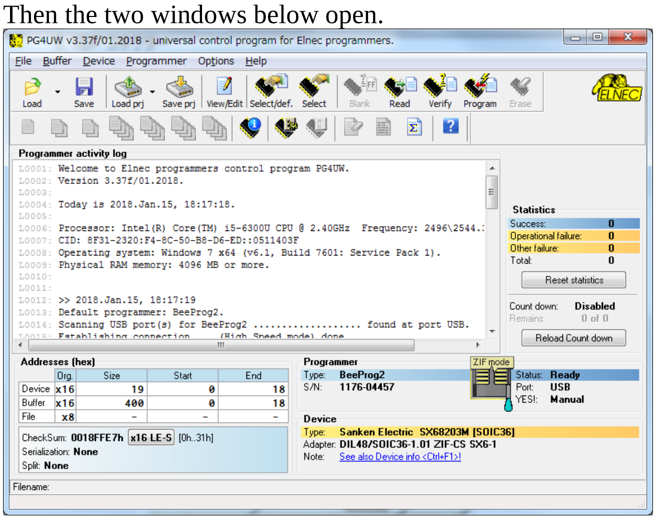
4) Connect the universal programmer to your PC.

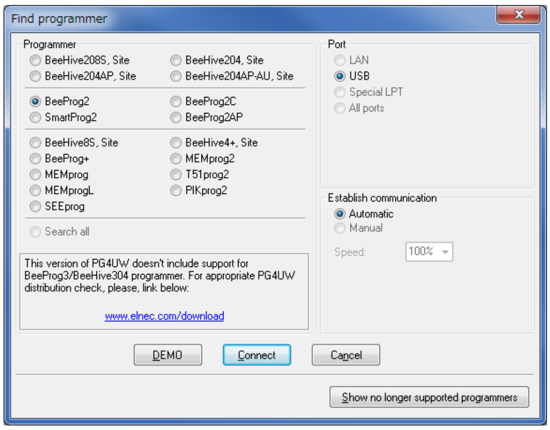
5) Turn on the universal programmer.

6) To launch the software you downloaded, double-click the **Elnec PG4UW** icon.

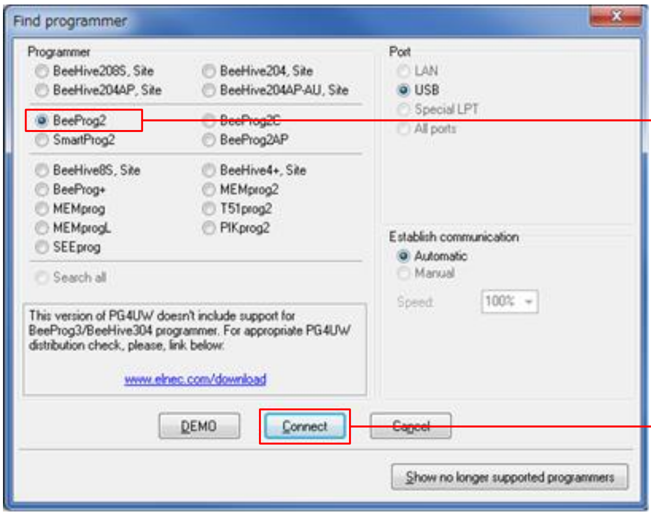


Then the two windows below open.





7) In the **Find programmer** window, establish a connection between the programmer and your PC.



