Application note

Magnet Selection for MLX9037x - Rotary Stray-Field Immune Mode

Contents

1. Scope

The application note provides a guideline to select a 4-pole magnet to be used in combination with the Gen 3 Triaxis® sensors, MLX9037x –100/500. Using the Rotary Stray-Field Immune Mode with the Triaxis rotary position sensor allows being robust to homogeneous stray field for a 180 deg absolute rotary position range.

The design of the magnetic angle measurement system is based on the needs of the particular application, such as the available airgap, accuracy requirements, temperature range and properties of the Triaxis® Hall sensor.

This document will only consider the end-of shaft magnetic circuit and provides an introduction of associated performances vs. the two main sources of error, ie mechanical and magnetic influences like eccentricity and tilting.

2. Related Melexis Products

MLX90371 Triaxis® Hall Rotary position sensor featuring analog
MLX90372 Triaxis® Hall Rotary position sensor featuring SENT / PWM
MLX90373 Triaxis® Hall Rotary position sensor featuring PSI-5
MLX90374 Triaxis® Hall Rotary position sensor featuring SENT & PWM

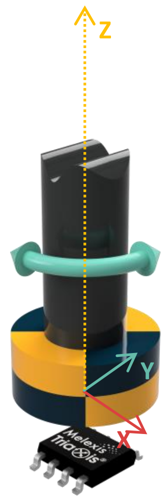


Figure 1 – MLX9037x

3. Magnetic Measurement Principle

The Figure 1 shows a typical example of an end-of-shaft application for which a 4 pole axial-magnetized magnet is rotating above the IC, and figure 2 shows the three corresponding magnetic flux densities (i.e. Bx, By and Bz) in the XY plane for a defined mechanical angle position equal to 0 deg. The 3 flux components are shown for information only and will be rejected in the measurement as the sensor is stray field immune.

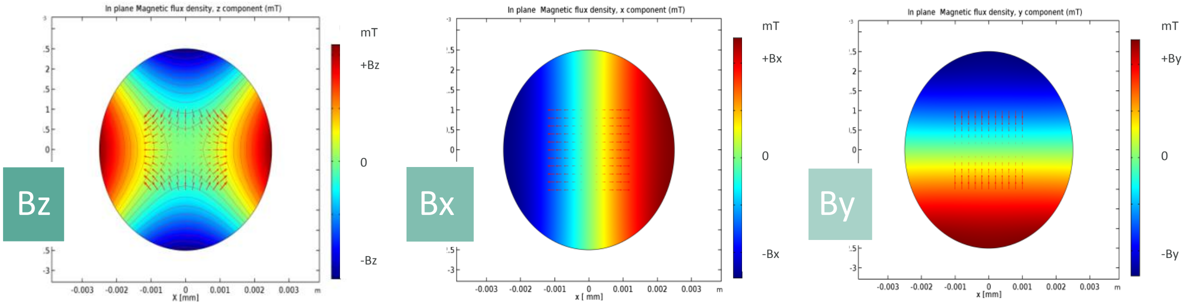


Figure 2 – Magnetic flux density Bx, By, Bz for the figure 1

The Triaxis® stray field immune Rotary position sensor measures instead four magnetic in-plane field gradients of the sensors in-plane field component applied parallel to the IC surface, $\frac{dB_X}{dX}, \frac{dB_Y}{dY}, \frac{dB_X}{dY}, \frac{dB_Y}{dX}$ and combines them into two in–plane gradient signals with a 45 deg phase shift, which represent a sine- and cosine wave while the magnet rotates. (see figure4).

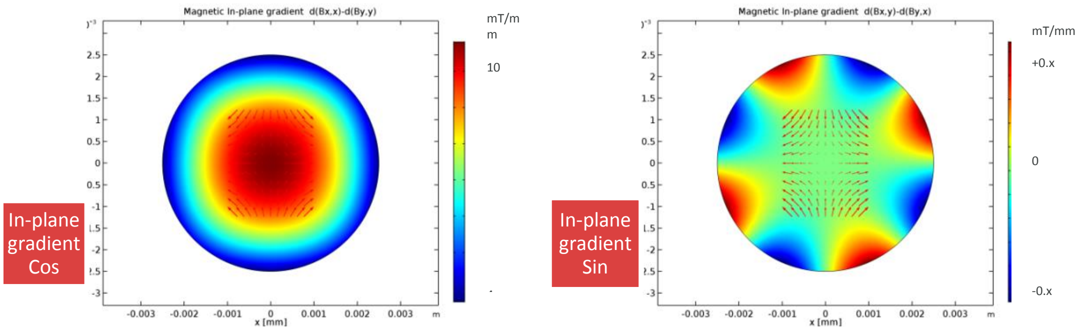


Figure 3 – Magnetic in-plane field gradients (dBx/dX- dBy/dY) , (dBx/dY+ dBy/dX) for the fig. 1

