iC-MU AN3

ROTARY CALIBRATION AND PROGRAMMING

SCOPE OF THE DOCUMENT

This document is intended to support developers during the iC-MU Series design-in process. Based on our experience in typical applications the goal is to convey the information in a pragmatic way. Application specific values given in this document like - but not limited to - mechanical tolerances or tolerable analogue errors are no definite values. They are meant as approximate guide values. Such values need to be verified and validated in the light of the specific application, the specific performance criteria and overall required operating conditions.

This document is only applicable for iC-MU Series GUI revision B1 or later.

GUI revision	Applicable iC-MU AN3 revision
B1 or later	revision D1 or later
Ax	revision Cx (on request)

Table 1: Applicable iC-MU AN3 revision depending on the iC-MU Series GUI revision.

TOOLS DOCUMENTATION FOR CALIBRATION AND PROGRAMMING

1. iC-MU Website (www.ichaus.com/mu)
2. iC-MU150 Website (www.ichaus.com/mu150)
3. iC-MU200 Website (www.ichaus.com/mu200)
4. iC-MU Datasheet (www.ichaus.com/mu_datasheet_en)
5. iC-MU150 Datasheet (www.ichaus.com/mu150_datasheet_en)
6. iC-MU200 Datasheet (www.ichaus.com/mu200_datasheet_en)
7. iC-Haus USB PC Adapter MB3U-I2C, MB4U, or MB5U (www.ichaus.com/tools)
8. iC-MU MU1D Demo Board (www.ichaus.com/MU1D_evalmanual_en)
9. iC-MU MU1M Demo Board (www.ichaus.com/MU1M_evalmanual_en)
10. iC-MU150 MU1M Demo Board (www.ichaus.de/MU150_MU1M_evalmanual_en)
11. iC-MU200 MU6M Demo Board (www.ichaus.de/MU200_MU6M_evalmanual_en)
12. iC-Haus iC-MU Series GUI (suitable for all chips in the iC-MU Series family)
    (a) with included LabVIEW RTE (www.ichaus.com/MU_gui_rte)
    (b) without LabVIEW RTE (www.ichaus.com/MU_series_gui)

All described procedures and settings apply to all chips in the iC-MU Series family. Please check the respective product websites for documentation and tools.

MECHANICAL TOLERANCES

Understanding the allowable mechanical tolerances of an iC-MU Series based system is required for a successful calibration and reliable product implementation.

The tolerances given below are **static** tolerances. These tolerances refer to the acceptable mechanical misalignment that can be accepted during the initial assembly of an iC-MU Series based encoder system. Analog signal errors or Nonius mismatch caused by these static mechanical mounting tolerances can be compensated by the analog and Nonius calibration.

Mechanical play that occurs during the operation of an iC-MU Series based encoder system (dynamic mechanical tolerances) has a negative impact on the system performance in terms of position accuracy and Nonius reserve.

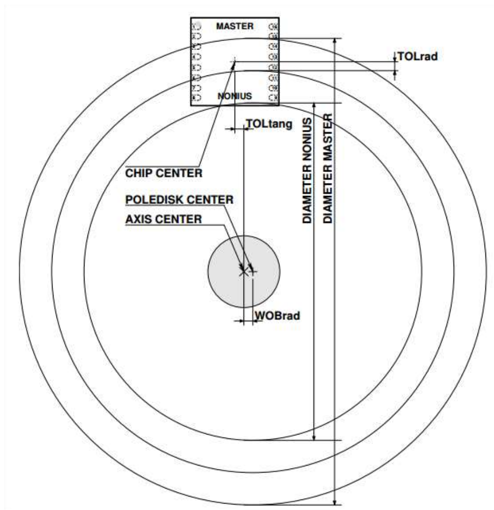

Figure 1: Definition of radial, tangential and eccentricity tolerances

iC-MU Series datasheet Item No.	Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
301	TOLrad	Permissible Radial Displacement				0.5	mm
302	TOLtang	Permissible Tangential Displacement				0.5	mm
303	WOBrad	Permissible eccentricity of the magnetic pole wheel	MPC = 0x4 MPC = 0x5, 0x6			0.06 0.1	mm
	P2	iC-MU Package surface to magnetic coating surface distance	all package variants	0.2	0.4	0.6	mm
	P2	iC-MU150 Package surface to magnetic coating surface distance	all package variants	0.2	0.5	0.7	mm
	P2	iC-MU200 Package surface to magnetic coating surface distance	all package variants	0.3	0.6	0.8	mm

Table 2: Permissible static mechanical alignment tolerances for initial assembly

i The P2 (package surface to magnetic coating surface distance) values given above are recommendations only. The suitability of these values needs to be evaluated and verified in the final application on a case to case basis.

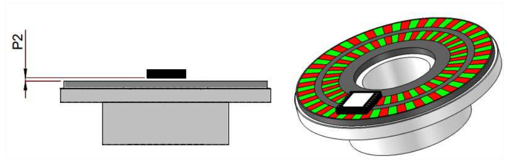

Figure 2: Air gap iC-MU Series to magnetic pole wheel

Figure 3: Radial magnetic pole wheel example

Please refer to iC-MU Series magnetic pole wheel specifications (MU2S, MU18S, or equivalent) for positioning information of iC-MU Series relative to the magnetic pole wheel.

SETUP

The following assumes that the BiSS interface with adaptive timeout is used for calibration. The basic procedure is also valid for calibration via the SPI interface, SPI specific settings have to be considered accordingly.

1. Mount the iC-MU Series magnetic pole wheel and MU1M module according to the mechanical specifications in chapter "MECHANICAL TOLERANCES".
2. Connect the ribbon cable from the MU1M to the MU1D board connector J1.
3. Connect the MB5U adapter to the MU1D board connector J2.
4. Ensure that JP1, JP5 and JP6 are closed. It is recommended to power the MU1D board via an external stabilized and filtered power supply. Ensure that JP2 and JP3 are open in that case. If no external power supply is available the board can also be powered via connector J2 using the MB5U adapter. In this case ensure that JP2 is closed.

