Application Note

MLX90381 End of Line Calibration

Contents

1. Scope

The document explains the End of Line calibration / signal processing to compensate the non-ideal magnetic field angle components of the application. In this document you will find an overview of the contributors to the angle nonlinearity error in the application, calibration methods that can be used to reduce the angle nonlinearity error and an explanation on the calibration of the gain and offset of the sensor in the application.

2. Related Documents, Products and Tools

Related Products

- MLX90381 - Triaxis® pico-resolver

Related Documents

- Datasheet MLX90381
- Application Note MLX90381 I^{2}C Communication Protocol for End of Line Calibration
- Application Note Magnet-sensor positioning for Off-Axis and Through-Shaft applications [1]

Related Tools

- http://www.melexis.com/magnetic-design-simulator

3. Glossary of Terms

Gauss (G) / Tesla (T)	Units for the magnetic flux density: 1 mT = 10 G.
NLE	Nonlinearity error of the output angle.
SMM	Sensitivity mismatch: difference in sensitivity between OUT_1 and OUT_2 signal of the sensor + difference in amplitude between B_1 and B_2 components of the magnet.
OMM	Offset mismatch: difference in offset (V_{OQ}) of OUT_1 and OUT_2 vs. 50%V_{DD} offset level + difference in offset level between B_1 and B_2 components of the magnet.
DP	Discontinuity Point.
PHI	Signal phase shift.
ORTH β	Orthogonality error of the module β_{IMC}, β_{Magnet} and β_{RPM}.
τ_D	Tracking Delay in in micro seconds.
τ_{ORTH}	Phase delay between SIN and COS output in micro seconds.
V_{OQ}	Output Quiescent Voltage (%V_{DD}): output level when magnetic flux density = 0mT.
$\varepsilon^T V_{OQ}$	Output Offset Temperature Drift.
S	Sensitivity of the hall element times the gain of the amplifier (%V_{DD}/mT).
LIN	Signal nonlinearity
SPAN	Peak to peak value of the output signal after one full 360-degree period.
OFFSET	Mean or average value of the output signal after one full 360-degree period.
µC	Micro controller
RPM	Revolutions Per Minute

[1] *Available via Softdist. Request an access to your local representative*

4. Angle Nonlinearity – Component Description

4.1. Introduction

This section of the application note explains the different components of the angular nonlinearity. It will help you understand the total error budget of your application and the MLX90381 and how to recognize the different nonlinearity components.

The MLX90381 is a monolithic sensor IC sensitive to the flux density applied orthogonally and parallel to the IC surface. The MLX90381 can sense the magnetic flux density in 3 directions: X-Y-Z. The 2 outputs can be assigned to either X, Y, or Z making the sensor compatibility with End-of-shaft and through-shaft magnetic configurations.

This application note uses B_1 and B_2 to address the 2 magnetic field components used for the angle calculation. B_1 and B_2 can be B_X and B_Y, B_X and $B_{Z,}$ or B_Z and B_Y, depending of the sensor axis mode configuration.

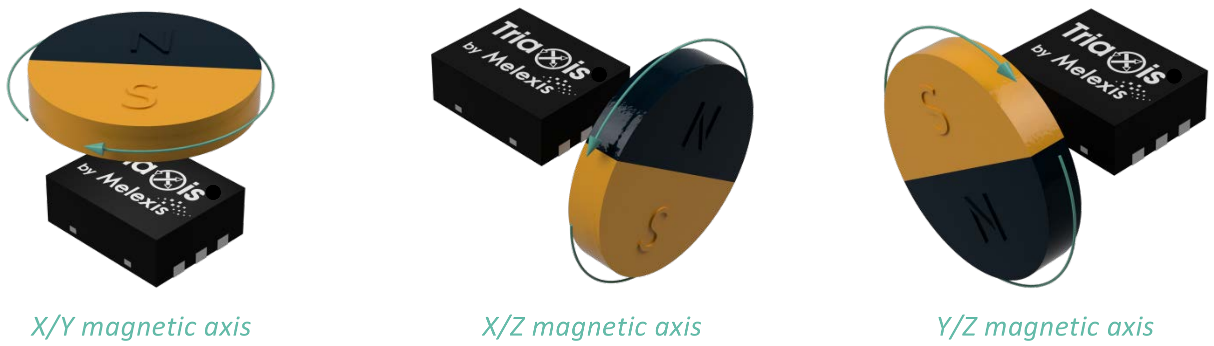

Figure 1: Magnetic axis – depicted as end-of-shaft for all three modes

4.2. Description

4.2.1. Sensor

The embedded micro controller or ECU of the module performs the signal processing on the angle information, the SIN/COS signal from the MLX90381. The angle α is calculated from the arctangent of SIN and COS:

$\alpha = atan2(SIN, COS)$ or $\alpha = atan2(OUT_2, OUT_1)$

The sensors OUT_1 and OUT_2 output voltages are proportional to the applied magnetic field components. B_1 and B_2 are the components of the applied magnetic field angle.

$OUT_1 = V_{OQ1} + S_1 \times B_1$ and $OUT_2 = V_{OQ2} + S_2 \times B_2$

Where:
V_{OQ} is the offset level of the analog signal (%V_{DD}) (temperature dependent).
S is the sensitivity of the hall element times the gain of the amplifier (%V_{DD}/mT) (temperature dependent).

The MLX90381 is programmable sensor which allows an End of Line calibration of the magnetic parameters of the sensor during final test. This calibration is performed in the application. S_1, S_2, V_{OQ1} and V_{OQ2} are calibrated for a minimum sensitivity mismatch SMM and offset mismatch OMM.

The offset drift ($\varepsilon^T V_{OQ}$), orthogonality error ($\beta_{IMC} + \beta_{RPM}$), output driver linearity (LIN) and signal phase shift (PHI_{RPM}) are parameters which cannot be calibrated with a sensor parameter. They need to be corrected by the ECU.

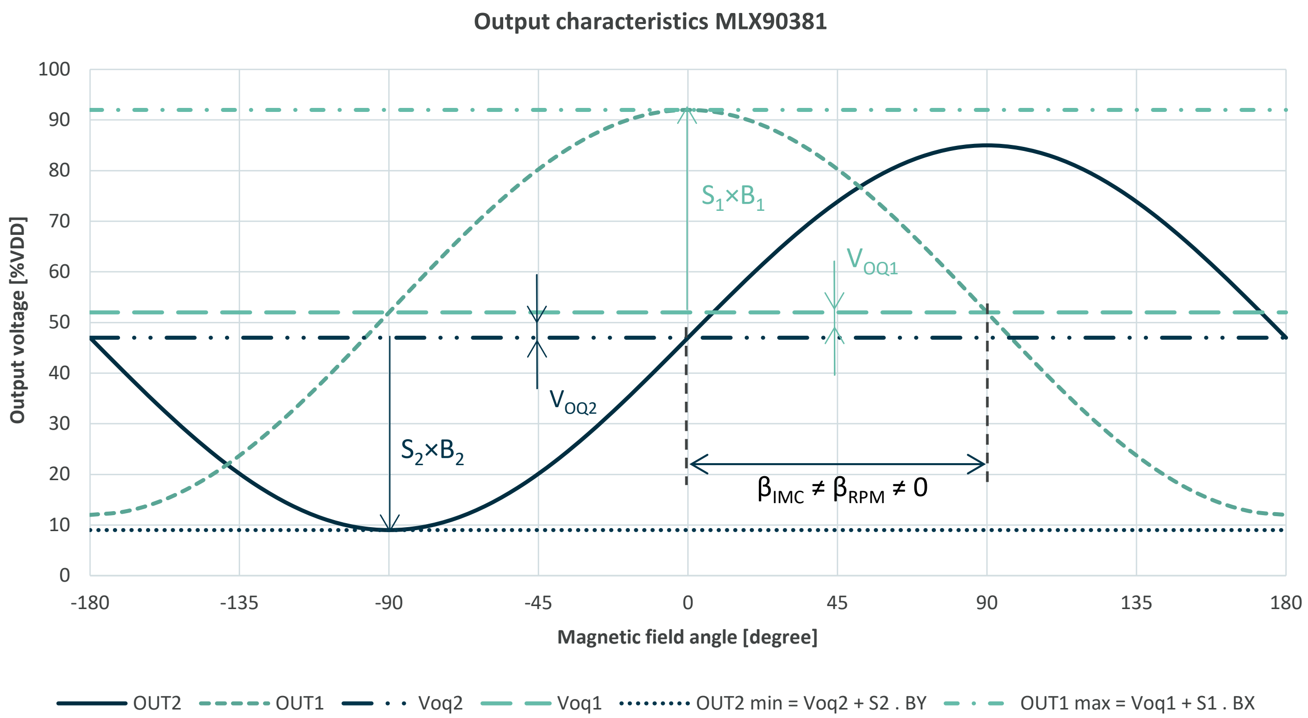

Figure 2: Output characteristics MLX90381

4.2.2. Magnet

To have the optimum linearity with respect to a magnet position α, the signals B_1 and B_2 should be described as follows:

$$B_1 \div \sin(90° - \alpha) \div \cos\alpha$$

$$B_2 \div \sin\alpha$$

In reality, the **magnetic field** at the **sensor element**, can be described according to the following formulas:

$$B_{1,A} = B(T) \times \sin(90° - \alpha + \beta_{Magnet})$$

$$B_1 = B_{1,O}(T) + B_{1,A}$$

$$B_{2,A} = B(T) \times \sin(\alpha)$$

$$B_2 = B_{2,O}(T) + B_{2,A}$$

Where:
T is the temperature.
$B_{1,O}$ is the component B_1 offset (temperature dependent).
$B_{2,O}$ is the component B_2 offset (temperature dependent).
β_{Magnet} is the orthogonality error or phase error between the 2 components of the field.
$B_{1,A}$ is the component B_1 amplitude (temperature dependent).
$B_{2,A}$ is the component B_2 amplitude (temperature dependent).

