Freescale Semiconductor
Application Note

Document Number: AN4986
Rev 0, 10/2014

Automated PMSM Parameter Identification

by: Josef Tkadlec

Contents

1 Introduction

Advanced motor control techniques, such as the sensorless Field Oriented Control (FOC), require knowledge of motor parameters to properly set current controllers and the BEMF observer. Conventional Permanent Magnet Synchronous Motor (PMSM) measurement techniques are described in-depth in Reference [1]. On the one hand, the techniques are accurate and reliable, on the other hand, they are time-consuming, require extra equipment, and the user must have background knowledge of motor control. For this reason, Freescale has developed easy to use electrical parameter measurement routines. These routines are delivered as a part of a motor control application and controlled using the Motor Control Application Tuning (MCAT) Tool and FreeMASTER.

This application note describes the MCAT *motor identification tab*, briefly explains how the measurement routines work, provides step-by-step instructions to run the identification process in MCAT, and explains how to troubleshoot faults and warnings that occur during the measurement process. This motor parameter identification process is an extension of the PMSM sensorless control application, however, this application note describes only the *motor identification tab* of the MCAT tool.

2 MCAT motor identification tab description

The MCAT motor identification tab shown in Figure 1 consists of the following sections:

- **Application scales**—includes quantities that cannot be measured, such as hardware scales, nominal speed, and the number of pole-pairs.
- **Rs and Ls measurement**—defines the parameters of stator resistance (*Rs*) and stator inductance (*Ls*) within the measured signal.
- **Number of pole-pairs assistant**—enables the user to determine the number of pole-pairs.
- **Measured Rs and Ls**—displays identified motor parameters.

MCAT offers two tuning modes:

- Basic—highly recommended for users who are not experienced in motor control theory. The number of required input parameters is reduced. The fields that require user input are displayed with a white background. The fields that are automatically preset by MCAT are displayed with a gray background and are read-only.
- Expert—all input parameters are accessible and editable by the user. However, their setting requires a certain level of expertise in motor control theory.