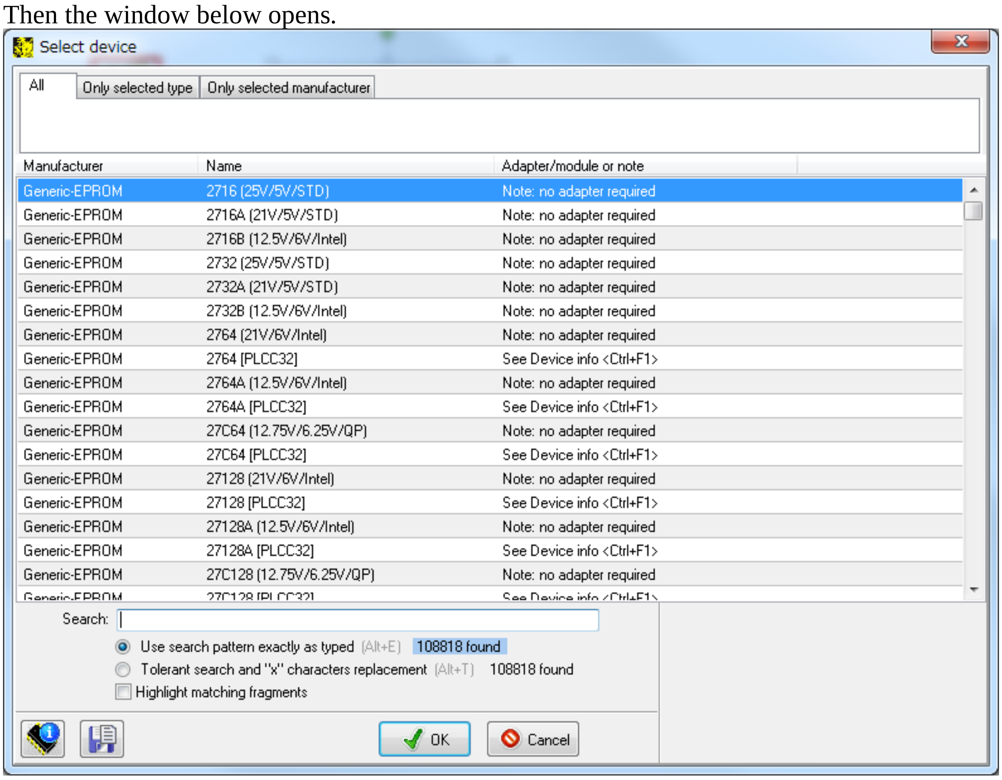
1. Select the programmer you purchased.

