NXP Semiconductors
User Guide

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# MCUXpresso SDK Field-Oriented Control (FOC) of 3-Phase PMSM and BLDC motors

# Contents

# Chapter 1 Introduction

This user's guide describes the implementation of the sensorless motor-control software for 3-phase Permanent Magnet Synchronous Motors (PMSM), including the motor parameters identification algorithm, on the NXP i.MX RT series crossover processors. The sensorless control software and the PMSM control theory in general are described in design reference manual DRM148 *Sensorless PMSM Field-Oriented Control (FOC)*. The NXP Freedom (FRDM-MC-LVPMSM) is used as the hardware platform for the PMSM control reference solution. The hardware-dependent part of the sensorless and sensored control software, including a detailed peripheral setup and the Motor Control (MC) peripheral drivers, are addressed as well. The motor parameters identification theory and algorithms are presented in this document. The last part of the document introduces and explains the user interface represented by the Motor Control Application Tuning (MCAT) page based on the FreeMASTER run-time debugging tool. These tools provide a simple and user-friendly way for the motor parameter identification, algorithm tuning, software control, debugging, and diagnostics.

This document describes how to run and control the Permanent Magnet Synchronous Motor (PMSM) project using i.MX RT Series Crossover Processors with the Freedom development board. The software provides sensorless/sensored field-oriented vector position, speed, torque, and scalar control. You can control the application using the board buttons or via FreeMASTER. The motor identification and application tuning is done using the MCAT tool integrated in the FreeMASTER page. The required software, hardware setup, jumper settings, project arrangement, and user interface are described in the following sections.

Available motor control examples, supported motors and possible control methods are listed in Table 1. More detailed description of the examples will be discussed in Available motor control examples chapter.

Table 1. Available examples and control methods

| | | Possible control methods in SDK example | | | | |
|---|---|---|---|---|---|---|
| **Example** | **Supported motor** | Scalar & Voltage | Current FOC (Torque) | Sensorless Speed FOC | Sensored Speed FOC | Sensored Position FOC |
| pmsm_enc | Linix 45ZWN24-40 (default motor) | ✓ | ✓ | ✓ | N/A | N/A |
| | Teknic M-2310P (with ENC) | ✓ | ✓ | ✓ | ✓ | ✓ |

NOTE
The latest documentation for the motor control SDK is available on http://www.nxp.com/motorcontrol_pmsm.

# Chapter 2 Hardware setup

The PMSM Field-Oriented Control (FOC) application runs on the FRDM-MC-LVPMSM development platform with the i.MX RT1060-EVK development tools, in combination with the Teknic M-2310P or Linix 45ZWN24-40 permanent magnet synchronous motors.

## 2.1 FRDM-MC-LVPMSM

This evaluation board, in a shield form factor, effectively turns an NXP Freedom development board or an evaluation board into a complete motor-control reference design, compatible with existing NXP Freedom development boards and evaluation boards. The Freedom motor-control headers are compatible with the Arduino™ R3 pin layout.

The FRDM-MC-LVPMSM low-voltage, 3-phase Permanent Magnet Synchronous Motor (PMSM) Freedom development platform board has the power supply input voltage of 24-48 VDC with a reverse polarity protection circuitry. The auxiliary power supply of 5.5 VDC is created to supply the FRDM MCU boards. The output current is up to 5 A RMS. The inverter itself is realized by a 3-phase bridge inverter (six MOSFETs) and a 3-phase MOSFET gate driver. The analog quantities (such as the 3-phase motor currents, DC-bus voltage, and DC-bus current) are sensed on this board. There is also an interface for speed and position sensors (encoder, hall). The block diagram of this complete NXP motor-control development kit is shown in Figure 1.

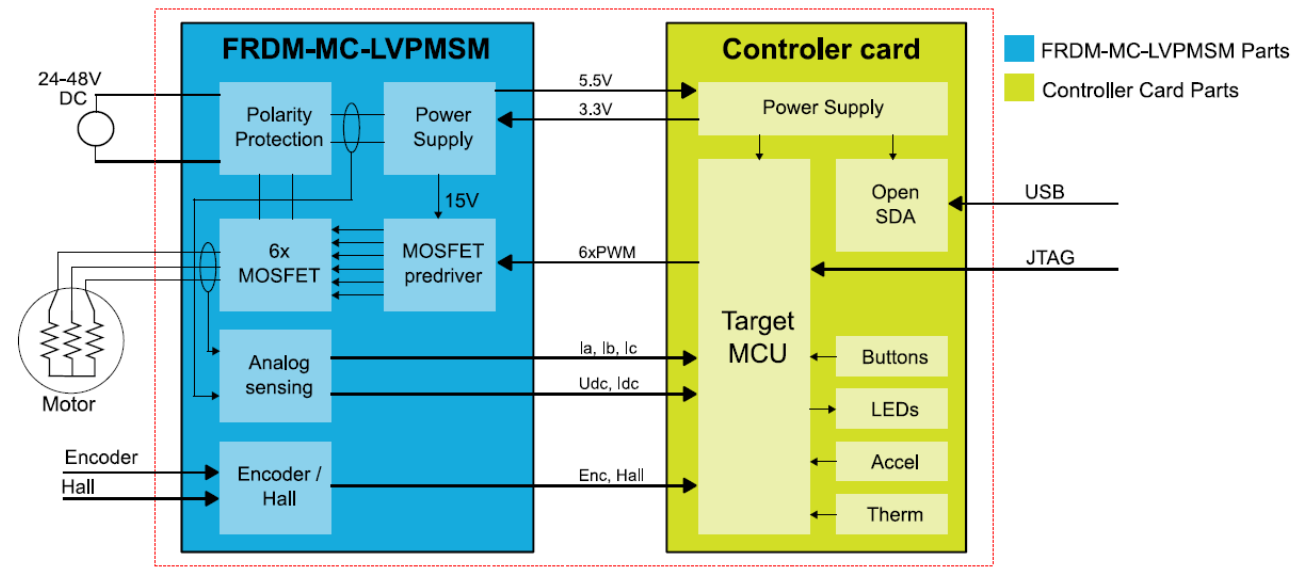


Figure 1. Motor-control development platform block diagram

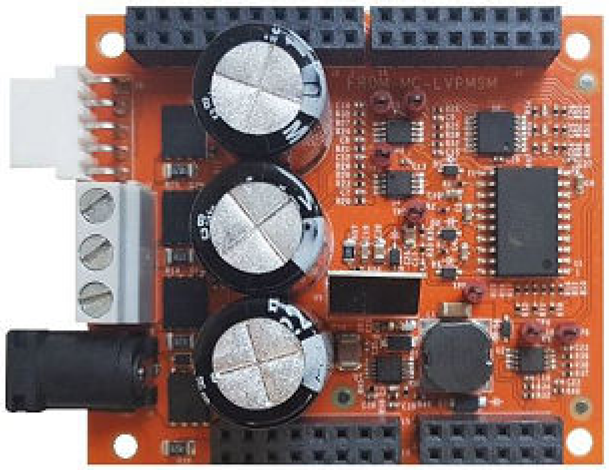


Figure 2. FRDM-MC-LVPMSM

The FRDM-MC-LVPMSM board does not require a complicated setup. For more information about the Freedom development platform, see www.nxp.com.

## 2.2 Linix 45ZWN24-40 motor

The Linix 45ZWN24-40 motor is a low-voltage 3-phase permanent-magnet motor with hall sensor used in PMSM applications. The motor parameters are listed in Table 2.

Table 2. Linix 45ZWN24-40 motor parameters

| Characteristic | Symbol | Value | Units |
|---|---|---|---|
| Rated voltage | Vt | 24 | V |
| Rated speed | - | 4000 | RPM |
| Rated torque | T | 0.0924 | Nm |
| Rated power | P | 40 | W |
| Continuous current | Ics | 2.34 | A |
| Number of pole-pairs | pp | 2 | - |

Figure 3. Linix 45ZWN24-40 permanent magnet synchronous motor

The motor has two types of connectors (cables). The first cable has three wires and is designated to power the motor. The second cable has five wires and is designated for the hall sensors' signal sensing. For the PMSM sensorless application, only the power input wires are needed.

## 2.3 Teknic M-2310P motor

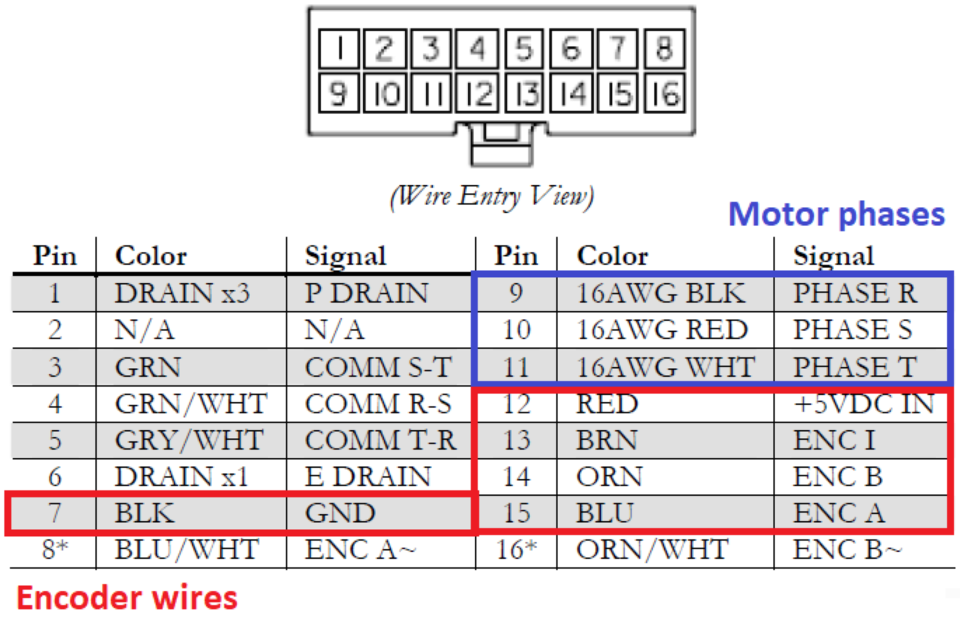
The Teknic M-2310P-LN-04K motor is a low-voltage 3-phase permanent-magnet motor used in PMSM applications. The motor has two feedback sensors (hall and encoder). For information on the wiring of feedback sensors, see the datasheet on the manufacturer web page. The motor parameters are listed in Table 3.

Table 3. Teknic M-2310P motor parameters

| Characteristic | Symbol | Value | Units |
|---|---|---|---|
| Rated voltage | Vt | 40 | V |
| Rated speed | - | 6000 | RPM |
| Rated torque | T | 0.247 | Nm |
| Rated power | P | 170 | W |
| Continuous current | Ics | 7.1 | A |
| Number of pole-pairs | pp | 4 | - |

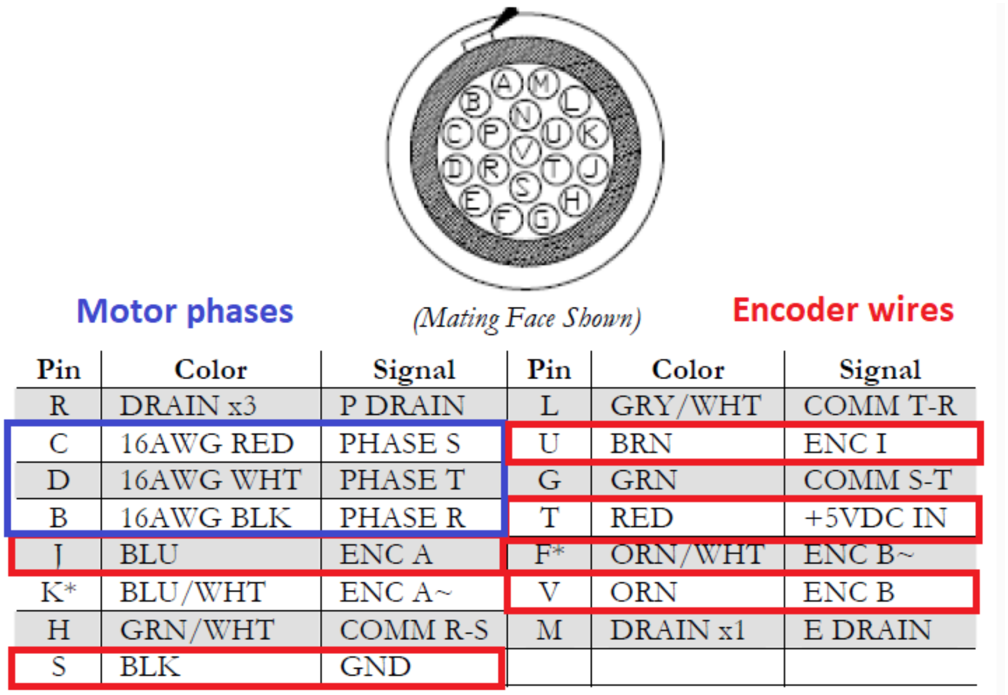
Figure 4.  Teknic M-2310P permanent magnet synchronous motor

For the sensorless control mode, you need only the power input wires. If used with the hall or encoder sensors, connect also the sensor wires to the NXP Freedom power stage.


1 2 3 4 5 6 7 8
9 10 11 12 13 14 15 16
(Wire Entry View)
Motor phases
Encoder wires

| Pin | Color | Signal | Pin | Color | Signal |
|---|---|---|---|---|---|
| 1 | DRAIN x3 | P DRAIN | 9 | 16AWG BLK | PHASE R |
| 2 | N/A | N/A | 10 | 16AWG RED | PHASE S |
| 3 | GRN | COMM S-T | 11 | 16AWG WHT | PHASE T |
| 4 | GRN/WHT | COMM R-S | 12 | RED | +5VDC IN |
| 5 | GRY/WHT | COMM T-R | 13 | BRN | ENC I |
| 6 | DRAIN x1 | E DRAIN | 14 | ORN | ENC B |
| 7 | BLK | GND | 15 | BLU | ENC A |
| 8* | BLU/WHT | ENC A~ | 16* | ORN/WHT | ENC B~ |

Figure 5.  Teknic motor connector type 1



| Pin | Color | Signal | Pin | Color | Signal |
|---|---|---|---|---|---|
| R | DRAIN x3 | P DRAIN | L | GRY/WHT | COMM T-R |
| C | 16AWG RED | PHASE S | U | BRN | ENC I |
| D | 16AWG WHT | PHASE T | G | GRN | COMM S-T |
| B | 16AWG BLK | PHASE R | T | RED | +5VDC IN |
| J | BLU | ENC A | F* | ORN/WHT | ENC B~ |
| K* | BLU/WHT | ENC A~ | V | ORN | ENC B |
| H | GRN/WHT | COMM R-S | M | DRAIN x1 | E DRAIN |
| S | BLK | GND | | | |

Figure 6. Teknic motor connector type 2

## 2.4 i.MX RT1060/1064 Evaluation Kit (MIMXRT1060-EVK, MIMXRT1060-EVKB, MIMXRT1064-EVK)

MIMXRT1060-EVK, MIMXRT1060-EVKB and MIMXRT1064-EVK are a 4-layer, hole-through, USB-powered PCBs. It includes the i.MX RT106x crossover processor, featuring NXP's advanced implementation of the Arm Cortex-M7 core. This cores operates at up to 600 MHz to provide high CPU performance and the best real-time response.

Table 4. MIMXRT1060-EVK, MIMXRT1060-EVKB and MIMXRT1064-EVK jumper settings

| Jumper | Setting | Jumper | Setting | Jumper | Setting |
|---|---|---|---|---|---|
| J1 | 5-6 | J13 | open | J44 | 1-2 |
| J3 | 1-2 | J15 | open | J47 | 1-2 |
| J4 | 1-2 | J26 | open | J48 | 1-2 |
| J5 | 1-2 | J36 | 1-2 | J49 | 1-2 |
| J7 | 1-2 | J43 | 1-2 | J50 | 1-2 |

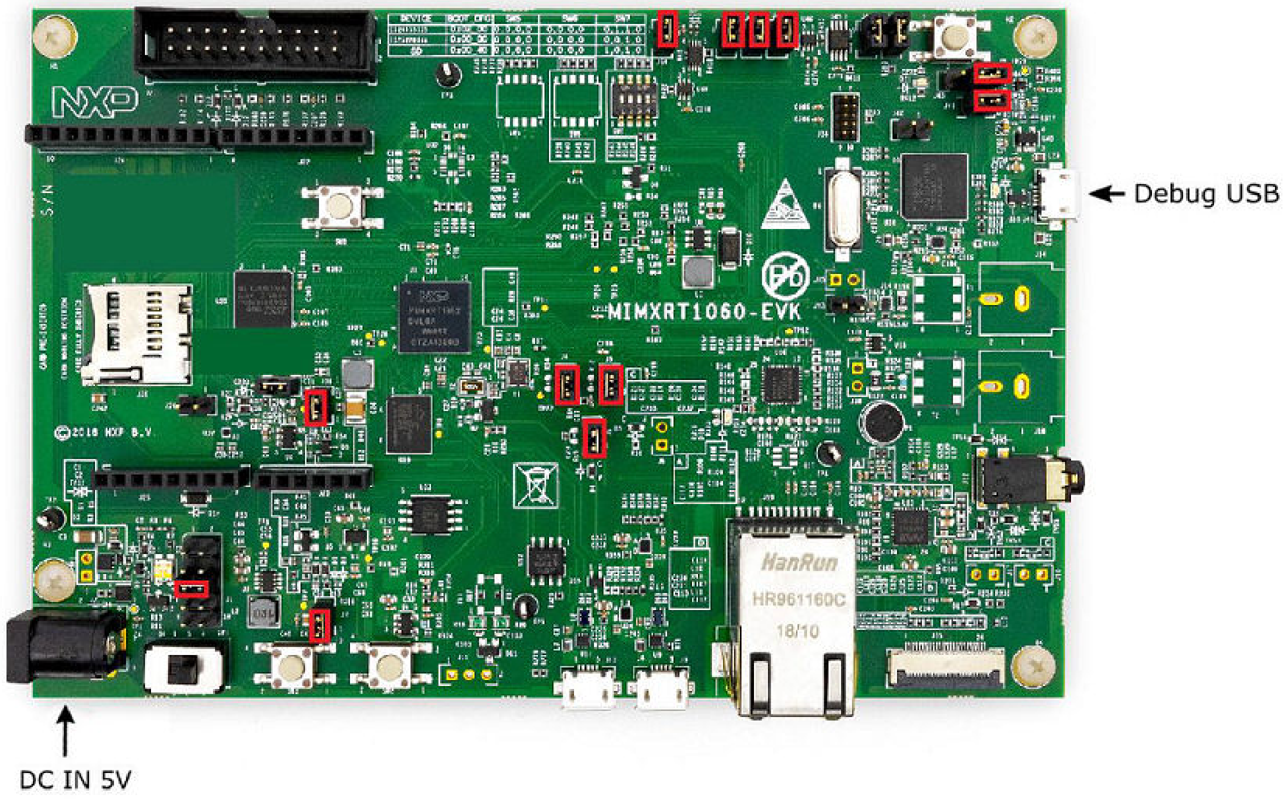


Figure 7. MIMXRT1060-EVK board with highlighted jumper settings (valid also for MIMXRT1060-EVKB and MIMXRT1064-EVK)

The motor-control application requires the PWM signals to be connected from the MCU to the power stage. For a correct connection, solder the R278, R279, R280, and R281 resistors to the board. These resistors are located on the bottom side of the EVK board. For more details, see the schematic.

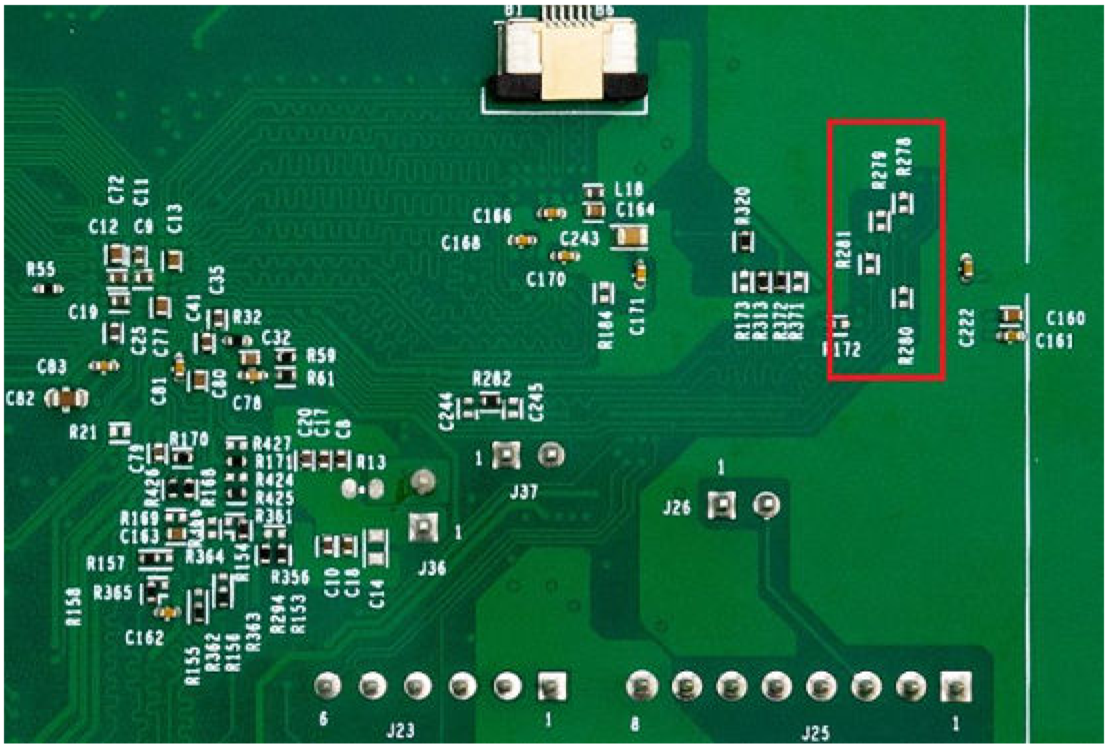


Figure 8. Resistor needed for proper operation on the bottom side of the EVK board

For more information about the MIMXRT1060-EVK, MIMXRT1060-EVKB or MIMXRT1064-EVK hardware (processor, peripherals, and so on), see the *MIMXRT1060/1064 Evaluation Kit Board Hardware User's Guide* (document MIMXRT10601064EKBHUG).