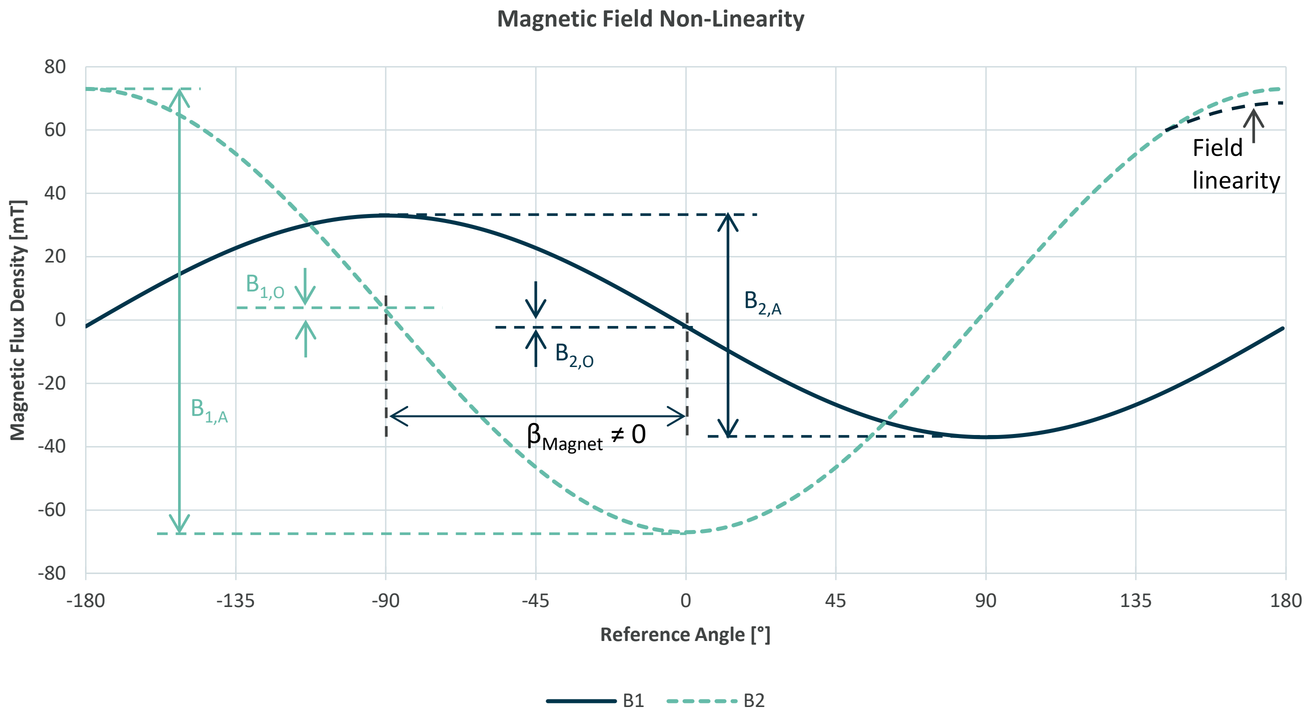

Figure 3: Non-ideal behaviors of the sine and cosine signals

4.2.3. Module

Before the arctangent calculation, the ECU needs to perform some signal corrections to compensate the non-ideal behavior of the sine and cosine signals.

Those non-ideal behaviors can be split in five main categories:

Signal Phase Shift: $PHI = PHI_{RPM} + PHI_{DP}$

Orthogonality Error: $ORTH = \beta_{Magnet} + \beta_{IMC} + \beta_{RPM}$

Offset mismatch:

$$OMM_1 \ = \ B_{1,O} \neq 0 + \ \varepsilon^T B_{1,O} \neq 0 + V_{OQ1} \neq 50\%V_{DD} + \varepsilon^T V_{OQ1} \neq 0$$
$$OMM_2 \ = \ B_{2,O} \neq 0 + \ \varepsilon^T B_{2,O} \neq 0 + V_{OQ2} \neq 50\%V_{DD} + \varepsilon^T V_{OQ2} \neq 0$$

The offset mismatch is the difference in offset (V_{OQ}) of OUT_1 and OUT_2 vs. 50%V_{DD} offset level + difference in offset level between B_1 and B_2 components of the magnet. Both sensor and magnet/module have temperature dependent components.

Sensitivity Mismatch: $SMM \ = \ B_{1,A} \neq B_{2,A} + S_1 \neq S_2$

The sensitivity mismatch is the difference in amplitude between OUT_1 and OUT_2 signal of the sensor + difference in amplitude between B_1 and B_2 components of the magnet.

Signal/Field Non-Linearity:

$$LIN_1 = B_1 \neq B \times \cos(\alpha)$$
$$LIN_2 = B_2 \neq B \times \sin(\alpha)$$

The non-ideal behavior of the sine and cosine signals depends on the type of application, magnetic construction of the application and the magnetization of the magnet.

For end-of-shaft applications, the non-ideal behaviors are relatively small as the flux density and the curve of the field lines remain fairly stable at the sensing point of the magnetic field angle while the magnet turns. “The sensor always measures the angle of the same field lines”.

For through-shaft applications the non-ideal behaviors are larger as the variation in flux density and the curve of the field lines are larger at the sensing point of the magnetic field angle while the magnet turns. “The sensor crosses different field lines”.

On module level the MLX90381 programmability of the parameters S_1, S_2, V_{OQ1} and V_{OQ2} can be used to calibrate the gain and offset of the sensor to fit with the $B_{1,A}$, $B_{2,A}$ and $B_{1,O}$, $B_{2,O}$ of the applied magnetic field.

What remains a residual SMM and OMM of the sensor plus magnet and the ORTH, PHI and LIN.

The following sections describe the five main categories in more detail.

4.3. Signal Phase Shift

The signal phase shift error or PHI_{RPM} is a tracking delay between the B1 - B2 components of the magnetic field and the analog output signal, OUT1 - OUT2. The PHI_{DP} is a static point that represents the 0-angle position of the application versus the 0-angle of the magnetic angle.

The tracking delay is determined by the output update period and the bandwidth settings of the filter. The tracking delay τ_D, is a constant delay expressed in µs. Please refer to the MLX90381 datasheet for the specifications.

The PHI_{RPM} is the absolute angle offset error (magnet angle vs. sensors output angle) in function of the magnet rotation speed.

$$PHI_{RPM} = \tau_D \times \frac{RPM}{166666.6667}$$

$$NLE_0 = a_0 = PHI_{RPM} + PHI_{DP}$$

Figure 4 shows the PHI_{RPM} error for 500, 2500, 5000, 25000 and 50000RPM for high bandwidth caused by τ_D.

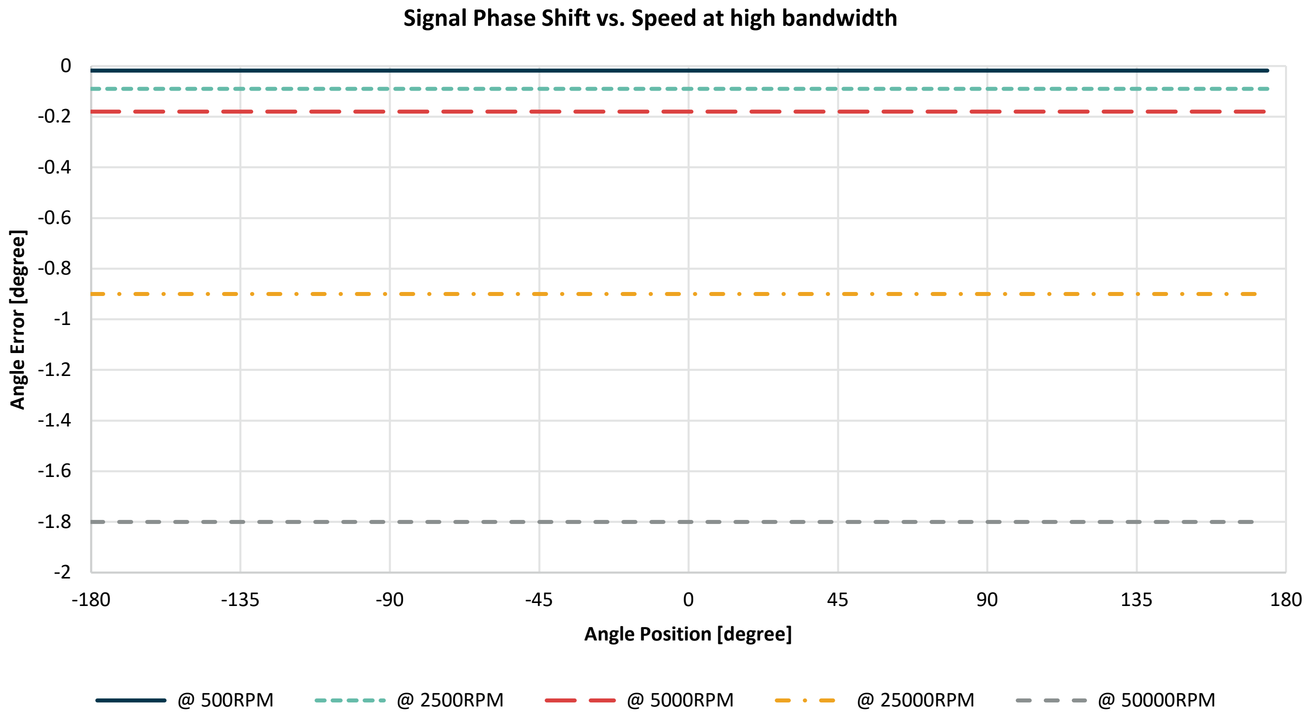

Figure 4: Signal phase shift vs. rotation speed

4.4. Orthogonality

The orthogonality error, also called the quadrature error, is a phase error between the sine and cosine signals, OUT_2 and OUT_1. This means that the phase separation of these two signals is not exactly 90 degrees. It translates into a double-period signal like the sensitivity mismatch error but in this case, it is unipolar, either positive or negative depending on the assignment of sine and cosine to OUT_2 and OUT_1 of the MLX90381 sensor.

