Application note

Magnet Selection for MLX9042x/90376 - Rotary Stray-Field Immune Mode

Contents

1. Scope

The application note provides a guideline to select a 2-pole magnet to be used in combination with some main stream sensing Triaxis® sensors, MLX9042x or performance sensing Triaxis® sensors, MLX90376-6x0. Using the axial field-differential angle sensor mode with the Triaxis rotary position sensor allows being robust to homogeneous stray field for a 360 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.

2. Related Melexis Products

MLX90425 Triaxis® Hall Rotary position sensor featuring ANALOG / PWM
MLX90426 Triaxis® Hall Rotary position sensor featuring SENT
MLX90376-6x0 Triaxis® Hall Rotary position sensor featuring analog / SENT / SPC / PWM

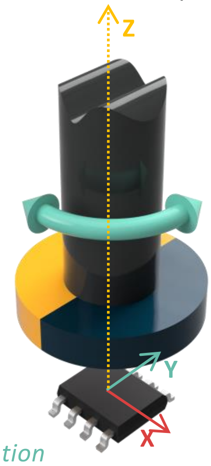

Figure 1 – End of shaft 360 deg rotary application

3. Magnetic Measurement Principle

The Figure 1 shows a typical example of an end-of-shaft application for which a 2 pole 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 2 flux components Bx & By are shown for information only and will be rejected in the measurement as the sensor only uses the axial- field differential ΔBz signal and is thereby stray field immune.

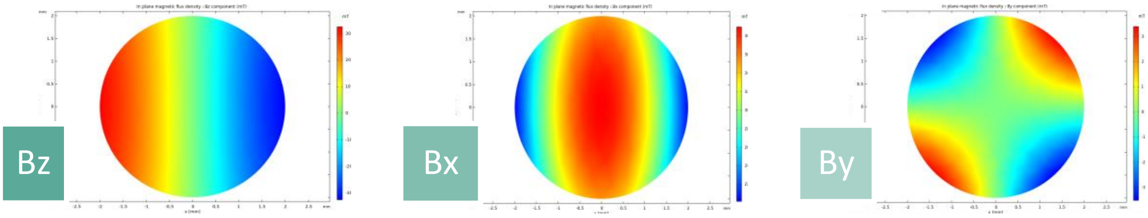

Figure 2 – Magnetic flux density Bx, By, Bz for the position shown in figure 1

The Triaxis® stray field immune Rotary position sensor measures the magnetic Bz signals at 4 different in-plane positions of the sensors at radius (r) applied perpendicular to the IC surface, $Bz@(r,0), Bz@(-r,0), Bz@(0,r), Bz@(0,-r)$ and combines them into two ΔBz signals with a 90 deg phase shift, which represent a sine- and cosine function while the magnet rotates 360 degrees. (see figure4).

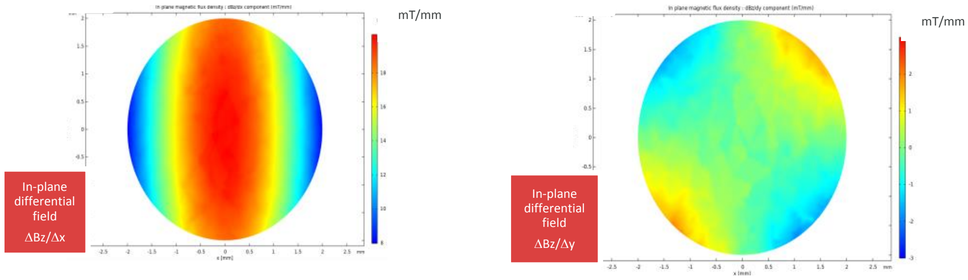

Figure 3 – Magnetic axial- field differential fields (ΔBz/ΔX) , (ΔBz/ΔY) for the fig. 2