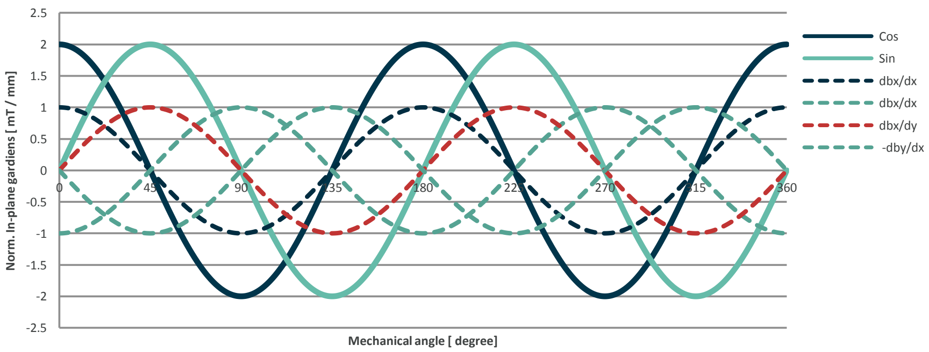


Figure 4 : In-plane field gradients for figure 1

The MLX9037x will further process the sine- and cosine wave signals to an absolute rotary position from 0 to 180 Degrees of any magnet rotating around its z-axis.

$$\alpha_{mech.} = Atan2\left(\frac{\left(\frac{dB_X}{dY}+\frac{dB_Y}{dX}\right)}{\left(\frac{dB_X}{dX}-\frac{dB_Y}{dY}\right)}\right)/\,2$$

4. Designs Rules: Magnetic Selection

As the design of any magnetic system is based on matching the needs of the application, it is mandatory to make the correct selection of the magnetic sensor and the magnet, as well as an understanding of the influences that determines the accuracy. The main requirements of the stray field immune Triaxis® sensors, related to the magnetic performance, will be used to illustrate how they need to be checked with the available choices of 4 pole magnets.

Table 1 is a summary of the major sensor requirements [1] that will be used for the magnet selection.

Product / Parameter	9037x DC - 100	9037x GO - 100	9037x VS - 100	9037x GO - 500	Condition / Unit
Number of magnetic poles	4	4	4	4	In-plane // IC surface
Sensor radius	0.5	0.5	0.5	0.5	[mm]
Die off axis	0	0.7	0	0.7	Distance vs. rotating Z –axis [mm]
Min. gradient Field[2] $\frac{\Delta B_{XY}}{\Delta XY}$	3.8 / 10	3.8 / 10	3.8 / 10	8.25/10	$\frac{1}{2}\sqrt{\left(\frac{dB_X}{dX}-\frac{dB_Y}{dY}\right)^2+\left(\frac{dB_X}{dY}+\frac{dB_Y}{dX}\right)^2}$ [mT/mm]
Max. field B_X, B_Y	25	25	25	67	$\sqrt{B_X^2+B_Y^2}$ [mT]
Package airgap	0.46	0.3	0.35	0.3	Distance IC surface – sensor [mm]
Package	SOIC-8	TSSOP-16	DMP-4	TSSOP-16	

Table 1: MLX9037x Stray field immune Sensor specifications

4.1. Mechanical description

The mechanical alignment between z-axis of rotation, magnet position and sensor position strongly determines measurement accuracy. Mechanical alignment errors as well as magnetization errors (Figure 5) can result in additional offset, phase shift, amplitude changes and non-linearity vs. the ideal sine and cosine output curves.

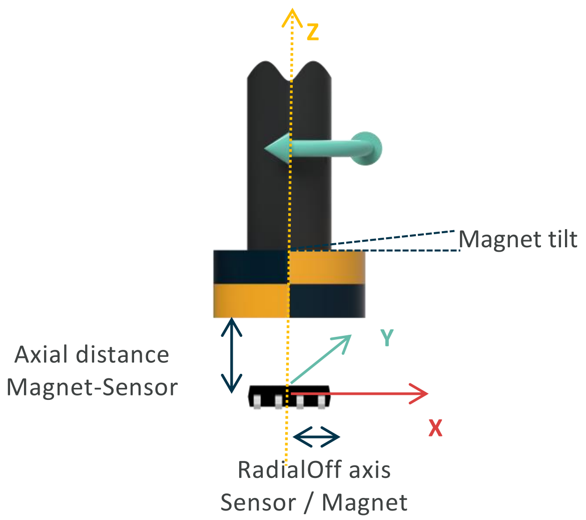


Figure 5 : Mechanical setup for angular sensing

[1] *For more details and latest specifications, please check the corresponding datasheet MLX9037x*

[2] *Min. gradient field has an impact on sensors noise and thermal performance, please check datasheet for more details.*

4.2. Magnets and material properties

The following table shows the magnet properties for the magnets A, B & C that are used in this application note.