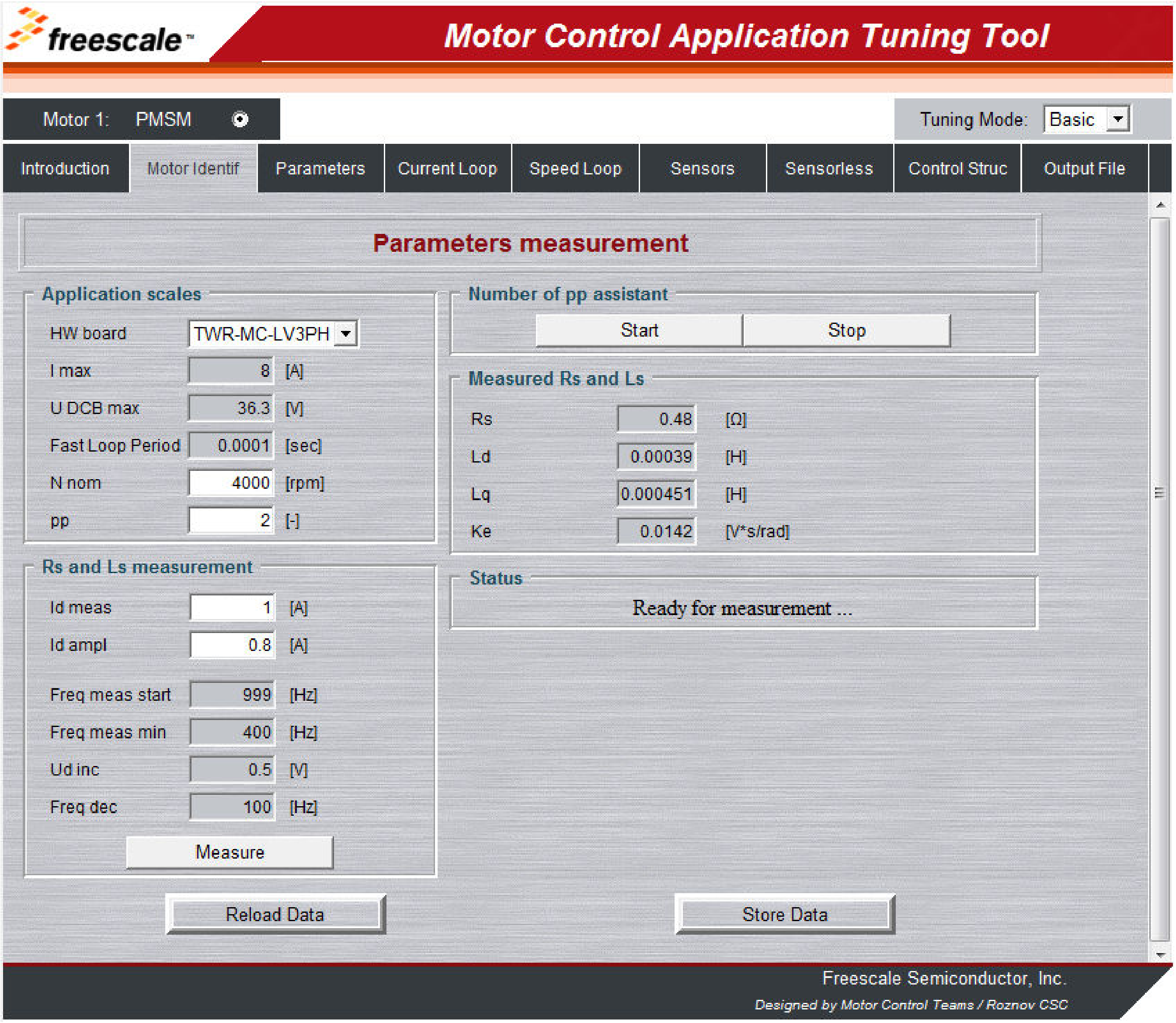

Figure 1. Motor identification tab

Table 1 lists the input parameters including their physical units, description, and accessibility.

Table 1. Motor identification tab parameter descriptions

Parameter	Unit	Description	Write Enable?
HW board	N/A	Selects the power stage (PS). There are three possible options depicted in Figure 2. Freescale low voltage power stage (TWR-MC-LV3PH) and Freescale high voltage power stage (FSL-HV-PS) have predefined hardware scales (**I max** and **U DCB max**) and **Fast Loop Period**. The third option, **User HW**, enables users to specify hardware scales and Fast Loop Period according to their own power stage and application.	Always
I max	[A]	Hardware board current scale.	User hardware board selected
U DCB max	[V]	Hardware board DC bus voltage scale.	User hardware board selected

Table continues on the next page...

Table 1. Motor identification tab parameter descriptions (continued)

Parameter	Unit	Description	Write Enable?
Fast Loop Period	[s]	Control loop period. In most cases inverted value of PWM frequency.	User hardware board selected
N nom	[rpm]	Motor nominal speed in rpm. This value can be found in the motor control datasheet.	Always
pp	[-]	Motor number of pole-pairs. If the pp is unknown, it can be determined using the *Number of pp assistant*	Always
Calib Rs	[Ω]	Resistance of the connected motor for power stage characterization purposes. Must be measured manually prior to characterization process. Be aware, that the resistance of the calibration resistor must be low enough to reach measurement current 2A. See Power stage characterization for more information	If hardware board == User HW
Id meas	[A]	DC current for *Rs* measurement. **Id meas** may be set as half of the motor nominal current, however, the maximum **Id meas** is 2A because the characterization is done from -2A to 2A.	Always
Id ampl	[A]	Amplitude of AC sinusoidal current for *Ls* measurement. **Id ampl** may be set as half of the motor nominal current.	Always
F meas start	[Hz]	Starting frequency of sinusoidal signal for *Ls* measurement. See Measurement for more information.	Expert tuning mode selected
F meas min	[Hz]	Minimal (end) frequency of sinusoidal signal for *Ls* measurement. See Measurement for more information.	Expert tuning mode selected
Ud inc	[V]	Voltage increment when measuring *Ls*. See Measurement for more information.	Expert tuning mode selected
Freq dec	[Hz]	Frequency decrement when measuring *Ls*. See Measurement for more information.	Expert tuning mode selected
Rs	[Ω]	*Rs* result.	Never
Ld	[H]	*Ld* result.	Never
Lq	[H]	*Lq* result.	Never
Ke	[V.s/rad]	*Ke* result.	Never