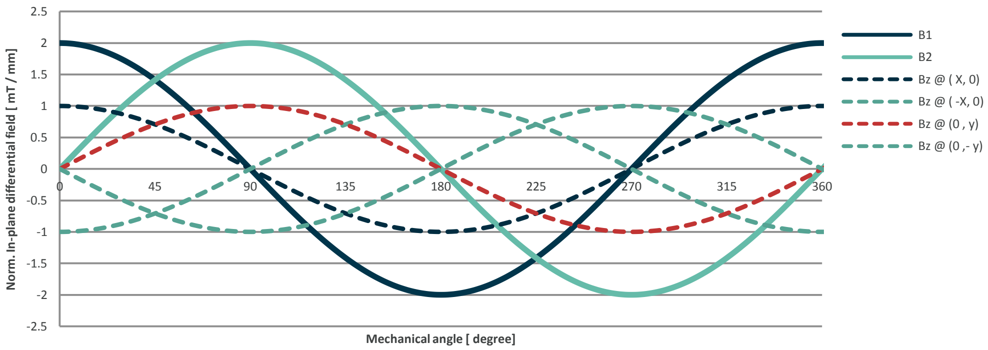

Figure 4 : In-plane field differentials for figure 1

The MLX9042x & MLX90376 will further process the sine- and cosine wave signals to an absolute rotary position from 0 to 360 Degrees of any 2pole magnet rotating around its z-axis.

$$\alpha_{mech.} = Atan2\left(\frac{\Delta B_Z}{\Delta x}, \frac{\Delta B_Z}{\Delta y}\right)$$

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 2 pole magnets.

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

Product / Parameter	90425 90426 DC -0x0	90376 ABA (ACA) DC – 6x0	90376 ABA (ACA) GO – 6x0	90376 ABA (ACA) GVD – 6x0	Condition / Unit
Number of magnetic poles	2	2	2	2	In-plane // IC surface
Sensor radius (r)	0.85	0.375 (0.7)	0.375 (0.7)	0.375 (0.7)	[mm]
Die off axis	N/A	N/A	0	0	Distance vs. rotating Z –axis [mm]
Min. differential Field[2] $\frac{\Delta B_{XY}}{\Delta XY}$	10	20..25 (10)	20..25 (10)	20..25 (10)	$\sqrt{\left(\frac{\Delta B_Z}{\Delta x}\right)^2 + \left(\frac{\Delta B_Z}{\Delta y}\right)^2}$ [mT/mm]
Max. field B_X, B_Y	N/A	N/A	N/A	N/A	$\sqrt{B_X^2 + B_Y^2}$ [mT]
Package airgap	0.46	0.46	0.33 / 0.54	0.5 / 0.77	Distance IC surface – sensor [mm]
Package	SOIC-8	SOIC-8	TSSOP-16	SMP4	

Table 1: MLX90425 – 90426 - 90376 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.

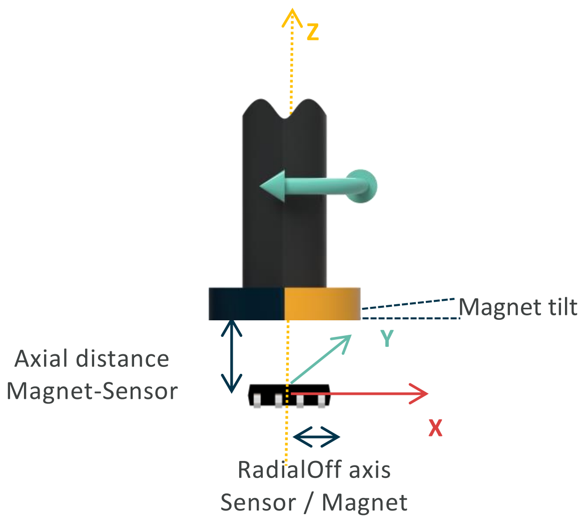

Figure 5 : Mechanical setup for angular sensing

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[1] *For more details and latest specifications, please check the corresponding datasheet MLX90425/90426/90376*
[2] *Min. 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 D, AL & A that are used in this application note.

Magnet	D_	AL_	A_
Magnetization	**D**iametrical	**A**xial-**L**ateral	**A**xial
Outer Diameter [mm]	6/10/14	6/10/14	6/10/14
Inner Diameter [mm]	0	0	0
Thickness [mm]	2.5	2.5	2.5
Br [mT]	1000…	540…	200…
Typ. Material	NdFeB , SmCo	Bonded NdFeB	Bonded Ferrite

Table 2: Magnet properties

The 3 magnets are a first selection to illustrate the effect of the diameter and additionally the choices of magnetic material & magnetization. A disk magnet is selected as base material to simplify the comparisons and manufacturing process. Using a disk magnet, there is typ sufficient strong field on the magnetic field sensing elements with sufficient homogeneity. Adding a hole is of no practical use as it can drastically reduce the field differentials.