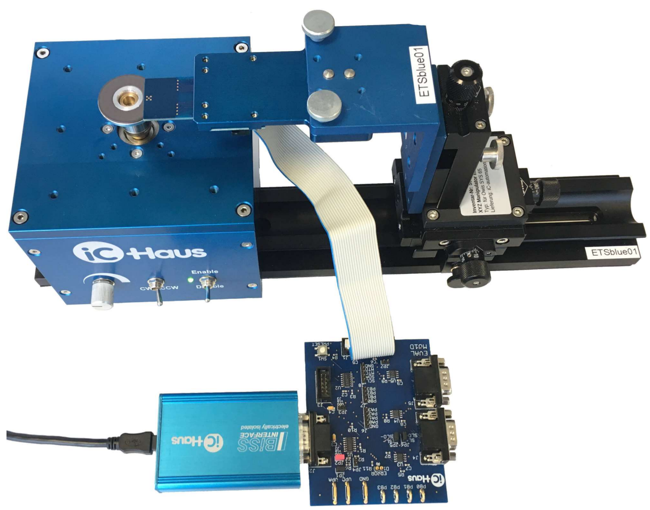

Figure 4: Example iC-MU Series test setup allowing X-, Y- and Z-Axis adjustments

5. Launch the iC-MU Series GUI. (Always ensure that the latest software version is used. It can be found at www.ichaus.com/software).
6. Connect to the iC-MU Series chip by pressing the <Disconnected> button. Verify that the status changes to <Connected>.

i In delivery state MU1M and MU6M are configured to SPI interface. Please refer to the respective evaluation kit specification on how to connect to iC-MU Series via the BiSS interface.

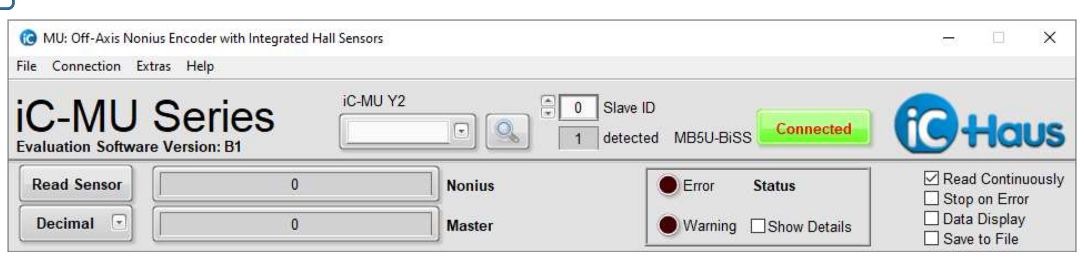

Figure 5: iC-MU Series GUI - Successful connection to the iC-MU Series chip

7. When using the MB5U adapter calibration can only be carried out in BiSS mode. For SPI calibration please use the MB3U-I2C adapter. Please verify that <Port A Configuration> under tab <Interface> is configured to the interface that is to be used for calibration.

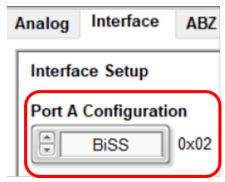

Figure 6: iC-MU Series GUI, Port A configured to BiSS

8. Ensure that <Amplitude Control> is enabled under tab <Analog>.

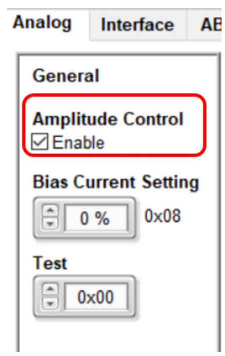

Figure 7: iC-MU Series GUI, Amplitude control enabled

9. Under the <Nonius> tab, select the following:

   (a) Hall Sensor Arrangement: Select <Rotative> for use with axial magnetic pole wheels (e.g. MU2S, MU18S...) or <Linear> for use with radial magnetic pole wheels or linear magnetic tapes (e.g. MU7S, MU1L, MU2L...).

   (b) Set the Master Period Count according to the magnetic pole wheel used (e.g. 32 master track magnetic pole pairs for MU2S / MU18S).

   (c) Filter Features: Select 39dB = 0x04. This is the recommended starting point for conducting the calibration procedure.

It is permissible to use a different filter setting for the calibration procedure. Please note that...

- higher filter settings (e.g. 45dB or 51dB) can reduce noise on the Nonius curve but might prolong the settling time of the analog calibration algorithm.
- lower filter settings (e.g. 27dB or 21dB) can increase noise on the Nonius curve but might shorten the settling time of the analog calibration algorithm.

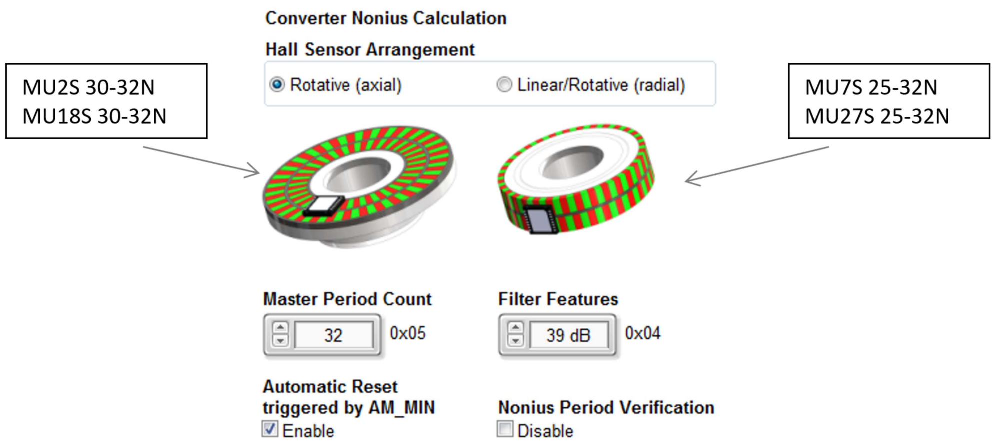

Figure 8: iC-MU Series GUI, <Nonius> tab settings

10. Under tab <CalibSetup> select <Singleturn calibration>.

    The setting of <Calibration Quality Check> determines the behavior of the analog calibration routine if the permissible value range of an iC-MU Series analog compensation parameter is exceeded.

    - Enabled: A warning message is generated and the analog calibration parameter are left unchanged.
    - Disabled: A warning message is generated and the analog compensation parameter are adjusted to the maximum possible compensation value.

    It is recommended to leave <Calibration Quality Check> enabled.