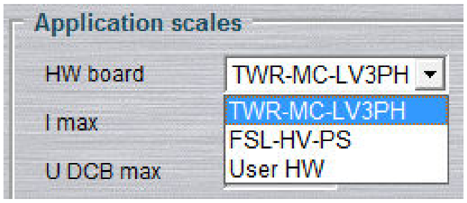

Figure 2. Hardware board selector

2.1 Power stage characterization

Each inverter introduces a total error count which includes dead-time, a current clamping effect, and transistor voltage drop. The total error count depends on the phase current and this dependency is measured during the power stage characterization process from -2A to +2A. An example of the inverter error characteristic is depicted in Figure 3. The acquired characterization data is saved to a file and used later for phase voltage correction during the *Rs* measurement process. Before performing characterization, a motor with a known *Rs* must be connected to the inverter and the value of its *Rs* set as

Calib Rs. Afterward, characterization may begin by pressing the **Calibrate** button. Characterization performs 65 current steps gradually, from -2A to +2A, each for 300 ms, so be aware that the process takes about 20s and the motor must withstand this load. It is recommended to use a motor with a low *Rs* for characterization purposes.

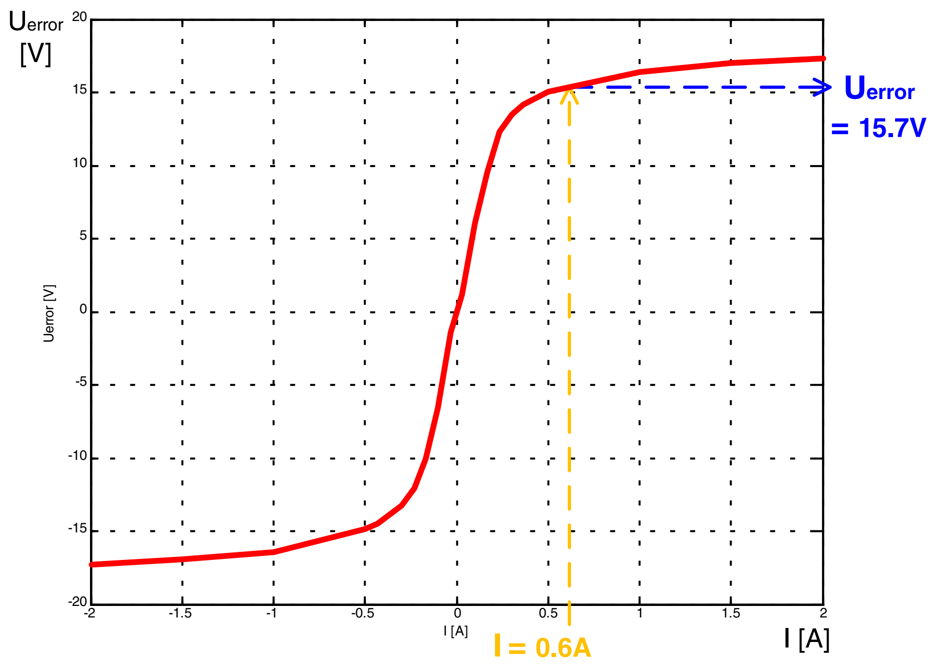

Figure 3. Transfer characteristic

Power stage characterization is necessary only for the user's hardware board. When Freescale power stages are used with the application, the characterization process can be omitted. The acquired characterization data is saved in a file, therefore, it is only necessary to do the characterization once, depending on the user's hardware.

2.2 Measurement

The motor parameter identification process measures *Rs*, *Ld*, *Lq* and *Ke* respectively.