Magnet	A	B	B'' Cross Cut-out	C
Outer Diameter [mm]	9	14	14	14
Inner Diameter [mm]	5	5	5	5
Thickness [mm]	4	3	3	3
Br [mT]	490	225	225	450
Material	Bonded NdFeB	Bonded Ferrite	Bonded Ferrite	Bonded NdFeB
Material Type	Isotropic	Anisotropic	Anisotropic	Isotropic
Magnetization	Axial	Axial	Axial	Top side Curved

Table 2: Magnet properties

The 3 magnets are a first selection to illustrate the effect of the outer diameter and additionally the choices of magnetic material & magnetization. The ring magnet is preferred as base material vs. disk, to stimulate the 4 pole symmetry in the center where there is ideally no field. With a disk magnet there is high risk of asymmetry due to the magnetization process.

4.3. Min. gradient field, max. field

The acceptable axial distance between magnet and sensor is defined by 2 requirements:

- The required signal-to-offset or signal-to-noise ratio for the max. airgap, specified by min. gradient Field $\frac{\Delta B_{XY}}{\Delta XY}$ in Table 1. The minimum gradient requirement will result in either a max. airgap definition for a selected magnet or a magnet definition for a required max. airgap.

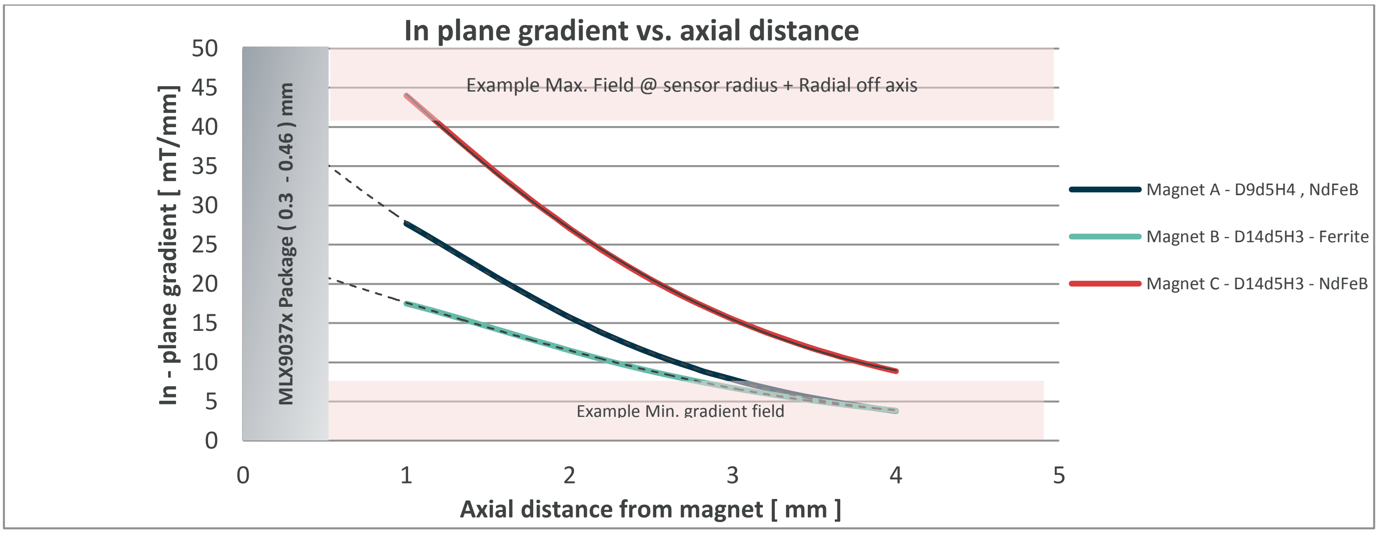


Figure 6 : In plane flux gradient vs. Axial distance from Magnet to Sensor (= Airgap)

- The magnetic saturation effect for the lower airgap limit is specified by Max field Bx, By in Table 1. The minimum airgap or the maximum allowed in plane gradient, needs to be checked vs. the saturation level of the internal magnetic concentrator by calculating the field density at the required max. Radial off axis + sensor radius + die off axis with the present in-plane gradient.
  The following formula is used to illustrating in figure 7 the maximum radial off axis vs. axial displacement, for the available packages (TSSOP / SOIC) / products (100-500).

  *In plane gradient [mT /mm] * (radial off axis + sensor radius + Die off- axis)[mm] < max. field [mT]*