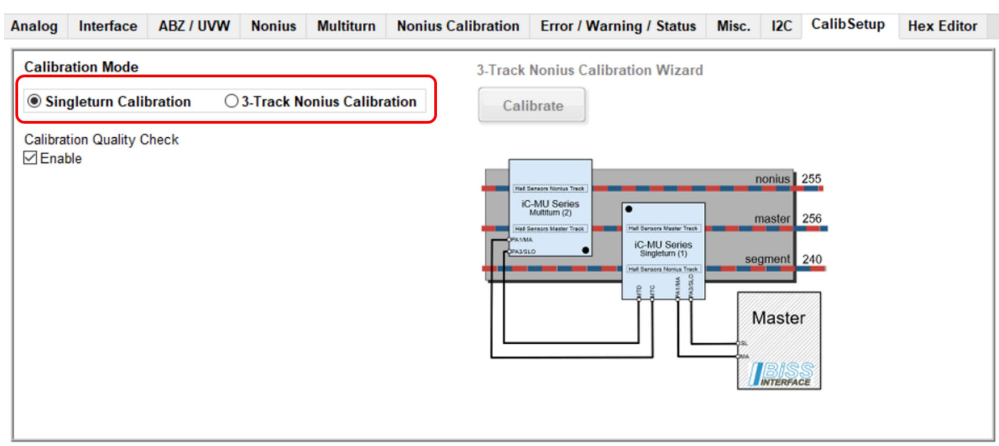

Figure 9: iC-MU Series GUI, <CalibSetup> tab settings

CALIBRATION

11. Calibrate the iC-MU BIAS current as described in the iC-MU Series specification.

The BIAS current calibration is used to equalize chip to chip variations mainly due to the chip manufacturing tolerances. It is prerequisite for adherence to the given electrical characteristics in the datasheet and also instrumental in the determination of the chip timings. The bias current has only to be calibrated once, re-calibration over the lifetime of the device is not necessary.

12. The interface settings for the calibration data acquisition can be adjusted under tab <Analog> → <Settings>, see Figure 10. Please see chapter ANNEX for further information on SPI and BiSS calibration settings.

<SPI Frequency>	The SPI clock frequency for SPI based calibration. The resulting calibration data sampling rate is calculated from the SPI clock rate and the respective payload length.
<BiSS Frequency>	The BiSS clock frequency must be selected so that the desired BiSS frame rate can be achieved. In case the BiSS frequency is too low to support the selected BiSS frame rate an error message is generated by the GUI. The default setting of 2 MHz is recommended.
<BiSS Frame Repetition Rate>	31.25 µs recommended. See ANNEX for further information.
<Calibration Time>	Determines the duration of the calibration data acquisition in seconds. For rotary systems the time should be selected so that multiple revolutions of the magnetic target are measured. The higher the number of recorded revolutions, the better the data averaging.

BiSS calibration is only possible with adapter MB4U or MB5U.

To avoid USB data loss during calibration data acquisition with the MB3U-I2C, MB4U or MB5U adapter...

- do not connect any other USB devices to the same USB bus as the adapter.
- close any unnecessary processes on the PC.

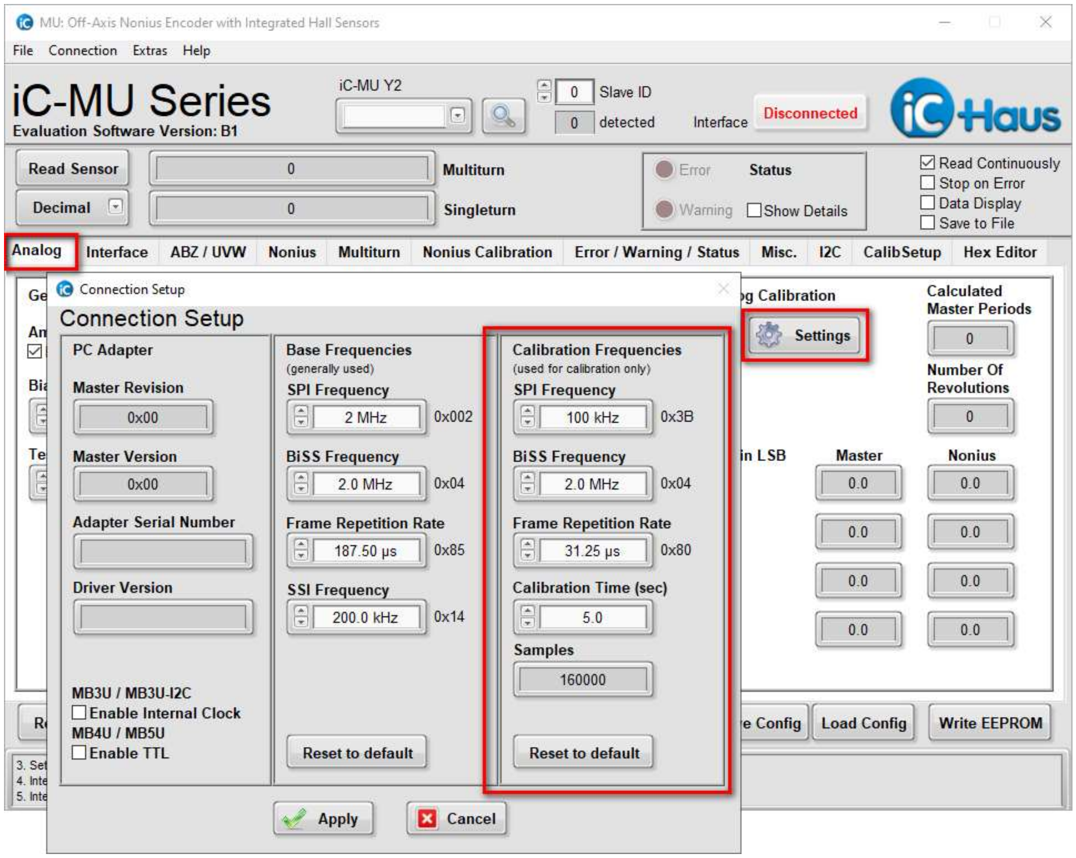

Figure 10: iC-MU Series GUI, Interface Setup

13. The analog calibration should be started with all analog signal conditioning parameters at their default value. The <Reset> button on the <Analog> tab can be used to reset the parameters to their default values.

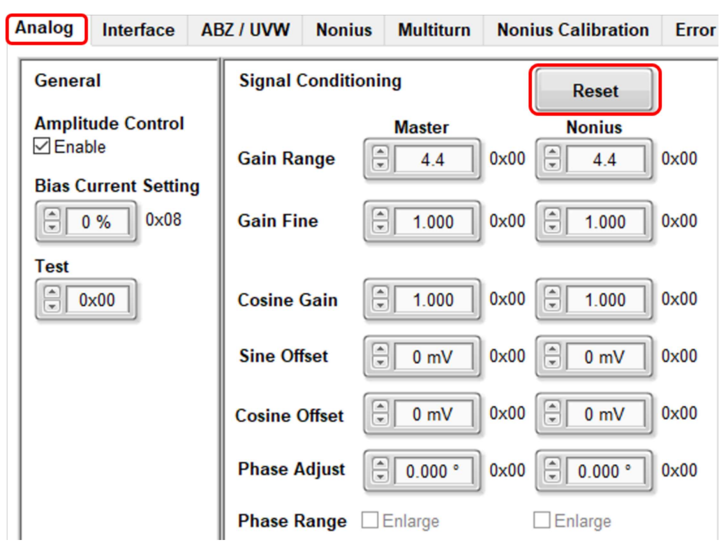

Figure 11: iC-MU Series GUI, Analog calibration - setting default values

For rotary radial or linear encoder systems it may be reasonable to start the analog calibration process with <Phase Adjust> values other than the default value. This is the case if a certain phase correction value is anticipated due to an already known pole pitch mismatch of the magnetic pole wheel / tape.