The orthogonality error has 3 components: β_{Magnet} is the magnetization of the magnet; β_{IMC} is the misalignment of the IMC on the hall-plates; and β_{RPM} is the phase delay τ_{ORTH} between the OUT_2 and OUT_1 signal in function of the applied angle speed. The τ_{ORTH} of the sensor is a constant of 1µs.

$$\beta_{RPM} = \tau_{ORTH} \times \frac{RPM}{166666.6667}$$

$$a_4 = \beta_{RPM} + \beta_{IMC} + \beta_{Magnet}$$

$$NLE_4 = a_4 \times cos(\alpha)^2$$

Figure 5 shows the β_{RPM} for 500, 2500, 5000, 25000 and 50000RPM caused by τ_{ORTH}.

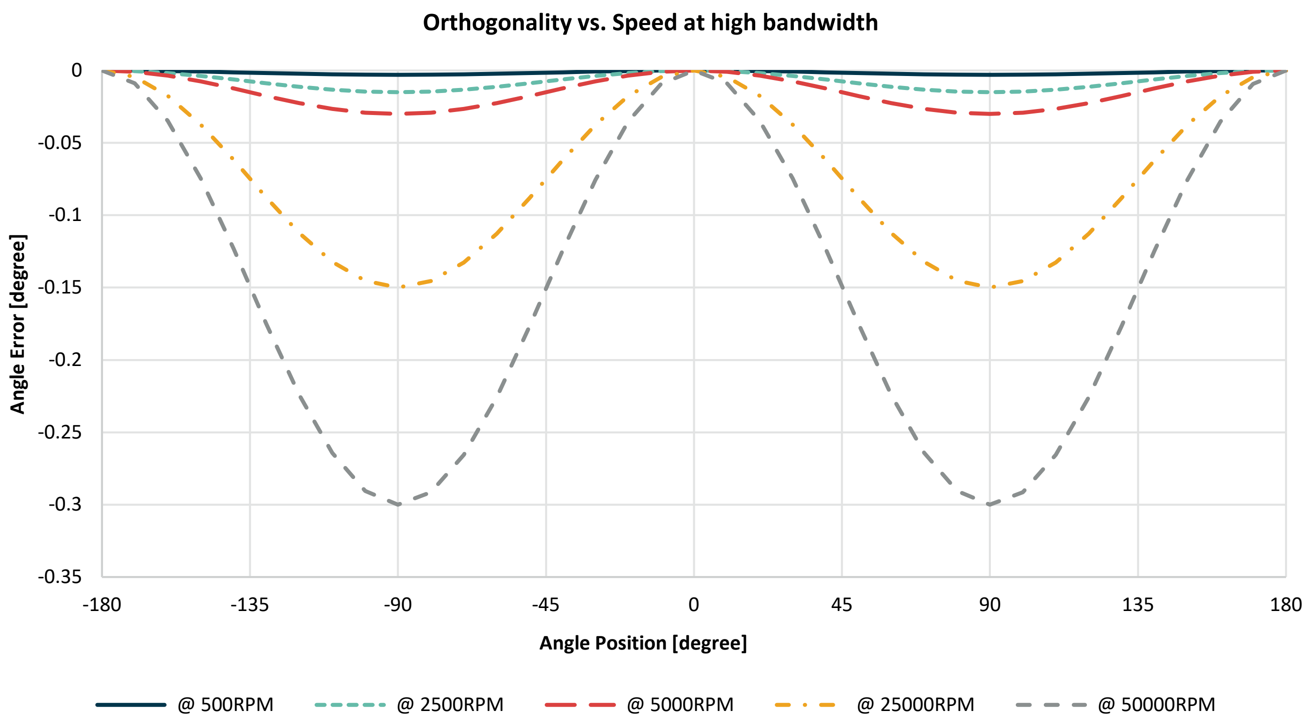

Figure 5: Orthogonality vs. rotation speed

4.5. Offset Mismatch

Through the on-chip dynamic offset cancellation mechanism (Hall plate spinning and chopper stabilized amplifier) and the calibration of the signal offset OUT_2 and OUT_1 ($V_{OQ1} = V_{OQ2} = 50\%V_{DD}$), the analog signals may show a residual offset and an offset of the magnetic design. Figure 6 and Figure 7 show the influence of the offset error (OMM vs. $50\%V_{DD}$) on the angular nonlinearity for various values of OMM= 0.2, 0.5, 1, 1.5 and 2.5 $\%V_{DD}$. Figure 8 shows the angle nonlinearity when both OUT_1 and OUT_2 have an offset error. The signature of the offset error is one period over 360 degrees.

$$NLE_{1,2} = a_1 \times \sin(\alpha) + a_2 \times \cos(\alpha)$$

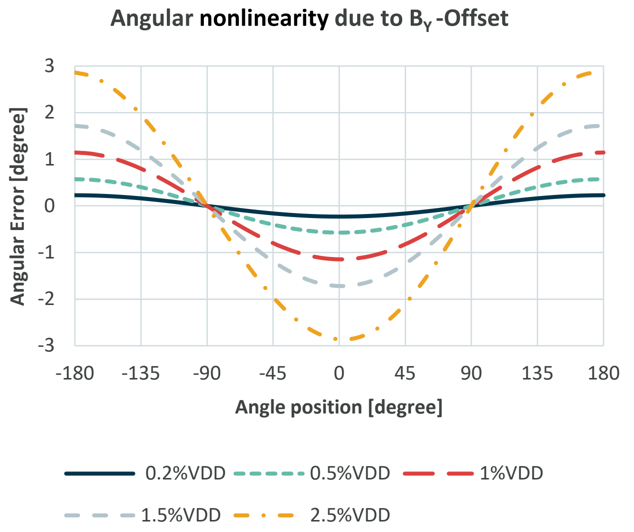

Figure 6: Offset on B_Y

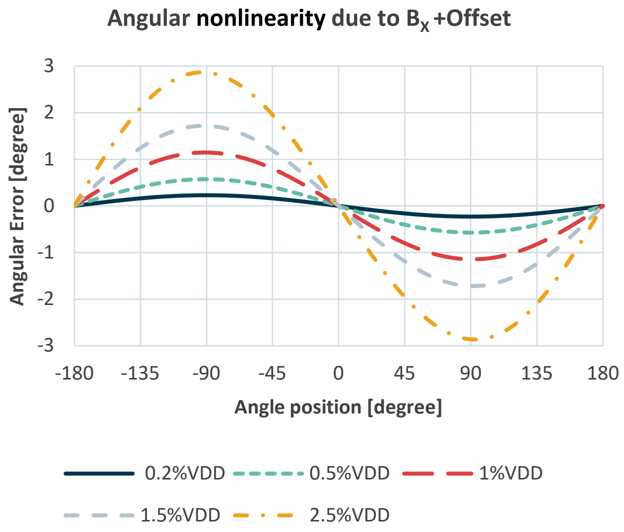

Figure 7: Offset on B_X

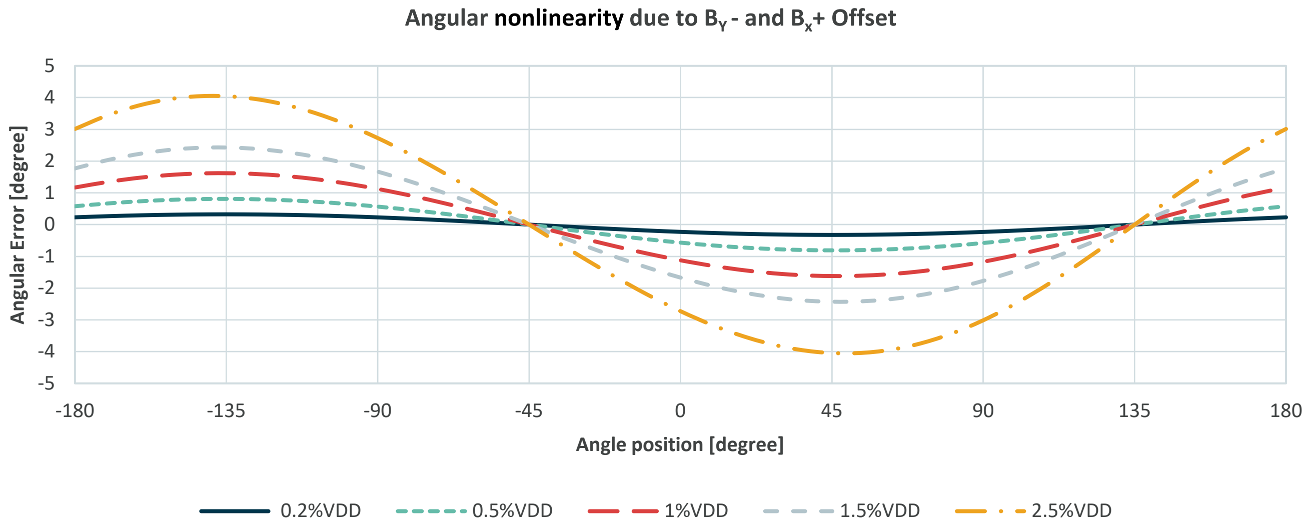

Figure 8: Offset on B_X and B_Y

The offset seen on the two output signals of the sensor, when a rotating magnet is applied, is a combination of temperature dependent offset of the magnetic field and the temperature dependent offset of the sensor.

The offset of the sensor and magnet at room temperature can be compensated by the V_{OQ} level of the sensors output drivers. See chapter: Calibration Sequence Sensor Parameters. The temperature dependent component, the offset drift, cannot be compensated by the sensor.