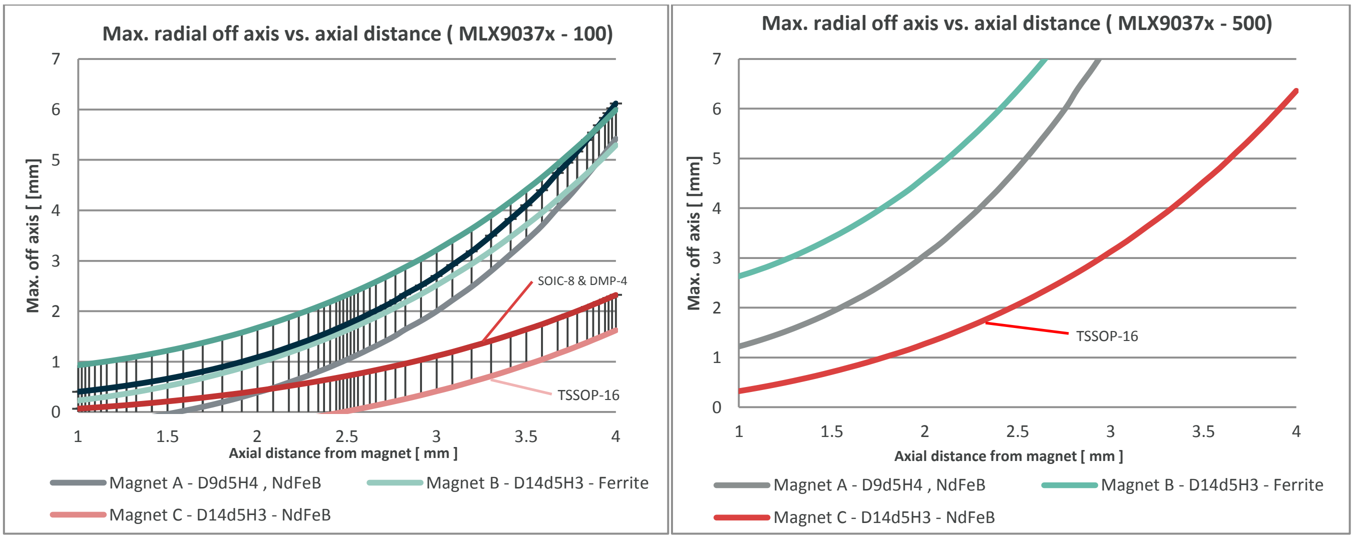
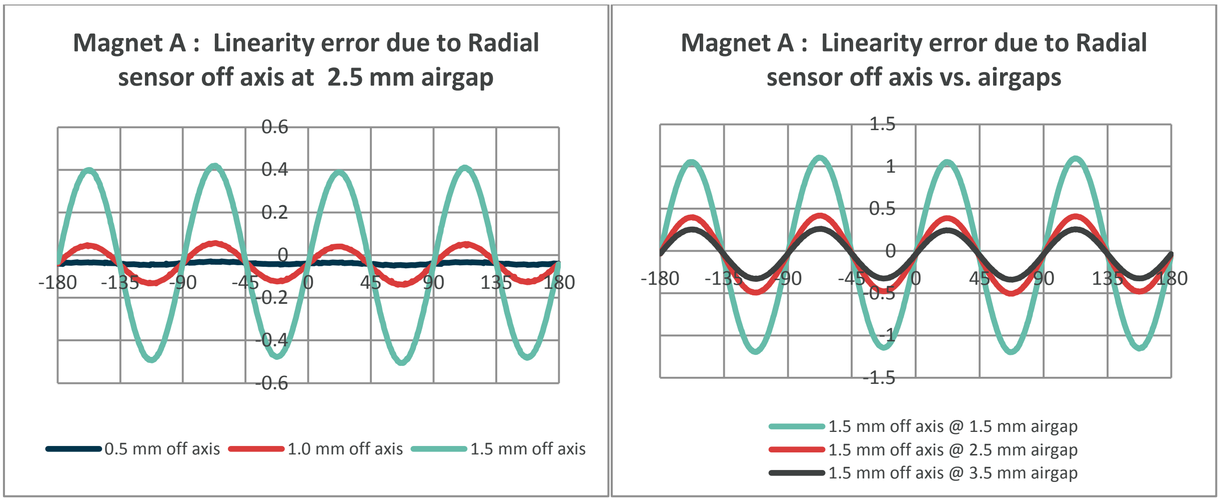


Figure 7 : Max. radial off axis vs. Axial distance from Magnet to Sensor

4.4. Radial sensor off axis

Off-axis position due to production tolerances, mechanical play and vibration will lead to non-linearity of the angle output signal. Figure 8 shows the typical non-linearity for a radial sensor off axis at different airgaps, with the ring shape magnet A, B and C.



