Magnet Selection Guide

AS5000 Series Magnetic Sensor Circuits

1 General Description

This document provides basic guidelines to the selection of magnets used in combination with the AS5000-Series magnetic rotary and linear motion detection circuits. It also provided suggestions for proper mounting of these magnets in the devices for which the rotating angle is being measured.

2 Measurement Principle

The AS5000-series magnetic sensor circuits are using integrated lateral Hall sensors in standard CMOS technology. Lateral Hall elements are sensitive to the magnetic field component perpendicular to their surface. This means they are only sensitive to magnetic fields vertical to the IC surface.

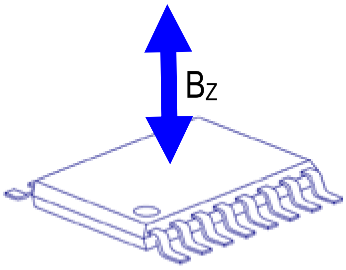


Fig. 1: Sensitivity of the integrated Hall elements

The AS500-series magnetic sensor circuits are a system-on-chip, they contain all components required to create a non-contact rotation angle or linear position measurement system. Basically, the only external component required is a magnet rotating over the surface of the IC.

Depending on the type of measurement (rotation, tilt, linear position), different magnets are used.

2.1 On-Axis Rotation Angle Measurement

In this type of measurement, a magnet rotates over the chip such that

- the center of the magnet,
- the center of rotation
- and the center of the chip

are in one vertical line (see Fig. 2).

The Hall elements on the chip are arranged in a circle of typ. 2.2mm diameter. The measurement principle for rotation angle measurement requires that the Hall elements on the IC can sense a full magnetic period as the magnet rotates. This requirement is obtained by using a diametrically magnetized magnet (see Fig. 2 and Fig. 8).

As the magnet rotates over the chip, The Hall sensors create sine and cosine signals with one period per revolution. An on-chip signal processor further interpolates these sinusoidal signals into absolute vectors from 0…360° with high resolution. Consequently, this method is capable of measuring absolute angle information.

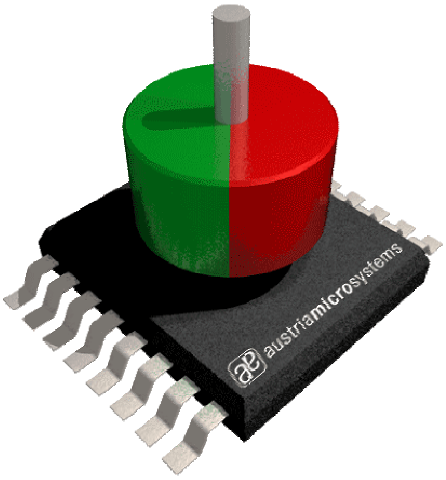


Fig. 2: On-axis rotation measurement with diametric magnet

2.2 Linear Position Measurement

For measuring linear position, the Hall sensors on the chip are arranged in a straight line. Likewise, the corresponding magnet is a so-called multipole strip, a magnetic bar with equally spaced north and south poles.

(see Fig. 3). The length of the poles matches the spacing of the Hall sensors on the chip. As the magnet slides over the Hall sensors again create sine and cosine signals, which are further interpolated into fine steps. As this method cannot provide absolute position information (theoretically only within one pole pair), it is typically used for incremental output, a digital format providing two phase shifted pulses (as the target moves. The phase shift determines the direction of movement (left, right) and the number of pulses are proportional to the travelled distance.

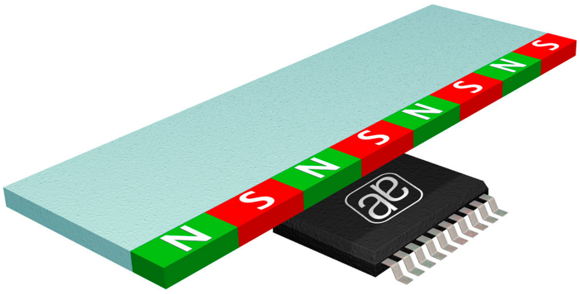


Fig. 3: Linear position measurement with multipole strip

2.3 Off-Axis Rotation Angle Measurement

In many cases, it is not possible to mount a magnet at the end of a shaft, for example if the rotating shaft is hollow or if another device, such as a brake, clutch or joint must be mounted at this location.