The output offset temperature drift of the sensor also depends on the sensitivity or gain programmed in the sensor. The chart below shows the typical output offset temperature drift characteristics for the full magnetic range for 125°C and 160°C. The higher the gain, the higher the output offset temperature drift of the sensor. Therefor it is better to have a strong magnetic field in the application, to reduce the effect of the output offset temperature drift on the angle accuracy in the application.

The output offset temperature drift of the MLX90381 is specified in the magnetic specifications of the datasheet. The output offset temperature drift plotted below is made from characterization data of a small population of samples and is indicative, see also the datasheet of the MLX90381.

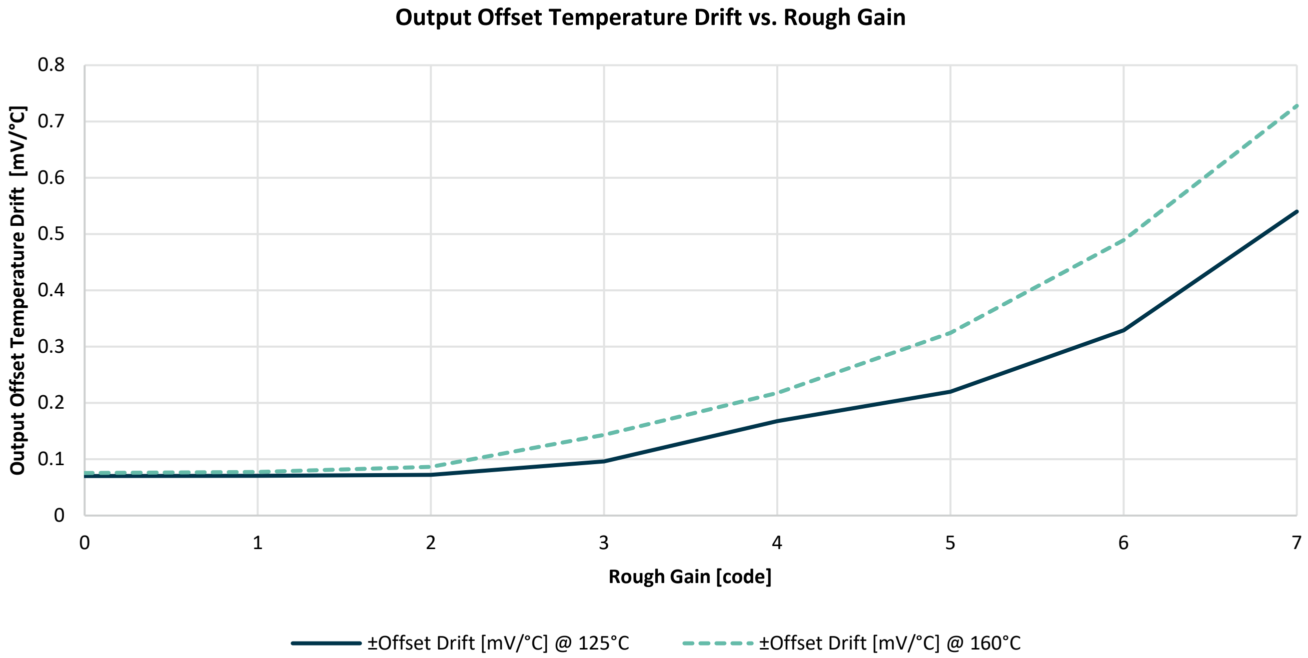

Figure 9: Output offset temperature drift vs. rough gain

4.6. Sensitivity Mismatch

The sensitivity mismatch depends on the selected magnetic axis configuration and the type of application.

For end-of-shaft applications, the amplitude mismatch of B_X - B_Y components is relatively small as the flux density and the curve of the field lines remain fairly stable at the sensing point of the magnetic field angle while the magnet turns. “The sensor always measures the angle of the same field lines”.

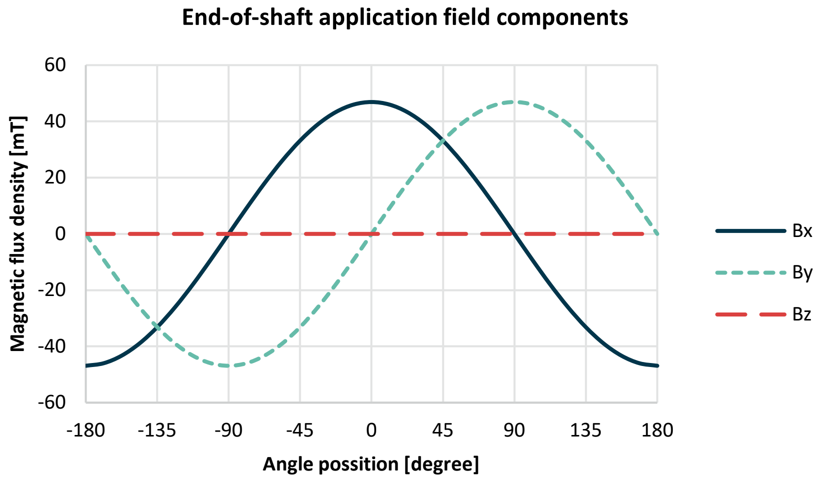

Figure 10: End-of-shaft application field components

End-of-Shaft

For through-shaft or off-axis applications the amplitude mismatch of B_Y – B_Z components is larger as the variation in flux density and the curve of the field lines are larger at the sensing point of the magnetic field angle while the magnet turns. “The sensor crosses different field lines”.

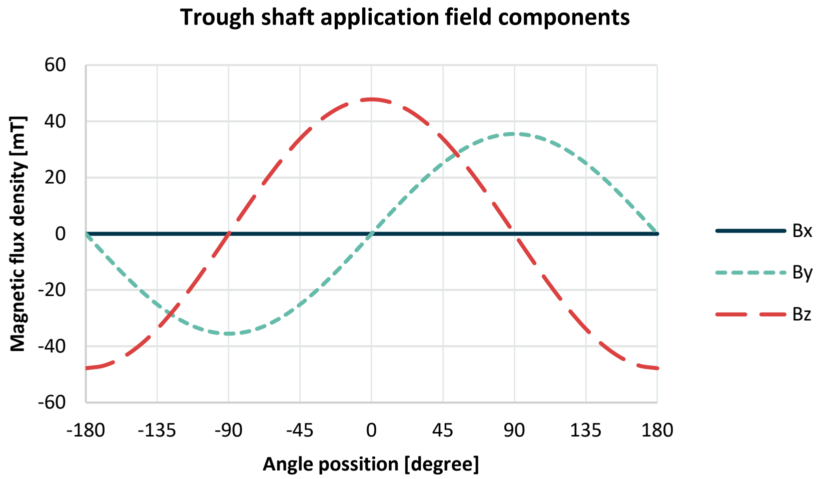

Figure 11: Through-shaft or off-axis application field components

Through-Shaft

Figure 12: Application modes

Next to the amplitude mismatch of the B_X - B_Y, B_Z - B_Y components, there is also a residual sensitivity mismatch of the two output signals of the sensor. Although all Hall signals (V_{HX}, V_{HY} and V_{HZ}) are generated by matched Hall Plates and amplified though a calibrated amplification chain, the two signals may show a residual difference in amplitude. The three main reasons for this mismatch are the non-perfect alignment of the Integrated Magneto Concentrator (IMC) with respect to the Hall plates constellation, a difference between the sensitivity of the different Triaxis® Hall Plates and the application dependent absence/presence

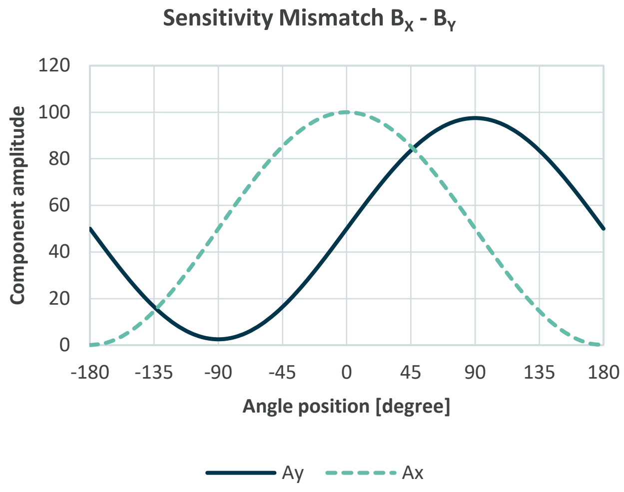

Figure 13: Sensitivity mismatch end-of-shaft

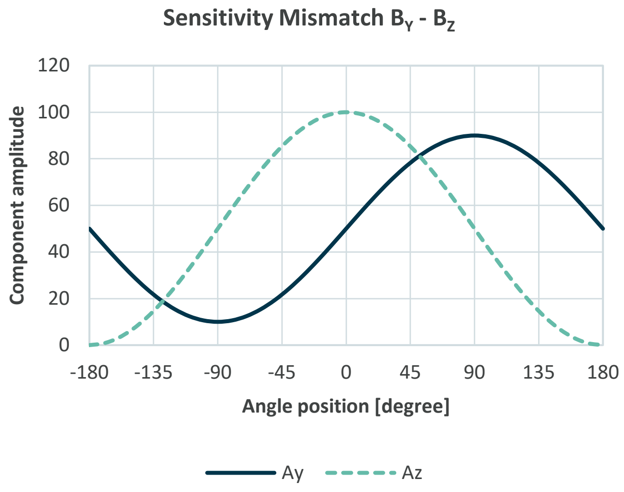

Figure 14: Sensitivity mismatch trough shaft

of the IMC magnetic gain.