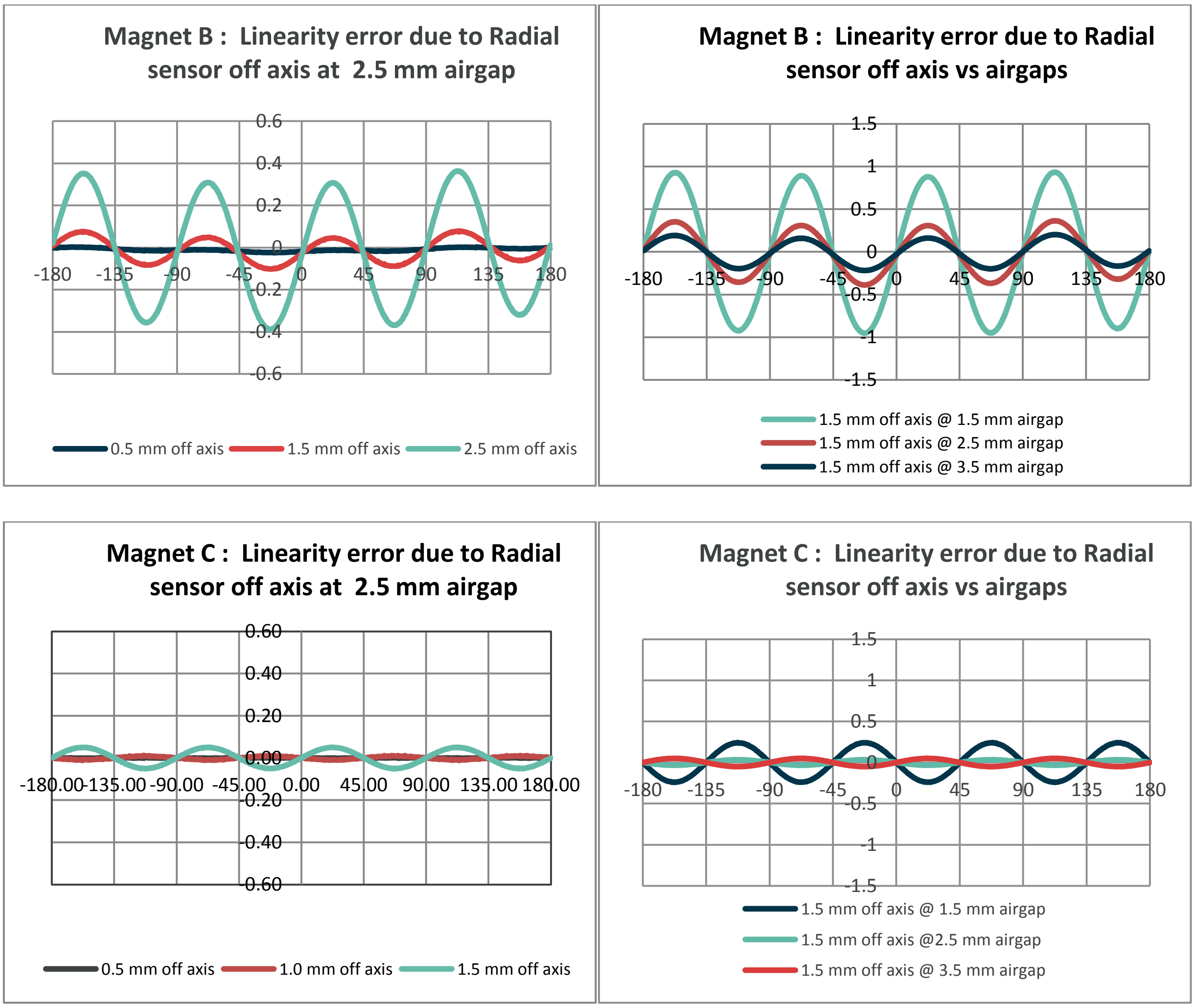


Figure 8 : Non-linearity error vs. radial sensor off axis vs. Axial distance from Magnet to Sensor

Angular errors due to a given radial sensor off axis misalignment will become smaller with an increasing diameter of the magnet and increasing axial distance. It can also be noticed from figure 8 & 9, that the curved magnetization of magnet C has a better robustness against eccentricity vs. the axial magnetized magnets A & B, thanks to the better in plane homogenous magnetic gradient field.

The non-linearity angle error, due to a radial sensor off axis, can be recognized from the shape as it has a typical 4th harmonic cosine and sine component. The maximum error for the different conditions and magnets vs. radial sensor off axis, is summered in figure 9.