For examples please check the radial / linear default .cfg files included in the GUI installation folder.

14. The "Automatic Analog Calibration" window is situated on the right hand side of the <Analog> tab. The individual controls and displays are explained below:
    (a) <Acquire Data> - This button starts the calibration routine.
    (b) <Adjust Analog> - When selected the analog calibration is carried out and the signal conditioning parameters (GX_x, VOSS_x, VOSC_x, PH_x, PHR_x) are adjusted accordingly. When the checkbox is deselected the current analog errors are measured only. The signal conditioning parameters remain untouched in that case.
    (c) <Adjust SPO> - When selected the Nonius calibration is carried out and the SPO parameters are adjusted accordingly. When the checkbox is deselected the current Nonius curve is measured only. The SPO parameters remain untouched in that case.
    (d) <Continuous> - When selected the calibration or measurement cycle is repeated until manually stopped. This can be especially useful to continuously observe analog error changes or changes in the Nonius curve when <Adjust Analog> and <Adjust SPO> are both deselected, thus sole measurements are conducted.
    (e) "Residual Errors in LSB" - The residual errors after the calibration routine has been carried out. When <Adjust Analog> is deactivated the measured uncompensated analog errors are displayed.
    (f) "Calculated Master Periods" - The number of magnetic master periods determined by the algorithm. The value needs to match the number of master periods selected by parameter <MPC>.
    (g) "Number Of Revolutions" - Displays how many full mechanical pole wheel revolutions have been recorded during calibration data acquisition. This should always be multiple rotations for rotary systems.

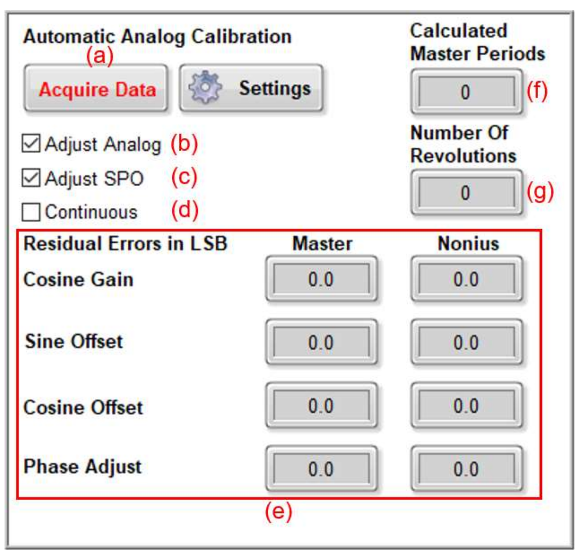

Figure 12: iC-MU Series GUI, Automatic Analog Calibration

15. Rotate the iC-MU Series magnetic pole wheel (please see ANNEX for information on permissible rotation speed). Ensure that both the <Adjust Analog> and <Adjust SPO> checkboxes are selected. Press <Acquire Data> to start the calibration routine.

> **i** If desired it is also possible to conduct the analog and Nonius calibration individually by only selecting the <Adjust Analog> or <Adjust SPO> checkbox. Since both calibrations are necessary for a properly functioning system, it is more convenient to perform both in one pass.

Both the analog and Nonius calibration are now carried out automatically. Calibration data is acquired and the analog compensation values and the <SPO> parameters are adjusted. Finally another measurement is automatically conducted to determine the residual analog errors and display the compensated Nonius curve on the <Nonius Calibration> tab. Please ensure that the magnetic pole wheel keeps rotating until the calibration routine is completely finished.

The rotary motion profile is not critical, but it must be ensured that the requirements in chapter ANNEX are met. During the data acquisition procedure it is permissible to...

- change the direction of motion
- vary the speed of motion
- stop the motion temporarily

16. Review the Analog calibration result. The "Residual Errors in LSB" are shown on the right hand side of the window (see Fig. 13). Ideally these values should be as close to zero as possible, indicating that the analog calibration algorithm determined suitable signal conditioning values. For residual error values significantly greater (e.g. +/-2 or more) the calibration routine may be repeated multiple times to further minimize the residual error.

    If the residual error keeps changing and never settles further troubleshooting of the system should be carried out. Some common issues are:

    - Poor mechanical setup of the system causing excessive mechanical play during calibration.
    - Bad quality or damage of the magnetic pole wheel.
    - Unsuitable calibration data acquisition settings resulting in insufficient data points per magnetic period (see ANNEX).
    - Excessive cogging torque when rotating the magnetic pole wheel.
    - Failure to record at least one full mechanical rotation for rotary systems.

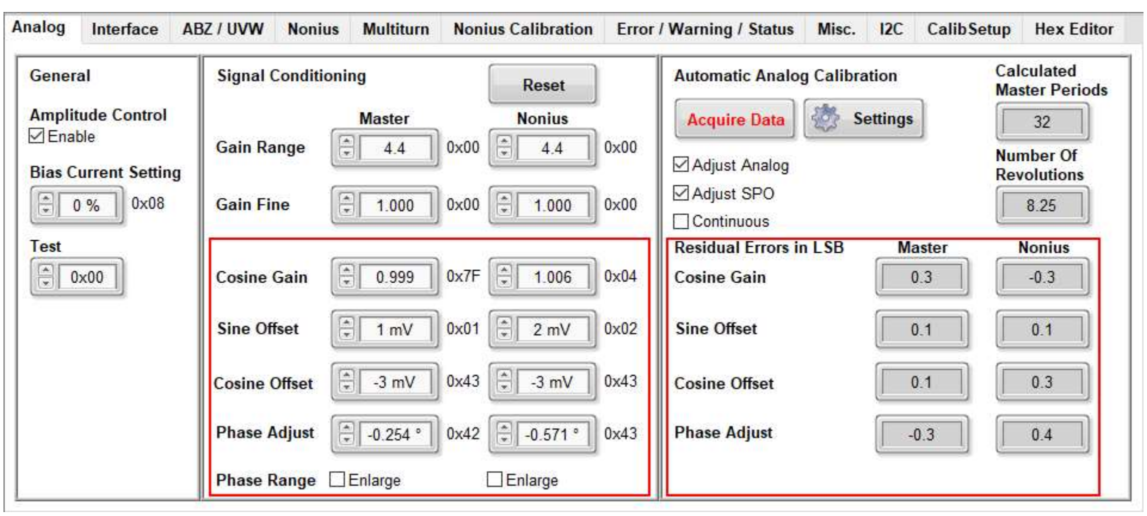

Figure 13: iC-MU Series GUI, Analog Calibration - Signal conditioning values and residual errors in LSB after successful analog calibration

On the left hand "Signal Conditioning" side of the window the analog signal conditioning parameters have been changed to the values determined by the calibration algorithm. The closer these values are to their default values the better the alignment of the iC-MU Series chip to the magnetic pole wheel is. Well aligned systems typically yield the following results:

- All Sine and Cosine Offset values are within +/- 10 mV.
- Both Phase Adjust values are within +/- 2°. For systems with an expected systematic phase error (e.g. radial rotary scanning / linear scanning) the values should be +/- 2° relative to the expected value.