Hardware assembling

1. Connect the FRDM-MC-LVPMSM shield on top of the MIMXRT1060-EVK or MIMXRT1060-EVKB or MIMXRT1064-EVK board.
2. On the top of FRDM-MC-PMSM shield connect by wires following pins:

Table 5. MIMXRT1060-EVK, MIMXRT1060-EVKB and MIMXRT1064-EVK pin assignment

| FRDM-MC-LVPMSM | Connection | MIMXRT1060-EVK, MIMXRT1060-EVKB, MIMXRT1064-EVK |
|---|---|---|
| PWM_AT | J3, 15 <-> J2, 12 | GPIO_SD_B0_00 |
| PWM_AB | J3, 13 <-> J2, 6 | GPIO_SD_B0_01 |
| PWM_BT | J3, 11 <-> J2, 8 | GPIO_SD_B0_02 |
| PWM_BB | J3, 9 <-> J2, 10 | GPIO_SD_B0_03 |
| PWM_CT | J3, 7 <-> J1, 12 | GPIO_AD_B0_10 |
| PWM_CB | J3, 5 <-> J1, 6 | GPIO_AD_B0_11 |
| 3V3 | J3, 4 <-> J2, 16 | 3V3 |
| ENC_A | J3, 3 <-> J2, 4 | GPIO_AD_B0_02 |

*Table continues on the next page...*

Table 5. MIMXRT1060-EVK, MIMXRT1060-EVKB and MIMXRT1064-EVK pin assignment (continued)

| FRDM-MC-LVPMSM | Connection | MIMXRT1060-EVK, MIMXRT1060-EVKB, MIMXRT1064-EVK |
|---|---|---|
| ENC_B | J3, 1 <-> J2, 2 | GPIO_AD_B0_03 |
| GND | J3, 14 <-> J3, 12 | GND |
| CUR_A | J2, 1 <-> J4, 4 | GPIO_AD_B1_11 |
| CUR_B | J2, 3 <-> J4, 12 | GPIO_AD_B1_00 |
| CUR_C | J2, 5 <-> J4, 10 | GPIO_AD_B1_01 |
| VOLT_DCB | J2, 7 <-> J1, 14 | GPIO_AD_B1_02 |
| CUR_DCB | J2, 9 <-> J1, 16 | GPIO_AD_B1_03 |

3. Connect the 3-phase motor wires to the screw terminals (J7) on the Freedom PMSM power stage.
4. Plug the USB cable from the USB host to the OpenSDA micro-USB connector (J41) on the EVK board.
5. Plug the 24-V DC power supply to the DC power connector on the Freedom PMSM power stage.

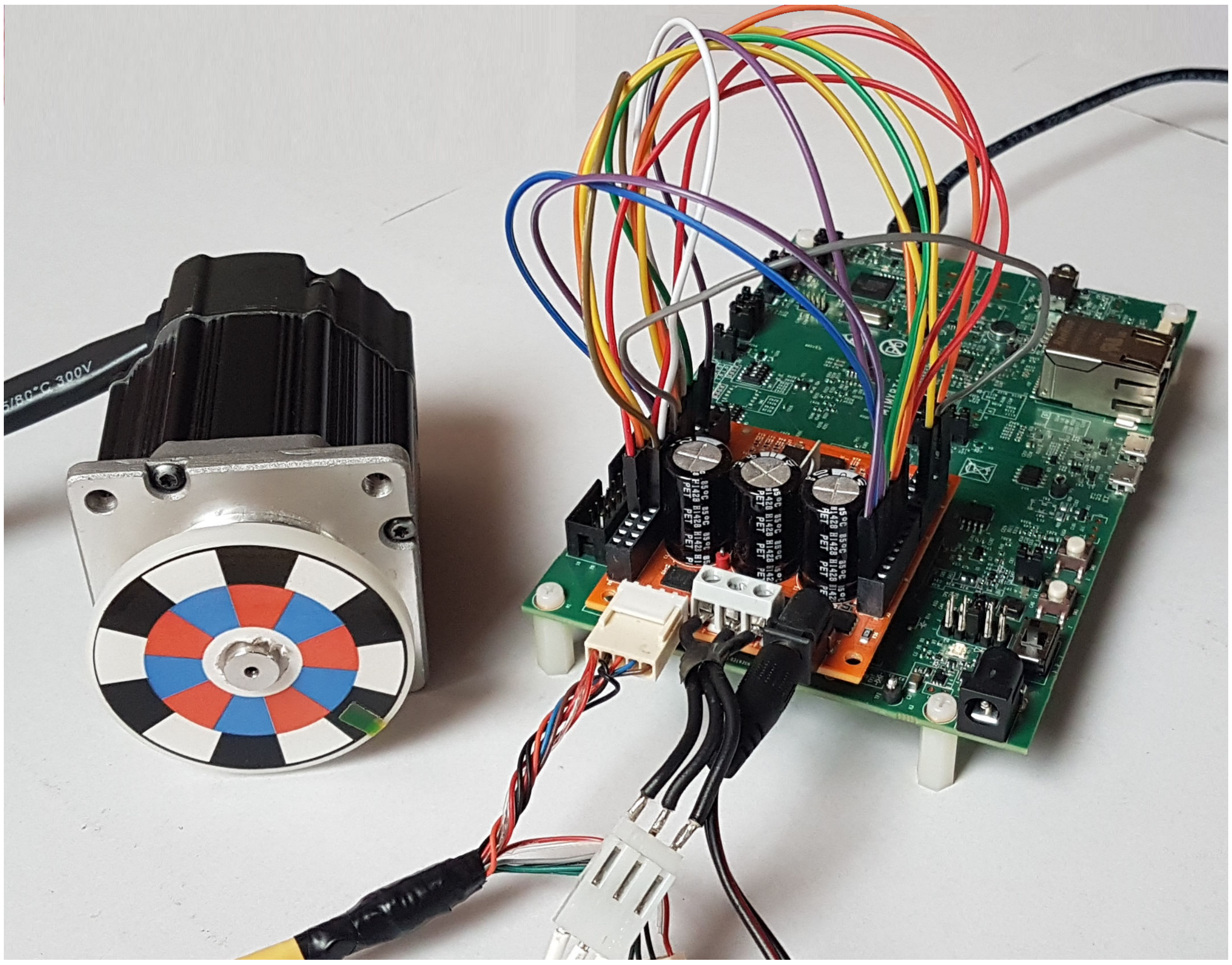


Figure 9. Assembled Fredome system

# Chapter 3
# RT crossover processors features and peripheral settings

This chapter describes the peripheral settings and application timing. The i.MX RT1xxx is a new processor family featuring NXP's advanced implementation of the Arm Cortex-M7 core.

## 3.1 i.MX RT106x

The MIMXRT1060-EVK, MIMXRT1060-EVKB and MIMXRT1064-EVK boards are platforms designed to showcase the features of the i.MX RT106x processors in small, low-cost packages. The MIMXRT106x-EVK/B boards are entry-level development boards, which help you to become familiar with the processors before investing a large amount of resources into more specific designs. The EVK boards provide various types of memory, especially the 64-Mbit Quad SPI flash and 512-Mbit Hyper flash.

### 3.1.1 RT1060/64 - Hardware timing and synchronization

Correct and precise timing is crucial for motor-control applications. Therefore, the motor-control-dedicated peripherals take care of the timing and synchronization on the hardware layer. In addition, it is possible to set the PWM frequency as a multiple of the ADC interrupt (ADC ISR) frequency where the FOC algorithm is calculated. In this case, the PWM frequency is equal to the FOC frequency.

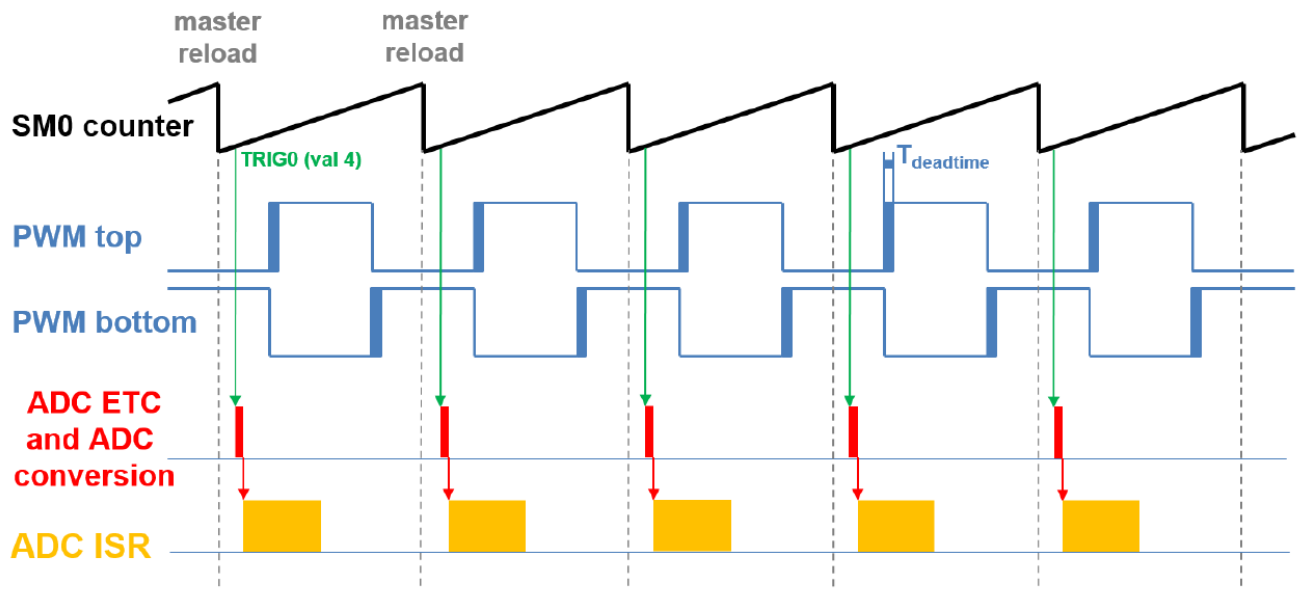


Figure 10. Hardware timing and synchronization on i.MX RT1060/64

- The top signal shows the eFlexPWM counter (SM0 counter). The dead time is emphasized at the PWM top and PWM bottom signals. The SM0 submodule generates the master reload at every opportunity.
- SM0 generates trigger 0 (when the counter counts to a value equal to the TRIG4 value) for the ADC_ETC (ADC External Trigger Control) with a delay of approximately $T_{deatime}/2$. This delay ensures correct current sampling at duty cycles close to 100 %.
- ADC_ETC starts the ADC conversion.
- When the ADC conversion is completed, the ADC ISR (ADC interrupt) is entered. The FOC calculation is done in this interrupt.

### 3.1.2 RT1060/64 - Peripheral settings

This section describes the peripherals used for motor control. On i.MX RT1060/1064, there are three submodules from the enhanced FlexPWM (eFlexPWM) used for 6-channel PWM generation and two 12-bit ADCs for the phase currents and DC-bus voltage measurement. The eFlexPWM and ADC are synchronized via submodule 0 from the eFlexPWM. The following settings are located in the *mc_periph_init.c* and *peripherals.c* files and their header files.

#### Clock Control Module (CCM)

The CCM generates and controls the clocks of various modules in the design and manages the low-power modes. This module uses the available clock sources to generate the clock roots.

The clock sources used in the motor-control application are:

- PLL1, also called ARM PLL, with a frequency of 1.2 GHz.
- PLL3, also called USB1 PLL with a frequency of 480 MHz.

The Arm clock core works at a frequency of 600 MHz and the clock source is PLL1 divided by 2. For this setting, the CBCMR[PRE_PERIPH_CLK_SEL], CBCDR[PERIPH_CLK_SEL], and CBCDR[AHB_PODF] registers are set in the *clock_config.c* file. The ADC, XBAR, and PWM are clocked from the IPG_CLK_ROOT output which has a frequency of 150 MHz. The CBCDR[IPG_PODF] register must be set for this setting. IPG_CLK_ROOT is sourced from AHB_CLK_ROOT. LPUART is sourced from PLL3 at a frequency of 480 MHz divided by 6.

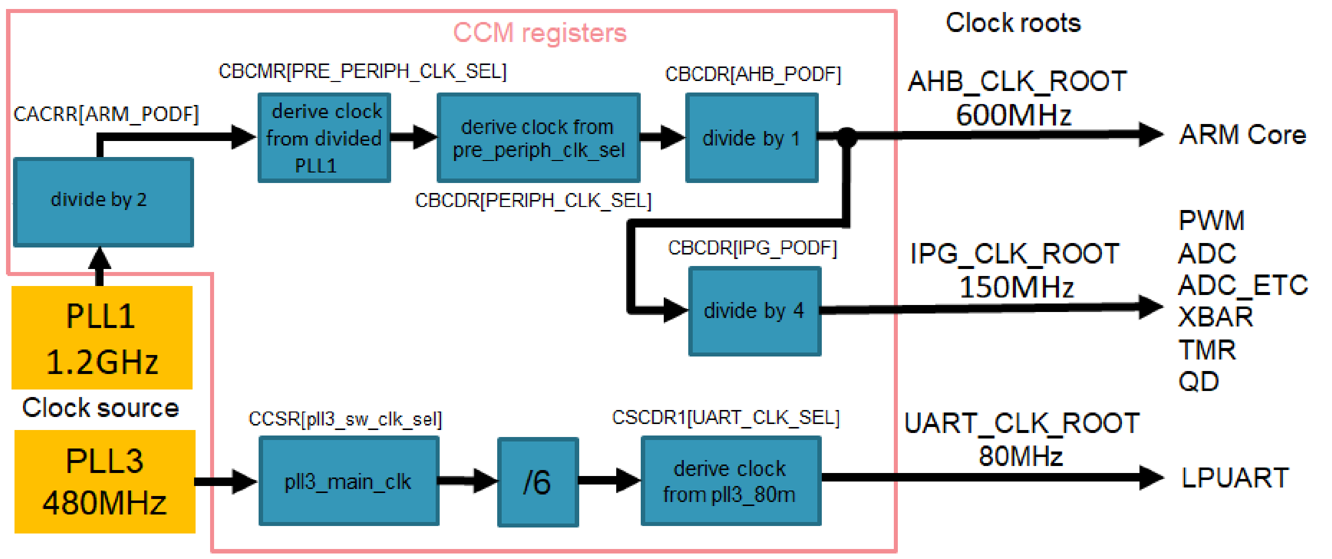


Figure 11. i.MX RT1060/1064 clock source for motor-control peripherals

The clock sources for the peripherals used for motor control are listed in Table 6.

Table 6. i.MX RT1060/1064 clock source for motor-control peripherals

| | Clock source | Clock root | Clock root frequency |
|---|---|---|---|
| Arm core | PLL2 | AHB_CLK_ROOT | 600 MHz |
| PWM | PLL2 | IPG_CLK_ROOT | 150 MHz |
| ADCs | PLL2 | IPG_CLK_ROOT | 150 MHz |
| ADC_ETC | PLL2 | IPG_CLK_ROOT | 150 MHz |
| XBAR | PLL2 | IPG_CLK_ROOT | 150 MHz |

*Table continues on the next page...*

Table 6. i.MX RT1060/1064 clock source for motor-control peripherals (continued)

| | Clock source | Clock root | Clock root frequency |
|---|---|---|---|
| TMR | PLL2 | IPG_CLK_ROOT | 150 MHz |
| QD | PLL2 | IPG_CLK_ROOT | 150 MHz |
| LPUART | PLL3 | UART_CLK_ROOT | 80 MHz |

For more details, see the i.MX RT1060 or i.MX RT1064 processor reference manuals.

### PWM generation - PWM1

- The eFlexPWM is clocked from the 150-MHz IPG_CLK_ROOT.
- Six channels from three submodules are used for the 3-phase PWM generation. Submodule 0 generates the master reload at event every n$^{th}$ opportunity, depending on the user-defined macro M1_FOC_FREQ_VS_PWM_FREQ.
- Submodules 1 and 3 get their clocks from submodule 0.
- The counters at submodules 1 and 3 are synchronized with the master reload signal from submodule 0 (submodule 2 is not used).
- Submodule 0 is used for synchronization with ADC_ETC. The submodule generates the output trigger after the PWM reload, when the counter counts to VAL4.
- The fault mode is enabled for channels A and B at submodules 0, 1, and 3 with automatic fault clearing (the PWM outputs are re-enabled at the first PWM reload after the fault input returns to zero).
- The PWM period (frequency) is determined by how long it takes the counter to count from INIT to VAL1. By default, INIT = -MODULO/2 = -7500 and VAL1 = MODULO/2 -1 = 7499. The eFlexPWM clock is 150 MHz so it takes 0.0001 s (10 KHz).
- Dead time insertion is enabled. The dead time length is defined by the user in the M1_PWM_DEADTIME macro.

### Over-current detection - CMP2

- The plus input for the CMP2 (CMP2_IN3) is taken from the analog pin.
- The minus input for the CMP2 (CMP2_IN7) is taken from the 6-bit DAC0 reference. The DAC reference is set to 3.197 V, which corresponds to 7.73 A (in the 8.25 A scale).
- The CMP filter is enabled and four consecutive samples must match.

### ADC external trigger control - ADC_ETC

The ADC_ETC module enables multiple users to share the ADC modules in the Time Division Multiplexing (TDM) way. The external triggers can be brought from the Cross BAR (XBAR) or other sources. The ADC scan is started via ADC_ETC.

- Both ADCs have set their own trigger chains.
- The trigger chain length is set to 2. The back-to-back ADC trigger mode is enabled.
- The SyncMode is on. In the SyncMode, ADC1 and ADC2 are controlled by the same trigger source. The trigger source is the PWM submodule 0.

### Analog sensing - ADC1 and ADC2

ADC1 and ADC2 are used for the MC analog sensing of currents and DC-bus voltage.

- The clock frequency for ADC1 and ADC2 is 75 MHz. It is taken from IPG_CLK_ROOT and divided by 2.
- The ADCs operate as 10-bit with the single-ended conversion and hardware trigger selected. The ADCs are triggered from ADC_ETC by the trigger generated by the eFlexPWM.

- The conversion-complete interrupt is enabled and serves the FOC fast-loop algorithm generated after the last scan is completed by ADC1.

### Quadrature Decoder (QD) module

The QD module is used to sense the position and speed from the encoder sensor.

- The direction of counting is set in the M1_POSPE_ENC_DIRECTION macro.
- The modulo counting and the modulus counting roll-over/under to increment/decrement revolution counter are enabled.

### Peripheral interconnection for i.MX RT1060 - XBARA1

The crossbar is used to interconnect the trigger from the PWM to the ADC_ETC and to connect the encoder (connected to GPIO) to the QD.

- The FLEXPWM1_PWM1_OUT_TRIG0_1 output trigger (generated by submodule 0) is connected to ADC_ETC_XBAR0_TRIG0.
- The encoder signal Phase A - IOMUX_XBAR_INOUT16 output is assigned to ENC1_PHASE_A_INPUT (GPIO_AD_B0_02 is configured as XBAR1_INOUT16 in the *pinmux.c*file).
- The encoder signal Phase B - IOMUX_XBAR_INOUT17 output is assigned to ENC1_PHASE_B_INPUT (GPIO_AD_B0_03 is configured as XBAR1_INOUT17 in the *pinmux.c* file).

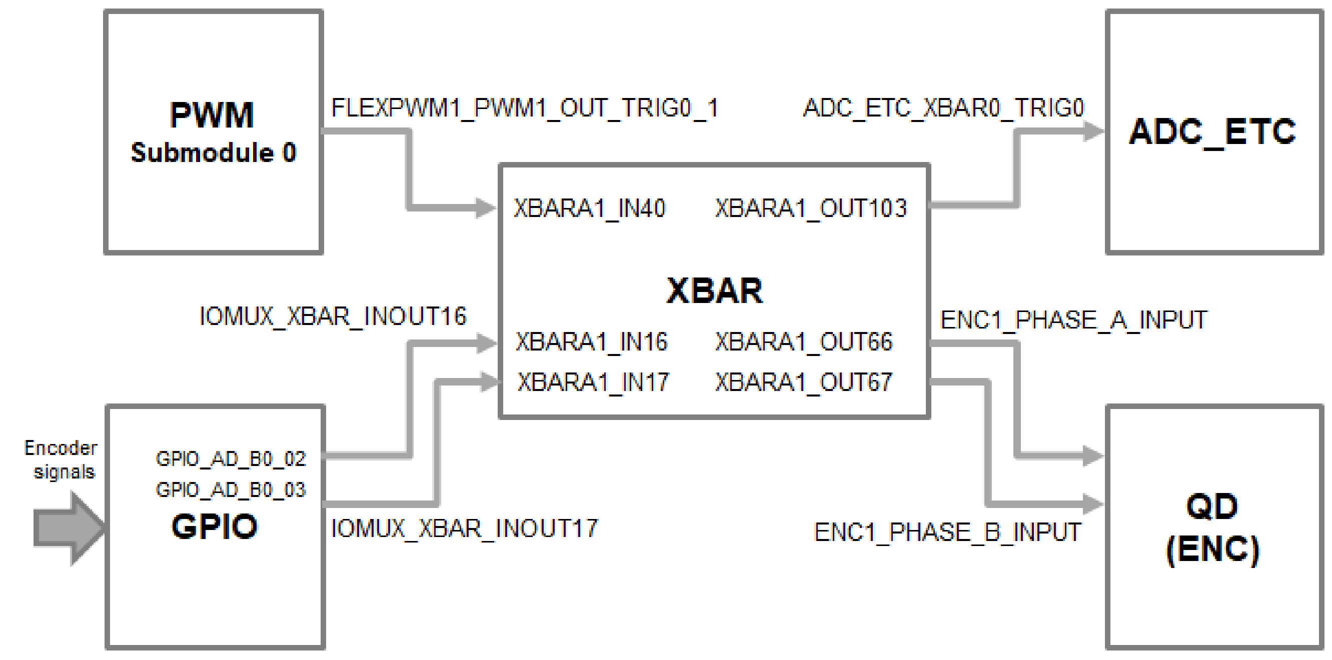


Figure 12. Crossbar interconnection for i.MX RT1060

### Slow-loop interrupt generation - TMR1

The QuadTimer module TMR1 is used to generate the slow-loop interrupt.

- QuadTimer TMR1 is clocked from IPG CLK ROOT divided by 16, so the clock frequency of TMR1 is 9.375 MHz.
- The slow loop is usually ten times slower than the fast loop. Therefore, the interrupt is generated after the counter counts from CNTR0 = 0 to COMP1 = IPG CLK ROOT / (16U * Speed Loop Freq). The speed-loop frequency is set in the M1_SPEED_LOOP_FREQ macro and equals 1000 Hz.
- An interrupt (which serves the slow-loop period) is enabled and generated at the reload event.

#### FreeMASTER communication—LPUART0

LPUART0 (Low-Power Universal Asynchronous Receiver and Transmitter) is used for the FreeMASTER communication between the MCU board and the PC.

- The baud rate is set to 115200 bit/s.
- The receiver and transmitter are both enabled.
- The other settings are set to default.

## 3.2 Available motor control examples

Following examples are available for the device specified in this document:

- pmsm_enc

Supported motors and possible control methods for each example are mentioned in the Introduction of this document.

### pmsm_enc example

This example can be used for the sensor and sensorless motor control application both. Default motor configuration is tuned for the Linix 45ZWN24-40 motor. Motor identification is implemented in this example. Changing motor configuration is described below.