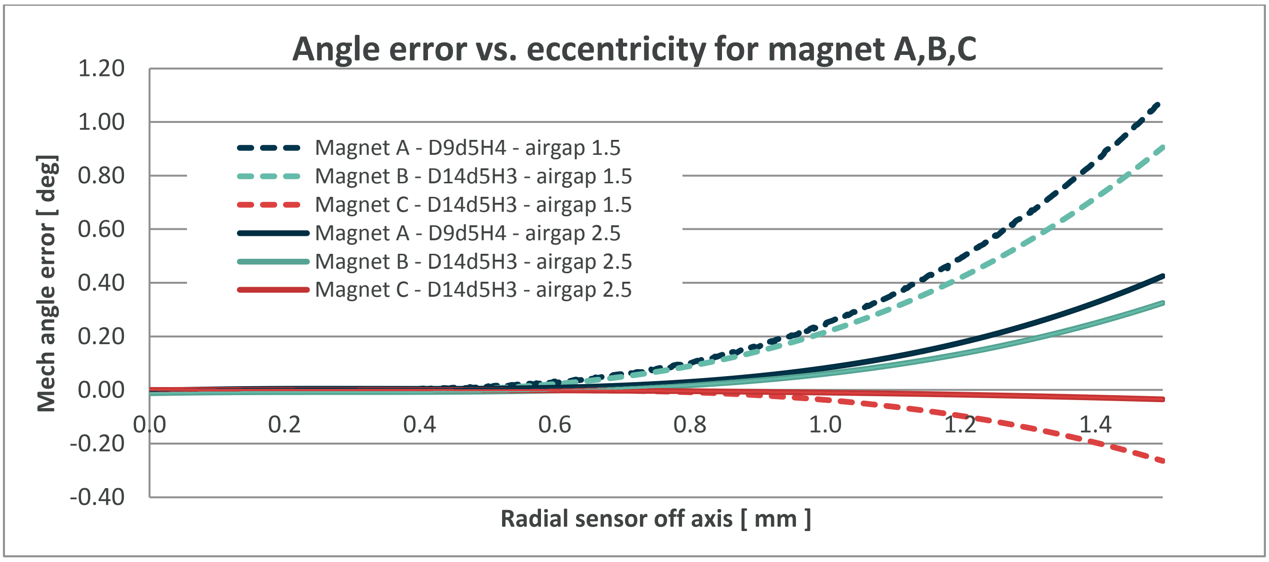


Figure 9 : max. Non-linearity error vs. radial sensor off axis & Axial distance from Magnet to Sensor

4.5. Radial magnet off axis & magnet tilt

Besides the sensor Off-axis position, this section illustrates that the radial magnet off-axis position or a magnet tilting can play a crucial role in the angle error contribution and also needs the proper investigation of the effect when selecting the magnet. Figure 10 shows the typical non-linearity for a radial magnet off axis at airgap 2.5 mm, with the ring shape magnet C.

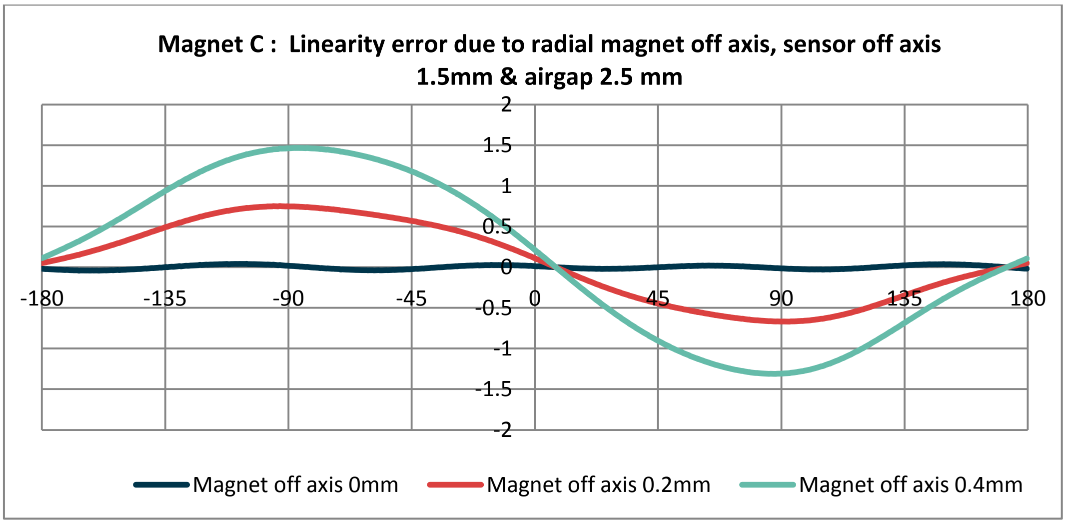


Figure 10 : Non-Linearity error vs. radial magnet off-axis

Figure 11 shows the typical non-linearity for a radial magnet off axis at airgap 2.5 mm, with the ring shape magnet C.