4.2.1. Diametrical magnetization

Generally a diametrical magnetization means a homogenous magnetization through the whole body and is oriented perpendicular to the cylinders/disk axis. Small magnets with diametrical magnetization not only generate a large diametrical field, they also generate a useful axial field right on the rotation axis.

To fulfill the min. field requirement of the sensor, smaller magnet diameters and/or strong magnetic material (NdFeB , SmCo) favors the axial field –differential sensor. Larger magnets make the field stronger and more homogeneous, but for axial field-differential sensors this does not work because more homogeneous fields make the differential drops. For diametrical magnetized magnets, the diameter is therefore limited as illustrated in fig 6.

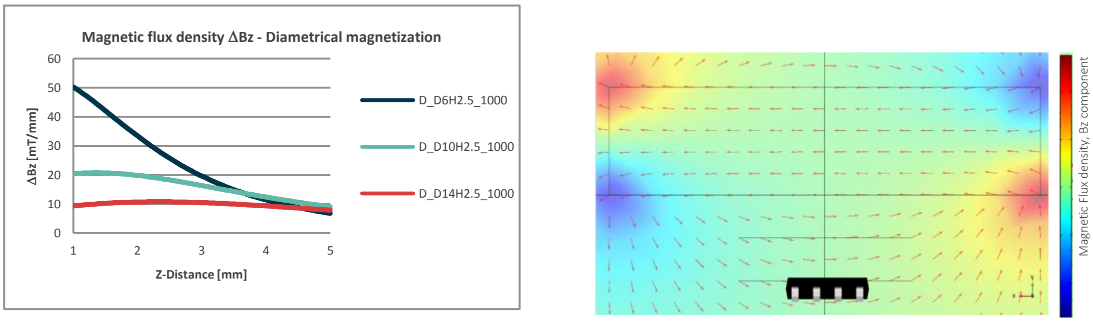

Figure 6 : Magnetic flux density ΔBz & flux lines for a diametrical magnetized magnet

4.2.2. Axial-lateral magnetization

Two pole axial-later sensor magnets are based on bow shaped magnetized disk with two poles per pole face. Optional there can be in depressions, ledges or floors to improve subjects like angular errors of field distributions[3]. The magnetization is oriented towards the z-direction, so that the main poles are always on one side of the magnet facing the sensor, as shown in the right picture of fig 7. The other side of the magnet has nearly no magnetic field which can be an advantage if mounted on a ferromagnetic shaft to limit the magnetic field strength losses. The axial – lateral magnetization allows us to achieve more differential signals vs the diametrical magnetization, but due to the location of the main poles on the top face of the magnet, the linear range between the poles is also degraded. However as the diameter of the magnet is not directly limited by a differential drop, as illustrated in fig 7, a larger magnet could be selected to compensate this linearity degradation if needed.

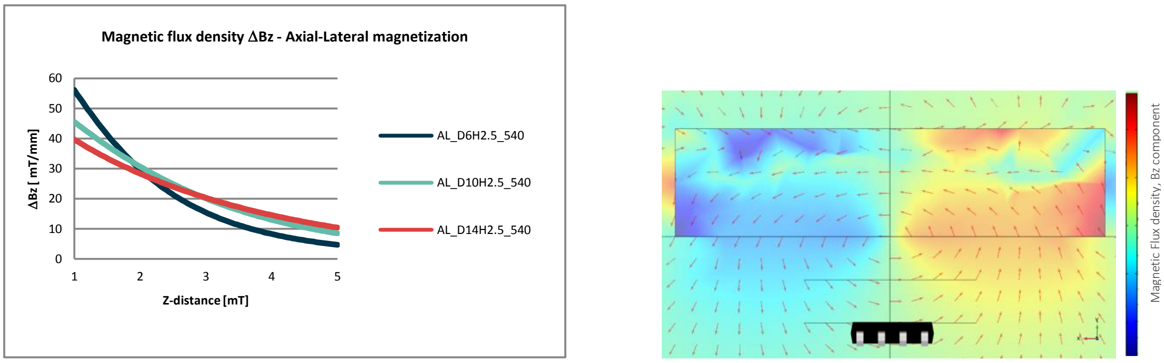

Figure 7 : Magnetic flux density ΔBz & flux lines for an axial-lateral magnetized magnet