#### Change motor configuration

Motor control examples contains two or more configuration files: *m1_pmsm_appconfig.h*, *m2_pmsm_appconfig.h* etc. Each of them contains constants tuned for the selected motor (Linix 45ZWN24-40 or Teknic M-2310P in case of the Freedom development platform, Mige 60CST-MO1330 in case of the High-voltage platform). There are two ways, how to change motor configuration corresponding to the connected motor. The first way is following:

- In the project example folder, find configuration file which will be used for.
- Rename this configuration file to *m1_pmsm_appconfig.h*.
- Rebuild project and load the code to the MCU.

The second way how to change motor configuration is described in MCAT FreeMASTER interface (Motor Control Application Tuning).

## 3.3 RT family - CPU load and memory usage

The following information apply to the application built using one of the following IDE: MCUXpresso IDE, IAR or Keil MDK. The memory usage is calculated from the *.map* linker file, including the 4-KB FreeMASTER recorder buffer allocated in RAM. In the MCUXpresso IDE, the memory usage can be also seen after project build in the Console window. The table below shows the maximum CPU load of the supported examples. The CPU load is measured using the SysTick timer. The CPU load is dependent on the fast-loop (FOC calculation) and slow-loop (speed loop) frequencies. In this case, it applies to the fast-loop frequency of 16 KHz and the slow-loop frequency of 1 KHz. The total CPU load is calculated using the following equations:

$$CPU_{fast} = cycles_{fast}\frac{f_{fast}}{f_{CPU}}100\ [\%]$$

$$CPU_{slow} = cycles_{slow}\frac{f_{slow}}{f_{CPU}}100\ [\%]$$

$$CPU_{total} = CPU_{fast} + CPU_{slow}\ \ [\%]$$

Where:

$CPU_{fast}$ - the CPU load taken by the fast loop.

$cycles_{fast}$ - the number of cycles consumed by the fast loop.

$f_{fast}$ - the frequency of the fast-loop calculation (16 KHz).

$f_{CPU}$ - CPU frequency.

$CPU_{slow}$ - the CPU load taken by the slow loop.

$cycles_{slow}$ - the number of cycles consumed by the slow loop.

$f_{slow}$ - the frequency of the slow-loop calculation (1 KHz).

$CPU_{total}$ - the total CPU load consumed by the motor control.

Table 7. Maximum CPU load (fast loop)

| | | debug configuration | |
|---|---|---|---|
| **Device** | **Example** | **Speed Control** | **Position Control** |
| i.MX RT1060 | pmsm_enc | 11.2% | 10.5% |

CPU load measured without defined RAM_RELOCATION macro. Measured CPU load apply to the application built using IAR IDE.

NOTE

The maximum CPU load is depending on executing functions from RAM or FLASH memory. Executing functions can be speeding up in RTCESL_cfg.h header file by using macro RAM_RELOCATION.

NOTE

Memory usage and maximum CPU load can differ depending on the used IDEs and settings.

# Chapter 4
# Project file and IDE workspace structure

All the necessary files are included in one package, which simplifies the distribution and decreases the size of the final package. The directory structure of this package is simple, easy to use, and organized in a logical manner. The folder structure used in the IDE is different from the structure of the PMSM package installation, but it uses the same files. The different organization is chosen due to a better manipulation with folders and files in workplaces and due to the possibility to add or remove files and directories. The "*pack_motor_board*" project includes all the available functions and routines, MID functions, scalar and vector control of the motor, FOC control, and FreeMASTER MCAT project. This project serves for development and testing purposes.

## 4.1 PMSM project structure

The directory tree of the PMSM project is shown in below.

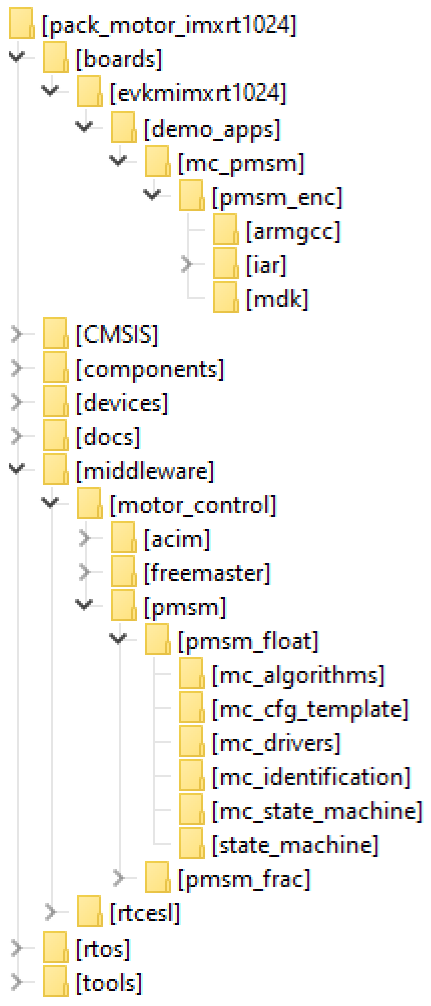


Figure 13. Directory tree

The main project folder *pack_motor_imxrt1xxx\boards\evkbimxrt1xxx\demo_apps\mc_pmsm\pmsm_enc\* contains these folders and files:

- *iar*—for the IAR Embedded Workbench IDE.
- *armgcc*—for the GNU Arm IDE.

- *mdk*—for the uVision Keil IDE.
- *m1_pmsm_appconfig.h*—contains the definitions of constants for the application control processes, parameters of the motor and regulators, and the constants for other vector-control-related algorithms. When you tailor the application for a different motor using the Motor Control Application Tuning (MCAT) tool, the tool generates this file at the end of the tuning process.
- *main.c*—contains the basic application initialization (enabling interrupts), subroutines for accessing the MCU peripherals, and interrupt service routines. The FreeMASTER communication is performed in the background infinite loop.
- *board.c*—contains the functions for the UART, GPIO, and SysTick initialization.
- *board.h*—contains the definitions of the board LEDs, buttons, UART instance used for FreeMASTER, and so on.
- *clock_config.c and .h*—contains the CPU clock setup functions. These files are going to be generated by the clock tool in the future.
- *mc_periph_init.c*—contains the motor-control driver peripherals initialization functions that are specific for the board and MCU used.
- *mc_periph_init.h*—header file for *mc_periph_init.c*. This file contains the macros for changing the PWM period and the ADC channels assigned to the phase currents and board voltage.
- *freemaster_cfg.h*—the FreeMASTER configuration file containing the FreeMASTER communication and features setup.
- *pin_mux and .h*—port configuration files. It is recommended to generate these files in the pin tool.
- *peripherals.c and .h*—MCUXpresso Config Tool configuration files.

The main motor-control folder *pack_motor_imxrt10xx\middleware\motor_control\* contains these subfolders:

- *pmsm*—contains main PMSM motor-control functions
- *freemaster*—contains the FreeMASTER project file *pmsm_float_enc.pmp*. Open this file in the FreeMASTER tool and use it to control the application. The folder also contains the auxiliary files for the MCAT tool.

The *pack_motor_imxrt1xxx\middleware\motor_control\pmsm\pmsm_float\* folder contains these subfolders common to the other motor-control projects:

- *mc_algorithms*—contains the main control algorithms used to control the FOC and speed control loop.
- *mc_cfg_template*—contains templates for MCUXpresso Config Tool components.
- *mc_drivers*—contains the source and header files used to initialize and run motor-control applications.
- *mc_identification*—contains the source code for the automated parameter-identification routines of the motor.
- *mc_state_machine*—contains the software routines that are executed when the application is in a particular state or state transition.
- *state_machine*—contains the state machine functions for the FAULT, INITIALIZATION, STOP, and RUN states.

# Chapter 5
# Tools

Install the FreeMASTER Run-Time Debugging Tool 3.1.4 and one of the following IDEs on your PC to run and control the PMSM application properly:

- IAR Embedded Workbench IDE v9.30.1 or higher
- MCUXpresso v11.6.0
- ARM-MDK - Keil µVision version 5.37

For pin_mux.c, clock_config.c or peripherals.c modifications is recommended use MCUXpresso Configuration Tool v12 or higher.

NOTE

For information on how to build and run the application in your IDE, see the *Getting Started with MCUXpresso SDK* document located in the *pack_motor_<booard>/docs* folder or find the related documentation at MCUXpresso SDK builder.

## 5.1 Compiler warnings

Warnings are diagnostic messages that report constructions that are not inherently erroneous and warn about potential runtime, logic, and performance errors. In some cases, warnings can be suspended and these warnings do not show during the compiling process. One of such special cases is the “unused function” warning, where the function is implemented in the source code with its body, but this function is not used. This case occurs when you implement the function as a supporting function for better usability, but you do not use the function for any special purposes for a while.

The IAR Embedded Workbench IDE suppresses these warnings:

- Pa082 - undefined behavior; the order of volatile accesses is not defined in this statement.
- Pa050 - non-native end of line sequence detected.

The Arm-MDK Keil µVision IDE suppresses these warnings:

- 6314 - No section matches pattern xxx.o (yy).

By default, there are no other warnings shown during the compiling process.

# Chapter 6 Motor-control peripheral initialization

The motor-control peripherals are initialized by calling the *MCDRV_Init_M1()* function during MCU startup and before the peripherals are used. All initialization functions are in the *mc_periph_init.c* source file and the *mc_periph_init.h* header file. The definitions specified by the user are also in these files. The features provided by the functions are the 3-phase PWM generation and 3-phase current measurement, as well as the DC-bus voltage and auxiliary quantity measurement. The principles of both the 3-phase current measurement and the PWM generation using the Space Vector Modulation (SVM) technique are described in *Sensorless PMSM Field-Oriented Control* (document DRM148).

The *mc_periph_init.h* header file provides several macros, which can be defined by the user:

- *M1_MCDRV_ADC_PERIPH_INIT*—this macro calls ADC peripheral initialization.
- *M1_MCDRV_PWM_PERIPH_INIT*—this macro calls PWM peripheral initialization.
- *M1_MCDRV_QD_ENC*—this macro calls QD peripheral initialization.
- *M1_PWM_FREQ*—the value of this definition sets the PWM frequency.
- *M1_FOC_FREQ_VS_PWM_FREQ*—enables you to call the fast-loop interrupt at every first, second, third, or n$^{th}$ PWM reload. This is convenient when the PWM frequency must be higher than the maximal fast-loop interrupt.
- *M1_SPEED_LOOP_FREQ* —the value of this definition sets the speed loop frequency (TMR1 interrupt).
- *M1_PWM_DEADTIME*—the value of the PWM dead time in nanoseconds.
- *M1_PWM_PAIR_PH[A..C]*—these macros enable a simple assignment of the physical motor phases to the PWM periphery channels (or submodules). You can change the order of the motor phases this way.
- *M1_ADC[1,2]_PH_[A..C]*—these macros are used to assign the ADC channels for the phase current measurement. The general rule is that at least one phase current must be measurable on both ADC converters and the two remaining phase currents must be measurable on different ADC converters. The reason for this is that the selection of the phase current pair to measure depends on the current SVM sector. If this rule is broken, a preprocessor error is issued. For more information about the 3-phase current measurement, see *Sensorless PMSM Field-Oriented Control* (document DRM148).
- *M1_ADC[1,2]_UDCB*—this define is used to select the ADC channel for the measurement of the DC-bus voltage.

In the motor-control software, these API-serving ADC and PWM peripherals are available:

- The available APIs for the ADC are:
  - *mcdrv_adc_t*—MCDRV ADC structure data type.
  - *void M1_MCDRV_ADC_PERIPH_INIT()*—this function is by default called during the ADC peripheral initialization procedure invoked by the *MCDRV_Init_M1()* function and should not be called again after the peripheral initialization is done.
  - *void M1_MCDRV_CURR_3PH_CHAN_ASSIGN(mcdrv_adc_t*)*—calling this function assigns proper ADC channels for the next 3-phase current measurement based on the SVM sector.
  - *void M1_MCDRV_CURR_3PH_CALIB_INIT(mcdrv_adc_t*)*—this function initializes the phase-current channel-offset measurement.
  - *void M1_MCDRV_CURR_3PH_CALIB(mcdrv_adc_t*)*—this function reads the current information from the unpowered phases of a stand-still motor and filters them using moving average filters. The goal is to obtain the value of the measurement offset. The length of the window for moving the average filters is set to eight samples by default.
  - *void M1_MCDRV_CURR_3PH_CALIB_SET(mcdrv_adc_t*)*—this function asserts the phase-current measurement offset values to the internal registers. Call this function after a sufficient number of *M1_MCDRV_CURR_3PH_CALIB()* calls.
  - *void M1_MCDRV_ADC_GET(mcdrv_adc_t*)*—this function reads and calculates the actual values of the 3-phase currents, DC-bus voltage, and auxiliary quantity.

- The available APIs for the PWM are:
  - — *mcdrv_pwma_pwm3ph_t*—MCDRV PWM structure data type.
  - — *void M1_MCDRV_PWM_PERIPH_INIT*—this function is by default called during the PWM periphery initialization procedure invoked by the *MCDRV_Init_M1()* function.
  - — *void M1_MCDRV_PWM3PH_SET(mcdrv_pwma_pwm3ph_t*)*—this function updates the PWM phase duty cycles.
  - — *void M1_MCDRV_PWM3PH_EN(mcdrv_pwma_pwm3ph_t*)*—this function enables all PWM channels.
  - — *void M1_MCDRV_PWM3PH_DIS (mcdrv_pwma_pwm3ph_t*)*—this function disables all PWM channels.
  - — *bool_t M1_MCDRV_PWM3PH_FLT_GET(mcdrv_pwma_pwm3ph_t*)*—this function returns the state of the over-current fault flags and automatically clears the flags (if set). This function returns true when an over-current event occurs. Otherwise, it returns false.
- The available APIs for the quadrature encoder are:
  - — *mcdrv_qd_enc_t*—MCDRV QD structure data type.
  - — *void M1_MCDRV_QD_PERIPH_INIT()*—this function is by default called during the QD periphery initialization procedure invoked by the *MCDRV_Init_M1()* function.
  - — *void M1_MCDRV_QD_GET(mcdrv_qd_enc_t*)*—this function returns the actual position and speed.
  - — *void M1_MCDRV_QD_SET_DIRECTION(mcdrv_qd_enc_t*)*—this function sets the direction of the quadrature encoder.
  - — *void M1_MCDRV_QD_CLEAR(mcdrv_qd_enc_t*)*—this function clears the internal variables and decoder counter.

# Chapter 7
# User interface

The application contains the demo mode to demonstrate motor rotation. You can operate it either using the user button, or using FreeMASTER. The NXP EVK boards include a user button associated with a port interrupt (generated whenever one of the buttons is pressed). At the beginning of the ISR, a simple logic executes and the interrupt flag clears. When you press the button, the demo mode starts. When you press the same button again, the application stops and transitions back to the STOP state.

The other way to interact with the demo mode is to use the FreeMASTER tool. The FreeMASTER application consists of two parts: the PC application used for variable visualization and the set of software drivers running in the embedded application. Data is transferred between the PC and the embedded application via the serial interface. This interface is provided by the CMSIS-DAP debugger included in the boards.

The application can be controlled using these two interfaces:

- The button on the MIMXRT1xxx-EVK development board (controlling the demo mode):
  - MIMXRT1060-EVK - SW8
- Remote control using FreeMASTER (chapter Remote control using FreeMASTER):
  - Using the Motor Control Application Tuning (MCAT) interface.
  - Setting a variable in the FreeMASTER Variable Watch.

If you are using your own motor (different from the default motors), make sure to identify all motor parameters. The automated parameter identification is described in the following sections.

# Chapter 8
# Remote control using FreeMASTER

This section provides information about the tools and recommended procedures to control the sensor/sensorless PMSM Field-Oriented Control (FOC) application using FreeMASTER. The application contains the embedded-side driver of the FreeMASTER real-time debug monitor and data visualization tool for communication with the PC. It supports non-intrusive monitoring, as well as the modification of target variables in real time, which is very useful for the algorithm tuning. Besides the target-side driver, the FreeMASTER tool requires the installation of the PC application as well. You can download FreeMASTER 3.0 at www.nxp.com/freemaster. To run the FreeMASTER application including the MCAT tool, double-click the *pmsm_float_enc.pmp* file located in the *pack_motor_imxrt1xxx\middleware\motor_control\freemaster* folder. The FreeMASTER application starts and the environment is created automatically, as defined in the **.pmp* file.

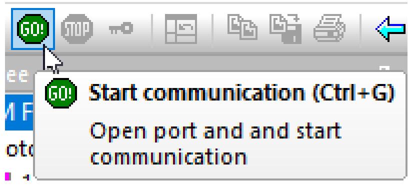
NOTE

In MCUXpresso can be FreeMASTER application run directly from IDE in *motor_control/freemaster* folder

## 8.1 Establishing FreeMASTER communication

The remote operation is provided by FreeMASTER via the USB interface. Perform the following steps to control a PMSM motor using FreeMASTER:

1. Download the project from your chosen IDE to the MCU and run it.
2. Open the FreeMASTER file *pmsm_x.pmp*. The PMSM project uses the TSA by default, so it is not necessary to select a symbol file for FreeMASTER.
3. Click the communication button (the green "GO" button in the top left-hand corner) to establish the communication.



Start communication (Ctrl+G)
Open port and and start communication

Figure 14. Green "GO" button placed in top left-hand corner

4. If the communication is established successfully, the FreeMASTER communication status in the bottom right-hand corner changes from "Not connected" to "RS232 UART Communication; COMxx; speed=115200". Otherwise, the FreeMASTER warning popup window appears.

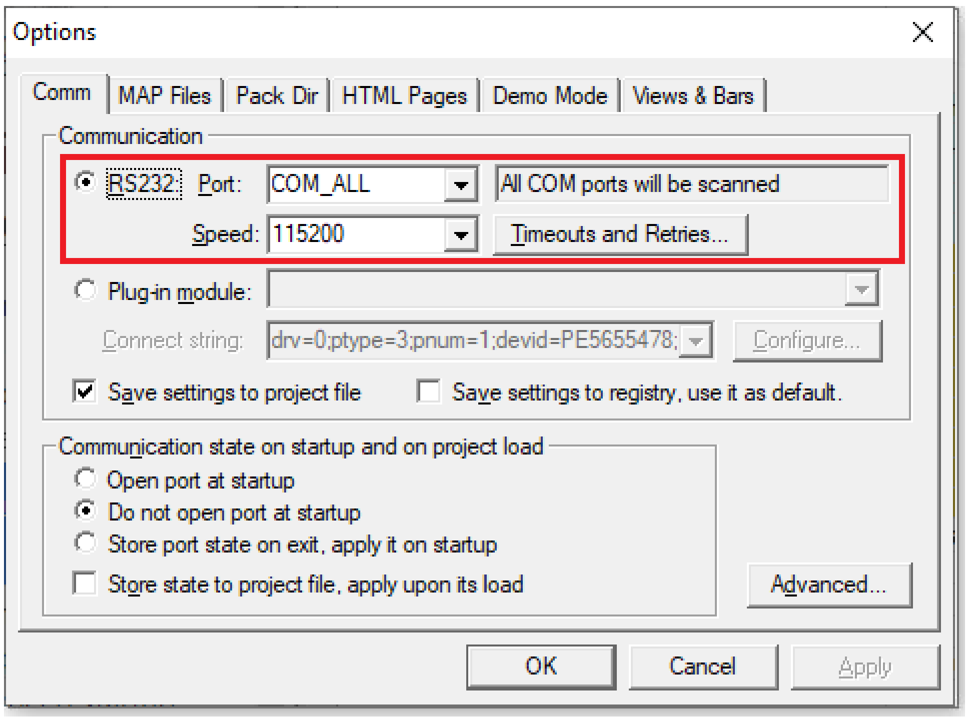
RS232 UART Communication; COM5; speed=115200

Figure 15. FreeMASTER—communication is established successfully

5. Press *F5* to reload the MCAT HTML page and check the App ID.
6. Control the PMSM motor by writing to a control variables in a variable watch.
7. If you rebuild and download the new code to the target, turn the FreeMASTER application off and on.

If the communication is not established successfully, perform the following steps:

1. Go to the "Project -> Options -> Comm" tab and make sure that the correct COM port is selected and the communication speed is set to 115200 bps.


Options

Comm | MAP Files | Pack Dir | HTML Pages | Demo Mode | Views & Bars

Communication

[✓ RS232] Port: COM_ALL — All COM ports will be scanned

Speed: 115200 — Timeouts and Retries...

Plug-in module:

Connect string: drv=0;ptype=3;pnum=1;devid=PE5655478;

Configure...

[✓ Save settings to project file] Save settings to registry, use it as default.

Communication state on startup and on project load

Open port at startup [✓ Do not open port at startup] Store port state on exit, apply it on startup

Store state to project file, apply upon its load

Advanced...

OK | Cancel | Apply

Figure 16. FreeMASTER communication setup window

2. Ensure, that your computer is communicating with the plugged board. Unplug and then plug in the USB cable and reopen the FreeMASTER project.

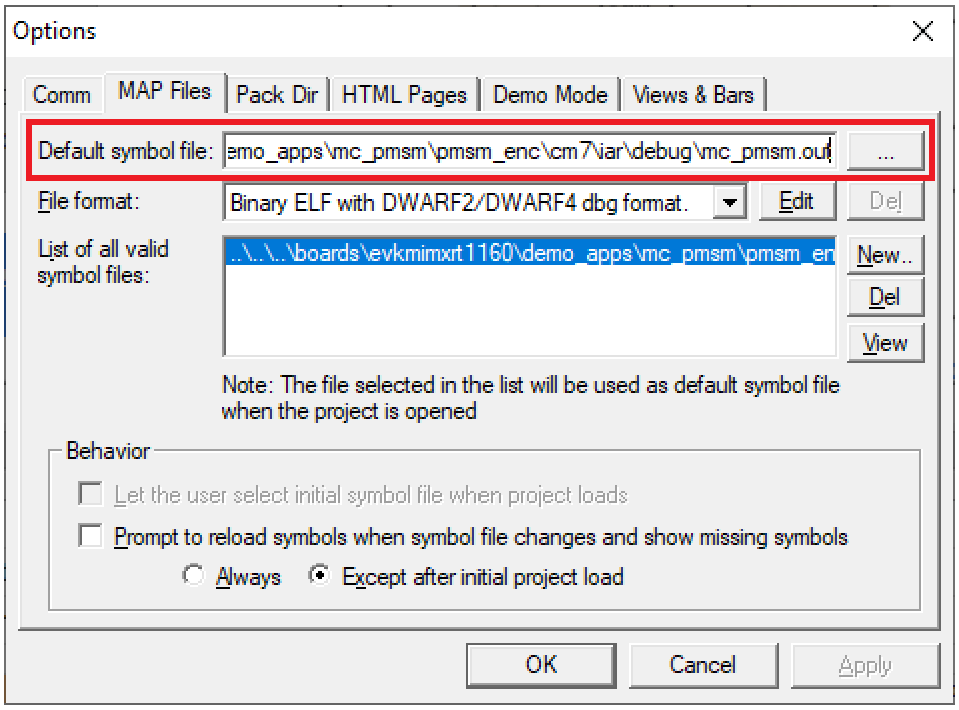
## 8.2 TSA replacement with ELF file

The Freemaster project for motor control example uses Target-Side Addressing (TSA) information about variable objects and types to be retrieved from the target application by default. With the TSA feature, you can describe the data types and variables directly in the application source code and make this information available to the FreeMASTER tool. The tool can then use this information instead of reading symbol data from the application's ELF/Dwarf executable file.