The analog calibration results shown in Figure 13 are considered very good.

The offset and phase signal conditioning limits above are only to be seen as a recommendation. The internal circuitry can compensate for even larger errors. As long as the control limits are not reached the system might still yield acceptable overall performance with a less accurate initial mechanical alignment. This needs to be evaluated and verified in the final application on a case to case basis. Nevertheless it is always advisable to mechanically adjust the system as accurately as possible in the respective application.

17. If the sine/cosine offset or phase adjust signal conditioning values are significantly above the recommended values consider the following:
    - **Sine/Cosine Offset:** Adjust the distance of the iC-MU Series package to the magnetic pole wheel surface (air gap). Typical values are given in Table 2 in chapter "MECHANICAL TOLERANCES". After adjustment repeat the analog calibration starting at Step 13.
    - **Phase Adjust:** Adjust the mechanical position (radial, tangential, or both) of the iC-MU Series chip to the magnetic pole wheel and redo the analog calibration starting at Step 13.

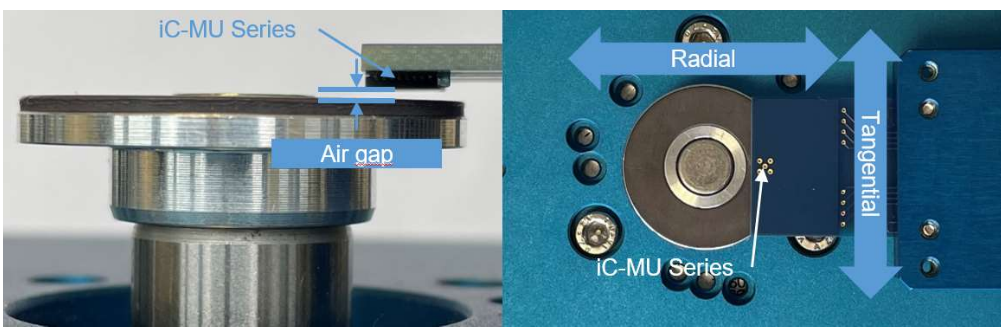

Figure 14: iC-MU Series - Mechanical adjustment

18. After the Analog calibration has been successfully performed, the result of the Nonius calibration (Adjust SPO) needs to be checked. Change to the <Nonius Calibration> tab.

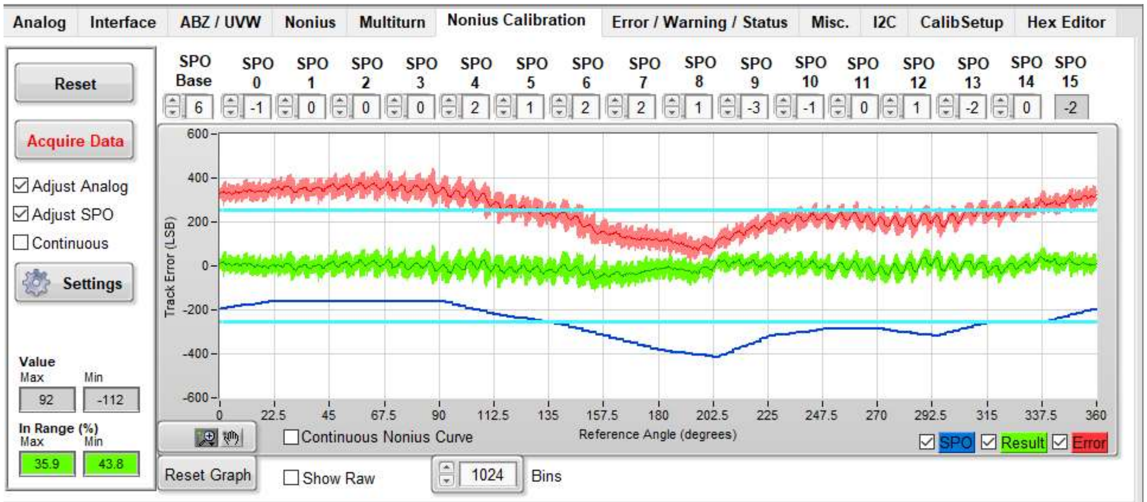

Figure 15: iC-MU Series GUI, Nonius calibration result

If selected three curves are shown:

- Red curve (Error): This is the uncorrected Nonius error curve
- Blue curve (SPO): This is the calculated correction curve
- **Green curve (Result):** This is the corrected Nonius curve.

The Nonius calibration is successful when the resulting green curve is centered between the limits marked by the bright blue lines with enough margin to either side. Keeping both the "In Range Max" and "In Range Min" values below 60% is recommended. This is equal to a Nonius margin of at least 40% to either side. Figure 16 below shows the definition of the nonius margin.

upper margin = 100% - "In Range Max"

lower margin = 100% - "In Range Min"

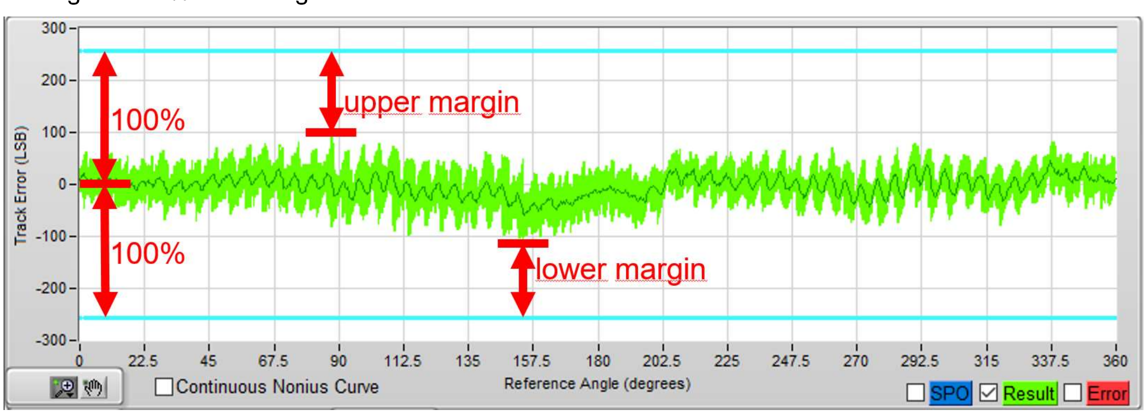

Figure 16: Calculation of the Nonius phase margin

The Nonius curve is affected by mechanical movement of the iC-MU Series relative to the magnetic target after the calibration has been conducted. Always ensure that the Nonius curve stays within the required limits under all operating conditions (especially temperature range) of the encoder system.