In this case, the same principle as the linear position method, described in 2.2 can be applied. The corresponding ring magnet is again a multipole type, with a pole pair length matching the spacing of the linear Hall array in the chip. But instead of using a magnetic bar, the multipole magnet is formed as a multipole ring (see Fig. 4 and Fig. 5)

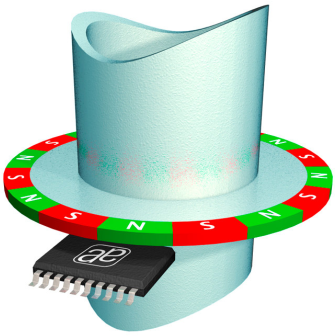


Fig. 4: Off-axis rotation angle measurement with multipole ring and axial mounting of the sensor

Fig. 5: Off-axis rotation angle measurement with multipole ring and radial mounting of the sensor

The sensor IC is mounted below the ring at a vertical distance of ~0.5 – 1.0 mm

2.3.1 Calculation examples for multi-pole magnetic rings

-see also: Application note. Multi-pole magnet requirements, available for download on the austriamicrosystems website.

The pole length of a multi-pole magnetic ring must match the nominal pole length of the linear encoder IC. Linear encoder ICs available from austriamicrosystems include

AS5304: pole length = 2.0 mm (interpolation = 160x)
AS5306 pole length = 1.2 mm (interpolation = 160x)
AS5311 pole length = 1.0 mm (interpolation = 1024x – incremental outputs)
AS5311 pole length = 1.0 mm (interpolation = 4096x – absolute outputs)

The diameter of a multipole magnet is calculated as:

$$d_{nom} = \frac{2*n*l_P}{\pi}$$

where: n = number of pole pairs on the ring
l_P = nominal pole length of encoder chip
d_{nom} = nominal magnet ring diameter

The nominal diameter is the locus at which the Hall sensors of the encoder IC should be placed. The exact location of the Hall sensors relative to the IC package are shown in the respective datasheet of the encoder IC.

The inner and outer ring diameter should be selected such that the nominal diameter is in the center of the ring.

Note the curvature of the ring may create additional linearity errors. These errors are reduced with increasing ring diameter.

Example 1:

Encoder IC = AS5304, axial mounting (Fig. 4)
magnetic ring properties
(defined by the available space of the given application)
diameter: ~ 28mm
width: ~4mm

The circumference for this diameter would be 28mm*π =87.9mm.

One pole for the AS5304 is 2.0mm, consequently the circumference must be a multiple of one pole pair = n * 4.0mm.

The closest fit is n=22 22 * 4 = 88mm

$$d_{nom} = \frac{2*22*2.0}{\pi} = 28.011mm$$

As the nominal diameter should be in the center of the magnet and the width of the magnet ring is selected as 4mm,
the inner diameter is chosen as 24mm
the outer diameter is chosen as 32mm

the resolution of this ring is:
pole pairs * interpolation factor =
22 * 160 = 3520 steps per revolutoin

Note: the magnet in the above example is available at the austriamicrosystems web shop as part number AS5000-MR20-44

Example 2:
Encoder IC = AS5304, radial mounting (Fig. 5)

magnetic ring properties
(defined by the available space of the given application)
shaft diameter: ~ 25mm
width: ~4mm
ring thickness: ~1.5mm
gap between magnet and IC: 0.5mm

The circumference at the locus of the Hall sensors must include the shaft diameter, the thickness of the magnet and the airgap:

diameter at Hall sensors =
25mm + 2* 1.5mm + 2* 0.5mm= 29mm.

The circumference for this diameter would be 29mm*π =91.1mm.
One pole for the AS5304 is 2.0mm, consequently the circumference must be a multiple of one pole pair = n * 4.0mm.
The closest fit is n=23   23 * 4 = 92mm

$$d_{nom} = \frac{2*23*2.0}{\pi} = 29.29mm$$

As the shaft diameter should not be changed (25mm), the remaining gap between shaft and IC is (29.29 – 25) / 2 = 2.15mm
the magnet thickness remains at 1.5mm,
the remaining airgap is 0.65mm.

the proper radial magnet dimensions for this example would be:

inner diameter: 25mm
outer diameter: 28mm
ring width : 4mm
airgap : 0.65mm

2.4 High resolution measurement of small angles

The measurement setup shown in Fig. 4 is a typical application for incremental off-axis angle sensing. A similar setup can be used to measure small angles with high resolution in absolute values. Linear Encoders, such as the AS5311 can also provide absolute information of the magnet's position within one pole pair. If the small angle measurement is set up such that the magnet moves exactly the length of one pole pair within the angle to be measured, an absolute high resolution angle measurement can be achieved.