An illustration of the amplitudes mismatch impact on angle nonlinearity is shown in Figure 15 and Figure 16. The signature is a double period and bipolar over 360 degrees, i.e. The thermal variation of sensitivity mismatch is negligible.

$$NLE_3 = a_3 \times \sin(2 \times \alpha)$$

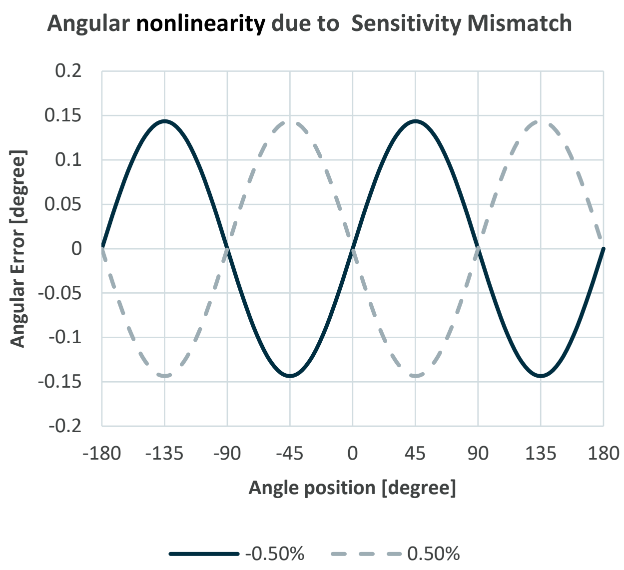

Figure 15: Angle nonlinearity due to sensitivity

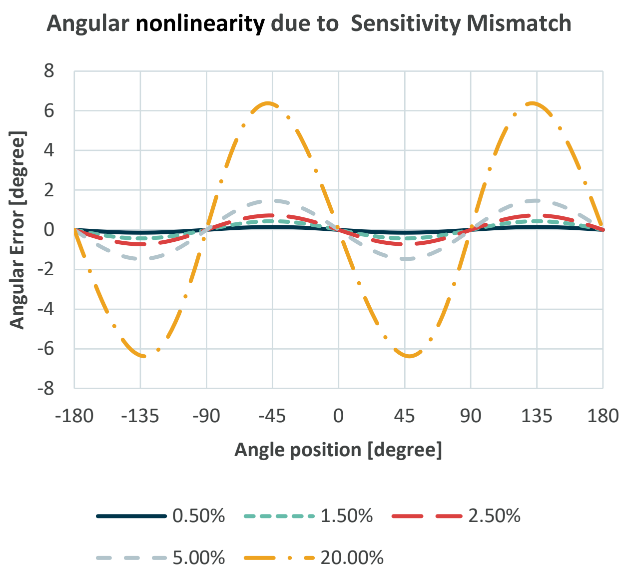

Figure 16: Angle nonlinearity due to sensitivity

mismatch *mismatch*

The amplitude seen on the two output signals of the sensor, when a rotating magnet is applied, is a combination of temperature dependent amplitude of the magnetic field and the temperature compensated amplitude of the sensor. The amplitude of the sensor output signals can be trimmed at room temperature by the programmable gain stage of the sensors. See chapter 5.4.The temperature drift of the magnetic field amplitude is compensated by the predefined TC_S, temperature compensation on the sensitivity of the sensor.

4.7. Signal Nonlinearity

There are three sources of nonlinearity on sensor level: the magnetic saturation, the applied field on the IMC location in X or Y direction is greater than 70mT or 160mT; electrical saturation, the gain of the sensor is set to high for the applied magnetics flux density; and the nonlinearity of the two output amplifiers.

For the magnetic design the magnetization of the sensor and the positioning of the sensor versus the magnet plays an important role. For a trough shaft and off-axis applications, the magnetization of the sensor has a higher impact on the signal nonlinearity than for End-of-shaft applications.

The signal non-linearity signature is easily recognizable: four periods over 360 degrees.

$$NLE_5 = a_5 \times \sin(4 \times \alpha)$$

Figure 17 and Figure 18 illustrate an exaggerated electrical saturation of the output signals and the resulting angle nonlinearity.

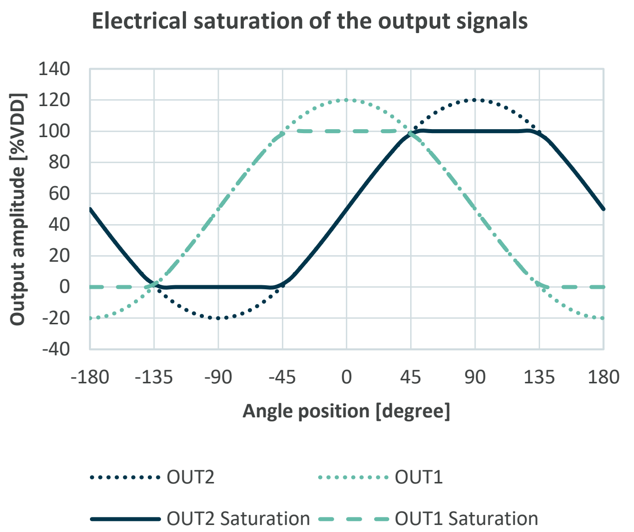

Figure 17: Electrical output signal saturation

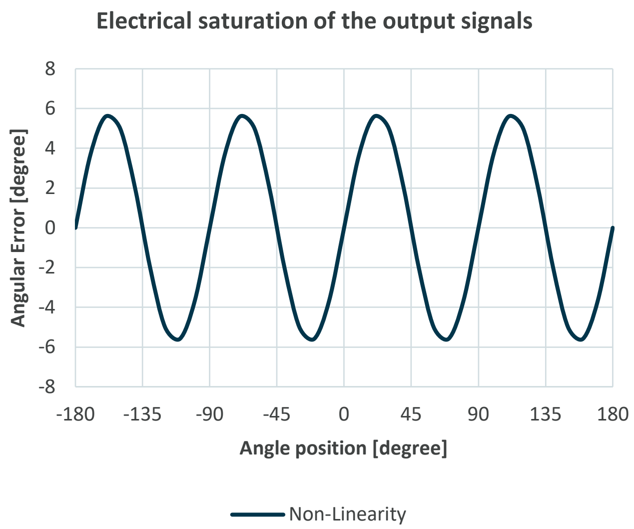

Figure 18: Angle nonlinearity due to signal saturation.

5. Angle Nonlinearity – Calibration Techniques

This chapter explains how to determine the MLX90381 correction parameters such as OMM, SMM, PHI and ORTH. There are different methods to find the optimum values for the correction parameters, which are explained in more detail in the next sections.

5.1. Least-Square Linear Fit Method

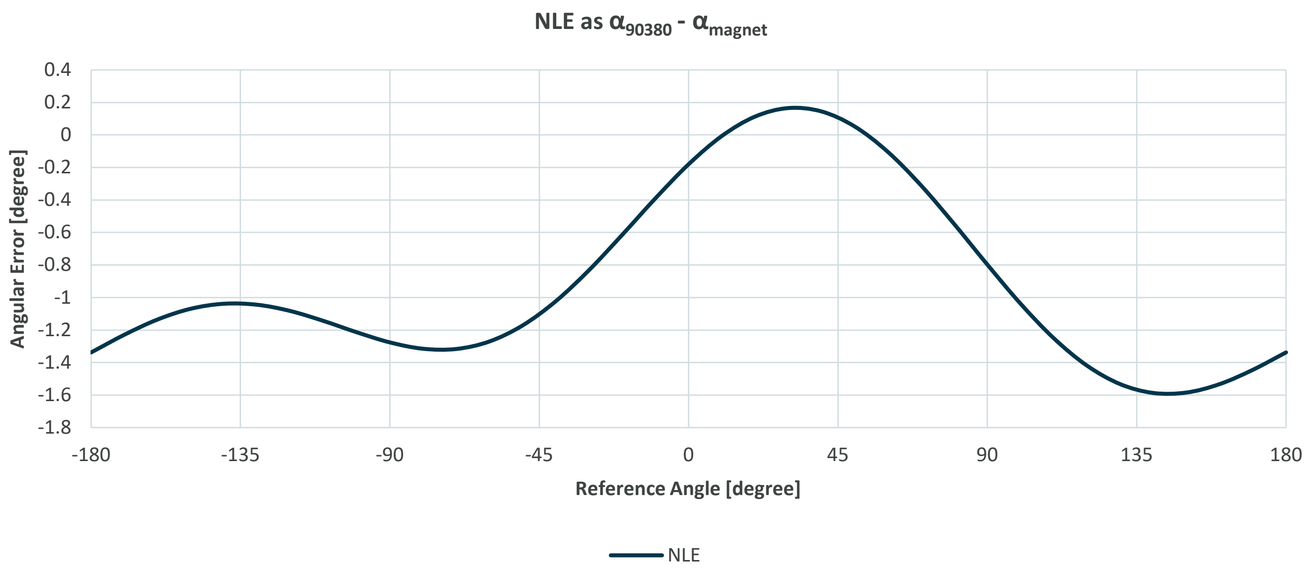

Figure 19: Calculate nonlinearity error

This technique requires a full rotation of the magnet with an absolute angle reference for the least-square linear fit calculation. This method calculates SMM, OMM, ORTH, PHI based on measurements. To analyze the linearity error, we first calculate the NLE as α_{90381} - $\alpha_{mechanical}$ (sensor angle – reference angle).

Secondly, we find the basic components from the nonlinearity error using a general LS Linear Fit, which finds the k-dimension linear curve values and the set of k-dimension linear fit coefficients, which describe the k-dimension linear curve that best represents the input data set using the least-squares solution.