This can be checked by deselecting the <Adjust Analog> and <Adjust SPO> checkboxes, rotating the target and pressing the <Aquire Data> button. This performs a measurement only, and allows to monitor the Nonius curve without adjustments to the signal conditioning or SPO parameters. The checkbox <Continuous> may be selected to loop the measurements until manually stopped.

When <Continuous Nonius Curve> is selected, the Nonius curve is displayed continuously over several revolutions. This feature can be useful to monitor a mechanical movement of the iC-MU Series relative to the magnetic target that happens over multiple rotations.

See Figure 17 for an example of the effect of a mechanical wobble over approx. 10 mechanical rotations on the continuous Nonius curve.

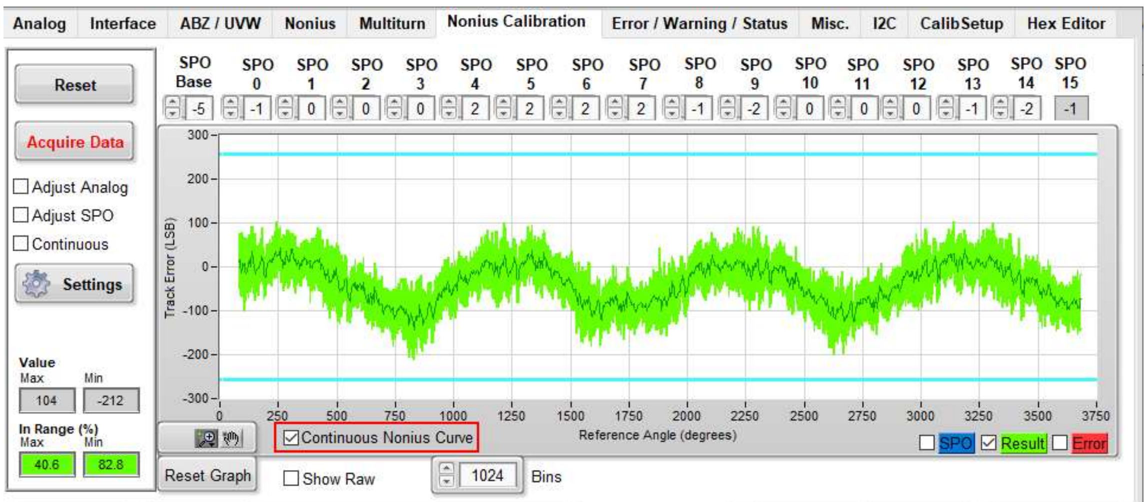

Figure 17: Example of continuous Nonius curve with mechanical wobble

If the Nonius margin is insufficient, further troubleshooting of the system needs to be conducted. Some common issues are:

- Poor chip to magnetic pole wheel alignment (radial, tangential or axial).
- Excessive mechanical play of the encoder system.
- Poor or missing analog calibration.
- Poor quality of the magnetic target.
- Wrong chip configuration.

19. After successful Nonius calibration select the <Error/Warning/Status> tab (Figure 18) and perform the following:

    (a) Under Status Register Configuration select <Accumulated>.
    This causes any status flags to be latched. The status flags are only reset if the status register is read and the underlying error condition is no longer present.

    (b) Select the <Show Details> checkbox. This will bring up the Status Information Window (see Figure 19).

    (c) Rotate the magnetic pole wheel and press the <Read Status> button in the Status Information Window after at least one full rotation of the magnetic target has been completed. No errors should be present.

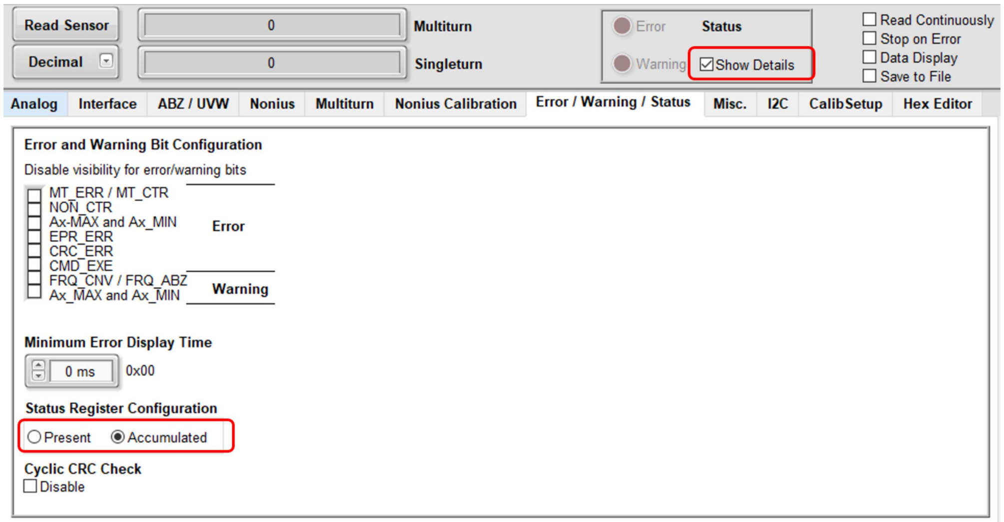

Figure 18: iC-MU GUI, <Error/Warning/Status> tab settings

Below is a summary of some common status flags that might be set at this point. Please always consult the respective iC-MU Series datasheet for in depth information on the status register:

- **Signal Error Clipping or Poor Level (AN_MAX, AM_MAX, AN_MIN, AM_MIN):** This indicates that the iC-MU-Series automatic amplitude control is close to the control limits. Ensure that the air gap is adjusted according to Table 2.
- **Invalid checksum internal RAM (CRC_ERR):** The CRC_ERR is set if the cyclic CRC check is configured by NCHK_CRC=0 and any changes to the RAM parameter settings are made without recalculating the checksum (command CRC_CALC) or writing to the EEPROM (command WRITE_ALL). This status flag may be safely ignored if iC-MU Series parameters are still adjusted during the setup and calibration procedure.
- **Period counter consistency error (NON_CTR):** This status flag is active if the computation of the absolute position fails at certain points of the magnetic code wheel. The absolute position can be incorrect. It is required to check the Nonius calibration and Nonius phase margin again.