FreeMASTER reads the TSA tables and uses the information automatically when an MCU board is connected. A great benefit of using the TSA are no issues with correct path to ELF/Dwarf file. The variables described by TSA tables may be read-only, so even if FreeMASTER attempts to write the variable, the value is actively denied by the target MCU side. The variables not described by any TSA tables may also become invisible and protected even for read-only access.

The use of TSA means more memory requirements for the target. If you don't want to use the TSA feature, you need to modify the example code and Freemaster project. Follow these steps:

- Open motor control project and rewrite macro FMSTR_USE_TSA from 1 to 0 in freemaster_cfg.h file.
- Build, download and run motor control project
- Open FreeMASTER project and click to Project → Options (or use shortcut Ctrl+T)
- Click to MAP Files tab and find Default symbol file (ELF/Dwarf executable file) located in IDE Output folder



Default symbol file: emo_apps\mc_pmsm\pmsm_enc\cm7\iar\debug\mc_pmsm.out

File format: Binary ELF with DWARF2/DWARF4 dbg format.

List of all valid symbol files: ..\..\..\boards\evkmimxrt1160\demo_apps\mc_pmsm\pmsm_en

Note: The file selected in the list will be used as default symbol file when the project is opened

Behavior

- [ ] Let the user select initial symbol file when project loads
- [ ] Prompt to reload symbols when symbol file changes and show missing symbols

Always [✓ Except after initial project load]

Figure 17. Default symbol file

- Click to OK and restart FreeMASTER communication.

For more information check FreeMASTER User Guide

## 8.3 MCAT FreeMASTER interface (Motor Control Application Tuning)

The PMSM sensor/sensorless FOC application can be easily controlled and tuned using the Motor Control Application Tuning (MCAT) plug-in for PMSM. The MCAT for PMSM is a user-friendly page, which runs within FreeMASTER. The tool consists of the tab menu, and workspace shown in Figure 18. Each tab from the tab menu represents one sub-module which enables tuning or control different aspects of the application. Besides the MCAT page for PMSM, several scopes, recorders, and variables in the project tree are predefined in the FreeMASTER project file to further simplify the motor parameter tuning and debugging.

When the FreeMASTER is not connected to the target, the “Board found” line (2) shows “Board ID not found”. When the communication with the target MCU is established, the “Board found” line is read from *Board ID* variable watch and displayed. If the connection is established and the board ID is not shown, press *F5* to reload the MCAT HTML page.

There are three action buttons in MCAT(3):

- **Load data** - MCAT input fields (e.g. motor parameters) are loaded from mX_pmsm_appconfig.h file (JSON formatted comments). Only existing mX_pmsm_appconfig.h files can be selected for loading. Actually loaded mX_pmsm_appcofig.h file is displayed in grey field (7).
- **Save data** - MCAT input fields (JSON formatted comments) and output macros are saved to mX_pmsm_appconfig.h file. Up to 9 files (m1-9_pmsm_appconfig.h) can be selected. A pop up window with user motor ID and description appears when a different mX_pmsm_appcofig.h file is selected. The motor ID and description is also saved in mX_pmsm_appcofig.h in form of JSON comment. At single motor control application the embedded code #includes m1_pmsm_appcofig.h only. Therefore, saving to higher indexed mX_pmsm_appcofig.h files has no effect at compilation stage.
- **Update target** - writes the MCAT calculated tuning parameters to FreeMASTER Variables which effectively updates the values on target MCU. These tuning parameters are updated in MCU's RAM memory. To write these tuning parameters to MCU's flash memory, m1_pmsm_appcofig.h must be saved, code re-compiled and downloaded to MCU.

NOTE

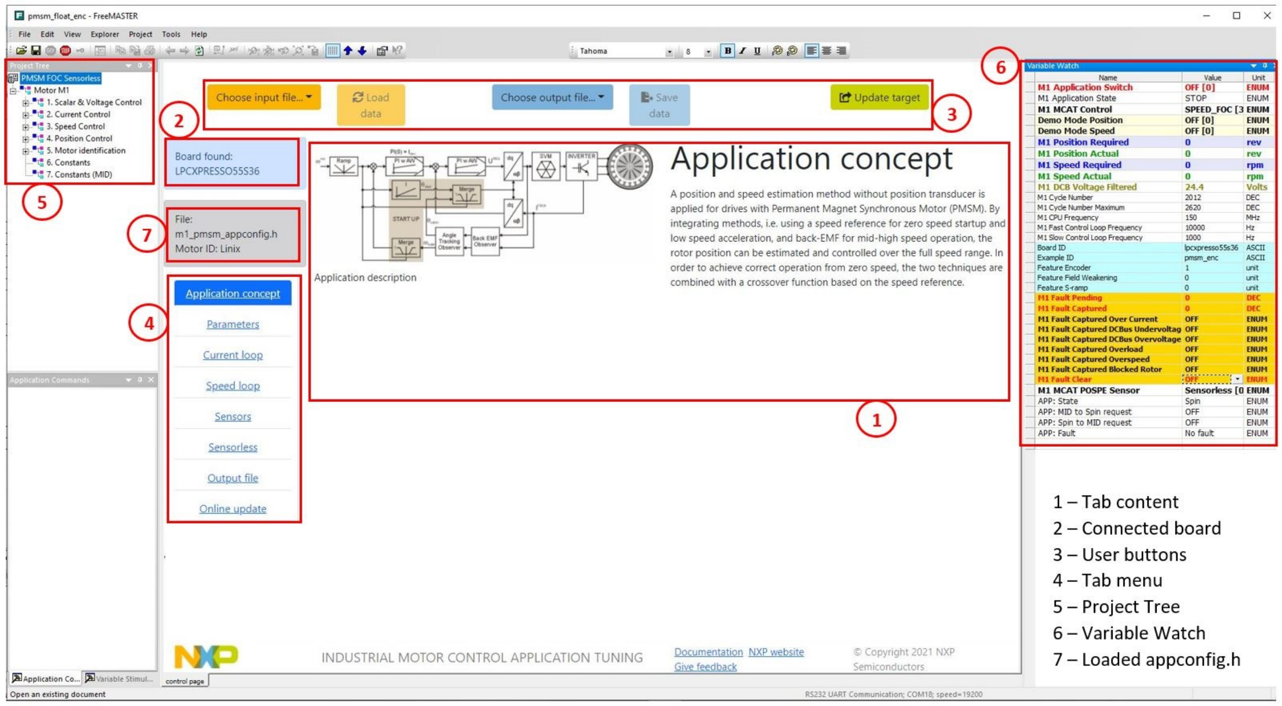
Path to mX_pmsm_appcofig.h file composes also from *Board ID* value. Therefore, FreeMASTER must be connected to target and *Board ID* value read prior using Save/Load buttons.

NOTE

Only **Update target** button updates values on target in real-time. Load/Save buttons operate with mX_pmsm_appcofig.h file only.

NOTE

MCAT may require internet connection. If no internet connection is available, CSS and icons may not be properly loaded.



Application concept

A position and speed estimation method without position transducer is applied for drives with Permanent Magnet Synchronous Motor (PMSM). By integrating methods, i.e. using a speed reference for zero speed startup and low speed acceleration, and back-EMF for mid-high speed operation, the rotor position can be estimated and controlled over the full speed range. In order to achieve correct operation from zero speed, the two techniques are combined with a crossover function based on the speed reference.

Variable Watch

| Name | Value | Unit |
|---|---|---|
| M1 Application Switch | OFF [0] | ENUM |
| M1 Application State | STOP | ENUM |
| M1 MCAT Control | SPEED_FOC [3 | ENUM |
| Demo Mode Position | OFF [0] | ENUM |
| Demo Mode Speed | OFF [0] | ENUM |
| M1 Position Required | 0 | rev |
| M1 Position Actual | 0 | rev |
| M1 Speed Required | 0 | rpm |
| M1 Speed Actual | 0 | rpm |
| M1 DCB Voltage Filtered | 24.4 | Volts |
| M1 Cycle Number | 2012 | DEC |
| M1 Cycle Number Maximum | 2620 | DEC |
| M1 CPU Frequency | 150 | MHz |
| M1 Fast Control Loop Frequency | 10000 | Hz |
| M1 Slow Control Loop Frequency | 1000 | Hz |
| Board ID | lpcxpresso55s36 | ASCII |
| Example ID | pmsm_enc | ASCII |
| Feature Encoder | 1 | unit |
| Feature Field Weakening | 0 | unit |
| Feature S-ramp | 0 | unit |
| M1 Fault Pending | 0 | DEC |
| M1 Fault Captured | 0 | DEC |
| M1 Fault Captured Over Current | OFF | ENUM |
| M1 Fault Captured DCBus Undervoltag | OFF | ENUM |
| M1 Fault Captured DCBus Overvoltage | OFF | ENUM |
| M1 Fault Captured Overload | OFF | ENUM |
| M1 Fault Captured Overspeed | OFF | ENUM |
| M1 Fault Captured Blocked Rotor | OFF | ENUM |
| M1 Fault Clear | OFF | ENUM |
| M1 MCAT POSPE Sensor | Sensorless [0 | ENUM |
| APP: State | Spin | ENUM |
| APP: MID to Spin request | OFF | ENUM |
| APP: Spin to MID request | OFF | ENUM |
| APP: Fault | No fault | ENUM |

1 – Tab content
2 – Connected board
3 – User buttons
4 – Tab menu
5 – Project Tree
6 – Variable Watch
7 – Loaded appconfig.h

Figure 18. FreeMASTER + MCAT layout

In the default configuration, the following tabs are available:

- “Application concept”—welcome page with the PMSM sensor/sensorless FOC diagram and a short description of the application.
- “Parameters”—this page enables you to modify the motor parameters, specification of hardware and application scales, alignment, and fault limits.
- “Current loop”—current loop PI controller gains and output limits.
- “Speed loop”—this tab contains fields for the specification of the speed controller proportional and integral gains, as well as the output limits and parameters of the speed ramp. The position proportional controller constant is also set here.
- “Sensors”—this page contains the encoder parameters and position observer parameters. Not available for all devices.
- “Sensorless”—this page enables you to tune the parameters of the BEMF observer, tracking observer, and open-loop startup.
- “Output file”—this tab shows all the calculated constants that are required by the PMSM sensor/sensorless FOC application. It is also possible to generate the *m1_pmsm_appconfig.h* file, which is then used to preset all application parameters permanently at the project rebuild.

- "Online update" — this tab shows actual values of variables on target and new calculated values, which can be used for update variables on the target.

The following sections provide simple instructions on how to identify the parameters of a connected PMSM motor and how to appropriately tune the application.

### 8.3.1 MCAT tabs' description

This chapter describes MCAT input parameres and equations used to calculate MCAT output (generated) parameters. In the default configuration, the below described tabs are available. Some tabs may be missing if not supported in the embedded code. There are general constants used at MCAT calutations listed in the following table:

Table 8. Constants used in equations

| Constant | Value | Unit |
|---|---|---|
| UmaxCoeff | 1.73205 | - |
| DiscMethodFactor | 1 | - |
| k_factor | 100 | - |
| pi | 3.1416 | - |

#### Application concept

This tab is a welcome page with the PMSM sensor/sensorless FOC diagram and a short description of the application.

#### Parameters

This tab enables modification of motor parameters, specification of hardware and application scales, alignment, and fault limits. All inputs are described in the following table. *MCAT group* and *MCAT name* helps to locate the parameter in MCAT layout. *Equation name* represents the input parameter in equations bellow.

Table 9. Parameters tab inputs

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| Motor parameters | PP | Pp | Motor number of pole-pairs. Obtain from motor manufacturer or use the pole-pair assitant to determine and then fill manually. | - |
| | Rs | Rs | Stator phase resistance. Obtain from motor manufacturer or use the electrical parameters identification and then fill manually. | [Ω] |
| | Ld | Ld | Stator direct inductance. Obtain from motor manufacturer or use the electrical parameters identification and then fill manually. | [H] |
| | Lq | Lq | Stator quadrature inductance. Obtain from motor manufacturer or use the electrical parameters identification and then fill manually. | [H] |

*Table continues on the next page...*

Table 9. Parameters tab inputs (continued)

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| | Ke | Ke | Motor electrical constant. Obtain from motor manufacturer or use the Ke identification and then fill manually. | [V.sec/rad] |
| | J | J | Drive inertia (motor + plant). Use the mechanical identification and then fill manually. | [kg.m2] |
| | Iph nom | IphNom | Nominal motor current. Obtain from motor manufacturer. | [A] |
| | Uph nom | UphNom | Nominal motor voltage. Obtain from motor manufacturer. | [V] |
| | N nom | Nnom | Nominal motor speed. Obtain from motor manufacturer. | [rpm] |
| Hardware scales | I max | Imax | Current sensing HW scale. Keep as-is in case of standard NXP HW or recalculate accoording to own schematic. | [A] |
| | U DCB max | UdcbMax | DCBus voltage sensing HW scale. Keep as-is in case of standard NXP HW or recalculate accoording to own schematic. | [V] |
| Fault limits | U DCB trip | UdcbTrip | DCBus braking resistor threshold. Braking resistor's transitor is turned on when DCbus voltage exceeds this threshold. | [V] |
| | U DCB under | UdcbUnder | DCBus under voltage fault threshold | [V] |
| | U DCB over | UdcbOver | DCBus over voltage fault threshold | [V] |
| | N over | Nover | Over speed fault threshold | [rpm] |
| | N min | Nmin | Minimal closed loop speed. When the required speed ramps down under this threshold the motor control state machine goes to freewheel state where top and bottom transistors are turned off and motor speeds down freely. Applies only for sensorless operation. | [rpm] |

*Table continues on the next page...*

Table 9. Parameters tab inputs (continued)

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| | E block | Eblock | Blocked rotor detection. When Bemf voltage drops under *E block* threshold for more than *E block per* (fast loop ticks), the blocked rotor fault is detected. | [V] |
| | E block per | EblockPer | | - |
| Application scales | N max | Nmax | Application speed scale. Keep about 10% margin above *N over*. | [rpm] |
| | U DCB IIR F0 | UdcbIIRf0 | Cut-off frequency of DCBus IIR filter | [Hz] |
| | Calibration duration | CalibDuration | ADC (phase current offset) calibration duration. Done every time transitioning from STOP to RUN. | [sec] |
| | Fault duration | FaultDuration | After fault condition disappeares wait defined time to clear pending faults bitfield and transition to STOP state. | [sec] |
| | Freewheel duration | FreewheelDuration | Free-wheel state duration. Freewheel state in entered when ramped speed drops under *N min*. | [sec] |
| | Scalar Uq min | ScalarUqMin | Scalar control voltage minimal value. | [V] |
| Alignment | Align voltage | AlignVoltage | Motor alignment voltage. | [V] |
| | Align duration | AlignDuration | Motor alignment duration. | [sec] |

Output equations (applies for saving to mX_pmsm_appcofig.h and also for updating a corresponding FreeMASTER variables):

M1_U_MAX = UdcbMax / UmaxCoeff;

M1_FREQ_MAX = Nmax / 60 * Pp;

M1_ALIGN_DURATION = AlignDuration / speedLoopSampleTime;

M1_CALIB_DURATION = CalibDuration / speedLoopSampleTime;

M1_FAULT_DURATION = FaultDuration / speedLoopSampleTime;

M1_FREEWHEEL_DURATION = FreewheelDuration / speedLoopSampleTime;

M1_E_BLOCK_PER = EblockPer;

M1_SPEED_ANGULAR_SCALE = 60 / (Pp * 2 * pi);

M1_N_MIN = Nmin / 60 * (Pp * 2 * pi);

M1_N_MAX = Nmax / 60 * (Pp * 2 * pi);

M1_N_ANGULAR_MAX = (60 / (Pp * 2 * pi));

M1_N_NOM = Nnom / 60 * (Pp * 2 * pi);

M1_N_OVERSPEED = Nover / 60 * (Pp * 2 * pi);

M1_UDCB_IIR_B0 = (2 * pi * UdcbIIRf0 * currentLoopSampleTime) / (2 + (2 * pi * UdcbIIRf0 * currentLoopSampleTime));

M1_UDCB_IIR_B1 = (2 * pi * UdcbIIRf0 * currentLoopSampleTime) / (2 + (2 * pi * UdcbIIRf0 * currentLoopSampleTime));

M1_UDCB_IIR_A1 = -(2 * pi * UdcbIIRf0 * currentLoopSampleTime - 2) / (2 + (2 * pi * UdcbIIRf0 * currentLoopSampleTime));

M1_SCALAR_VHZ_FACTOR_GAIN = UphNom*k_factor/100/(Nnom*Pp/60);

M1_SCALAR_INTEG_GAIN = 2*pi*Pp*Nmax/60*currentLoopSampleTime/pi;

M1_SCALAR_RAMP_UP = speedLoopIncUp*currentLoopSampleTime/60*Pp;

M1_SCALAR_RAMP_DOWN = speedLoopIncDown*currentLoopSampleTime/60*Pp;

### Current loop

This tab enables current loop PI controller gains and output limits tuning. All inputs are described in the following table. *MCAT group* and *MCAT name* helps to locate the parameter in MCAT layout. *Equation name* represents the input parameter in equations bellow.

Table 10. Current loop tab input

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| Loop parameters | Sample time | currentLoopSampleTime | Fast control loop period. This disabled value is read from target via FreeMASTER because application timing is set in embedded code by peripherals setting. This value is accesible only if target is not connected and value cannot be obtained from target. | [sec] |
| | F0 | currentLoopF0 | Current controller's bandwidth | [Hz] |
| | ξ | currentLoopKsi | Current controller's attenuation | - |
| Current PI controller limits | Output limit | currentLoopOutputLimit | Current controllers' output voltage limit = Duty cycle limit. Be careful setting this limit above 95% because it affects current sensing (Some minimal bottom transistors on time is required). | [%] |

Output equations (applies for saving to mX_pmsm_appcofig.h and also for updating a corresponding FreeMASTER variables):

M1_CLOOP_LIMIT = currentLoopOutputLimit / UmaxCoeff / 100;

M1_D_KP_GAIN = (2 * currentLoopKsi * 2 * pi * currentLoopF0 * Ld) - Rs;

M1_D_KI_GAIN = (2 * pi * currentLoopF0)^2 * Ld * currentLoopSampleTime / DiscMethodFactor;

M1_Q_KP_GAIN = (2 * currentLoopKsi * 2 * pi * currentLoopF0 * Lq) - Rs;

M1_Q_KI_GAIN = (2 * pi * currentLoopF0)^2 * Lq * currentLoopSampleTime / DiscMethodFactor;

### Speed loop

This tab enables speed loop PI controller gains and output limits tuning, required speed ramp parameters, feedback speed filter tuning, and position P controller gain tuning (available at sensored/encoder applications only). *MCAT group* and *MCAT name* helps to locate the parameter in MCAT layout. *Equation name* represents the input parameter in equations bellow.

Table 11.  Speed loop tab input

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| Loop parameters | Sample time | speedLoopSampleTime | Slow control loop period. This disabled value is read from target via FreeMASTER because application timing is set in embedded code by peripherals setting. This value is accesible only if target is not connected and value cannot be obtained from target. | [sec] |
| | F0 | speedLoopF0 | Speed controller's bandwidth | [Hz] |
| | ξ | speedLoopKsi | Speed controller's attenuation | - |
| Speed ramp | Inc up | speedLoopIncUp | Required speed maximal acceleration | [rpm/sec] |
| | Inc down | speedLoopIncDown | Required speed maximal decceleration | [rpm/sec] |
| Actual speed filter | Cut-off freq | speedLoopCutOffFreq | Speed feedback (before entering PI subtraction) filter bandwidth. | [Hz] |
| Speed PI controller limits | Upper limit | speedLoopUpperLimit | Maximal required Q-axis current (Speed controller's output). Q-axis current limitation equals to motor torque limitation. | [A] |
| | Lower limit | speedLoopLowerLimit | Minimal required Q-axis current (Speed controller's output). Q-axis current limitation equals to motor torque limitation. | [A] |
| Position P controller constans | PL_Kp | speedLoopPLKp | Position controller proportional constant in time domain. | |

Output equations (applies for saving to mX_pmsm_appcofig.h and also for updating a corresponding FreeMASTER variables):

varKt = 3 * Ke / (sqrt(3));

M1_SPEED_PI_PROP_GAIN = (2 * pi / 60 * (4 * speedLoopKsi * pi * speedLoopF0) * J / varKt);

M1_SPEED_PI_INTEG_GAIN = (2 * pi / 60 * ((2 * pi * speedLoopF0) * (2 * pi * speedLoopF0) * J) / (varKt * 10) * speedLoopSampleTime);

M1_SPEED_RAMP_UP = (speedLoopIncUp * speedLoopSampleTime / (60 / (Pp * 2 * pi)));

M1_SPEED_RAMP_DOWN = (speedLoopIncDown * speedLoopSampleTime / (60 / (Pp * 2 * pi)));

M1_SPEED_IIR_B0= (2 * pi * speedLoopCutOffFreq * currentLoopSampleTime) / (2 + (2 * pi * speedLoopCutOffFreq * currentLoopSampleTime));

M1_SPEED_IIR_B1 = (2 * pi * speedLoopCutOffFreq * currentLoopSampleTime) / (2 + (2 * pi * speedLoopCutOffFreq * currentLoopSampleTime));

M1_SPEED_IIR_A1 = -(2 * pi * speedLoopCutOffFreq * currentLoopSampleTime - 2) / (2 + (2 * pi * speedLoopCutOffFreq * currentLoopSampleTime));

### Sensors

Available at sensored (encoder) applications only. This tab enables setting the encoder properties and tuning encoder's tracking observer. *MCAT group* and *MCAT name* helps to locate the parameter in MCAT layout. *Equation name* represents the input parameter in equations bellow.