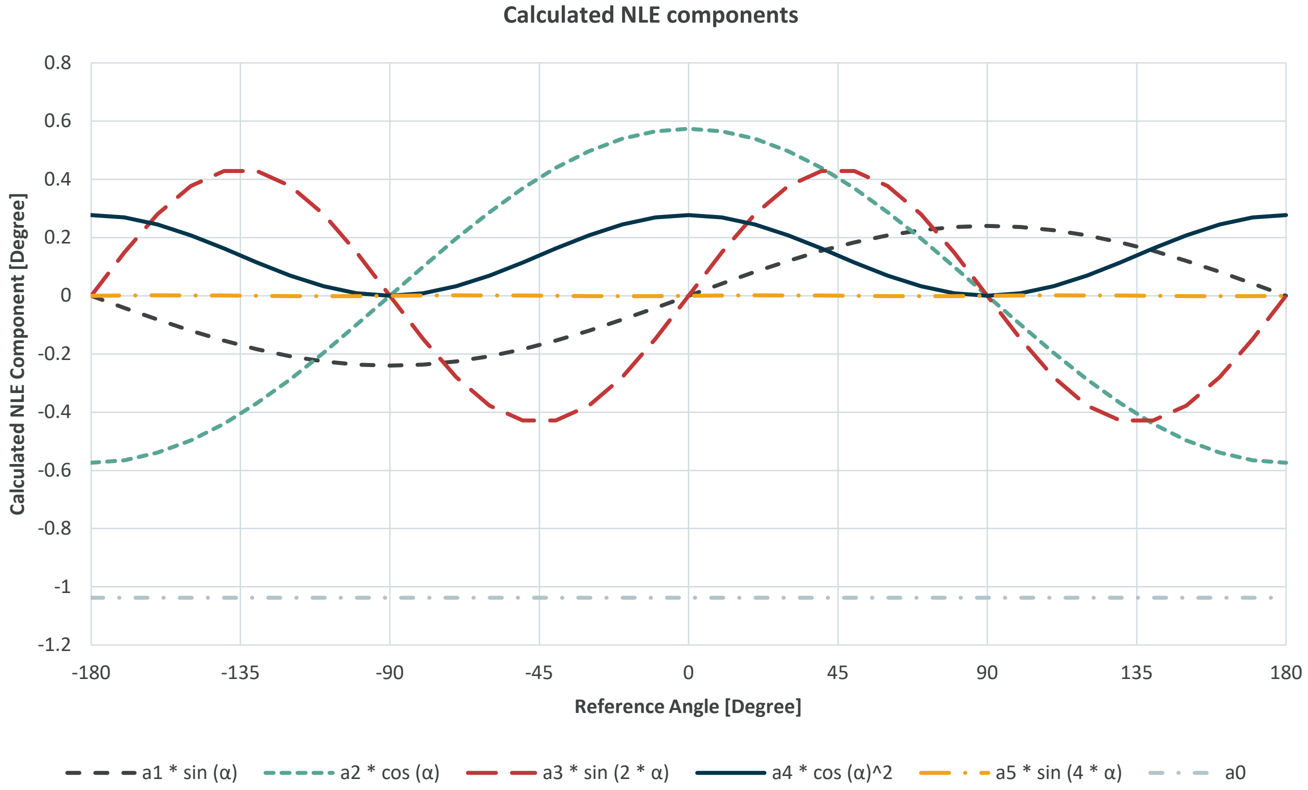

Figure 20: Calculated nonlinearity error components

The purpose is to find the set of least square coefficients "a" that best represent the set of data points (α_m, NLE). The relationship between α_m and NLE is of the form:

$$NLE = a_0 + a_1 \times \sin(\alpha) + a_2 \times \cos(\alpha) + a_3 \times \sin(2 \times \alpha) + a_4 \times \cos(\alpha)^2 + a_5 \times \sin(4 \times \alpha)$$

Where:
a_0 = absolute angle offset error (Phase Shift vs. absolute 0-degree position)
a_1 = amplitude of error created by OMM_1
a_2 = amplitude of error created by OMM_2
a_3 = amplitude of error created by SMM
a_4 = amplitude of error created by ORTH
a_5 = amplitude of error created by signal non-linearity

5.2. Min-Max Method

The technique requires a full rotation of the magnet with or without an absolute angle reference.

The SMM and OMM are calculated based on output measurements. The PHI and ORTH error are corrected with the theoretical constant from the formulas explained in the Least-Square Linear Fit Method above.

This method basically normalizes two signals by matching the SPAN and the OFFSET of the two signals.

The span of the OUT2 is corrected to match the SPAN of OUT1. The OFFSET of each signal is normalized to zero. It is a Simple technique which only requires four measurements.

Figure 21: Raw data

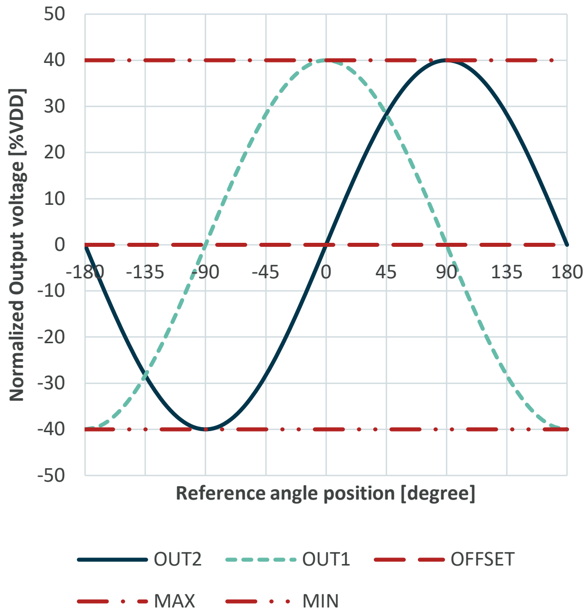

Figure 22: Normalized data

For the calculation of the sensitivity mismatch and the offset mismatch we need to measure the MIN and MAX output level of the two output signals (Marked in orange).

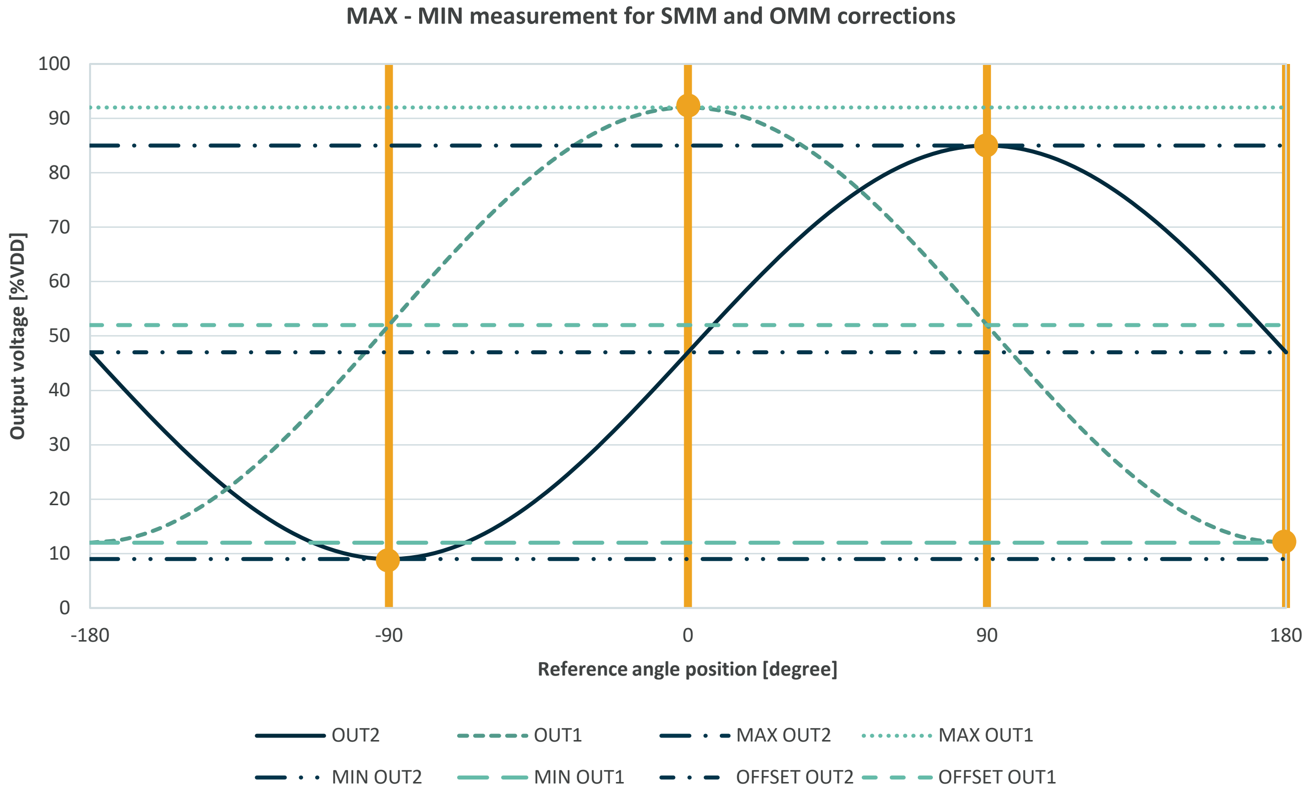

Figure 23: Four measurements for the MIN-MAX method

There are two techniques to obtain the measurements.

5.2.1. Absolute Positioning

With an absolute angle reference, four fix angles positioned at -90°, 0°, 90° and 180° are measured. For the measurement, an accurate reference angle is important to ensure that the actual MIN and MAX level is measured.

5.2.2. Min-Max Tracking Via Data Acquisition

The DAQ technique searches for the MIN-MAX level of the two output signals.

While the magnet turns the micro controller or DAQ setup keeps track on the SIN/COS signal and extracts the MIN and MAX level of OUT_1 and OUT_2. This method can also be performed by the micro controller start-up or on the fly.

At start-up the µC searches the MIN-MAX levels of the two output signals. After one or more full 360 degree turns of the magnet, depending on the filter technique, all data is collected to start the signal corrections to normalize both output signals. This allows the µC to perform dynamic angle corrections in the application.