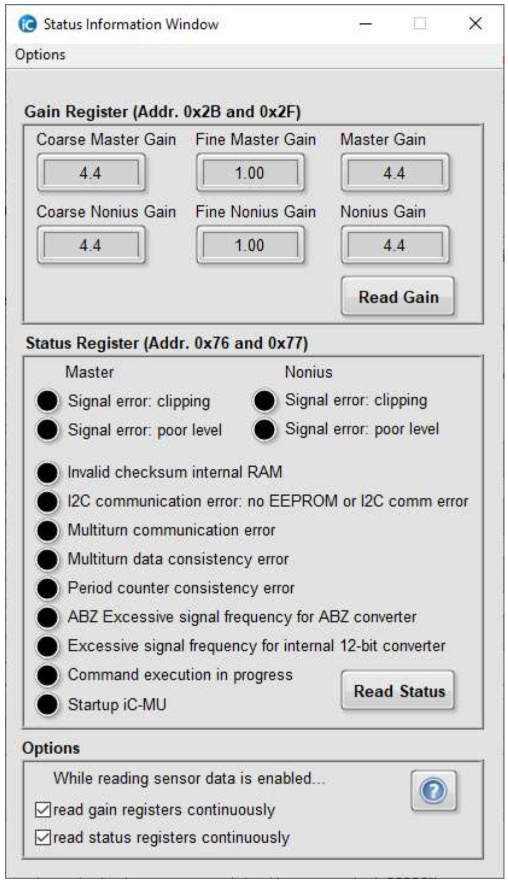

Figure 19: iC-MU Series GUI, Status Information Window

20. After successful Analog and Nonius Calibration and with no active Error/Warning flags the calibration is complete. Press <Write EEPROM> at the bottom of the GUI screen to store the settings in the connected EEPROM.

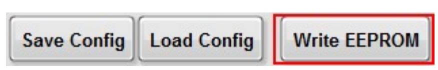

Figure 20: iC-MU Series GUI, Write EEPROM button

21. The calibration is now complete.

It is recommended to always check the quality of the calibration with suitable external measurement tools.

LINEAR CALIBRATION

The calibration procedure for linear measurement applications is mostly identical to the calibration of rotative applications. Differences are highlighted below.

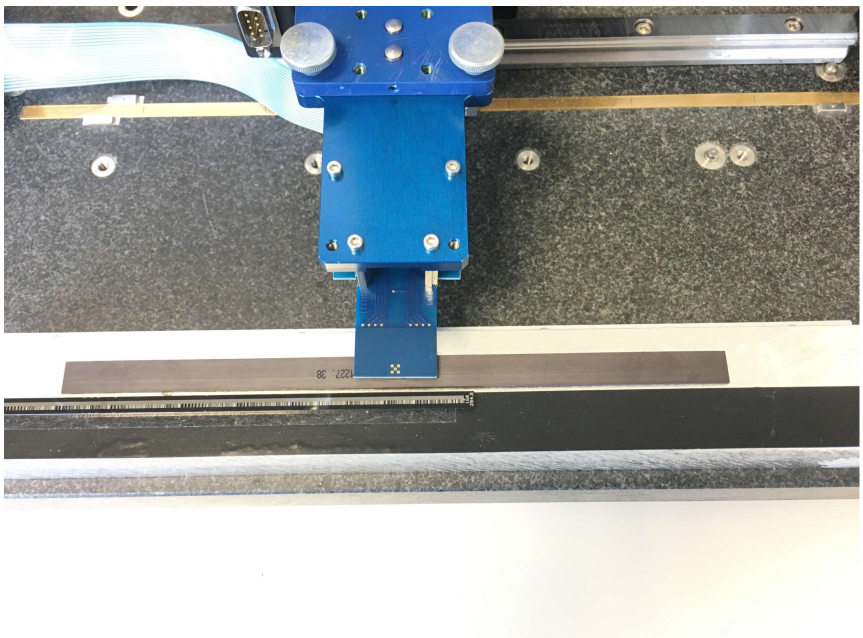

Figure 21: Linear measurement setup example

1. Ensure that <Linear/Rotative (Radial)> is selected under Hall Sensor Arrangement in Step 9. All other settings in Step 9 and 10 can stay the same as for the rotary calibration.
2. Choose the <Calibration Time> in Step 12 so that the linear measurement range is scanned multiple times. Please note that the linear motion needs to continue until the calibration routine is completely finished.

> **i** Only the linear measurement range that is to be used in the application needs to be calibrated.

3. Start the linear movement and conduct the calibration routine as per Step 15. As for the rotary motion profile the linear motion profile is also not critical.
4. Evaluate the Analog and Nonius calibration and finalize the calibration procedure as described in Step 16 and following. Please note that with linear measurement systems an excessive phase error (step 17) can be caused by a rotation of iC-MU Series to the magnetic tape about its own axis (see Figure 22).

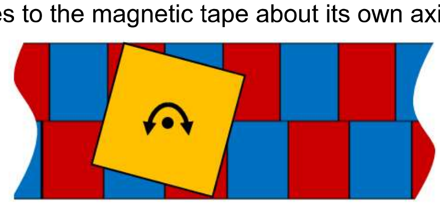

Figure 22: Linear measurement setup - Rotation of iC-MU Series about its own axis