4.2.3. Axial magnetization

Two pole axial sensor magnets are based on axially magnetized disk or cylinder with two poles per pole face, Optional there can have in depressions, ledges or floors to improve subjects like angular errors of field distributions[3]. The axial magnetization achieves maximal differential signals but shows lesser homogeneity which leads to an increase of the non-linearity of the signal. It allows one to select the weakest magnetic material to reduce cost.

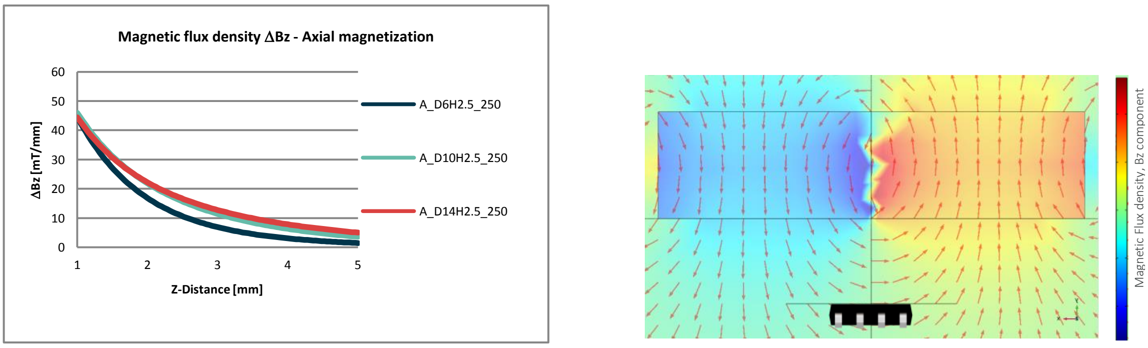

Figure 8 : Magnetic flux density ΔBz & flux lines for an axial magnetized magnet

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[3] *To be aligned with the magnet supplier for best process optimization.*

4.3. Min. differential field, max. field

The acceptable axial distance between magnet and sensor is defined by the min. field requirement:

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

A selection of magnetic material was made for the 3 different magnetizations with the same D10H2.5 mm magnet size, to achieve a comparable magnetic axial differential field at a typ airgap = 2.x mm.