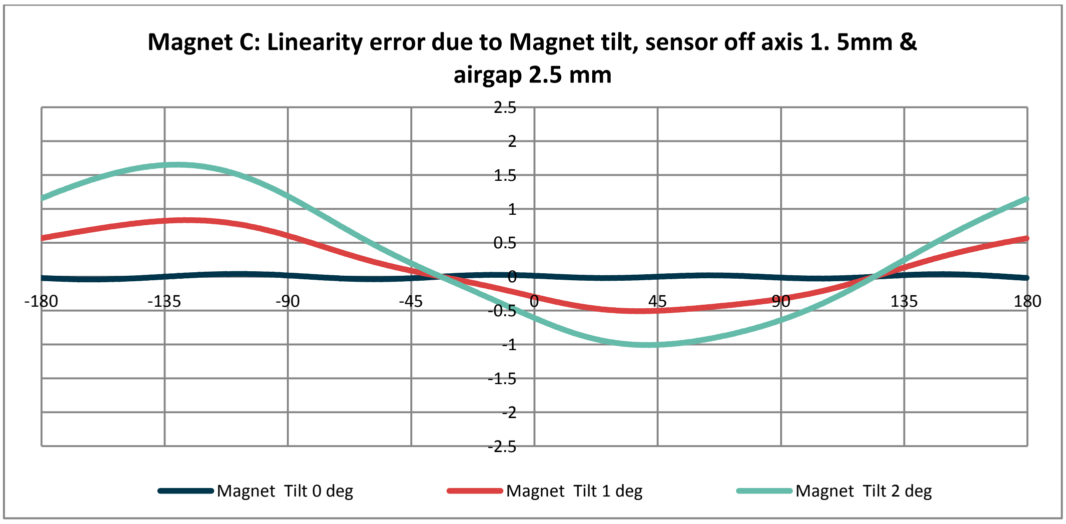


Figure 11 : Non-Linearity error vs. magnet tilt

When the magnet is shifted away from the center of the rotating shaft, it does not rotate around its own axis of symmetry and therefore the 4 pole symmetry of the magnet sensed by the sensor is broken. This effect will create a different error signature, as visible in fig. 10 & 11 and recognizable as a 1th harmonic cosine and sine shape. The same error shape will be created when magnetization errors, ie. Off axis magnetizations or unsymmetrical pole strength, are induced during the magnet manufacturing.

5. Magnet Recommendations & Optimization

Several different sizes, magnetization directions and shapes can be used for the Triaxis® stray field immune Rotary position sensor and the final selection of choice will usually be based on the application requirements.
Linearity errors due to static mechanical and magnetic misalignments as previously illustrated, like off axis in the XY plane are ideally compensated at customer through the linearization of the output transfer characteristic of the sensor. However to improve the robustness to eccentricity in general and to minimize the effect of dynamic mechanical drift error over lifetime, in most cases the best solution is to choose a magnet with big enough diameter, usable at a bigger axial distance and preferable more in- plane homogenous magnetic gradient field.

Plastic bonded Ferrite magnet (Magnet B) are typical from cost perspective a preferred solution, but also anisotropic, Axial magnetized, weaker and therefore by default not the ideal starting point for a design with high robustness against eccentricity. The axial magnetization is more sensitive to off-axis because the field lines are then changing rapidly under the magnet at the North/ south interface leading to less in- plane homogenous magnetic gradient field. To improve this homogenous characteristic, we propose to slightly modify mechanically the ring magnet B, to the illustrated Magnet B’ or B’’.

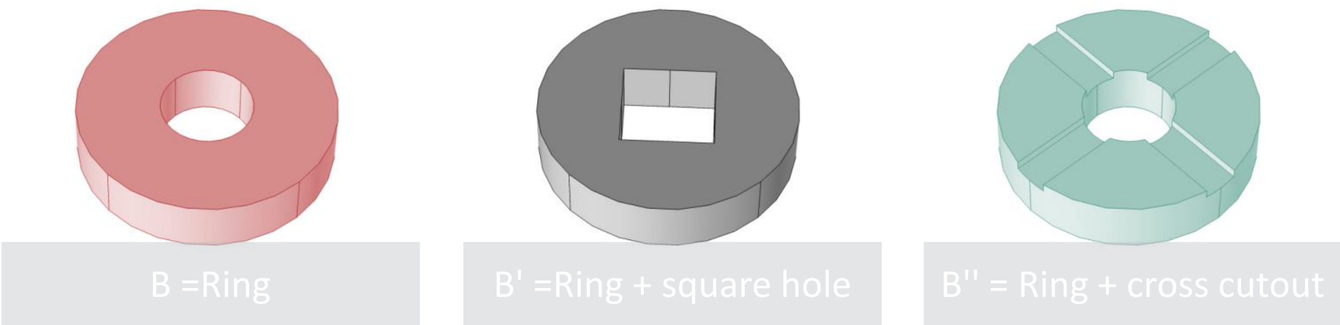


Figure 12 : Mech. variants of magnet B

Figure 12 shows the performance with magnet B and the big improvements with the modified magnets, at the condition of radial sensor off axis (1.5 mm) & radial Magnet off axis ([0, 0.1, 0.2, 0.3]mm) at 3 different airgaps.