Stator resistance (*Rs*) is measured with the DC current **Id meas** value, which is applied to the motor for 600 ms. Current control is enabled during *Rs* measurement and the current controllers' parameters are set to satisfy a slow response. *Rs* is calculated from Ohm's law when the actual phase voltage value is corrected using chracterization data.

For stator inductance (*Ls*) identification purposes, a sinusoidal measurement voltage is applied to the motor. During *Ls* measurement, the voltage control is enabled. The frequency and amplitude of the sinusoidal voltage are obtained before actual measurement, during the tuning process. The tuning process begins with a 0V amplitude and **F start** frequency, which are applied to the motor. The amplitude is gradually increased by **Ud inc** up to half of the DC bus voltage (DCbus/2) until **Id ampl** is reached. If **Id ampl** is not reached even with DCbus/2 and **F start**, the frequency of the measuring signal is gradually decreased by **F dec** down to **F min** again until **Id ampl** is reached. If **Id ampl** is still not reached, measurement will continue with DCbus/2 and **F min**. The tuning process is depicted in Figure 4. When the tuning process is complete, the sinusoidal measurement signal (with amplitude and frequency obtained during the tuning process) is applied to the motor. The total impedance of the RL circuit is then calculated from the voltage and current amplitudes and *Ls* is calculated from the total impedance of the RL circuit.

Direct inductance (*Ld*) and quadrature inductance (*Lq*) measurements are completed in the same way as *Ls*. Before the *Ld* and *Lq* measurement is taken, a DC current is applied to the D-axis, which aligns the rotor. For *Ld* measurement, the sinusoidal voltage is applied in the D-axis, and for *Lq* measurement, the sinusoidal voltage is applied in the Q-axis.