ROTARY CALIBRATION PROCEDURE FLOWCHART

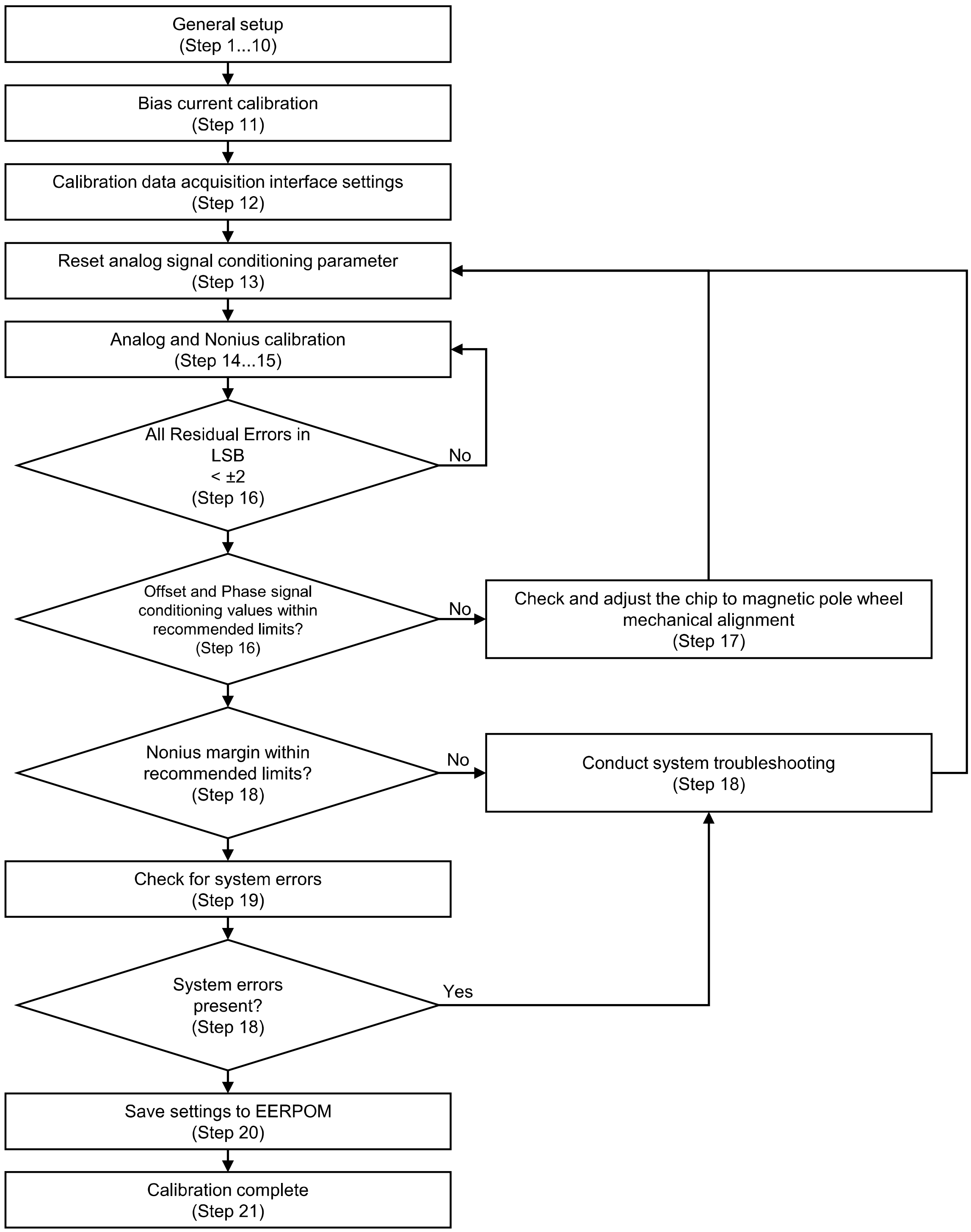

Figure 23: Rotary Calibration Procedure Flowchart

ANNEX

Analog calibration algorithm sampling requirements

For good calibration results a minimum of 128 samples per magnetic period (also referred to as electrical period) are required. A higher number of samples improves data averaging of the analog calibration algorithm. The total number of recorded samples must be at least 2048. This is relevant for linear systems, where only a small number of magnetic periods might be scanned.

Calibration via BiSS interface

A BiSS frame rate of 31,25µs is practical in most application scenarios and allows reasonable rotation or linear speeds during calibration data acquisition. For lower BiSS clock frequencies or low performance PCs it might be necessary to increase the BiSS frame rate e.g. to 62,5µs or higher to avoid data loss during calibration data acquisition.

Rotary Analog Calibration

Due to the requirements of at least 128 samples per magnetic period the maximum permissible rotation speed for a specific BiSS Frame Rate can be calculated as:

$$RPMmax\,[\frac{1}{min}] = \frac{60}{\text{BiSS Frame Rate [s]} \times MPC \times 128}$$

Example: 31,25 µs BiSS Frame Rate and 32 Master pole pairs magnetic pole wheel:

$$\frac{60}{31,25 \times 10^{-6}\,s \times 32 \times 128} = 468,8\,[\frac{1}{min}]$$

Linear Analog Calibration

Due to the requirements of at least 128 samples per magnetic period the maximum permissible linear motion speed for a specific BiSS Frame Rate can be calculated as:

$$Vmax\,[\frac{m}{s}] = \frac{MagneticPeriod\,[m]}{\text{BiSS Frame Rate [s]} \times 128}$$

Example: 31,25 µs BiSS Frame Rate and 4 mm magnetic period:

$$\frac{0,004\,m}{31,25 \times 10^{-6}\,s \times 128} = 1\,[\frac{m}{s}]$$

Calibration via MB3U-I2C SPI interface

For the MB3U-I2C adapter the SPI Frame Rate can be estimated as follows:

$$SPIFrameRate\,[s] = \frac{40}{\text{SPI Frequency [Hz]}} + 3 \times 10^{-6}\,[s]$$

Rotary Analog Calibration

Due to the requirements of at least 128 samples per magnetic period the maximum permissible rotation speed for a specific SPI frequency can be calculated as:

$$RPMmax\,[\frac{1}{min}] = \frac{60}{\text{SPI Frame Rate [s]} \times MPC \times 128}$$

Example: 100 kHz SPI frequency and 32 Master Pole Pairs magnetic pole wheel:
According to the formula above the SPI Frame Rate for 100 kHz SPI frequency is $403 \times 10^{-6}\,s$. The maximum permissible speed of rotation can then be calculated as:

$$\frac{60}{403 \times 10^{-6}\,s \times 32 \times 128} = 36,3\,[\frac{1}{min}]$$

Linear Analog Calibration

Due to the requirements of at least 128 samples per magnetic period the maximum permissible linear motion speed for a specific SPI Frame Rate can be calculated as:

$$Vmax\,[\frac{m}{s}] = \frac{MagneticPeriod\,[m]}{\text{SPI Frame Rate [s]} \times 128}$$

Example: 100 kHz SPI frequency and 4 mm magnetic period:
According to the formula above the SPI Frame Rate for 100 kHz SPI frequency is $432.5 \times 10^{-6}\,s$. The maximum permissible linear speed can then be calculated as:

$$\frac{0,004\,m}{403 \times 10^{-6}\,s \times 128} = 0.0775\,[\frac{m}{s}]$$

REVISION HISTORY

Rel.	Rel. Date*	Chapter	Modification	Page
D1	2022-02-02	All	Initial release for GUI revision B1 or later.	all

* Release Date format: *YYYY-MM-DD*