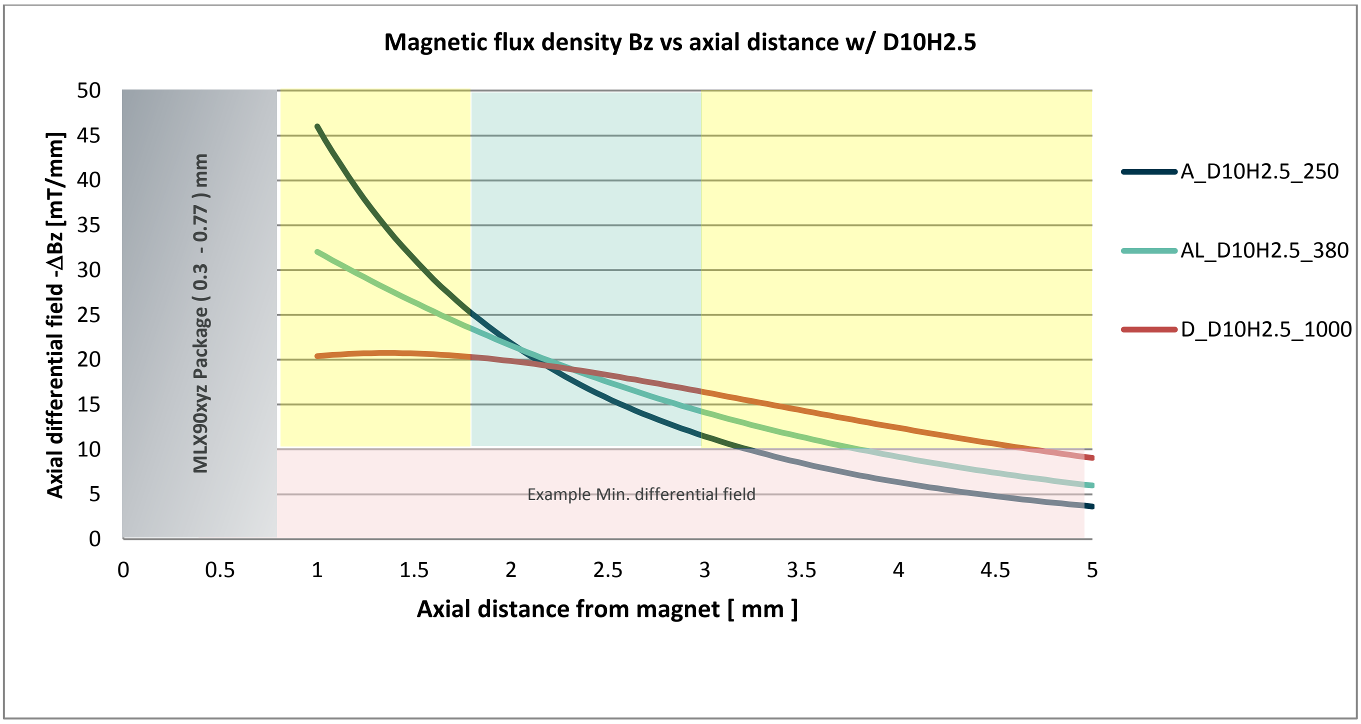

Figure 9 : Axial field-differential vs. Axial distance from Magnet to Sensor (= Airgap)

- The lower airgap limit for Traxis sensor was typically defined by the max. field Bx,By and restricted by the saturation level of the internal magnetic concentrator. As the axial field-differential sensing mode measures the Bz fields without the internal magnetic concentrator, this limitation is no longer applicable. However, depending on the selected magnetization and sensor, the non-linearity of field signal and bigger HE radius can have an impact on the error budget at closer airgaps as shown in chapter 4.5 This therefore can have an impact on the choice of the min airgap.

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 10 shows the typical relative non-linearity vs the center position for a radial sensor off axis at different airgaps, with the magnet A, D and AL.