5.2.3. Calculation

Sensitivity mismatch:

$$SMM = \frac{S_2 \times B_2}{S_1 \times B_1} = \frac{SPAN_{OUT2}}{SPAN_{OUT1}}$$

Where:

$$SPAN_{OUT1} = MAX_{OUT1} - MIN_{OUT1}$$

$$SPAN_{OUT2} = MAX_{OUT2} - MIN_{OUT2}$$

Offset mismatch:

$$OFFSET_{OUT1} = \frac{(MAX_{OUT1} + MIN_{OUT1})}{2}$$

$$OFFSET_{OUT2} = \frac{(MAX_{OUT2} + MIN_{OUT2})}{2}$$

The angle α is calculated from the arctangent of SIN over COS:

$$\alpha = ATAN2(SIN, COS)$$

Where:

$$SIN = (OUT_2 - OFFSET_{OUT2}) \times SMM$$

$$COS = (OUT_1 - OFFSET_{OUT1})$$

Or:

$$SIN = \frac{(OUT_2 - OFFSET_{OUT2})}{SPAN_{OUT2}}$$

$$COS = \frac{(OUT_1 - OFFSET_{OUT1})}{SPAN_{OUT1}}$$

If desired the angle α can be corrected for Phase shift and Orthogonality with the theoretical constant for the nominal speed of the application:

Signal Phase Shift:

$$PHI_{RPM} = \tau_D \times \frac{RPM}{166666.6667}$$

$$NLE_0 = a_0 = PHI_{RPM} + DP$$

Orthogonality:

$$\beta_{RPM} = \tau_{ORTH} \times \frac{RPM}{166666.6667}$$

$$a_4 = \beta_{RPM} + \beta_{IMC} + \beta_{Magnet}$$

$$NLE_4 = a_4 \times Cos(\alpha)^2$$

The angle α is calculated from the arctangent of SIN over COS with PHI and ORTH correction:

$$\alpha = \alpha - NLE_0 - NLE_4$$

5.3. Orthogonality Method

The orthogonality error β_IMC and β_Magnet can be corrected with the following method. **After** the output data is normalized by the Min-Max method, the orthogonality error can be calculated with the vector of two or four 90° shifted angle measurements from -135°, -45°, 45° and 135°.

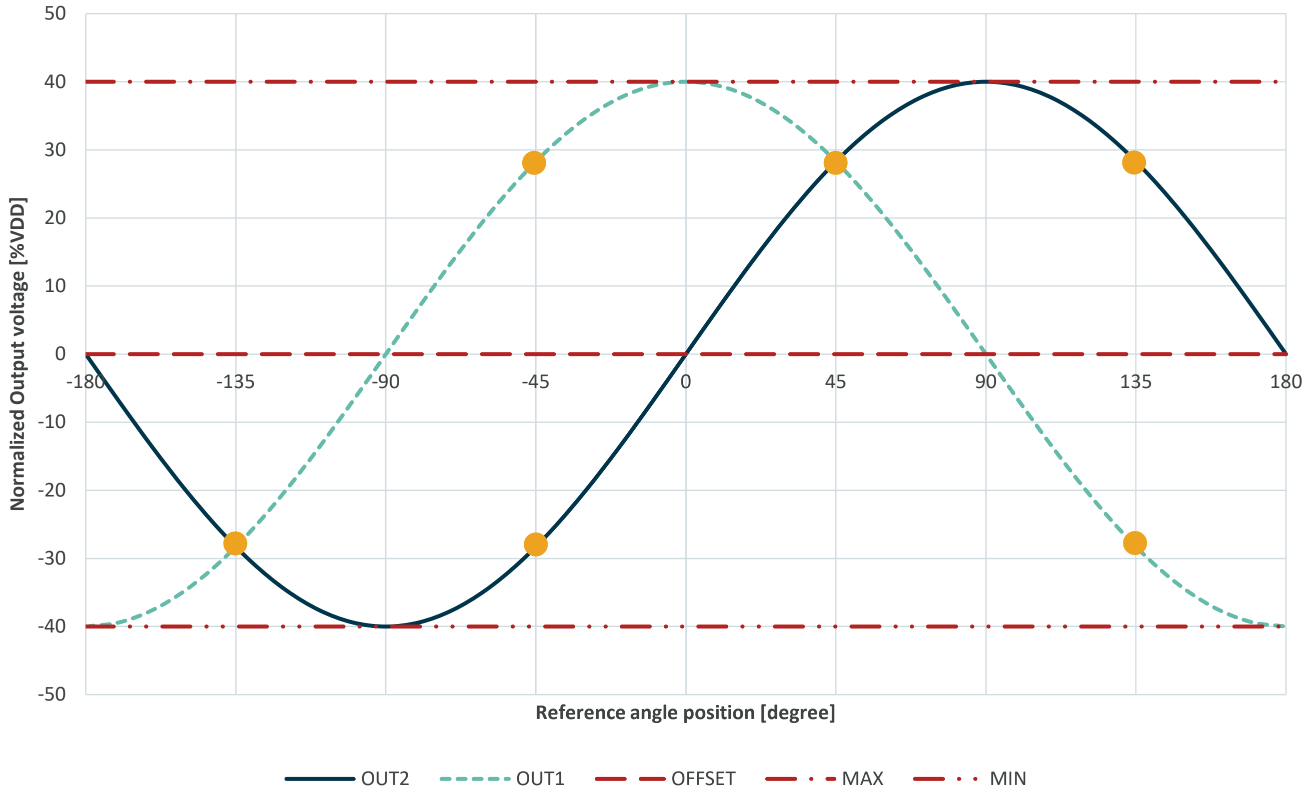

Figure 24: Eight measurements (four per output) for the orthogonality method

There are two techniques to obtain the measurements.

5.3.1. Absolute Angle Reference

With an absolute angle reference, two or four fix angles, positioned at -135°, -45°, 45° and 135° are measured. For the measurement, an accurate reference angle is important.

5.3.2. Relative Angle Reference

One can use the sensors angle as a reference, after the Min-Max calibration method is applied for SMM and OMM. The Min-Max calibration method is important to ensure a reference angle as accurate as possible.

5.3.3. Calculation

Vectors:

$$V_{-135} = \sqrt{COS_{-135}{}^2 + SIN_{-135}{}^2}$$

$$V_{-45} = \sqrt{COS_{-45}{}^2 + SIN_{-45}{}^2}$$

$$V_{45} = \sqrt{COS_{45}{}^2 + SIN_{45}{}^2}$$

$$V_{135} = \sqrt{COS_{135}{}^2 + SIN_{135}{}^2}$$

Where:

$$SIN = \frac{(OUT_2 - OFFSET_{OUT2})}{SPAN_{OUT1}}$$

$$COS = \frac{(OUT_1 - OFFSET_{OUT1})}{SPAN_{OUT1}}$$

Orthogonality error:

$$\beta = 2 \times \mathrm{atan2}\left(\frac{V_{135} - V_{45}}{V_{135} + V_{45}}\right)$$

Or:

$$\beta = 2 \times \mathrm{atan2}\left(\frac{(V_{135} + V_{-45}) - (V_{-135} + V_{45})}{(V_{135} + V_{-45}) + (V_{-135} + V_{45})}\right)$$

$$NLE_4 = \beta \times Cos(\alpha)^2$$

5.4. Calibration Sequence Sensor Parameters

This section describes the procedure to calibrate the gain (RG and FG) and the offset (V_{OQ}) of the sensor outputs. The following calibration sequences should be done for each output depending on axis configuration of the sensor.

The principle of the calibration sequence is as follows. The sensor is first measured with the factory trimmed or customer default RG, FG and V_{OQ} settings. From the measurements one can calculate the difference from the desired output characteristics for output span and offset and calculate a new RG, FG and V_{OQ} based on the formulas listed in the chapter “Descriptions of End User Programmable Items” of the MLX90381 datasheet. The output span and offset are measure with the Min-Max method explained in chapter 5.2. The communication protocol to read and write the memory of the sensor is described in the Application Note MLX90381 I2C Communication Protocol for End of Line Calibration.

The sequence goes as follows:

STEP 1. Read the MTP memory to get the default programmed values for Rough Gain, Fine Gain and V_{OQ} from the sensor.

Example:	RG MTP Code	FG MTP Code	V_{OQ} MTP Code
Default Programmed MTP codes	4	19	15

STEP 2. Measure output span with the default programmed values.

Example:	Output level Min	Output level Max	Output Span	Output Offset
Default Programmed MTP codes	21.036[%V_{DD}]	79.117[%V_{DD}]	58.081[%V_{DD}]	50.076[%V_{DD}]

STEP 3. Calculate new MTP parameters for RG, FG and V_{OQ} to fit the target transfer curve.