Table 12. Sensors tab input

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| Quadrature encoder | Pulse number | sensorEncPulseNumber | Number of quadrature encoder pulses. Obtain this value from encoder manufacturer OR estimate based on speed/ position comparison of Scalar controlled application with encoder processing running on background. | [pulses] |
| | Direction | sensorEncDir | Encoder direction / Phase A&B order. | - |
| | Minimal speed | sensorEncNmin | Encoder minimal speed. | [rpm] |
| Position observer parameters | Sample time | sensorObsrvParSampleTime | Current control loop sampling period. This disabled value is read from target via FreeMASTER because application timing is set in embedded code by peripherals setting. This value is accesible only if target is not connected and value cannot be obtained from target. | [sec] |
| | F0 | sensorObsrvParF0 | Position observer bandwidth | [Hz] |
| | ξ | sensorObsrvParKsi | Position observer attenuation | - |

Output equations (applies for saving to mX_pmsm_appcofig.h and also for updating a corresponding FreeMASTER variables):

M1_POSPE_KP_GAIN = (4.0 * pi * sensorObsrvParKsi * sensorObsrvParF0);

M1_POSPE_KI_GAIN = ((2*pi*sensorObsrvParF0)^2 * sensorObsrvParSampleTime);

M1_POSPE_INTEG_GAIN = (sensorObsrvParSampleTime / pi / DiscMethodFactor);

M1_POSPE_ENC_N_MIN = sensorEncNmin;

M1_POSPE_MECH_POS_GAIN = (32768/((sensorEncPulseNumber*4)/2));

### Sensorless

This tab enables Bemf observer and Tracking observer parameters tuning and open-loop startup tuning. *MCAT group* and *MCAT name* helps to locate the parameter in MCAT layout. *Equation name* represents the input parameter in equations bellow.

Table 13. Sensorless tab input

| MCAT group | MCAT name | Equation name | Description | Unit |
|---|---|---|---|---|
| BEMF observer parameters | F0 | sensorlessBemfObsrvF0 | BEMF observer bandwidth | [Hz] |
| | ξ | sensorlessBemfObsrvKsi | BEMF observer attenuation | - |
| Tracking observer parameters | F0 | sensorlessTrackObsrvF0 | Tracking observer bandwidth | [Hz] |
| | ξ | sensorlessTrackObsrvKsi | Tracking observer attenuation | - |
| Open loop start-up parameters | Start-up ramp | sensorlessStartupRamp | Open loop startup ramp | [rpm/sec] |
| | Start-up current | sensorlessStartupCurrent | Open loop startup current | [A] |
| | Merging Speed | sensorlessMergingSpeed | Merging speed | [rpm] |
| | Merging Coefficient | sensorlessMergingCoeff | Merging coefficient (100% = merging is done within one electrical revolution) | [%] |

Output equations (applies for saving to mX_pmsm_appcofig.h and also for updating a corresponding FreeMASTER variables):

M1_I_SCALE = (Ld / (Ld + currentLoopSampleTime * Rs));

M1_U_SCALE = (currentLoopSampleTime / (Ld + currentLoopSampleTime * Rs));

M1_E_SCALE = (currentLoopSampleTime / (Ld + currentLoopSampleTime * Rs)) ;

M1_WI_SCALE = (Lq * currentLoopSampleTime / (Ld + currentLoopSampleTime * Rs));

M1_BEMF_DQ_KP_GAIN = ((2 * sensorlessBemfObsrvKsi * 2 * pi * sensorlessBemfObsrvF0 * Ld - Rs));

M1_BEMF_DQ_KI_GAIN = (Ld * (2 * pi * sensorlessBemfObsrvF0)^ 2 * currentLoopSampleTime);

M1_TO_KP_GAIN = 2 * sensorlessTrackObsrvKsi * 2 * pi * sensorlessTrackObsrvF0;

M1_TO_KI_GAIN = ((2 * pi * sensorlessTrackObsrvF0)^ 2) * currentLoopSampleTime;

M1_TO_THETA_GAIN = (currentLoopSampleTime / pi);

M1_OL_START_RAMP_INC = (sensorlessStartupRamp * currentLoopSampleTime / (60 / (Pp * 2 * pi)));

M1_MERG_SPEED_TRH = (sensorlessMergingSpeed / (60 / (Pp * 2 * pi)));

M1_MERG_COEFF = ((sensorlessMergingCoeff / 100) * (60 / (Pp * sensorlessMergingSpeed)) / currentLoopSampleTime / 2 / 32768);

TO_IIR_cutoff_freq = 1 / (2 * speedLoopSampleTime) * 0.8;

M1_TO_SPEED_IIR_B0 = (2 * pi * TO_IIR_cutoff_freq * currentLoopSampleTime) / (2 + (2 * pi * TO_IIR_cutoff_freq * currentLoopSampleTime));

M1_TO_SPEED_IIR_B1 = (2 * pi * TO_IIR_cutoff_freq * currentLoopSampleTime) / (2 + (2 * pi * TO_IIR_cutoff_freq * currentLoopSampleTime));

M1_TO_SPEED_IIR_A1 = -(2 * pi * TO_IIR_cutoff_freq * currentLoopSampleTime - 2) / (2 + (2 * pi * TO_IIR_cutoff_freq * currentLoopSampleTime));

## 8.4 Motor Control Modes

In the "Project Tree" you can choose between the scalar control and the FOC control using the appropriate FreeMASTER tabs. The application can be controlled through the FreeMASTER variables watch which correspond to the control structure selected in FreeMASTER project tree. This is useful for application tuning and debugging. Required control structure must be selected in the

"M1 MCAT Control" variable. Then use "M1 Application Switch" variable to turn on or off the application. Set/clear "M1 Application Switch" variable also enables/disables all PWM channels.

Control structure

The scalar control diagram is shown in figure below. It is the simplest type of motor-control techniques. The ratio between the magnitude of the stator voltage and the frequency must be kept at the nominal value. Hence, the control method is sometimes called Volt per Hertz (or V/Hz). The position estimation BEMF observer and tracking observer algorithms (see Sensorless PMSM Field-Oriented Control (document DRM148) for more information) run in the background, even if the estimated position information is not directly used. This is useful for the BEMF observer tuning.

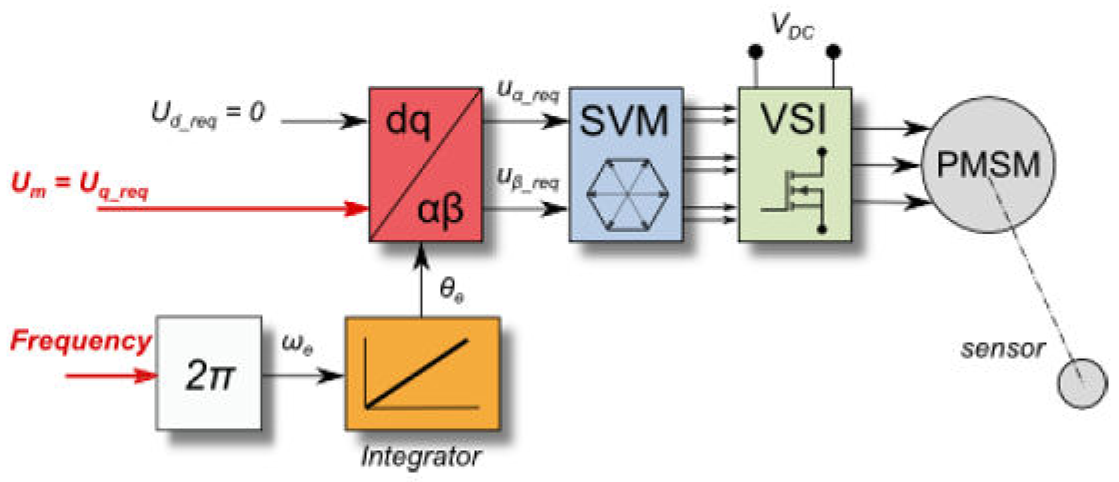


Figure 19. Scalar control mode

The block diagram of the voltage FOC is in figure below. Unlike the scalar control, the position feedback is closed using the BEMF observer and the stator voltage magnitude is not dependent on the motor speed. Both the d-axis and q-axis stator voltages can be specified in the “M1 MCAT Ud Required” and “M1 MCAT Uq Required” fields. This control method is useful for the BEMF observer functionality check.

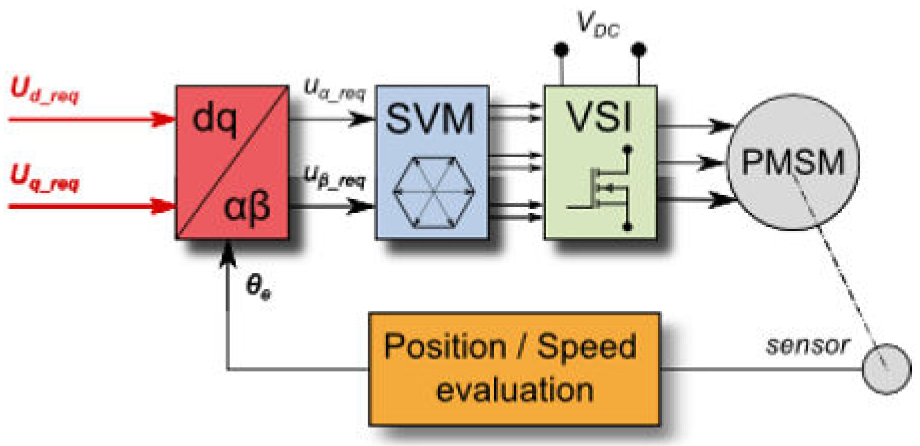


Figure 20. Voltage FOC control mode

The current FOC (or torque) control requires the rotor position feedback and the currents transformed into a d-q reference frame. There are two reference variables (“M1 MCAT Id Required” and “M1 MCAT Iq Required”) available for the motor control, as shown in the block diagram in figure below. The d-axis current component "M1 MCAT Id Required" is responsible for the rotor flux control. The q-axis current component of the current "M1 MCAT Iq Required" generates torque and, by its application, the motor starts running. By changing the polarity of the current "M1 MCAT Iq Required", the motor changes the direction of rotation. Supposing that the BEMF observer is tuned correctly, the current PI controllers can be tuned using the current FOC control structure.

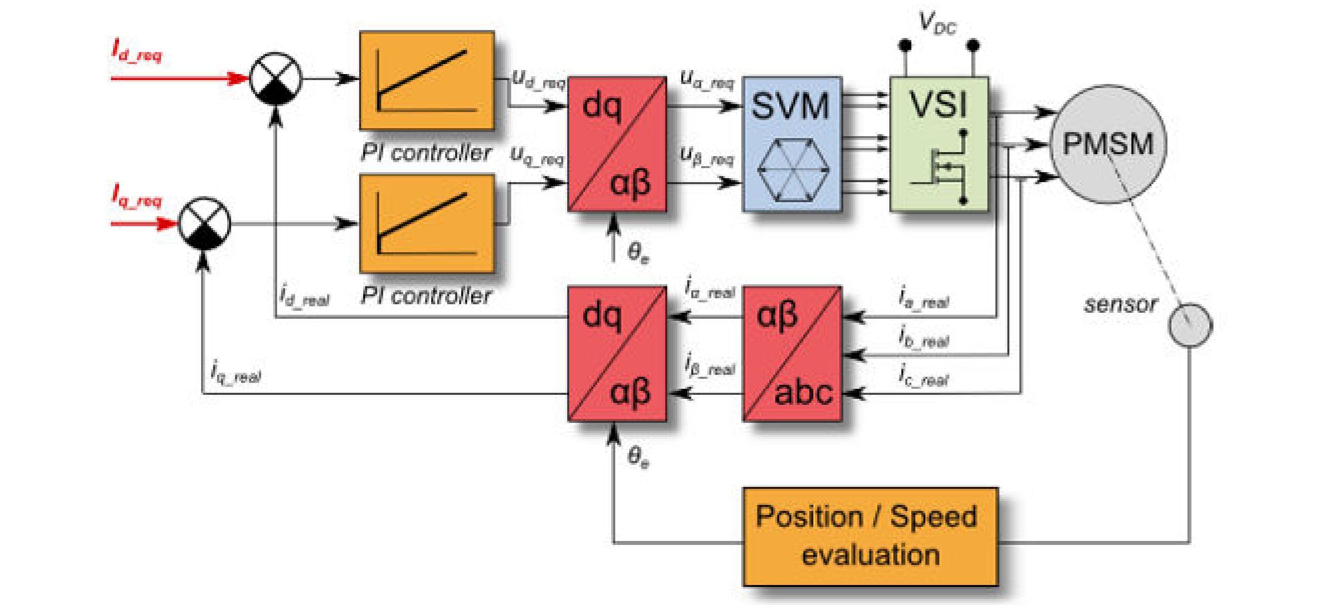


Figure 21. Current (torque) control mode

The speed PMSM sensor/sensorless FOC (its diagram is shown in figure below) is activated by enabling the speed FOC control structure. Enter the required speed into the “M1 Speed Required” field. The d-axis current reference is held at 0 during the entire FOC operation.

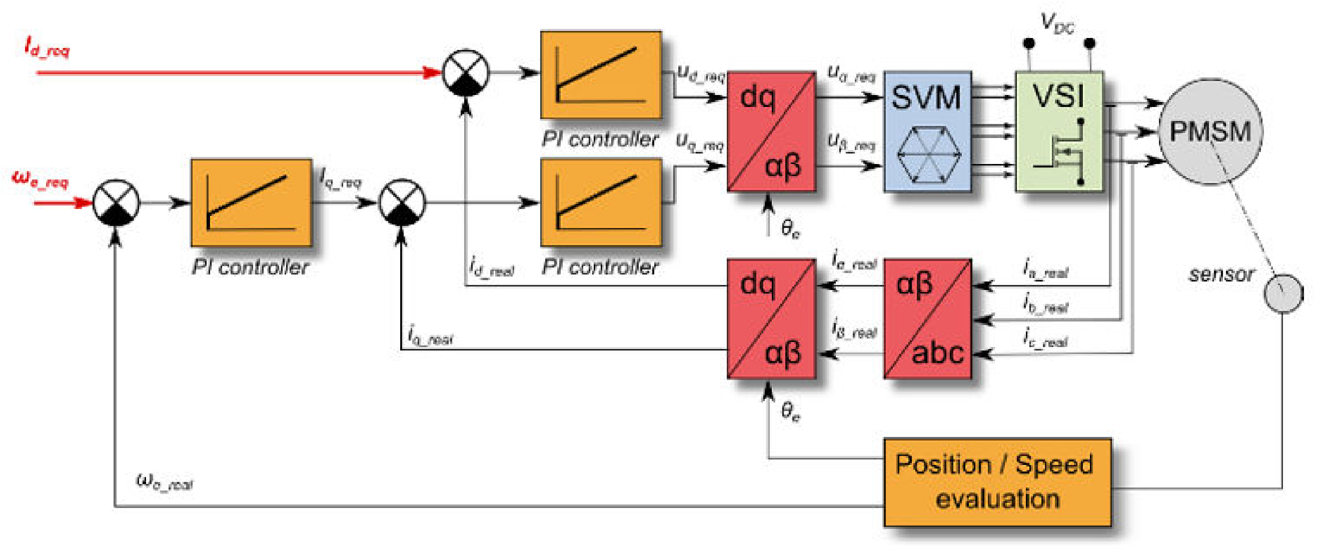


Figure 22. Speed FOC control mode

The position PMSM sensor FOC is shown in figure below (available for sensored/encoder based applications only). The position control using the P controller can be tuned in the “Speed loop” menu tab. An encoder sensor is required for the feedback. Without the sensor, the position control does not work. A braking resistor is missing on the FRDM-MC-LVPMSM board. Therefore, it is needed to set a soft speed ramp (in the “Speed loop” menu tab) because the voltage on the DC-bus can rise when braking the quickly spinning shaft. It may cause the overvoltage fault.

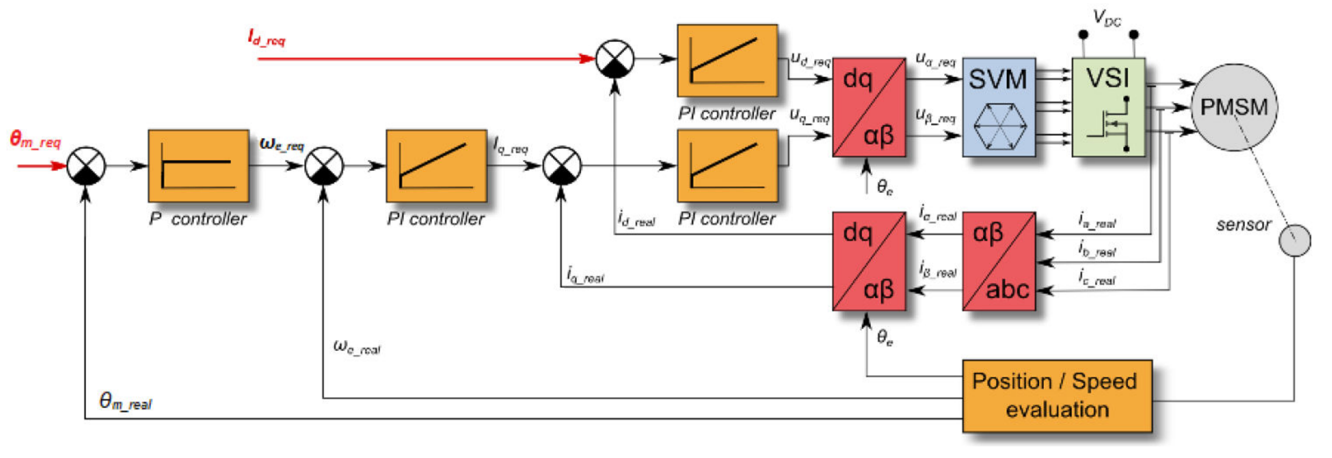


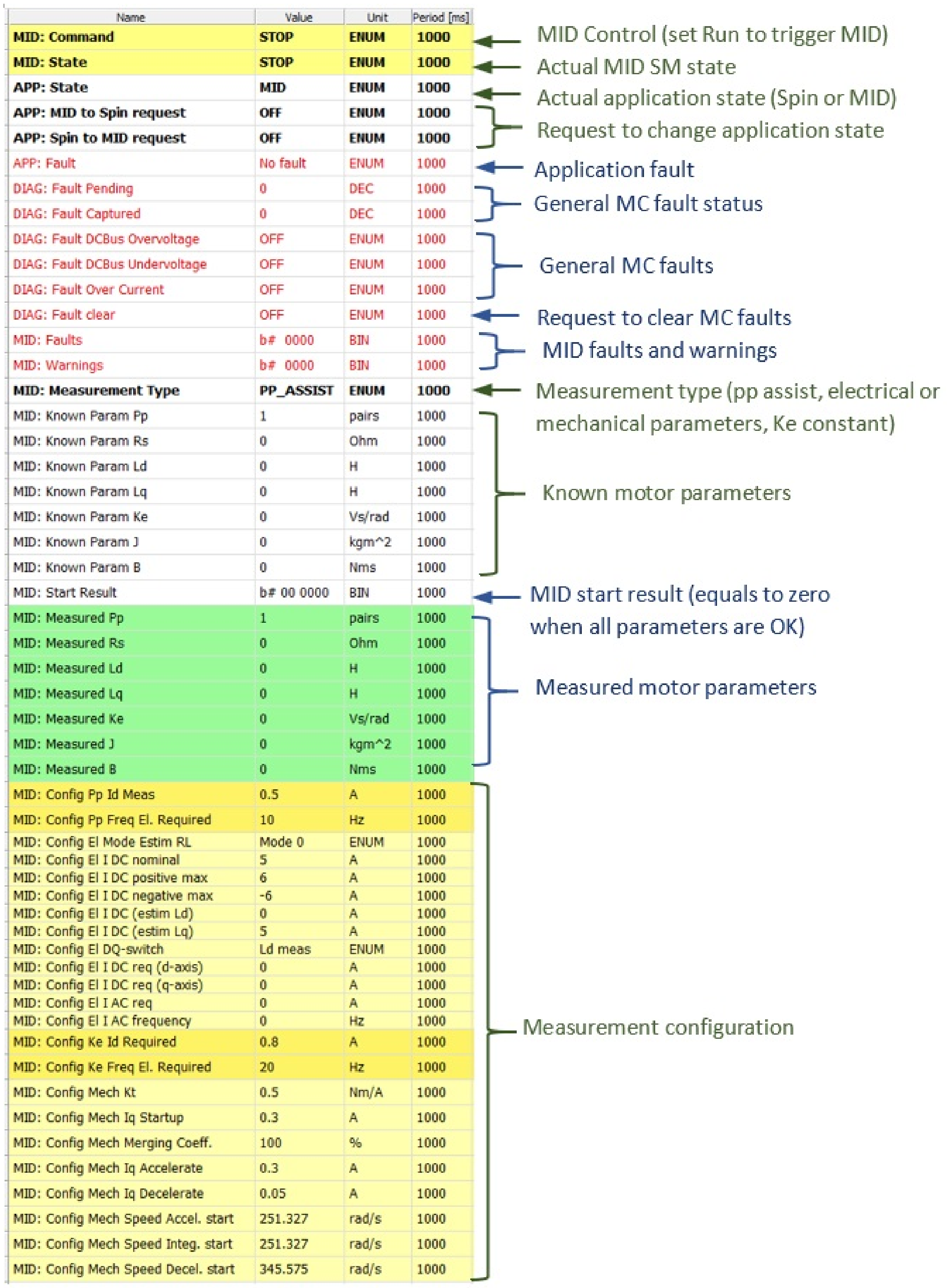
Figure 23. Position FOC control mode

## 8.5 Switch between Spin and MID

User can switch between two main modes of application: *Spin* and *MID* (Motor identification). *Spin* is for control PMSM (see MCAT FreeMASTER interface (Motor Control Application Tuning)). *MID* is for motor parameters identification (see Motor parameter identification using MID). Actual mode of application is shown in *APP: State* variable watch. The mode change can be made by *APP: MID to Spin request* or *APP: Spin to MID request* variables watch. The result of the change mode request shows *APP: Fault* variable watch. *MID fault* occurs when parameters identification still runs or MID state machine is in the fault state. *Spin fault* occurs when *M1 Application switch* variable watch is ON or *M1 Application state* variable watch is not STOP.