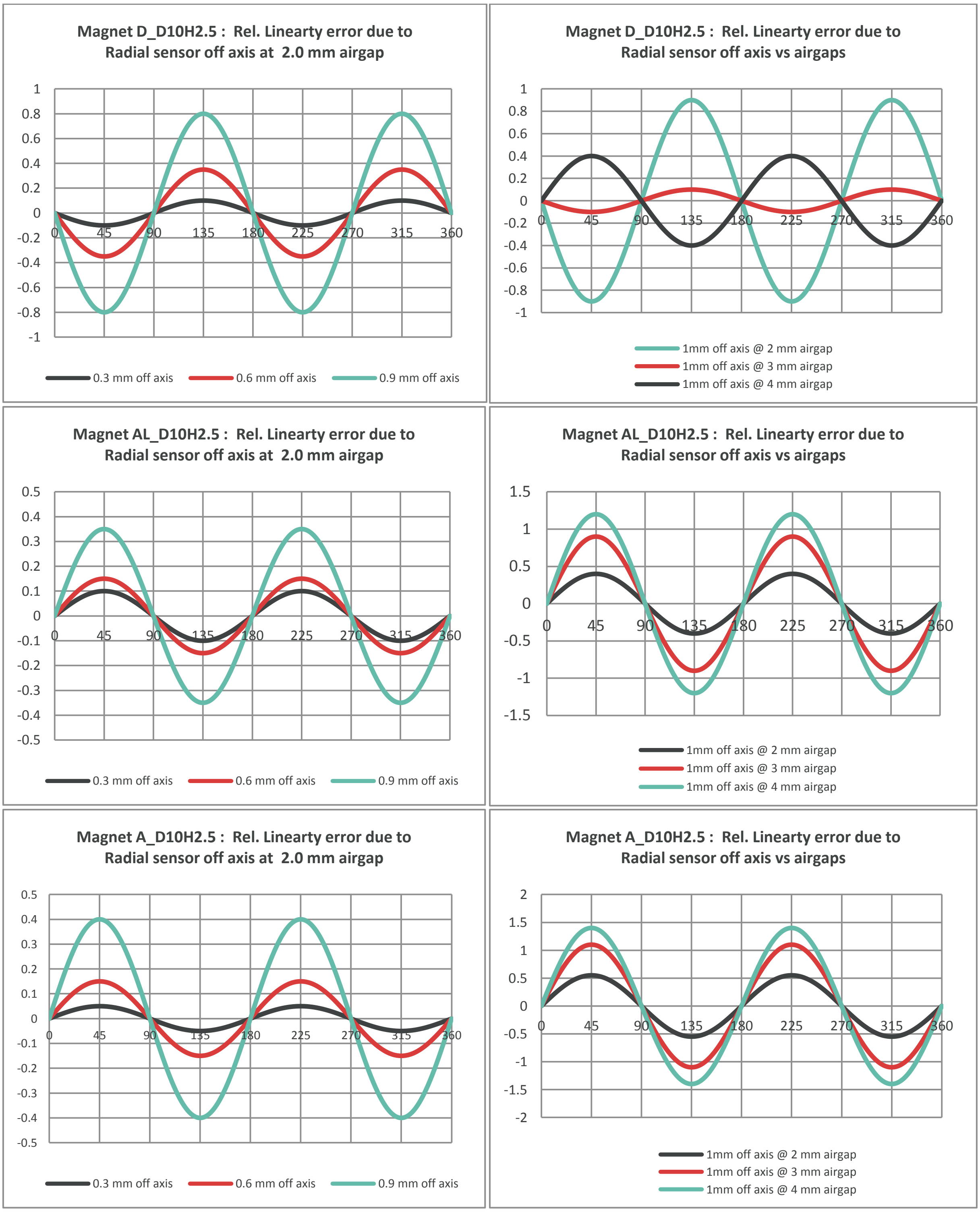

Figure 10 : Non-linearity error vs. radial sensor off axis vs. Axial distance from Magnet to Sensor

Angular errors due to a given radial sensor off axis misalignment will become smaller with an increasing diameter of the magnet and decreasing axial distance. It can also be noticed from figure 10 & 11, that the diametrical magnetization for all diameters has a better robustness against eccentricity vs. the axial & axial-lateral magnetized magnets, thanks to the better in plane homogenous magnetic differential field.

The relative non-linearity angle error, due to a radial sensor off axis, can be recognized from the shape as it has a typical 2nd harmonic cosine and sine component. The maximum error for the different conditions and magnets vs. radial sensor off axis, is summered in figure 11.