2. Click **Connect**.

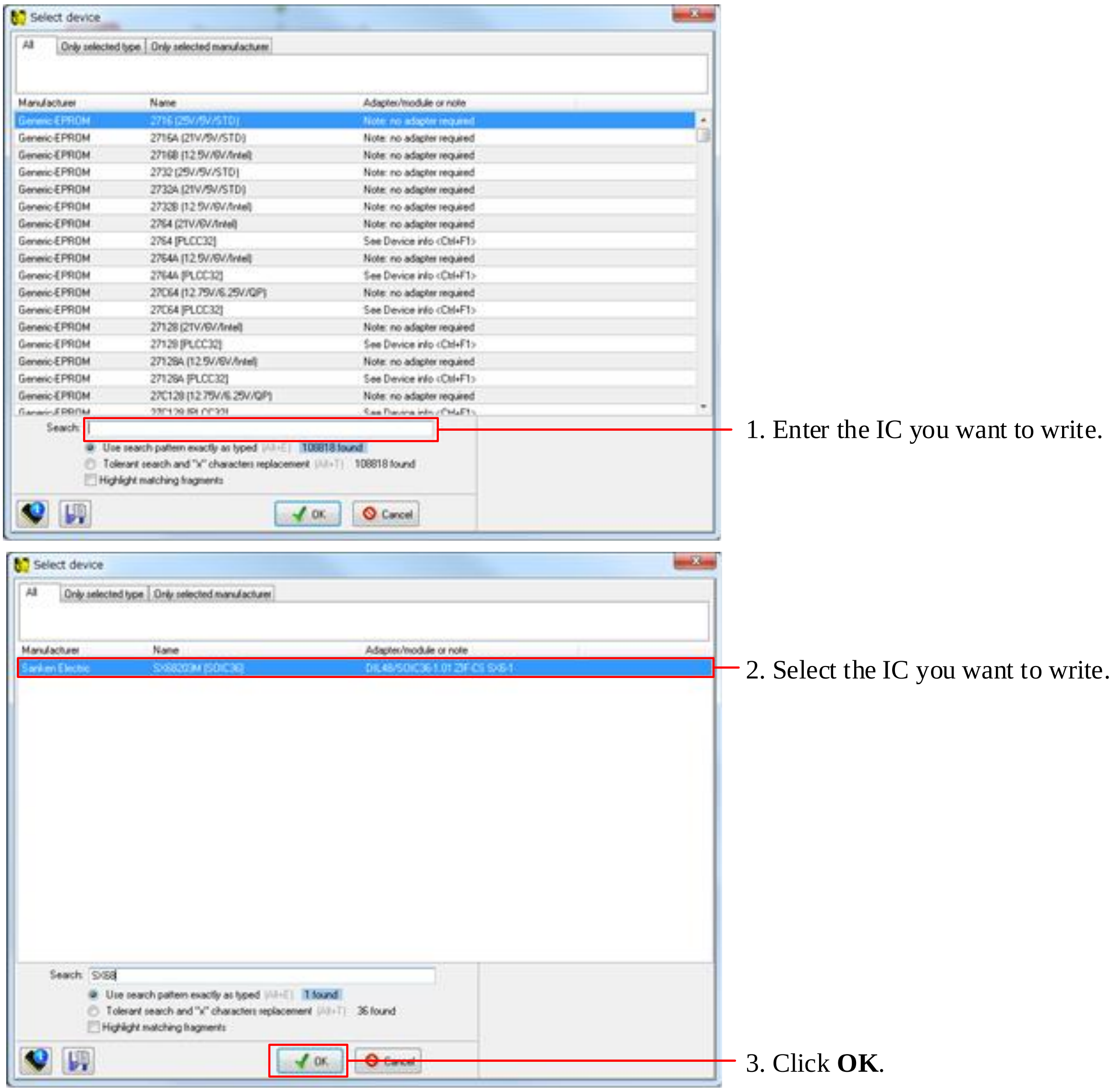
Importing a Parameter File (.rst) into the Programmer

8) Click the **Select** button on the toolbar.

Then the window below opens.

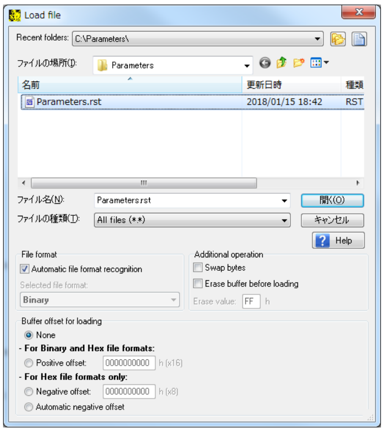


9) In the **Select device** window, select the IC you want to write.

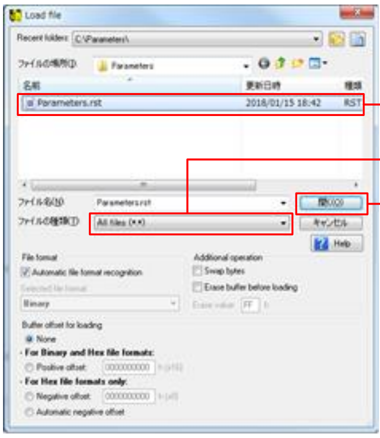


10) Click the **Load** button on the toolbar.

Then the window below opens.



11) From the **Load file** window, import the parameter file (.rst) you want to write.



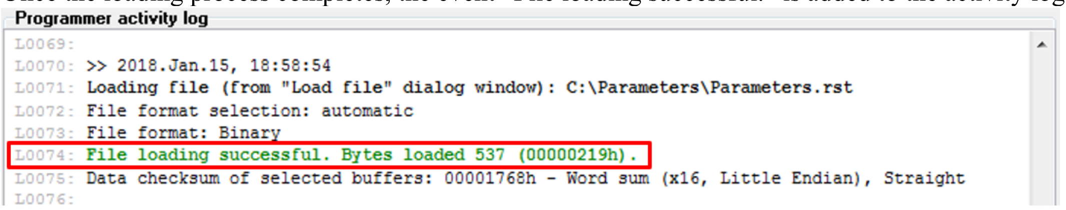
1. Select the parameter file you want to import.