## 8.6 Identifying parameters of user motor

Because the model-based control methods of the PMSM drives provide high performance (e.g. dynamic response, efficiency), obtaining an accurate model of a motor is an important part of the drive design and control. For the implemented FOC algorithms, it is necessary to know the value of the stator resistance $R_s$, direct inductance $L_d$, quadrature inductance $L_q$, and BEMF constant $K_e$. Unless the default PMSM motor described above is used, the motor parameter identification is the first step in the application tuning. This section shows how to identify user motor parameters using MID. MID is written in floating-point arithmetics. Each MID algorithm is described in detail in MID algorithms. MID is controlled via the FreeMASTER "Motor Identification" page shown in Figure 24.



| Name | Value | Unit | Period [ms] |
|---|---|---|---|
| **MID: Command** | **STOP** | **ENUM** | **1000** |
| **MID: State** | **STOP** | **ENUM** | **1000** |
| **APP: State** | **MID** | **ENUM** | **1000** |
| **APP: MID to Spin request** | **OFF** | **ENUM** | **1000** |
| **APP: Spin to MID request** | **OFF** | **ENUM** | **1000** |
| APP: Fault | No fault | ENUM | 1000 |
| DIAG: Fault Pending | 0 | DEC | 1000 |
| DIAG: Fault Captured | 0 | DEC | 1000 |
| DIAG: Fault DCBus Overvoltage | OFF | ENUM | 1000 |
| DIAG: Fault DCBus Undervoltage | OFF | ENUM | 1000 |
| DIAG: Fault Over Current | OFF | ENUM | 1000 |
| DIAG: Fault clear | OFF | ENUM | 1000 |
| MID: Faults | b# 0000 | BIN | 1000 |
| MID: Warnings | b# 0000 | BIN | 1000 |
| **MID: Measurement Type** | **PP_ASSIST** | **ENUM** | **1000** |
| MID: Known Param Pp | 1 | pairs | 1000 |
| MID: Known Param Rs | 0 | Ohm | 1000 |
| MID: Known Param Ld | 0 | H | 1000 |
| MID: Known Param Lq | 0 | H | 1000 |
| MID: Known Param Ke | 0 | Vs/rad | 1000 |
| MID: Known Param J | 0 | kgm^2 | 1000 |
| MID: Known Param B | 0 | Nms | 1000 |
| MID: Start Result | b# 00 0000 | BIN | 1000 |
| MID: Measured Pp | 1 | pairs | 1000 |
| MID: Measured Rs | 0 | Ohm | 1000 |
| MID: Measured Ld | 0 | H | 1000 |
| MID: Measured Lq | 0 | H | 1000 |
| MID: Measured Ke | 0 | Vs/rad | 1000 |
| MID: Measured J | 0 | kgm^2 | 1000 |
| MID: Measured B | 0 | Nms | 1000 |
| MID: Config Pp Id Meas | 0.5 | A | 1000 |
| MID: Config Pp Freq El. Required | 10 | Hz | 1000 |
| MID: Config El Mode Estim RL | Mode 0 | ENUM | 1000 |
| MID: Config El I DC nominal | 5 | A | 1000 |
| MID: Config El I DC positive max | 6 | A | 1000 |
| MID: Config El I DC negative max | -6 | A | 1000 |
| MID: Config El I DC (estim Ld) | 0 | A | 1000 |
| MID: Config El I DC (estim Lq) | 5 | A | 1000 |
| MID: Config El DQ-switch | Ld meas | ENUM | 1000 |
| MID: Config El I DC req (d-axis) | 0 | A | 1000 |
| MID: Config El I DC req (q-axis) | 0 | A | 1000 |
| MID: Config El I AC req | 0 | A | 1000 |
| MID: Config El I AC frequency | 0 | Hz | 1000 |
| MID: Config Ke Id Required | 0.8 | A | 1000 |
| MID: Config Ke Freq El. Required | 20 | Hz | 1000 |
| MID: Config Mech Kt | 0.5 | Nm/A | 1000 |
| MID: Config Mech Iq Startup | 0.3 | A | 1000 |
| MID: Config Mech Merging Coeff. | 100 | % | 1000 |
| MID: Config Mech Iq Accelerate | 0.3 | A | 1000 |
| MID: Config Mech Iq Decelerate | 0.05 | A | 1000 |
| MID: Config Mech Speed Accel. start | 251.327 | rad/s | 1000 |
| MID: Config Mech Speed Integ. start | 251.327 | rad/s | 1000 |
| MID: Config Mech Speed Decel. start | 345.575 | rad/s | 1000 |

MID Control (set Run to trigger MID)
Actual MID SM state
Actual application state (Spin or MID)
Request to change application state
Application fault
General MC fault status
General MC faults
Request to clear MC faults
MID faults and warnings
Measurement type (pp assist, electrical or mechanical parameters, Ke constant)
Known motor parameters
MID start result (equals to zero when all parameters are OK)
Measured motor parameters
Measurement configuration

Figure 24. MID FreeMASTER control

### Motor parameter identification using MID

The whole MID is controlled via the FreeMASTER "Variable Watch". Motor Identification (MID) sub-block shown in Figure 24. The motor parameter identification workflow is following:

1. Set the *MID: Command* variable to STOP.
2. Select the measurement type you want to perform via the *MID: Measurement Type* variable:
   - PP_ASSIST - Pole-pair identification assistant.
   - EL_PARAMS - Electrical parameters measurement.
   - Ke - BEMF constant measurement.
   - MECH_PARAMS - Mechanical parameters measurement.
3. Insert the known motor parameters via the *MID: Known Param* set of variables. All parameters with a non-zero known value are used instead of measured parameters (if necessary).
4. Set the measurement configuration paramers in the *MID: Config* set of variables.
5. Start the measurement by setting *MID: Command* to RUN.
6. Observe the *MID Start Result* variable for the MID measurement plan validity (see Table 16) and the actual *MID: State*, *MID: Faults* (see Table 14), and *MID: Warnings* (see Table 15) variables.
7. If the measurement finishes successfully, the measured motor parameters are shown in the *MID: Measured* set of variables and *MID: State* goes to STOP.

### MID faults and warnings

The MID faults and warnings are saved in the format of masks in the *MID: Faults* and *MID: Warnings* variables. Faults and warnings are cleared automatically when starting a new measurement. If a MID fault appears, the measurement process immeadiately stops and brings the MID state machine safely to the STOP state. If a MID warning appears, the measurement process continues. Warnings report minor issues during the measurement process. See Table 14 and Table 15 for more details on individual faults and warnings.

Table 14. Measurement faults

| Fault mask | Fault description | Fault reason | Troubleshooting |
|---|---|---|---|
| b#0001 | Electrical parameters measurement fault. | Some required value cannot be reached or wrong measurement configuration. | Check whether measurement configuration is valid. |
| b#0010 | Mechanical measurement timeout. | Some part of the mechanical measurement (acceleartion, deceleration) took too long and exceeded 10 seconds. | Raise the *MID: Config Mech Iq Accelerate* or lower the *MID: Config Mech Iq Decelerate*. |

Table 15. Measurement warnings

| Warning mask | Warning description | Warning reason | Troubleshooting |
|---|---|---|---|
| b#0001 | $K_e$ is out of range. | The measured $K_e$ is negative. | Visualy check whether the motor was spinning properly during the $K_e$ measurement. |

The MID measurement plan is checked after starting the measurement process. If a necessary parameter is not scheduled for the measurement and not set manually, the MID is not started and an error is reported via the *MID: Start Result* variable.

Table 16. MID Start Result variable

| MID Start Result mask | Description | Troubleshooting |
|---|---|---|
| b#00 0001 | Error during initialization electrical parameters measurement. | Check whether inputs to the *MCAA_EstimRLInit_FLT* are valid. |
| b#00 0010 | The $R_s$ value is missing. | Schedule electrical measurement or enter $R_s$ value manually. |
| b#00 0100 | The $L_d$ value is missing. | Schedule electrical measurement or enter $L_d$ value manually. |
| b#00 1000 | The $L_q$ value is missing. | Schedule electrical measurement or enter $L_q$ value manually. |
| b#01 0000 | The $K_e$ value is missing. | Schedule $K_e$ for measurement or enter its value manually. |
| b#10 0000 | The *Pp* value is missing. | Enter the *Pp* value manually. |

## 8.7 MID algorithms

This section describes how each MID algorithm works.

### Stator resistance measurement

The stator resistance $R_s$ is averaged from the DC steps, which are generated by the algorithm. The DC step levels are automatically derived from the currents inserted by user. For more details, please, refer to the documentation of *AMCLIB_EstimRL* function from AMMCLib.

### Stator inductances measurement

Injection of the AC/DC currents is used for the inductances ($L_d$, $L_q$) estimation. Injected AC/DC currents are automatically derived from the currents inserted by user. The default AC current frequency is 500 Hz. For more detail, please, refer to the documentation of *AMCLIB_EstimRL* function from AMMCLib.

### BEMF constant measurement

Before the actual BEMF constant $K_e$ measurement, the BEMF and Tracking observers parameters are recalculated from the previously measured or manually set $R_s$, $L_d$, and $L_q$ parameters. To measure $K_e$, the motor must spin. During the measurement, the motor is open-loop driven at the user-defined frequency *MID: Config Ke Freq El. Required* with the user-defined current *MID: Config Ke Id Required* value. When the motor reaches the required speed, the BEMF voltages obtained by the BEMF observer are filtered and $K_e$ is calculated:

$$K_e = \frac{U_{BEMF}}{\omega_{el}} \; [\Omega]$$

When $K_e$ is being measured, you have to visually check to determine whether the motor is spinning properly. If the motor is not spinning properly, perform these steps:

- Ensure that the number of *pp* is correct. The required speed for the $K_e$ measurement is also calculated from *pp*. Therefore, inaccuracy in *pp* causes inaccuracy in the resulting $K_e$.
- Increase *MID: Config Ke Id Required* variable to produce higher torque when spinning during the open loop.
- Decrease *MID: Config Ke Freq El. Required* variable to decrease the required speed for the $K_e$ measurement.

### Number of pole-pair assistant

The number of pole-pairs cannot be measured without a position sensor. However, there is a simple assistant to determine the number of pole-pairs (PP_ASSIST). The number of the *pp* assistant performs one electrical revolution, stops for a few seconds, and then repeats. Because the pp value is the ratio between the electrical and mechanical speeds, it can be determined as the number of stops per one mechanical revolution. It is recommended not to count the stops during the first mechanical revolution because the alignment occurs during the first revolution and affects the number of stops. During the PP_ASSIST measurement, the current loop is enabled and the $I_d$ current is controlled to *MID: Config Pp Id Meas*. The electrical position is generated by integrating the open-loop frequency *MID: Config Pp Freq El. Required*. If the rotor does not move after the start of PP_ASSIST assistant, stop the assistant, increase *MID: Config Pp Id Meas*, and restart the assistant.

### Mechanical parameters measurement

The moment of inertia $J$ and the viscous friction $B$ can be identified using a test with the known generated torque $T$ and the loading torque $T_{load}$.

$$\frac{d\omega_m}{dt} = \frac{1}{J}(T - T_{load} - B\omega_m)\ [rad/s^2]$$

The $\omega_m$ character in the equation is the mechanical speed. The mechanical parameter identification software uses the torque profile. The loading torque is (for simplicity reasons) said to be 0 during the whole measurement. Only the friction and the motor-generated torque are considered. During the first phase of measurement, the constant torque $T_{meas}$ is applied and the motor accelerates to 50 % of its nominal speed in time $t_1$. These integrals are calculated during the period from $t_0$ (the speed estimation is accurate enough) to $t_1$:

$$T_{int} = \int_{t_0}^{t_1} T dt\ [Nms] \qquad \omega_{int} = \int_{t_0}^{t_1} \omega_m dt\ [rad/s]$$

During the second phase, the rotor decelerates freely with no generated torque, only by friction. This enables you to simply measure the mechanical time constant $\tau_m = J/B$ as the time in which the rotor decelerates from its original value by 63 %.

The final mechanical parameter estimation can be calculated by integrating:

$$\omega_m(t_1) = \frac{1}{J}T_{int} - \frac{B}{J}\omega_{int} + \omega_m(t_0)\ [rad/s]$$

Te moment of inertia is:

$$J = \frac{\tau_m T_{int}}{\tau_m[\omega_m(t_1) - \omega_m(t_0)] + \omega_{int}}\ [kgm^2]$$

The viscous friction is then derived from the relation between the mechanical time constant and the moment of inertia. To use the mechanical parameters measurement, the current control loop bandwidth $f_{0,Current}$, the speed control loop bandwidth $f_{0,Speed}$, and the mechanical parameters measurement torque $Trq_m$ must be set.

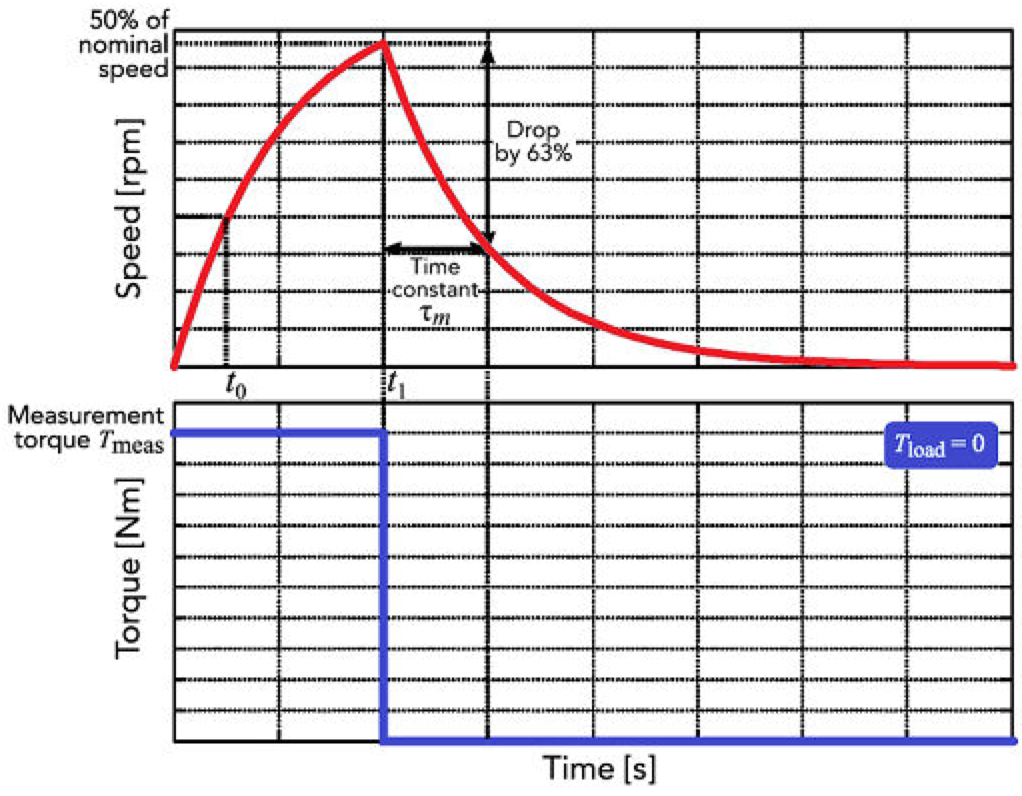


Figure 25. PMSM identification tab

## 8.8 Electrical parameters measurement control

This section describes how to control electrical parameters measurement, which contains measuring stator resistance $R_s$, direct inductance $L_d$ and quadrature inductance $L_q$. There are available 4 modes of measurement which can be selected by *MID: Config El Mode Estim RL* variable.

Function *MCAA_EstimRLInit_FLT* must be called before the first use of *MCAA_EstimRL_FLT*. Function *MCAA_EstimRL_FLT* must be called periodically with sampling period *F_SAMPLING*, which can be definied be user. Maximum sampling frequency *F_SAMPLING* is 10 kHz. In the scopes under "Motor identification" FreeMASTER sub-block can be observed measured currents, estimated parameters etc.

### Mode 0

This mode is automatic, inductances are measured at a single operating point. Rotor is not fixed. User has to specify nominal current (*MID: Config El I DC nominal* variable). The AC and DC currents are automatically derived from the nominal current. Frequency of the AC signal set to default 500 Hz.

The function will output stator resistance $R_s$, direct inductance $L_d$ and quadrature inductance $L_q$.

### Mode 1

DC stepping is automatic at this mode. Rotor is not fixed. Compared to the *Mode 0*, there will be performed an automatic measurement of the inductances for a definied number (*NUM_MEAS*) of different DC current levels using positive values of the DC current. The $L_{dq}$ dependency map can be seen in the "Inductances (Ld, Lq)" recorder. User has to specify following parameters before parameters estimation:

- *MID: Config El I DC (estim Lq)* - Current to determine $L_q$. In most cases nominal current.
- *MID: Config El I DC positive max* - Maximum positive DC current for the $L_{dq}$ dependency map measurement.

Injected AC and DC currents are automatically derived from the *MID: Config EI I DC (estim Lq)* and *MID: Config EI I DC positive max* currents. Frequency of the AC signal set to default 500 Hz.

The function will output stator resistance $R_s$, direct inductance $L_d$ , quadrature inductance $L_q$ and $L_{dq}$ dependency map.

### Mode 2

DC stepping is automatic at this mode. Rotor must be mechanically fixed after initial alignment with the first phase. Compared to the *Mode 1*, there will be performed an automatic measurement of the inductances for a definied number (*NUM_MEAS*) of different DC current levels using both positive and negative values of the DC current. The estimated inductances can be seen in the "Inductances (Ld, Lq)" recorder. User has to specify following parameters before parameters estimation:

- *MID: Config EI I DC (estim Ld)* - Current to determine $L_d$. In most cases 0 A.
- *MID: Config EI I DC (estim Lq)* - Current to determine $L_q$. In most cases nominal current.
- *MID: Config EI I DC positive max* - Maximum positive DC current for the $L_{dq}$ dependency map measurement. In most cases nominal current.
- *MID: Config EI I DC negative max* - Maximum negative DC current for the $L_{dq}$ dependency map measurement.

Injected AC and DC currents are automatically derived from the *MID: Config EI I DC (estim Ld)*, *MID: Config EI I DC (estim Lq)*, *MID: Config EI I DC positive max* and *MID: Config EI I DC negative max* currents. Frequency of the AC signal set to default 500 Hz.

The function will output stator resistance $R_s$, direct inductance $L_d$ , quadrature inductance $L_q$ and $L_{dq}$ dependency map.

### Mode 3

This mode is manual. Rotor must be mechanically fixed after alignment with the first phase. $R_s$ is not calculated at this mode. The estimated inductances can be observed in the "Ld" or "Lq" scopes. The following parameters can be changed during the runtime:

- *MID: Config EI DQ-switch* - Axis switch for AC signal injection (0 for injection AC signal to d-axis, 1 for injection AC signal to q-axis).
- *MID: Config EI I DC req (d-axis)* - Required DC current in d-axis.
- *MID: Config EI I DC req (q-axis)* - Required DC current in q-axis.
- *MID: Config EI I AC req* - Required AC current injected to the d-axis or q-axis.
- *MID: Config EI I AC frequency* - Required frequency of the AC current injected to the d-axis or q-axis.

## 8.9 Initial configuration setting and update

1. Open the PMSM control application FreeMASTER project containing the dedicated MCAT plug-in module.
2. Select the “Parameters” tab.
3. Leave the measured motor parameters or specify the parameters manually. The motor parameters can be obtained from the motor data sheet or using the PMSM parameters measurement procedure described in *PMSM Electrical Parameters Measurement* (document AN4680). All parameters provided in Table 17 are accessible. The motor inertia J expresses the overall system inertia and can be obtained using a mechanical measurement. The J parameter is used to calculate the speed controller constant. However, the manual controller tuning can also be used to calculate this constant.

Table 17. MCAT motor parameters

| Parameter | Units | Description | Typical range |
|---|---|---|---|
| pp | [-] | Motor pole pairs | 1-10 |
| Rs | [Ω] | 1-phase stator resistance | 0.3-50 |
| Ld | [H] | 1-phase direct inductance | 0.00001-0.1 |

*Table continues on the next page...*

Table 17. MCAT motor parameters (continued)

| Parameter | Units | Description | Typical range |
|---|---|---|---|
| Lq | [H] | 1-phase quadrature inductance | 0.00001-0.1 |
| Ke | [V.sec/rad] | BEMF constant | 0.001-1 |
| J | [kg.m$^2$] | System inertia | 0.00001-0.1 |
| Iph nom | [A] | Motor nominal phase current | 0.5-8 |
| Uph nom | [V] | Motor nominal phase voltage | 10-300 |
| N nom | [rpm] | Motor nominal speed | 1000-2000 |

4. Set the hardware scales—the modification of these two fields is not required when a reference to the standard power stage board is used. These scales express the maximum measurable current and voltage analog quantities.
5. Check the fault limits—these fields are calculated using the motor parameters and hardware scales (see Table 18).

Table 18. Fault limits

| Parameter | Units | Description | Typical range |
|---|---|---|---|
| U DCB trip | [V] | Voltage value at which the external braking resistor switch turns on | U DCB Over ~ U DCB max |
| U DCB under | [V] | Trigger value at which the undervoltage fault is detected | 0 ~ U DCB Over |
| U DCB over | [V] | Trigger value at which the overvoltage fault is detected | U DCB Under ~ U max |
| N over | [rpm] | Trigger value at which the overspeed fault is detected | N nom ~ N max |
| N min | [rpm] | Minimal actual speed value for the sensorless control | (0.05~0.2) *N max |

6. Check the application scales—these fields are calculated using the motor parameters and hardware scales.

Table 19. Application scales

| Parameter | Units | Description | Typical range |
|---|---|---|---|
| N max | [rpm] | Speed scale | >1.1 * N nom |
| E block | [V] | BEMF scale | ke* Nmax |
| kt | [Nm/A] | Motor torque constant | - |

7. Check the alignment parameters—these fields are calculated using the motor parameters and hardware scales. The parameters express the required voltage value applied to the motor during the rotor alignment and its duration.
8. Click the “Store data” button to save the modified parameters into the inner file.

## 8.10 Control structure modes

1. Select the scalar control in the "M1 MCAT Control" FreeMASTER variable watch.
2. Set the "M1 Application Switch" variable to "ON". The application state changes to “RUN”.

3. Set the required frequency value in the “M1 Scalar Freq Required” variable; for example, 15 Hz in the “Scalar & Voltage Control” FreeMASTER project tree. The motor starts running.
4. Select the “Phase Currents” recorder from the “Scalar & Voltage Control” FreeMASTER project tree.
5. The optimal ratio for the V/Hz profile can be found by changing the V/Hz factor directly using the “M1 V/Hz factor” variable. The shape of the motor currents should be close to a sinusoidal shape (Figure 26). Use the following equation for calculation V/Hz factor:

$$VHz_{factor} = \frac{U_{phnom} \cdot k_{factor}}{\frac{pp \cdot N_{nom}}{60} \cdot 100} \ [V / Hz]$$

where $U_{phnom}$ is the nominal voltage, $k_{factor}$ is ratio within range 0-100%, $pp$ is the number of pole-pairs and $N_{nom}$ are the nominal revolutions. Changes V/Hz factor won't be propagated to the m1_pmsm_appconfig.h!