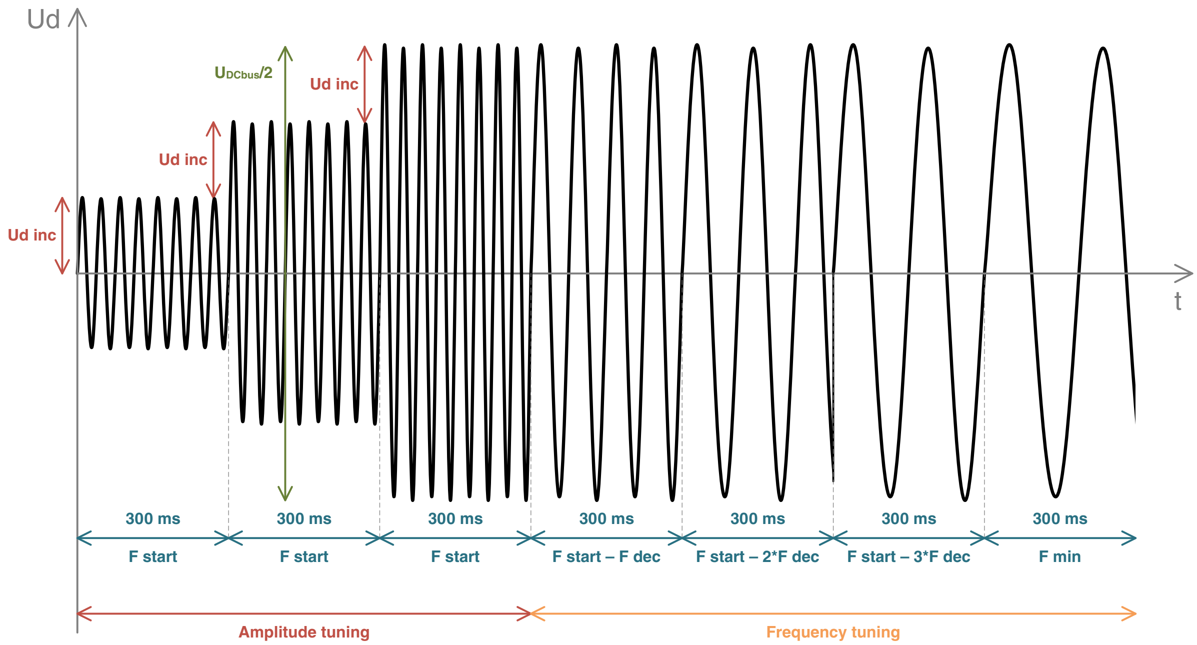

Figure 4. Sinusoidal signal tuning

Prior to the actual *ke* measurement, the MCAT tool calculates the current controllers and BEMF observer constants from the previously measured *Rs*, *Ld*, and *Lq*. To be able to measure *ke*, the motor must spin. Id is controlled through **Id meas** and the electrical open-loop position is generated by integrating the required speed, which is derived from **N nom**. When the motor reaches the required speed, BEMF voltages obtained by the BEMF observer are filtered and *ke* is calculated:

$$ke = \frac{U_{BEMF}}{\omega_{el}}$$

Equation 1

When *ke* is being measured, the user must visually check to determine whether the motor is spinning properly. If the motor is not spinning properly use the following steps:

- Ensure that the number of **pp** is correct. The required speed for ke measurement is also calculated from pp, therefore, an inaccuracy in pp causes inaccuracy in the resultant *ke*.
- Increase **Id meas** to produce higher torque when spinning during the open-loop.
- Decrease **N nom** to decrease the required speed for the *ke* measurement.

As soon as identification is complete, the motor parameters are passed to the *Parameters* tab in MCAT automatically.

2.3 Number of pole-pair assistant

The number of pole-pairs cannot be measured without a position sensor, however, there is a simple assist to determine the number of pole-pairs (**pp**). The *Number of pp assistant* performs one electrical revolution and stops for 2.4s, and then repeats. Because the **pp** value is a ratio between 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 an alignment occurs during the first revolution which affects the number of stops. During the pp measurement, the current loop is enabled and current Id is controlled by **Id meas**. The electrical position is generated by integrating the open-loop speed. If the rotor does not move after the start of the *Number of pp assistant*, stop the assistant, increase **Id meas**, and start the assistant again.

3 Using the motor identification tab

1. Select your hardware board.
   - When using the TWR-LV-3PH power stage with DC bus voltage of 24 V, PWM frequency of 10 kHz, and dead-time of 0.5 µs, select TWR-LV-3PH.
   - When using the Freescale high-voltage power stage with DC bus voltage of 325 V, PWM frequency of 10 kHz, and dead-time of 0.5 µs, select FSL-HV-PS.
   - When using a different configuration than mentioned above, select User HW.
2. Enter **I max**, **U DCB max**, **Fast Loop Period** and **N nom** if accessible. For more information, see Table 1.
3. Enter **Id meas** and **Id ampl**. For more information, see Table 1.
4. Enter **F start**, **F min**, **Ud inc**, **F dec** if you are in Expert mode. For more information, see Measurement.
5. Enter **pp** if you already know it, or use the *Number of pp assistant*. For more information, see Number of pole-pair assistant.
6. Perform characterization when not using a Freescale power stage. For more information, see Power stage characterization.
7. Start the identification by pressing the **Measure** button.
8. If a fault or warning occurs, check Fault handling to troubleshoot.
9. If measurement is successful, read the motor control parameters and remember that these parameters are fed to the *Parameters* tab automatically.
10. Continue with the controllers' parameters tuning according to Reference [2].

This entire step-by-step process is depicted in Figure 5.