2. Select "All files (*.*)".

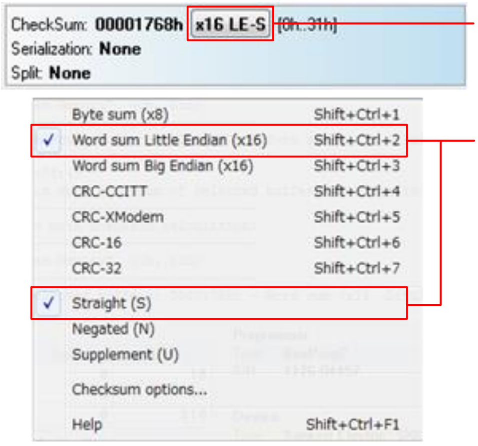
3. Click **Open**.

You don't have to make any changes to the group boxes below:
File format
Additional operation
Buffer offset for loading

In the main window, the **Programmer activity log** group box will be updated.
Once the loading process completes, the event "File loading successful." is added to the activity log.



12) In the **Address (hex)** group box, change the checksum settings.



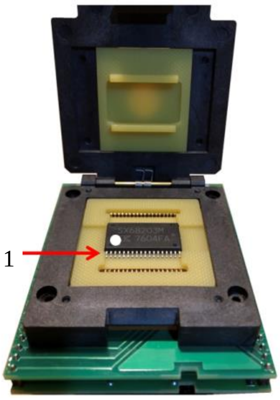
1. Click the command button in the **CheckSum** field.

2. Add check marks to these options.

Writing Parameters to the IC

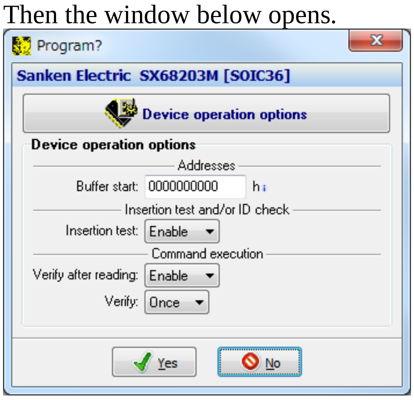
13) Insert the IC into the adaptor.
When inserting the IC, use the pickup tool enclosed in the adaptor package.

Pin 1



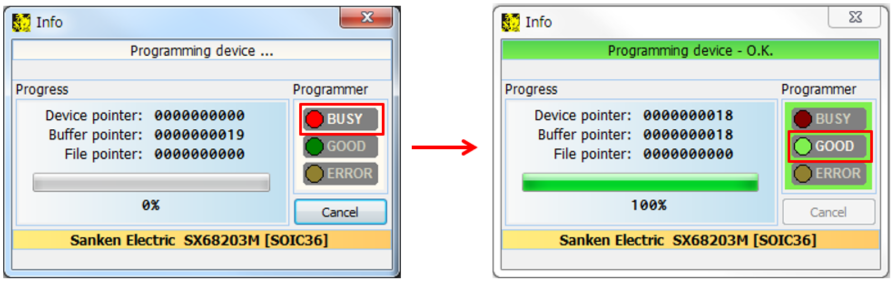
14) Click the **Program** button on the toolbar.

Then the window below opens.

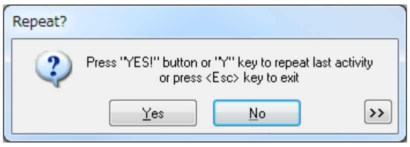


15) Click **Yes** in the **Program?** dialog box.