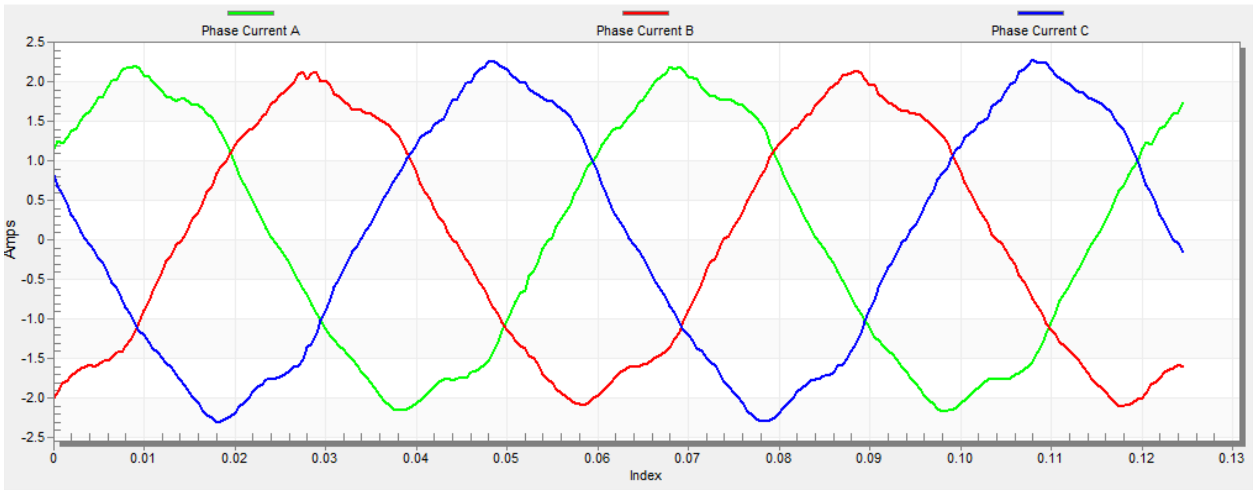


Figure 26. Phase currents

6. Select the “Position” recorder to check the observer functionality. The difference between the “Position Electrical Scalar” and the “Position Estimated” should be minimal (see Figure 27) for the Back-EMF position and speed observer to work properly. The position difference depends on the motor load. The higher the load, the bigger the difference between the positions due to the load angle.

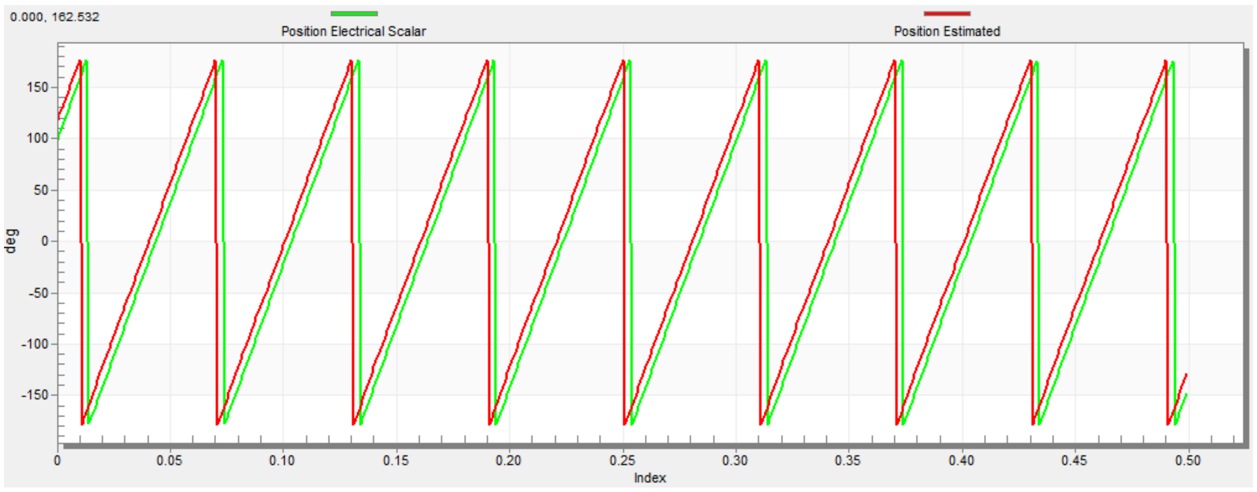


Figure 27. Generated and estimated positions

7. If an opposite speed direction is required, set a negative speed value into the “M1 Scalar Freq Required” variable.
8. The proper observer functionality and the measurement of analog quantities is expected at this step.
9. Enable the voltage FOC mode in the "M1 MCAT Control" variable while the main application switch "M1 Application Switch" is turned off.
10. Switch the main application switch on and set a non-zero value in the “M1 MCAT Uq Required” variable. The FOC algorithm uses the estimated position to run the motor.

## 8.11 Encoder sensor setting

The encoder sensor settings are in the “Sensors” tab. The encoder sensor enables you to compute speed and position for the sensored speed. For a proper encoder counting, set the number of encoder pulses per one revolution and the proper counting direction. The number of encoder pulses is based on information about the encoder from its manufacturer. If the encoder sensor has more pulses per revolution, the speed and position computing is more accurate. The counting direction is provided by connecting the encoder signals to the NXP Freedom board and also by connecting the motor phases. The direction of rotation can be determined as follows:

1. Navigate to the “Scalar & Voltage Control” tab in the project tree and select "SCALAR_CONTROL" in the "M1 MCAT Control" variable.
2. Turn the application switch on. The application state changes to “RUN”.
3. Set the required frequency value in the “M1 Scalar Freq Required” variable; for example 15 Hz. The motor starts running.
4. Check the encoder direction. Select the “Encoder Direction Scope” from the “Scalar & Voltage Control” project tree. If the encoder direction is right, the estimated speed is equal to the measured mechanical speed. If the measured mechanical speed is opposite to the estimated speed, the direction must be changed. The first way is change "M1 Encoder Direction" variable - only 0 or 1 values is allowed. The second way is invert the encoder wires—phase A and phase B (or the other way round).

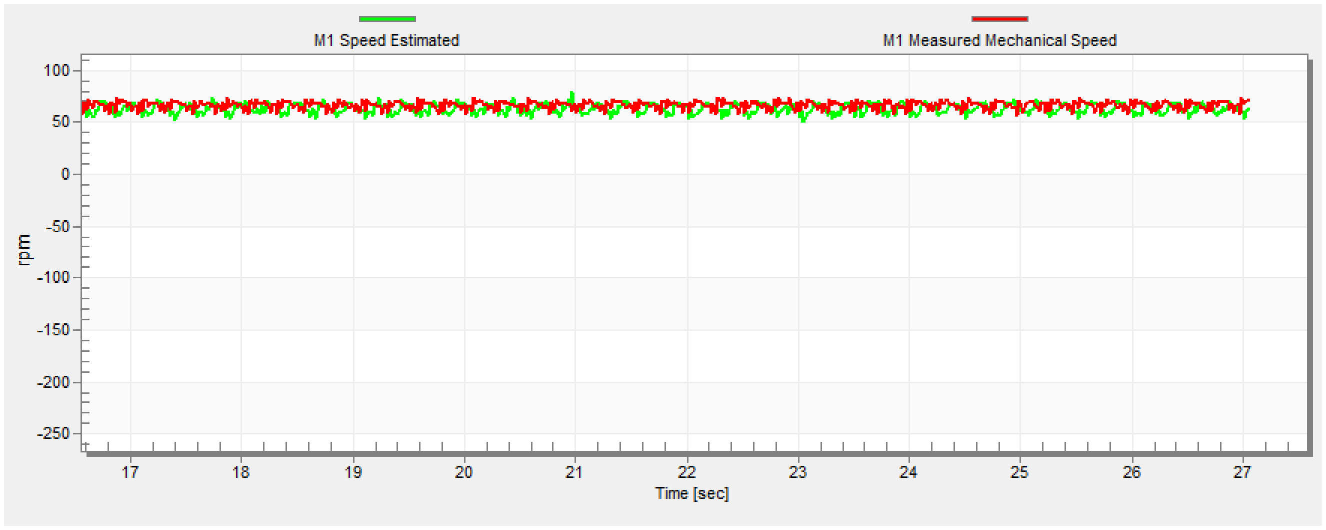


Figure 28. Encoder direction—right direction

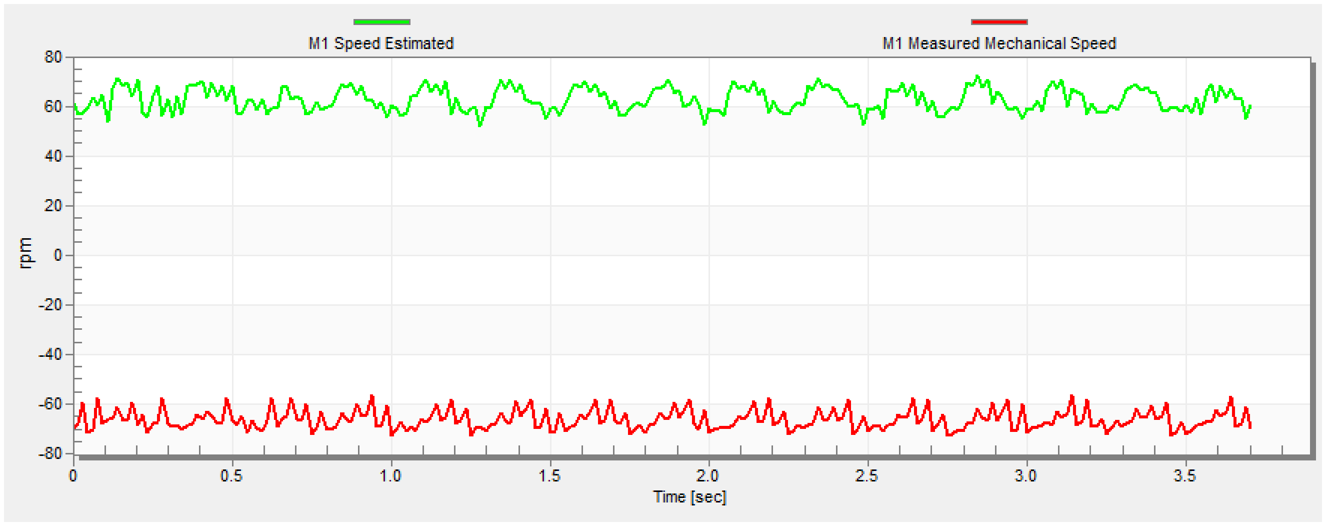


Figure 29. Encoder direction—wrong direction

## 8.12 Alignment tuning

For the alignment parameters, navigate to the “Parameters” MCAT tab. The alignment procedure sets the rotor to an accurate initial position and enables you to apply full start-up torque to the motor. A correct initial position is needed mainly for high start-up loads (compressors, washers, and so on). The aim of the alignment is to have the rotor in a stable position, without any oscillations before the startup.

1. The alignment voltage is the value applied to the d-axis during the alignment. Increase this value for a higher shaft load.
2. The alignment duration expresses the time when the alignment routine is called. Tune this parameter to eliminate rotor oscillations or movement at the end of the alignment process.

## 8.13 Current loop tuning

The parameters for the current D, Q, and PI controllers are fully calculated using the motor parameters and no action is required in this mode. If the calculated loop parameters do not correspond to the required response, the bandwidth and attenuation parameters can be tuned.

1. Lock the motor shaft.
2. Set the required loop bandwidth and attenuation and click the “Update target” button in the “Current loop” tab. The tuning loop bandwidth parameter defines how fast the loop response is whilst the tuning loop attenuation parameter defines the actual quantity overshoot magnitude.
3. Select the “Current Controller Id” recorder.
4. Select the “Current Control” in the FreeMASTER project tree, select "CURRENT_FOC" in "M1 MCAT Control" variable. Set the “M1 MCAT Iq required” variable to a very low value (for example 0.01), and set the required step in “M1 MCAT Id required”. The control loop response is shown in the recorder.
5. Tune the loop bandwidth and attenuation until you achieve the required response. The example waveforms show the correct and incorrect settings of the current loop parameters:
   - The loop bandwidth is low (110 Hz) and the settling time of the Id current is long (Figure 30).

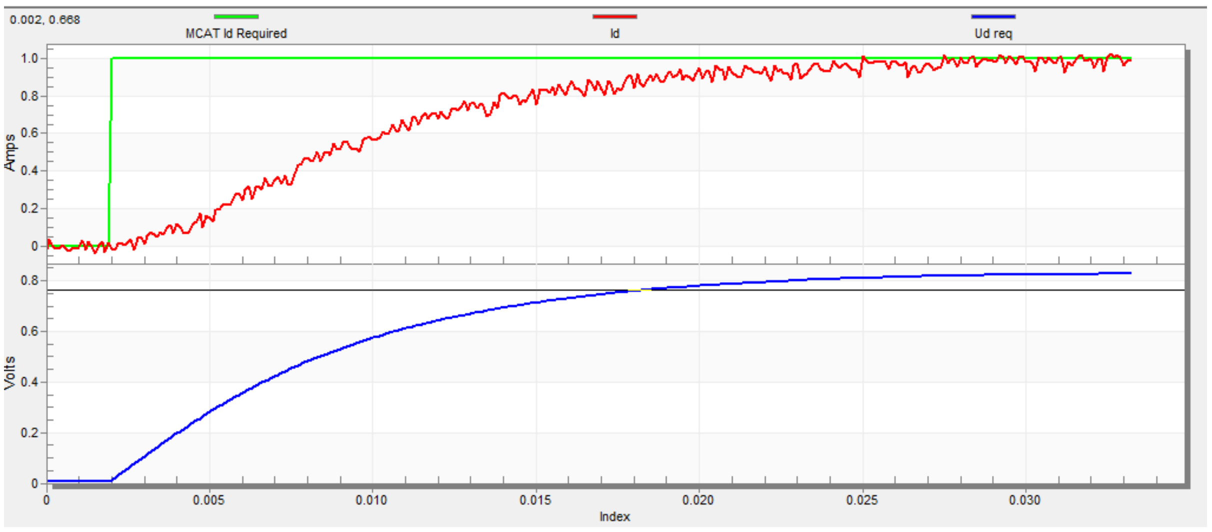


Figure 30. Slow step response of the Id current controller

- The loop bandwidth (400 Hz) is optimal and the response time of the Id current is sufficient (see Figure 31).

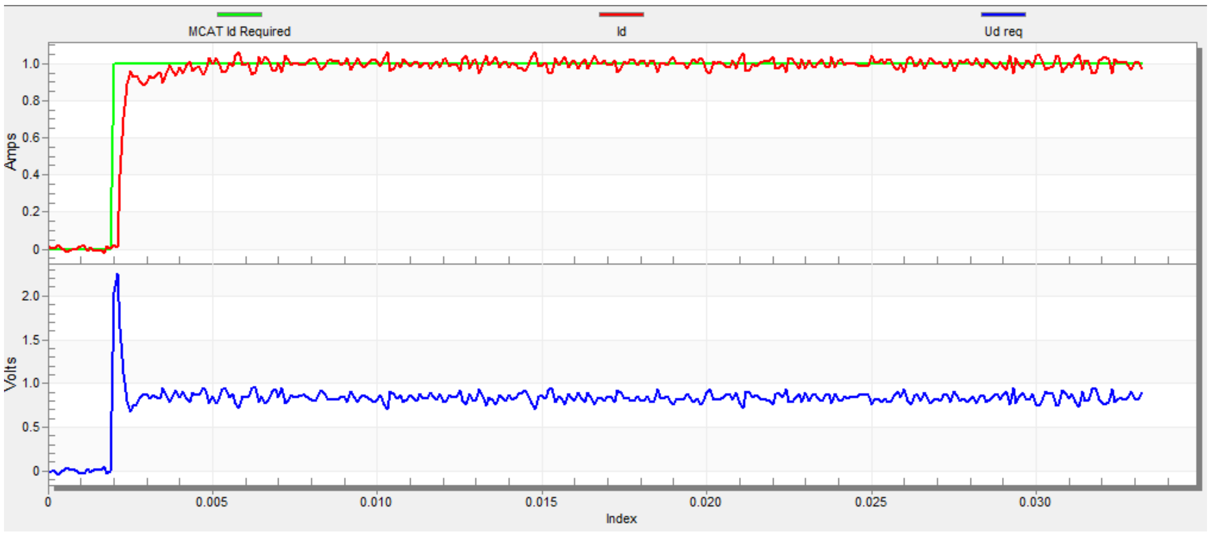


Figure 31. Optimal step response of the Id current controller

- The loop bandwidth is high (700 Hz) and the response time of the Id current is very fast, but with oscillation and overshoot (see Figure 32).

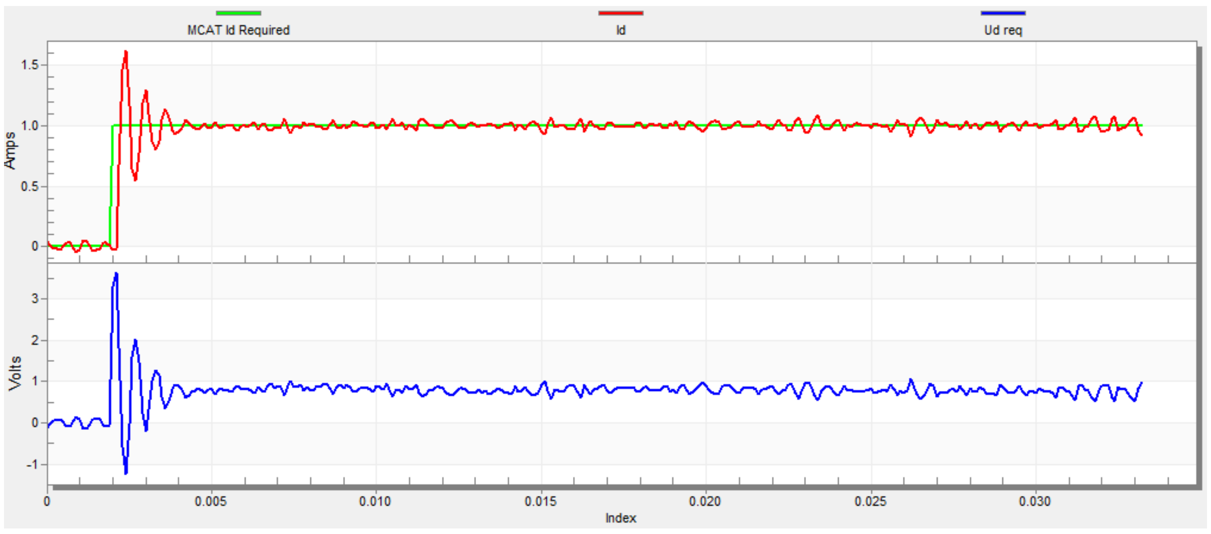


Figure 32. Fast step response of the Id current controller

## 8.14 Speed ramp tuning

1. The speed command is applied to the speed controller through a speed ramp. The ramp function contains two increments (up and down) which express the motor acceleration and deceleration per second. If the increments are very high, they can cause an overcurrent fault during acceleration and an overvoltage fault during deceleration. In the “Speed” scope, you can see whether the “Speed Actual Filtered” waveform shape equals the “Speed Ramp” profile.
2. The increments are common for the scalar and speed control. The increment fields are in the “Speed loop” tab and accessible in both tuning modes. Clicking the “Update target” button applies the changes to the MCU. An example speed profile is shown in Figure 33. The ramp increment down is set to 500 rpm/sec and the increment up is set to 3000 rpm/sec.
3. The start-up ramp increment is in the “Sensorless” tab and its value is usually higher than that of the speed loop ramp.

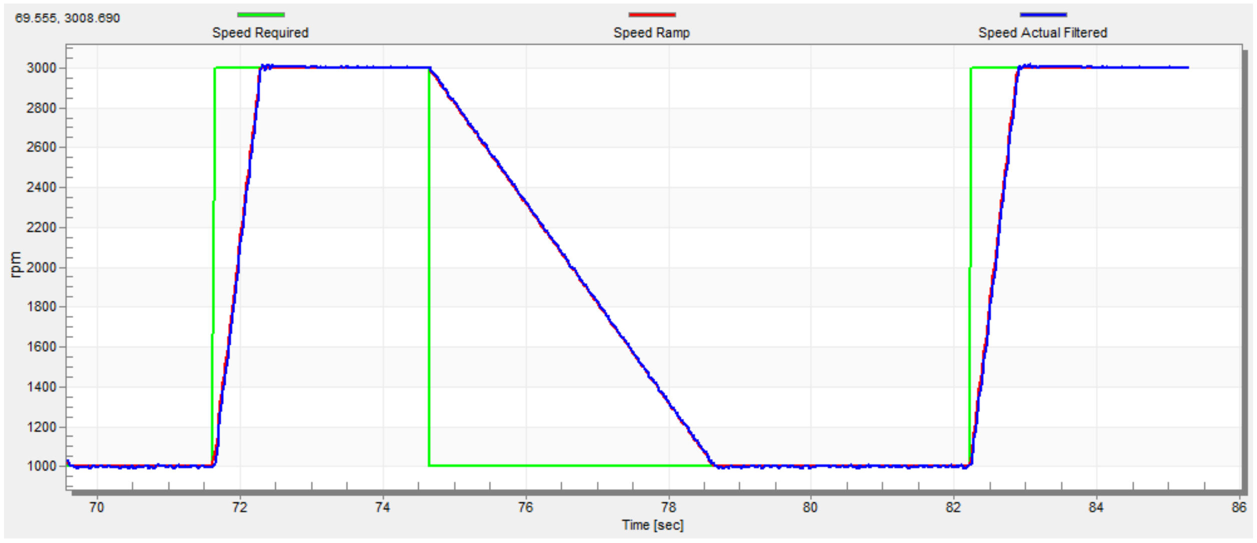


Figure 33. Speed profile

## 8.15 Open loop startup

1. The start-up process can be tuned by a set of parameters located in the “Sensorless” tab. Two of them (ramp increment and current) are accessible in both tuning modes. The start-up tuning can be processed in all control modes besides the scalar control. Setting the optimal values results in a proper motor startup. An example start-up state of low-dynamic drives (fans, pumps) is shown in Figure 34.
2. Select the “Startup” recorder from the FreeMASTER project tree.
3. Set the start-up ramp increment typically to a higher value than the speed-loop ramp increment.
4. Set the start-up current according to the required start-up torque. For drives such as fans or pumps, the start-up torque is not very high and can be set to 15 % of the nominal current.
5. Set the required merging speed—when the open-loop and estimated position merging starts, the threshold is mostly set in the range of 5 % ~ 10 % of the nominal speed.
6. Set the merging coefficient—in the position merging process duration, 100 % corresponds to a half of an electrical revolution. The higher the value, the faster the merge. Values close to 1 % are set for the drives where a high start-up torque and smooth transitions between the open loop and the closed loop are required.
7. Click the “Update Target” button to apply the changes to the MCU.
8. Select “SPEED_FOC” in the "M1 MCAT Control" variable.
9. Set the required speed higher than the merging speed.
10. Check the start-up response in the recorder.
11. Tune the start-up parameters until you achieve an optimal response.
12. If the rotor does not start running, increase the start-up current.
13. If the merging process fails (the rotor is stuck or stopped), decrease the start-up ramp increment, increase the merging speed, and set the merging coefficient to 5 %.