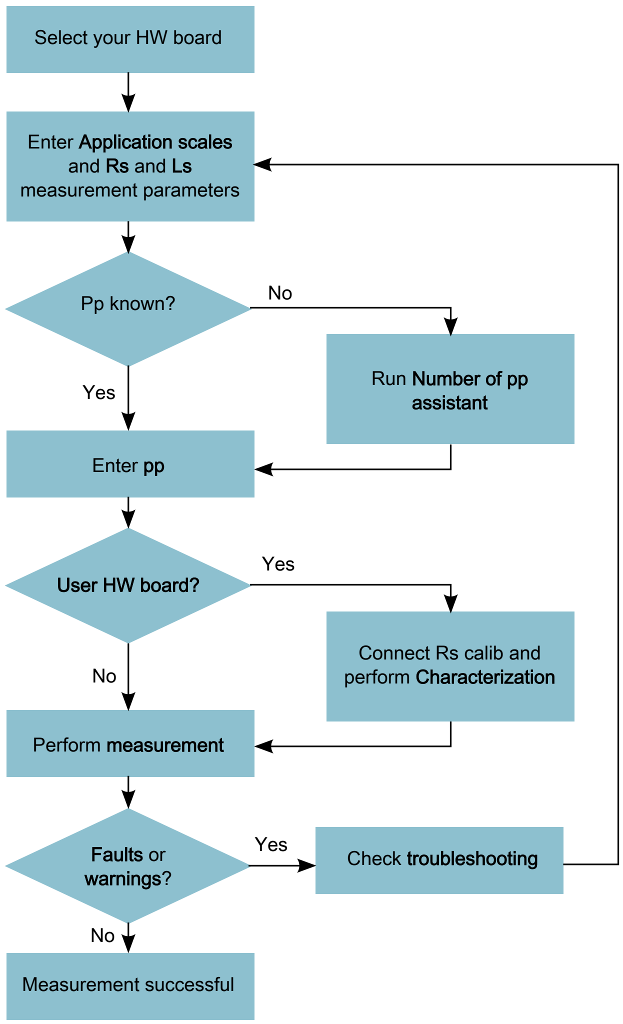

Figure 5. Step-by-step flow chart

4 Fault handling

There are several faults and warnings which can occur during the measurement or calibration processes. These measurement faults are not be confused with application faults, such as DC bus undervoltage or overspeed. The measurement faults and warnings serve to inform the user that something went wrong during the measurement process. There are 3 measurement faults described in Table 2, together with their reason and possible troubleshooting. If one of these faults occurs, the identification process ends immediately and informs the user by a message depicted in Figure 6.

Table 2. Faults description

Fault No.	Fault description	Fault reason	Troubleshooting
01	Motor not connected	Id > 50mA cannot be reached with the available DC bus voltage.	Confirm that a motor is connected.

Table continues on the next page...

Table 2. Faults description (continued)

Fault No.	Fault description	Fault reason	Troubleshooting
02	Rs too high for calibration	Id = 2A cannot be reached with the available DC bus voltage.	Use a motor with a lower Rs for power stage characterization.
03	Wrong characteristic data	Characteristic data, which is used for voltage correction, does not correspond to the actual power stage.	Select **User HW** and perform the calibration.

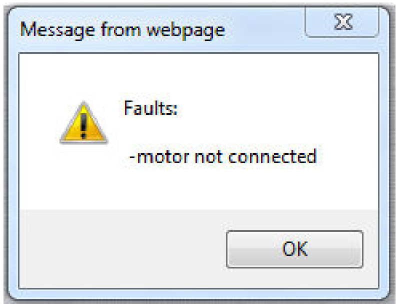

Figure 6. Fault example

Unlike faults, warnings do not stop the identification process immediately, but instead inform the user that something nonessential failed. There are two warnings that can occur during the measurement process, described in Table 3.

Table 3. Warnings description

Warning No.	Warning description	Warning reason	Troubleshooting
01	Current measurement **Id_meas** not reached	User defined **Id meas** was not reached, so the measurement was taken with a lower **Id meas**.	Raise the DC bus voltage to reach the **Id meas** or lower the **Id meas** to avoid this warning.
02	Current amplitude measurement **Id_ampl** not reached	User defined **Id_ampl** was not reached, so the measurement was taken with a lower **Id_ampl**.	Raise the DC bus voltage or lower the **F min** to reach the **Id_ampl** or lower the **Id_ampl** to avoid this warning.

5 References

The following references are available on http://www.freescale.com :

1. *PMSM Electrical Parameters Measurement* (Document AN4680).
2. *Tuning 3-Phase PMSM Sensorless Control Application Using MCAT Tool* (Document AN4912).

Document Number AN4986
Revision 0, 10/2014