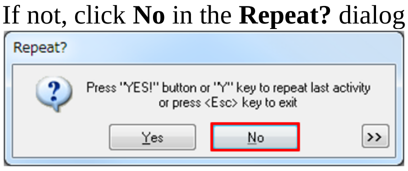
Then, a parameter writing process starts. Once the writing process starts, in the **Programmer** pane on the **Info** window, the status indicator **BUSY** lights up. When the writing process completes, the **BUSY** indicator stops lighting and then the **GOOD** indicator lights up. When the writing process fails, the **ERROR** indicator lights up.



After the writing process completes, the **Repeat?** dialog box appears.

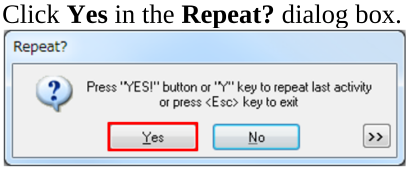


16) Remove the IC that underwent the writing process from the adaptor.
If you want to repeat a writing process to another IC, go to Step 17).
If not, click **No** in the **Repeat?** dialog box.



17) Insert another IC to the adaptor.

18) Click **Yes** in the **Repeat?** dialog box.



Then, a parameter writing process starts.
You can repeat Steps 16) to 18).

4.5. Reading Parameters

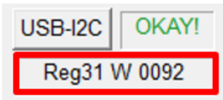
There are two ways to read the parameters written to the EEPROM: automatic or manual reading.

4.5.1. Automatic Parameter Reading

To perform an automatic parameter reading process, follow the steps below:

1) Connect the demo boad and the control PC.
   See Steps 1) to 2) in Section 2.3.
2) Twist the VSP pin voltage-adjusting resistor, VSP_VR, fully counterclockwise.
   With this setting, applying a 1.5 V voltage to the VCCx pin allows a 1.5 V voltage to be applied to the VSP pin as well. For more details, see Table 3-20.
3) In the **VSP/VM Voltages** group box, set the **VSP SleepV** and **VSPRun Min** parameters.
   Be sure to set the parameters to fall within the range below (see Section 3.6):
   VSP SleepV < VSP pin voltage (1.5 V) < VSPRun Min.
4) Apply 15 V to the VCCx pin.
   Voltages are applied respectively as follows: VCC = 15 V, V_{SP} = 1.5 V.
5) To launch the GUI, double-click the **SX682xxM_Serial_Interface_V3p6.exe** file.

A parameter reading process then automatically starts to read the EEPROM-stored parameters. DO NOT operate the GUI until the reading process ends. As in the image below, the status indicator right under the **USB-I2C** indicator starts to display the registers currently being read, one after another. As a sign of completion, the status indicator stops switching and changes the letter in its display from "R" to "W".



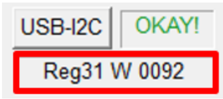
The corresponding parameters on the GUI are also updated. In case any writing error has occurred, the NVC counter value (i.e., the number of writes) is decremented after the parameter reading process completed. The GUI displays an NVC counter value of the latest writing process which has been completed successfully.

4.5.2. Manual Parameter Reading

To perform a manual parameter reading process, follow the steps below:

1) Establish communications between the control PC and IC (see Steps 1) to 3) in Section 2.3).
2) Click the **Read Registers** button.

A parameter reading process then starts. DO NOT operate the GUI until the reading process ends. As in the image below, the status indicator right under the **USB-I2C** indicator starts to display the registers currently being read, one after another. As a sign of completion, the status indicator stops switching and changes the letter in its display from “R” to “W”.



The corresponding parameters on the GUI are also updated. In case any writing error has occurred, the NVC counter value (i.e., the number of writes) is decremented after the parameter reading process completed. The GUI displays an NVC counter value of the latest writing process which has been completed successfully.