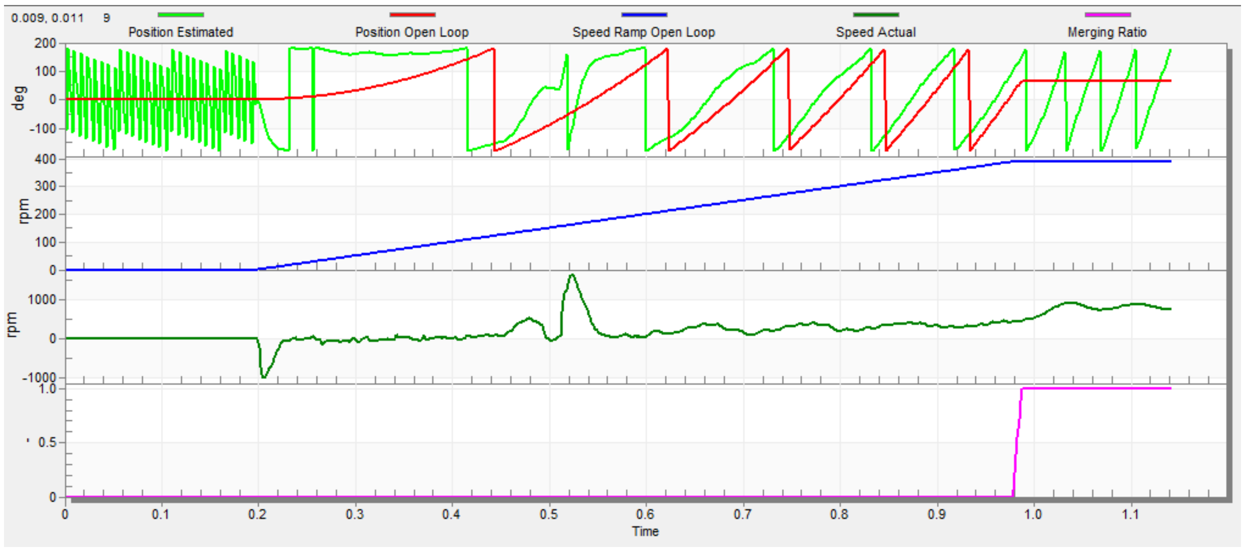


Figure 34. Motor startup

## 8.16 BEMF observer tuning

1. The bandwidth and attenuation parameters of the BEMF observer and the tracking observer can be tuned. Navigate to the "Sensorless" MCAT tab.
2. Set the required bandwidth and attenuation of the BEMF observer—the bandwidth is typically set to a value close to the current loop bandwidth.

3. Set the required bandwidth and attenuation of the tracking observer—the bandwidth is typically set in the range of 10 – 20 Hz for most low-dynamic drives (fans, pumps).
4. Click the “Update target” button to apply the changes to the MCU.
5. Select the “Observer” recorder from the FreeMASTER project tree and check the observer response in the "Observer" recorder.

### 8.17 Speed PI controller tuning

The motor speed control loop is a first-order function with a mechanical time constant that depends on the motor inertia and friction. If the mechanical constant is available, the PI controller constants can be tuned using the loop bandwidth and attenuation. Otherwise, the manual tuning of the P and I portions of the speed controllers is available to obtain the required speed response (see the example response in Figure 35). There are dozens of approaches to tune the PI controller constants. The following steps provide an approach to set and tune the speed PI controller for a PM synchronous motor:

1. Select the “Speed Controller” option from the FreeMASTER project tree.
2. Select the “Speed loop” tab.
3. Check the “Manual Constant Tuning” option—that is, the “Bandwidth” and “Attenuation” fields are disabled and the “SL_Kp” and “SL_Ki” fields are enabled.
4. Tune the proportional gain:
   - Set the “SL_Ki” integral gain to 0.
   - Set the speed ramp to 1000 rpm/sec (or higher).
   - Run the motor at a convenient speed (about 30 % of the nominal speed).
   - Set a step in the required speed to 40 % of $N_{nom}$.
   - Adjust the proportional gain “SL_Kp” until the system responds to the required value properly and without any oscillations or excessive overshoot:
     - If the “SL_Kp” field is set low, the system response is slow.
     - If the “SL_Kp” field is set high, the system response is tighter.
     - When the “SL_Ki” field is 0, the system most probably does not achieve the required speed.
     - Click the “Update Target” button to apply the changes to the MCU.
5. Tune the integral gain:
   - Increase the “SL_Ki” field slowly to minimize the difference between the required and actual speeds to 0.
   - Adjust the “SL_Ki” field such that you do not see any oscillation or large overshoot of the actual speed value while the required speed step is applied.
   - Click the “Update target” button to apply the changes to the MCU.
6. Tune the loop bandwidth and attenuation until the required response is received. The example waveforms with the correct and incorrect settings of the speed loop parameters are shown in the following figures:
   - The “SL_Ki” value is low and the “Speed Actual Filtered” does not achieve the “Speed Ramp” (see Figure 35).

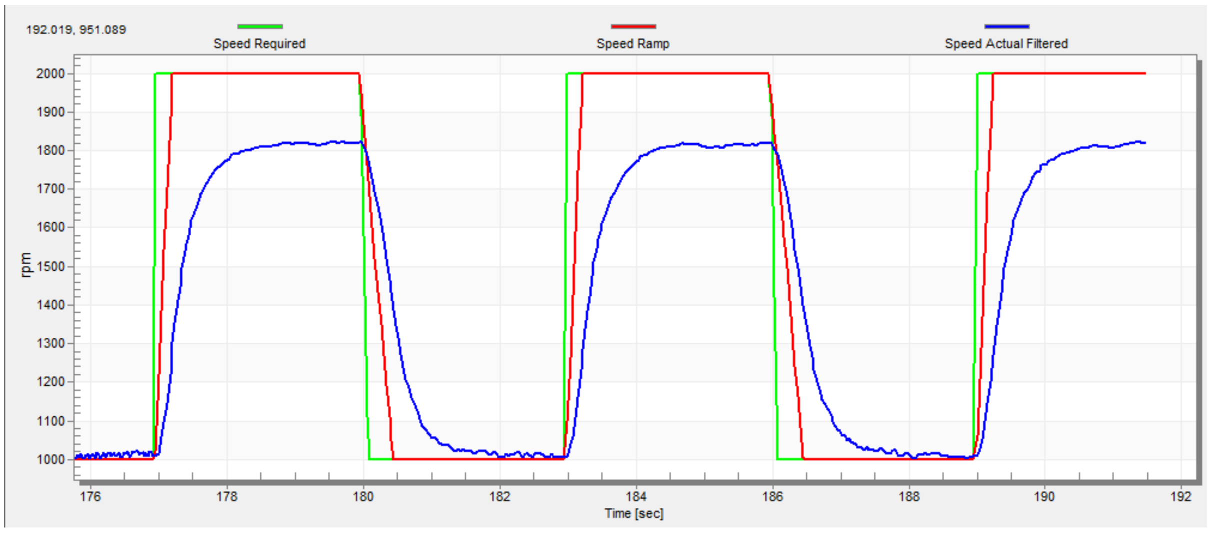


Figure 35. Speed controller response—SL_Ki value is low, Speed Ramp is not achieved

- The “SL_Kp” value is low, the “Speed Actual Filtered” greatly overshoots, and the long settling time is unwanted (see Figure 36).

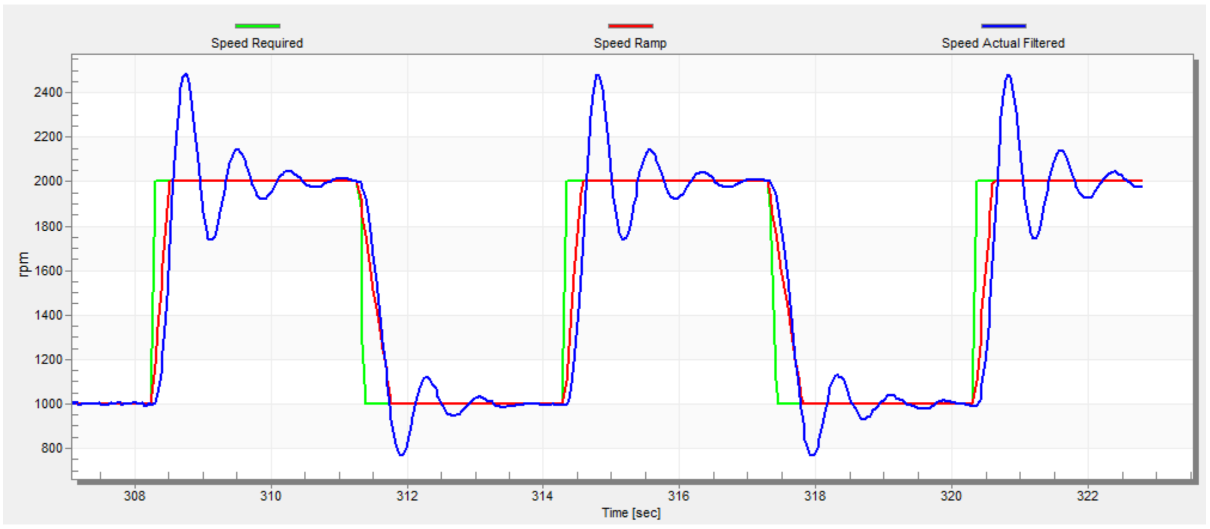


Figure 36. Speed controller response—SL_Kp value is low, Speed Actual Filtered greatly overshoots

- The speed loop response has a small overshoot and the “Speed Actual Filtered” settling time is sufficient. Such response can be considered optimal (see Figure 37).

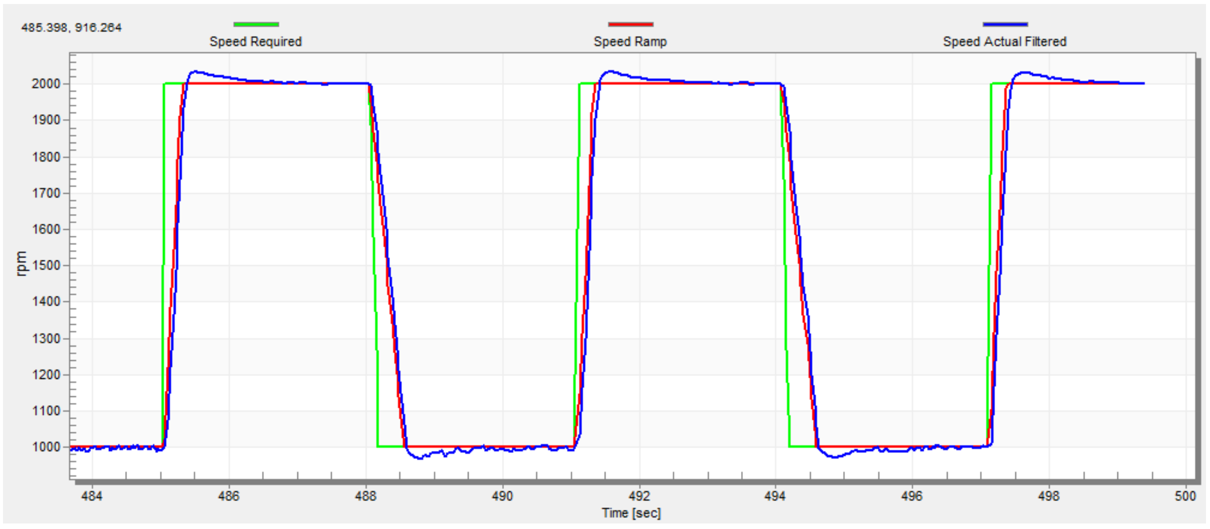


Figure 37. Speed controller response—speed loop response with a small overshoot

## 8.18 Position P controller tuning

The position control loop can be tuned using the proportional gain “M1 Position Loop Kp Gain” variable. It is a proportional controller that can be used to unpretend the position-control systems. The key for the the optimal position response is a proper value of the controller, which simply multiplies the error by the proportional gain (Kp) to get the controller output. The predefined base value can be manually changed. An encoder sensor must be used for a working position control. The following steps provide an example of how to set the position P controller for a PM synchronous motor:

1. Select the “Position Controller” scope in "Position Control" tab in the FreeMASTER project tree.
2. Tune the proportional gain in the position P controller constant:
   - Set a small value of “PL_Kp” (M1 Position Loop Kp Gain).
   - Select the position control, and set the required position in "M1 Position Required" variable (for example; 10 revolutions).
   - Select the “Position Controller” scope and watch the actual position response.
3. Repeat the previous steps until you achieve the required position response.

The “PL_Kp” value is low and the actual position response on the required position is very slow.

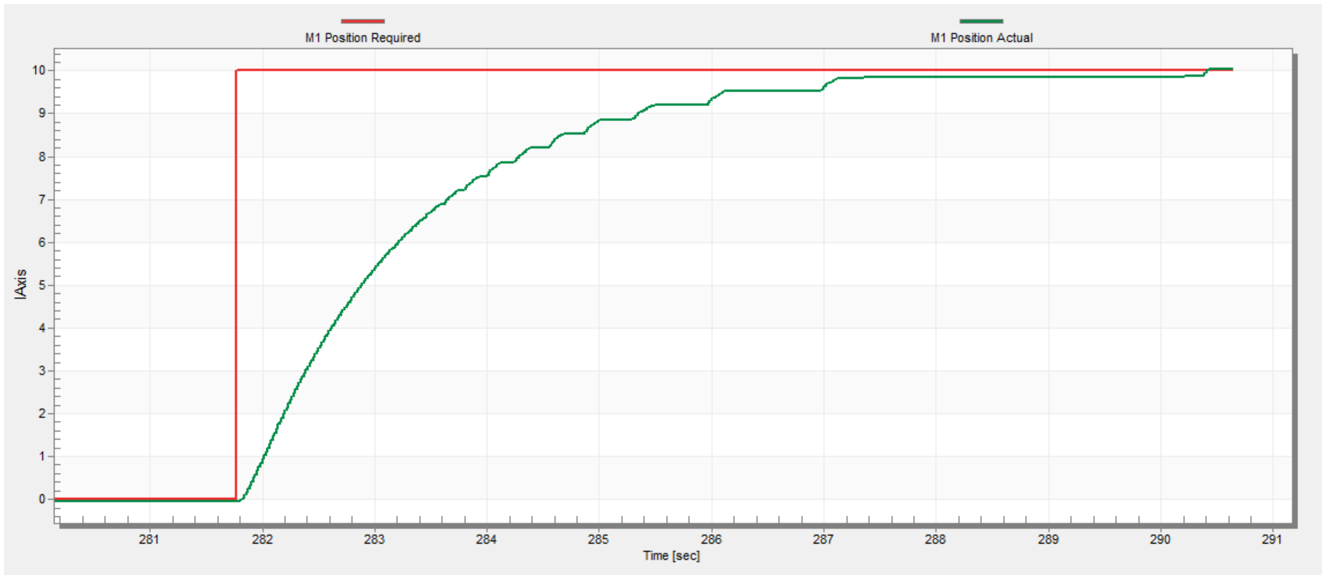


Figure 38. Position controller response—PL_Kp value is low, the actual position response is very slow

The “PL_Kp” value is too high and the actual position overshoots the required position.

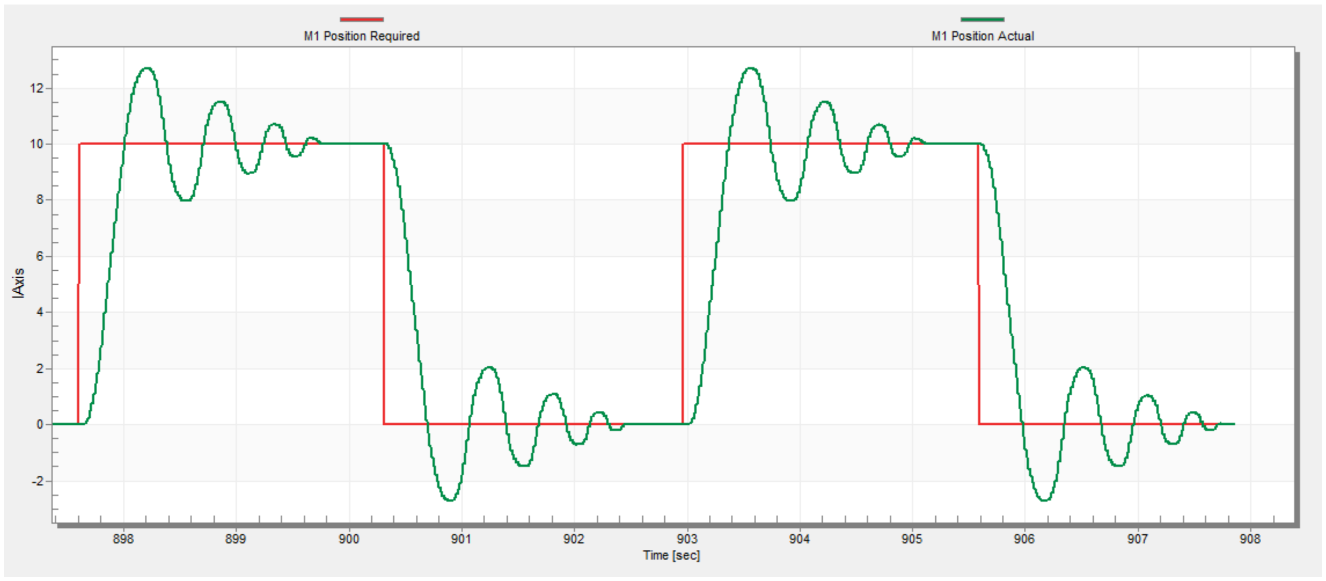


Figure 39. Position controller response—PL_Kp value is too high and the actual position overshoots

The “PL_Kp” value and the actual position response are optimal.

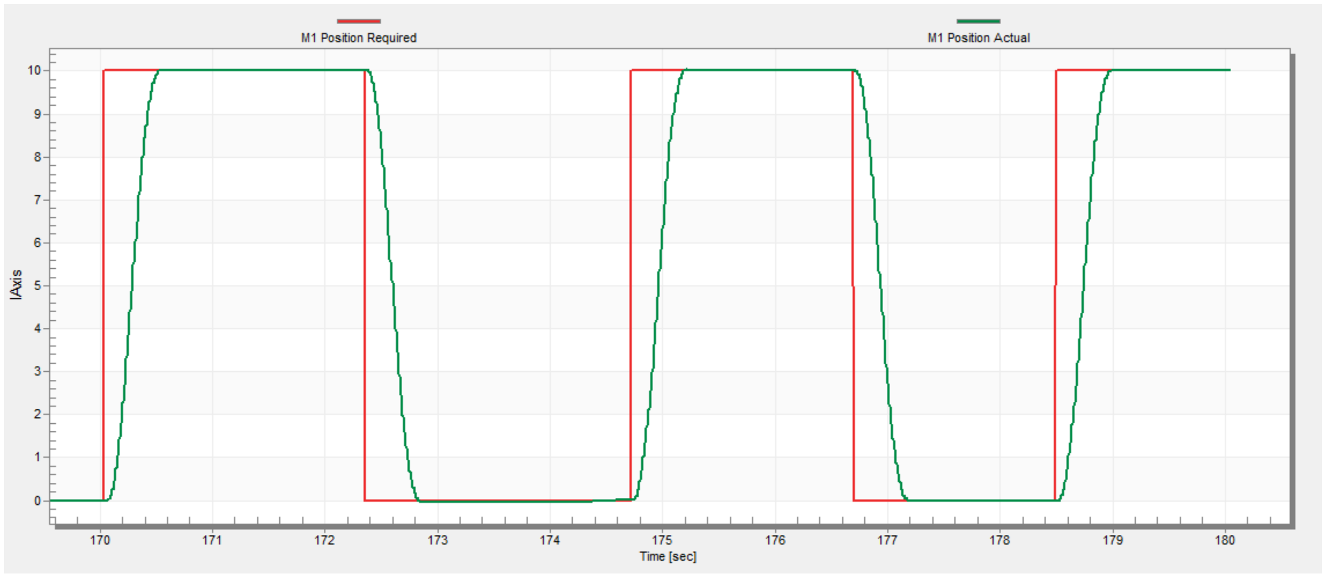


Figure 40. Position controller response—the actual position response is good

# Chapter 9 Conclusion

This application note describes the implementation of the sensor and sensorless Field-Oriented Control of a 3-phase PMSM on the NXP MIMXRT1xxx EVK board with the FRDM-MC-LVPMSM NXP Freedom Development Platform. The hardware-dependent part of the control software is described in Hardware setup. The motor-control application timing is described in RT crossover processors features and peripheral settings and the peripheral initialization is described in Motor-control peripheral initialization. The motor user interface and remote control using FreeMASTER are as follows. The motor parameters identification theory and the identification algorithms are described in Identifying parameters of user motor.

# Chapter 10
# Acronyms and abbreviations

Table 20. Acronyms and abbreviations

| Acronym | Meaning |
|---|---|
| ADC | Analog-to-Digital Converter |
| ACIM | Asynchronous Induction Motor |
| ADC_ETC | ADC External Trigger Control |
| AN | Application Note |
| BLDC | Brushless DC motor |
| CCM | Clock Controller Module |
| CPU | Central Processing Unit |
| DC | Direct Current |
| DRM | Design Reference Manual |
| ENC | Encoder |
| FOC | Field-Oriented Control |
| GPIO | General-Purpose Input/Output |
| LPIT | Low-power Periodic Interrupt Timer |
| LPUART | Low-power Universal Asynchronous Receiver/Transmitter |
| MCAT | Motor Control Application Tuning tool |
| MCDRV | Motor Control Peripheral Drivers |
| MCU | Microcontroller |
| PDB | Programmable Delay Block |
| PI | Proportional Integral controller |
| PLL | Phase-Locked Loop |
| PMSM | Permanent Magnet Synchronous Machine |
| PWM | Pulse-Width Modulation |
| QD | Quadrature Decoder |
| TMR | Quad Timer |
| USB | Universal Serial Bus |
| XBAR | Inter-Peripheral Crossbar Switch |
| IOPAMP | Internal operational amplifier |

# Chapter 11
# References

These references are available on www.nxp.com:

1. *Sensorless PMSM Field-Oriented Control* (document DRM148)
2. *Motor Control Application Tuning (MCAT) Tool for 3-Phase PMSM* (document AN4642)
3. *PMSM Field-Oriented Control on MIMXRT10xx EVK User's Guide* (document PMSMFOCRT10xxUG)
4. *PMSM Field-Oriented Control on MIMXRT10xx EVK* (document AN12214)

# Chapter 12
# Useful links

1. MCUXpresso SDK for Motor Control www.nxp.com/motorcontrol
2. i.MX RT1024-EVK board
3. i.MX RT1060-EVK board
4. i.MX RT1064-EVK board
5. i.MX RT1160-EVK board
6. i.MX RT1170-EVK board
7. i.MX RT Crossover MCUs
8. FRDM-MC-PMSM Freedome Development Platform
9. MCUXpresso IDE - Importing MCUXpresso SDK
10. MCUXpresso Config Tool
11. MCUXpresso SDK Builder (SDK examples in several IDEs) https://mcuxpresso.nxp.com/en/welcome

# Chapter 13
# Revision history

Revision history summarizes the changes done to the document since the initial release.

Table 21. Revision history

| Revision number | Date | Substantive changes |
|---|---|---|
| 0 | 07/2022 | Initial release |

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