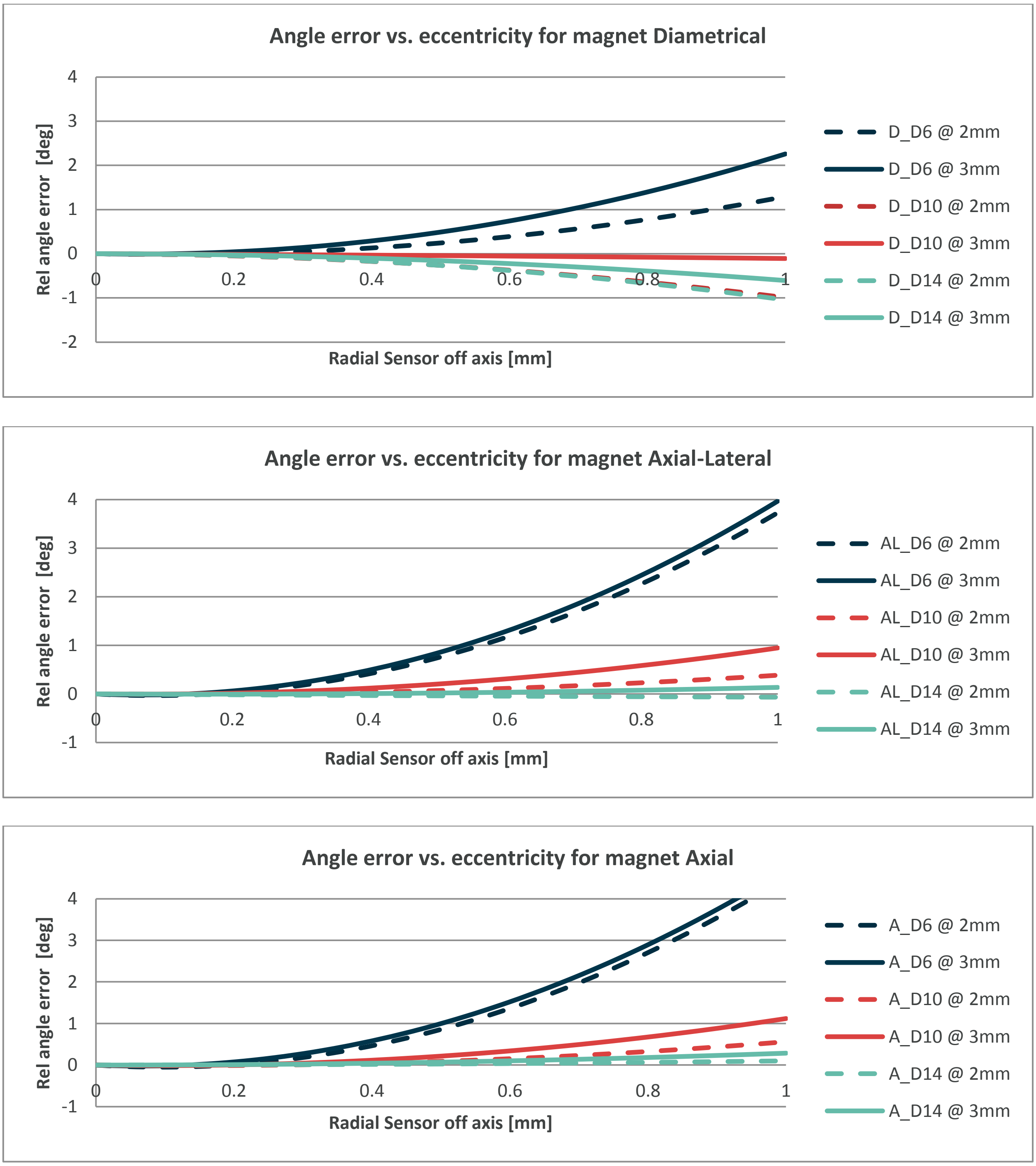

Figure 11 : max. Non-linearity error vs. radial sensor off axis & Axial distance from Magnet to Sensor

4.5. Non linearity vs airgap

Axial and Axial-lateral magnetized magnets have less in plane homogenous magnetic differential field, which in combination with bigger HE sensing radius, can create a non-linearity of field signal, resulting in a 4th harmonic non linearity angle error at close airgaps. This can impact on the error budget at closer airgaps and therefore can have an impact on the choice of min airgap.

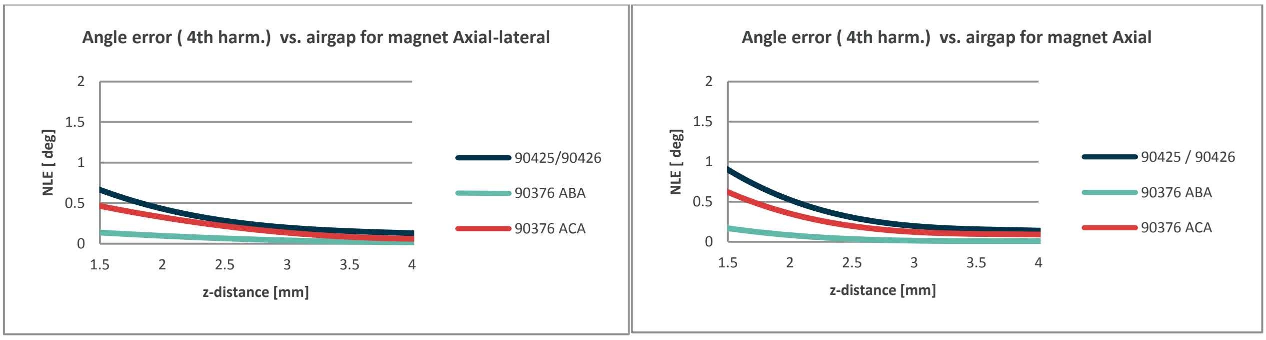

Figure 12 : max. 4th harmonic Non-linearity error vs. Axial distance from Magnet to Sensor