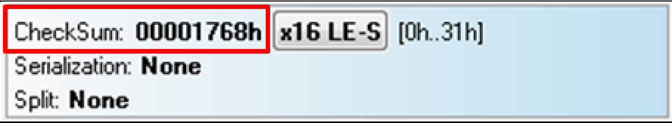
In case you have done either of the following operations after power-on, the individual setting values on the GUI are stored into the RAM even without clicking the **Send Registers** button:

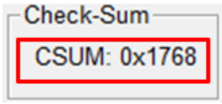
- If you have clicked the **Default** button
- If you have imported a parameter file by clicking the **Load** button

If so, the GUI does not read the EERPOM-stored parameters after you clicked the **Read Registers** button. Instead, the GUI starts to read the RAM-stored parameters.

4.6. Setting the Checksum

The Elnec's programmer offers the checksum options as a verify function. The GUI employs the checksum "Word SUM Little Endian (x16)". When you set the programmer checksum to the Word SUM Little Endian (x16), both values displayed in the following fields are matched: the **CheckSum** field of the programmer and the **Check-Sum** field of the GUI.

<table>
<tr><th>Programmer</th><th>GUI</th></tr>
<tr><td>


</td><td>


</td></tr>
</table>

This checksum setting helps you check if the GUI-adjusted parameter values have been successfully written to the IC. For more details on the programmer setting, see Step 12) in Section 4.4.2.

The default checksum value displayed on the GUI is "0x1768". For each default parameter value, see Figure 4-2.

5. FAQ

Question	Answer
Why the GUI does not launch?	The operating system your control PC uses may NOT our required operating environment. Please check your current operating environment and use a PC with Windows 7 or later.
I tried to run the motor for the first time, but it didn't rotate properly. What should I do?	If you have connected the AC power supply to the connector CN1, please try a DC power supply. Here is how to run the motor with a DC power supply: First, connect the DC power supply to the DC-Link connector. Next, check the motor operation by applying a voltage of 40 V. Then, increase the voltage gradually while monitoring the motor operation.
Why does the GUI display the status indicator **POR** in red after motor startup?	When the IC restarts operating, the GUI displays the status indicator **POR** in red to alarm a possible error such as an instantaneous power failure. This is because ground potential fluctuations due to an inrush current at motor startup may have induced the V3 pin voltage to cause a decrease. Therefore, please try the following measures to protect the V3 pin from having a voltage drop: ● Remove superimposed noise to the V3 pin. ● Suppress inrush current.
What are "open loop" and "closed loop"?	An open loop is a control loop where a rotor position is not estimated. When commutation current is forced to flow through a stator, a rotating magnetic field is generated, which drives a rotor to follow in a synchronous manner. A closed loop is a feedback-controlled loop where a rotor position is estimated. The rotor position is estimated from the motor's back EMF (BEMF: Back Electromotive Force).
Why does the GUI display the status indicator **LOS** in red at open-to-closed loop frequency control changeover?	When a loss-of-synchronization condition is detected, the GUI displays the status indicator **LOS** in red. This means that the IC cannot detect a back EMF condition properly. The faster the motor rotation, the larger the back EMF. In the **Start Up** group box, adjust the **RampU Frequ** and **RampU Curnt** setting values so that the IC can detect a back EMF condition with a faster rotation speed in the open-loop control.
What should I do when a data writing process is unstable?	Please initialize all the registers by writing "0x0000", and then write your desired parameter values to the IC. If no improvement is seen even after troubleshooting, please replace the IC with another one.
Why can't I perform a data reading process?	The password-locked mode may have been enabled. The Config[11] is the register for setting a password to the EEPROM. If you have set a value other than "0" to the Config[11], any data reading process cannot be performed. Please perform a reading process via the serial communications (SCL or SDA) that you have established, and then disable the password-locked mode (see Section 4.2.2).
How do I check the number of writing processes?	You can check the number of EEPROM writes by reading data from the Register 28 Read. Note that the programmer cannot perform such data reading. Please perform a reading process via the serial communications (SCL or SDA) that you have established.

6. About Trademarks and Registered Trademarks

- Windows® is either registered trademark of Microsoft Corporation in the United States and/or other countries.
- All rights and title in and to any specific trademark or tradename belong to Sanken and such original right holder(s).

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- No anti-radioactive ray design has been adopted for the Sanken Products.
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