Calculate offset correction:

The output offset level of the sensor can be calculated from the output span measurement with the following formula:

$$\text{Output Offset}_{\text{Default Programmed}} = \frac{\text{Output level Max} + \text{Output level Min}}{2} = 50.076$$

The output offset correction to fit the output offset target is calculated as follows:

$\text{Output Offset}_{\text{Target}} = 50[\%V_{DD}]$

$$\text{Output Offset}_{\text{correction}} = \frac{\text{Output Offset}_{\text{Target}} - \text{Output Offset}}{0.25[\%V_{DD}]} = \frac{50 - 50.076}{0.25} = \text{-}0.306 = 0$$

$$V_{OQ}\text{ MTP Code} = V_{OQ}\text{ MTP Code}_{\text{Default Programmed}} + \text{Output Offset}_{\text{correction}} = 15 + 0 = 15$$

Calculate gain correction:

First, we calculate the Total Gain value for the default programmed settings:

$\text{Rough Gain}_{\text{RG MTP Code}} = RG_4 = 31.5$

$$\text{Fine Gain}_{\text{FG MTP Code}} = \frac{\text{FG MTP code} \times 0.5}{31} + 0.5 = \frac{19 \times 0.5}{31} + 0.5 = 0.806$$

$\text{Total Gain}_{\text{Default Programmed}} = 31.5 \times 0.806 = 25.389$

Next, we calculate the Gain Correction from the ratio between target span vs. Measured output span:

$\text{Output Span}_{\text{Target}}$ = 80 [%V_{DD}]

$$\text{Output Span}_{\text{Correction}} = \frac{\text{Output Span}_{\text{Target}}}{\text{Output Span}} = \frac{80}{58.081} = 1.377$$

From this we can calculate the total gain needed to fit the target span:

$$\text{Total Gain}_{\text{Correction}} = \text{Total Gain}_{\text{Default Programmed}} \times \text{Output Span}_{\text{Correction}} = 25.389 \times 1.377 = 34.961$$

Before we calculate the FG we first select the RG in which the needed Total Gain fits within the range of that Rough Gain. The Rough Gain MTP Code is selected from the RG specifications listed in the chapter "Descriptions of End User Programmable Items" of the MLX90381 datasheet.

$$\text{Rough Gain}_{\text{New RG Code}} = RG_5 = 53.2$$

From the selected RG and the Total Gain correction we can calculate the attenuation we need for the FG:

$$FG_{\text{Correction}} = \frac{\text{Total Gain}_{\text{Correction}}}{\text{Rough Gain}_{\text{New RG Code}}} = \frac{34.961}{53.2} = 0.657$$

$$\text{New FG code} = \frac{(\text{FG correction - 0.5}) \times 31}{0.5} = \frac{(0.657 - 0.5) \times 31}{0.5} = 8.849 = 9$$

STEP 4. Program Full: program the gain and offset correction in MTP of the sensor.

Example:	RG MTP Code	FG MTP Code	V_{OQ} MTP Code
New MTP codes	5	9	15

STEP 5. Measure output span with gain correction value for Rough Gain and Fine Gain.

Example:	Output level Min	Output level Max	Output Span	Output Offset
New MTP codes	9.892[%V_{DD}]	90.296[%V_{DD}]	80.404[%V_{DD}]	50.094[%V_{DD}]

If needed, a fine tuning of the FG MTP Code can be considered keeping in mind the trimming resolution of the sensor.

6. Points of Attention

With an End of Line calibration of the sensor, the NLE of the reported angle can be reduced. The sensor programmable parameters can be used to reduce the NLE of the angle caused by a sensitivity/amplitude mismatch and an offset mismatch. The remaining NLE on the reported angle can be reduced by compensation techniques in the embedded µC.

A good magnetic design is also important to reach a low NLE on the reported angle. A strong magnetic field and/or a limited operational temperature range will lead to a lower NLE on the reported angle over the full temperature range of the sensor. As listed above in this application note, a higher sensor gain will lead to a higher offset drift of the sensor outputs. A higher temperature range will also lead to a higher NLE drift on the reported angle. A dynamic compensation of offset and gain in the embedded µC can reduce the NLE drift on the reported angle.

Depending on the NLE requirements of the application and the application constraints, try to select a magnet and magnet vs. sensor position that leads to a strong magnetic field on the sensing element.

Figure 25 shows an indicative example of the NLE on the reported angle, based on a small population of sensors. The data represents the NLE on the reported angle after an End of Line calibration of the sensitivity/amplitude mismatch, offset mismatch, Orthogonality error and phase shift of the sensor for a magnetic field with a constant low rotation speed.

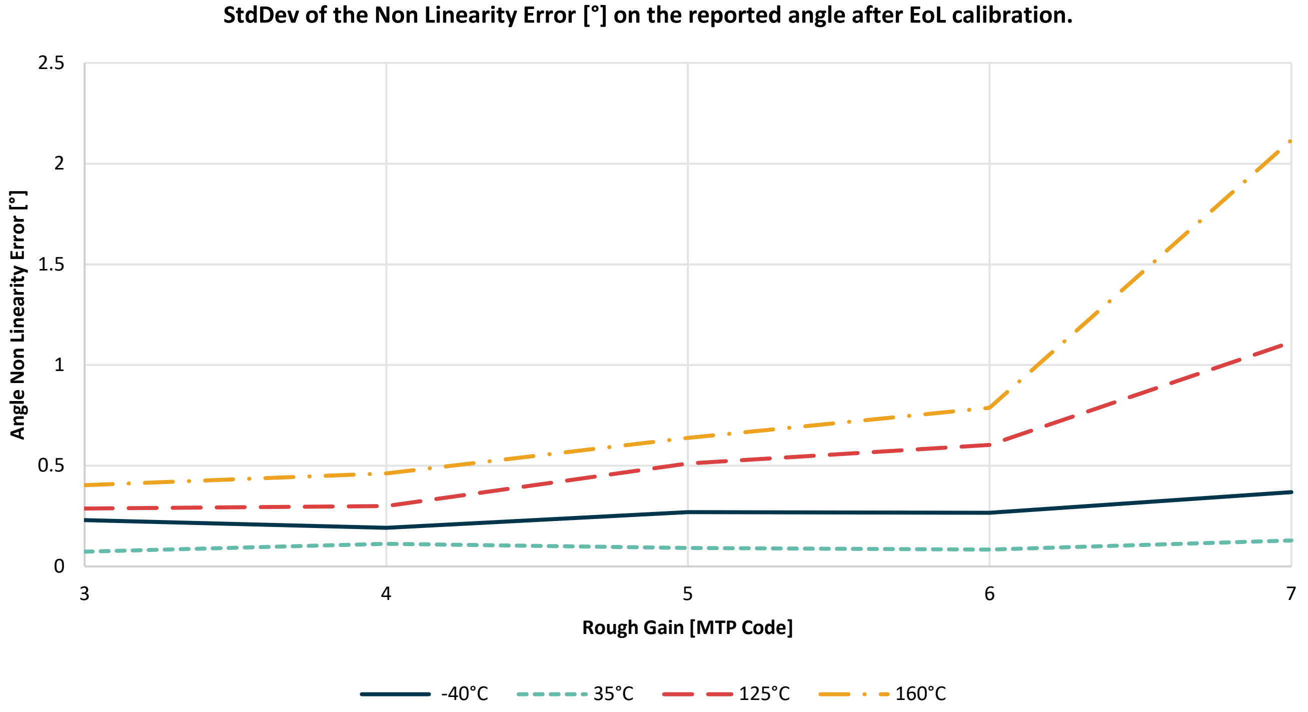

Figure 25: StdDev NLE after EoL calibration on a small population of sensors.

Figure 26 shows an indicative example of the NLE on the reported angle, based on a small population of sensors. The data represents the NLE on the reported angle after an End of Line calibration of the Orthogonality error and phase shift of the sensor for a magnetic field with a constant low rotation speed and a dynamic compensation of the sensitivity/amplitude mismatch and offset mismatch of the sensor.

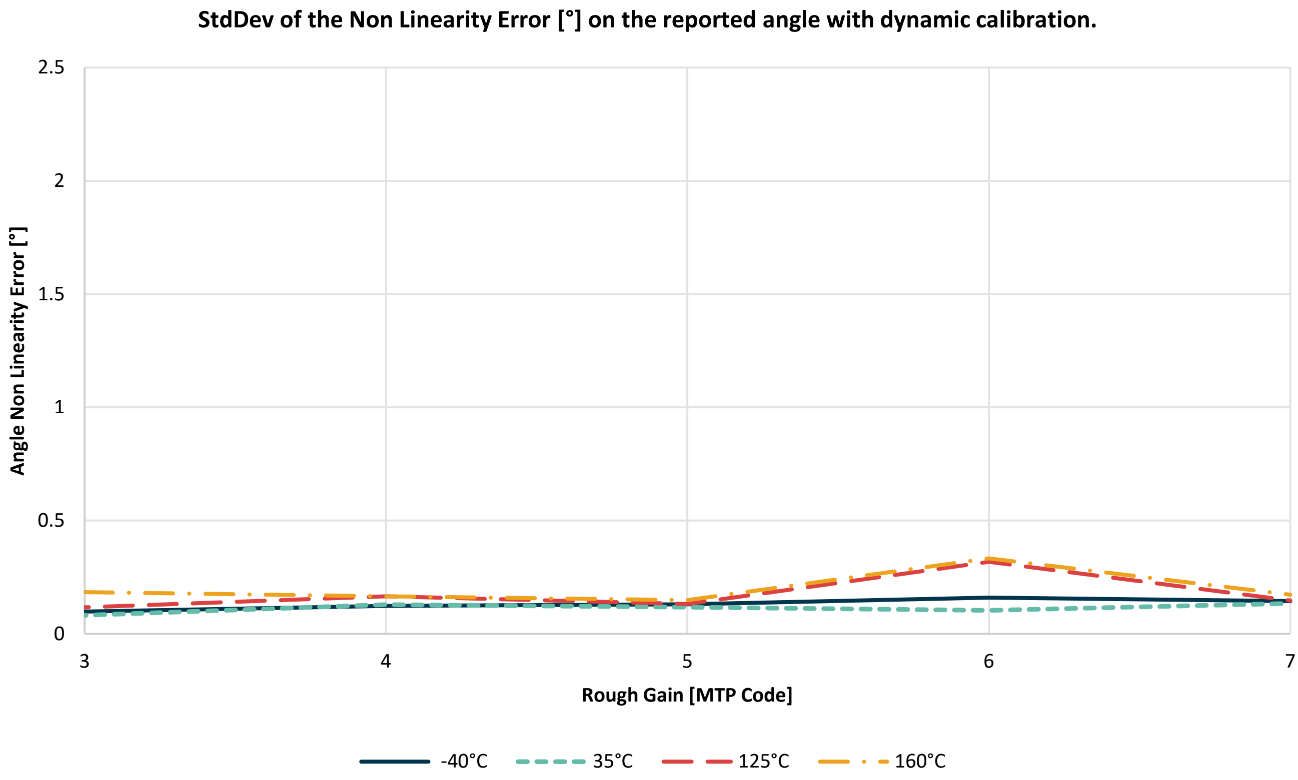

Figure 26: StdDev NLE after dynamic calibration on a small population of sensors.

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