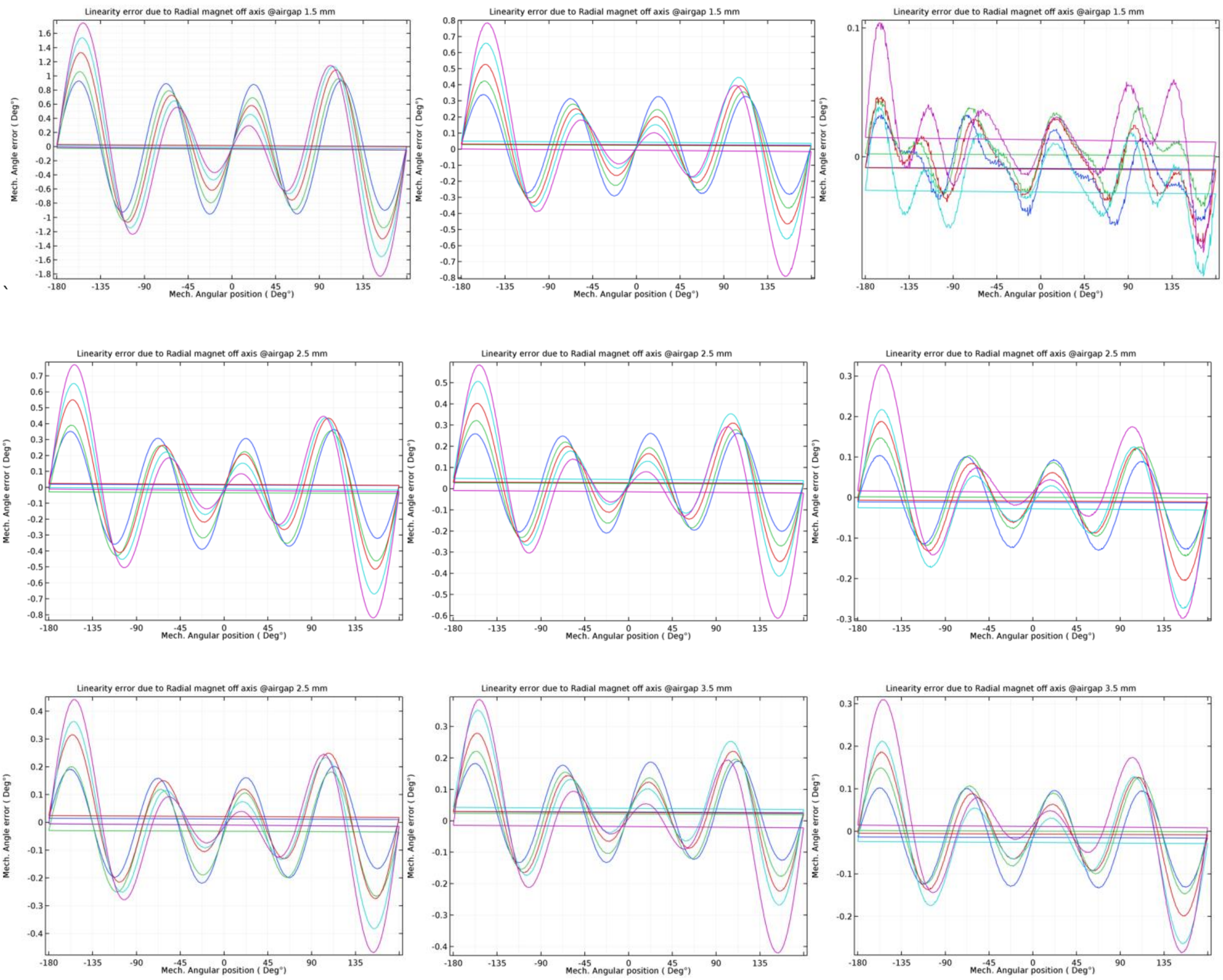


Figure 13 : Sensor off axis = 1.5 mm, Magnet off axis = [0, 0.1, 0.2, 0.3] mm @ airgap [1.5, 2.5, 3.5] mm

At bigger airgaps, the performance of magnet B'' is as expected comparable as magnet B, but especially for smaller airgap the effect is clearly visible. The 2 x 0.5 mm cross cutout modification at the N/S interface, forces the field lines to follow a more in- plane homogenous transition, leading to a 10 x smaller error at close airgap.

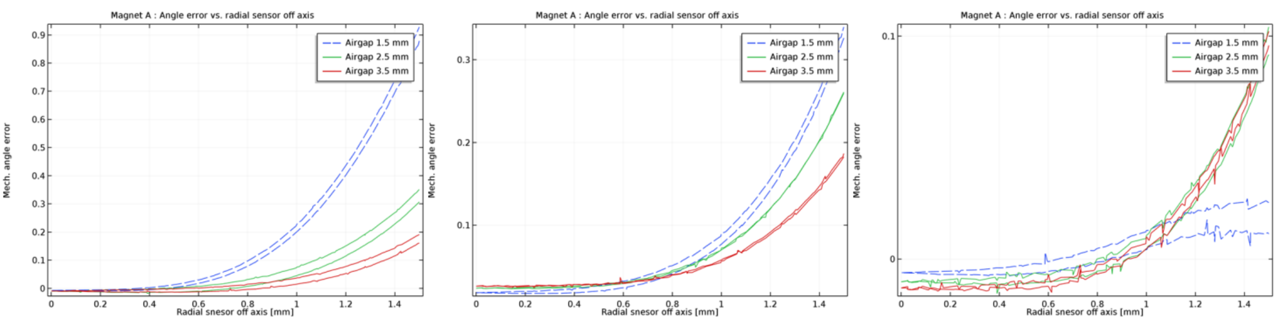


Figure 14 : max. Non-Linearity error vs. radial sensor off axis & axial distance from Magnet to Sensor

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