5. Magnet Recommendations & Optimization

Several different sizes, magnetization directions and shapes can be used for the Triaxis® stray field immune axial field-differential angle sensor and the final selection of choice will usually be based on the application requirements.

The axial differential signals are typically increased with decreasing magnet diameter and the first selecting criteria to fulfill the min field requirement.
The axial and axial-lateral magnetization are typically generating more axial differential signals allowing cheaper magnetic material vs diametrical magnetized magnets , but 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 differential field. In order of eccentricity error performance, Diametrical magnets are best in class , followed by Axial – lateral and latest Axial magnetized magnets.

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.

Plastic bonded Ferrite magnet are typical from cost perspective a preferred solution, but typ. also anisotropic, Axial magnetized, generating more axial differential signals.

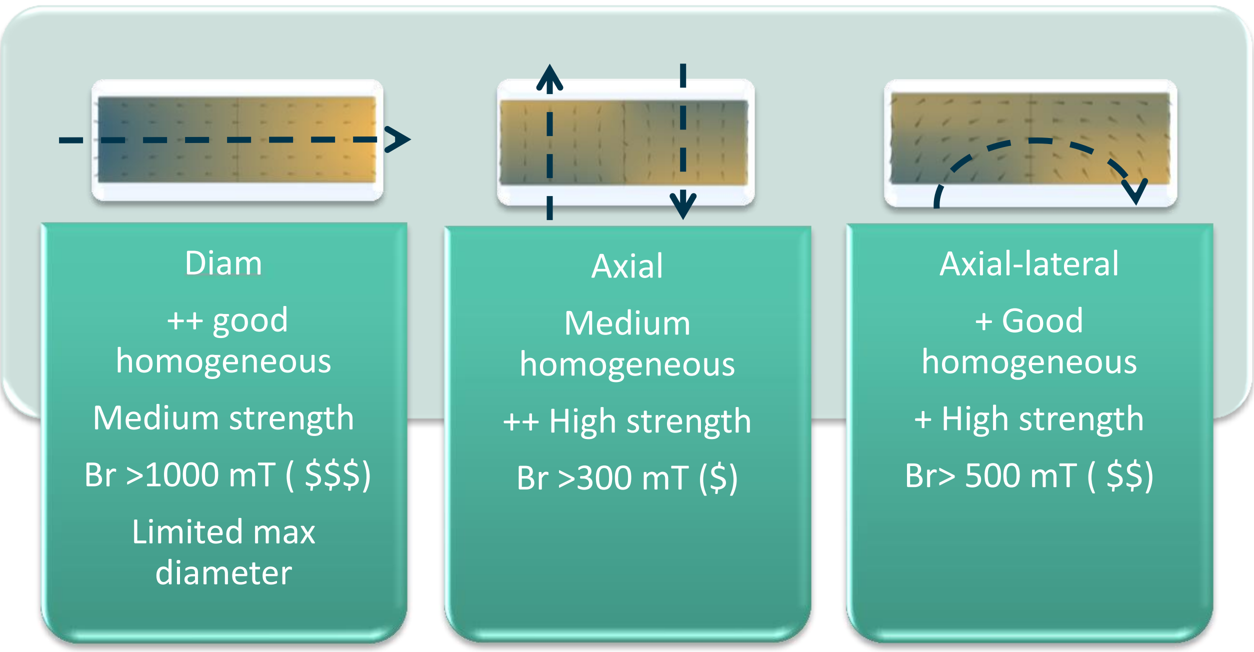

Figure 13 : Mech. variants of magnet , Strength vs off axis performance

6. Disclaimer

IATF 16949 and ISO 14001 Certified