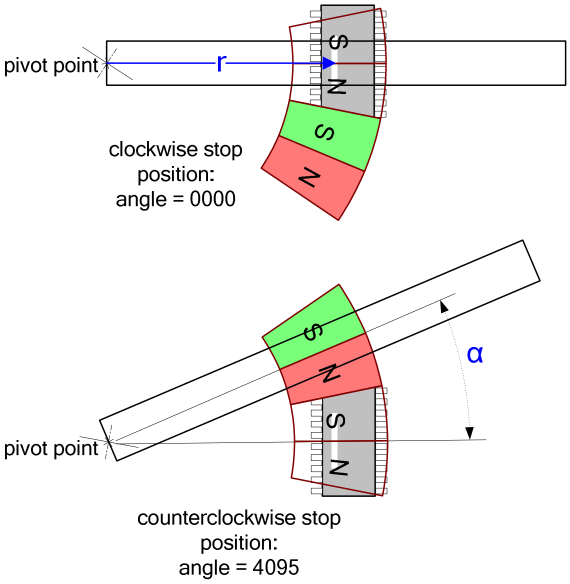


Fig. 6: small angle high resolution measurement setup

Fig. 6 shows an example of such a high resolution absolute measurement setup. The rectangular bar in this example is rotated about the pivot point by 22°. This angle can be resolved with a resolution of 12-bit (position 0…..4095), which results in an angle resolution of 0.0054° per step (= 22° / 4096) or an equivalent of ~16-bit per revolution.

The magnet, connected to the rotating bar must be placed such that it travels exactly one pole pair length from one stop position to the other.
In case of the AS5311, the pole pair length is 2 mm. This pole length is fixed, therefore the measured angle determines the correct placement of the IC + Magnet relative to the pivot point.
The distance: Hall Array to pivot point = measurement radius can be calculated as:

$$r = \frac{polelength*360}{\pi*\alpha} \Rightarrow forAS5311: r = \frac{114.6}{\alpha}$$

where: r = measurement radius
(distance: pivot point to Hall array)
α = measured maximum angle

In the above example, using an AS5311 chip with a nominal pole length of 1.0mm and an angle stroke of 22°, the measurement radius would be 5.2mm .

2.5 Tilt Measurement

The on-axis rotation angle measurement principle described in 2.1 can also be used for tilt measurement, for example for non-contact joysticks.
For this type of measurement, an axial magnet is required (see Fig. 7), where the north and south poles lie in the center axis (top and bottom).
The output of the angle encoder changes accordingly, when an axial magnet is used instead of a diametrically magnetized magnet:

Encoder function	Diametrical	Axial
angle output	rotation angle	direction of tilt
magnitude output (not available on all products)	strength of magnetic field	degree of tilt

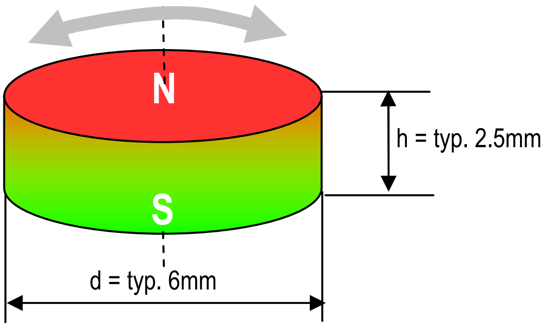


Fig. 7: Axial magnet for tilt and lateral shift measurement

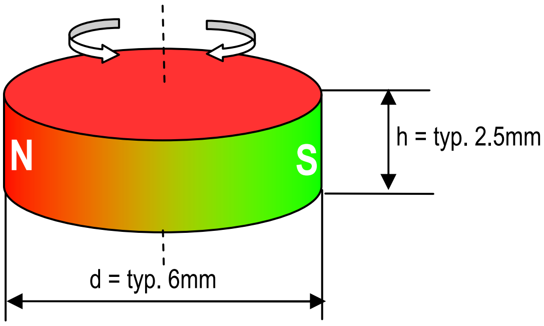


Fig. 8: Diametrically magnetized magnet for rotation angle measurements

2.6 Lateral Shift Measurement

Similar to the tilt measurement, an axially magnetized magnet is also used in manual input applications where a button containing the magnet is sliding over the chip in a cursor-like fashion in x- and y- direction.
In this kind of measurement, the differential signals of two opposite Hall sensors in x- and y- direction are evaluated:

X- position = right sensor – left sensor
Y- position = top sensor – bottom sensor

3 Magnet Materials

For on-axis rotation measurement (see 2.1) as well as
tilt measurement (see 2.5) and
lateral shift measurement (see 2.6)
it is recommended to use rare earth magnets such as Neodymium-Iron-Boron (NdFeB) or Samarium-Cobalt (SmCo) magnets. The latter ones are available as $SmCo_5$ or as Sm_2Co_{17} material.

For linear position (see 2.2) and off-axis rotation measurement (see 0), multipole magnets made of hard ferrite or rubber bonded strontium ferrite magnets can be used.

4 NdFeB vs. SmCo

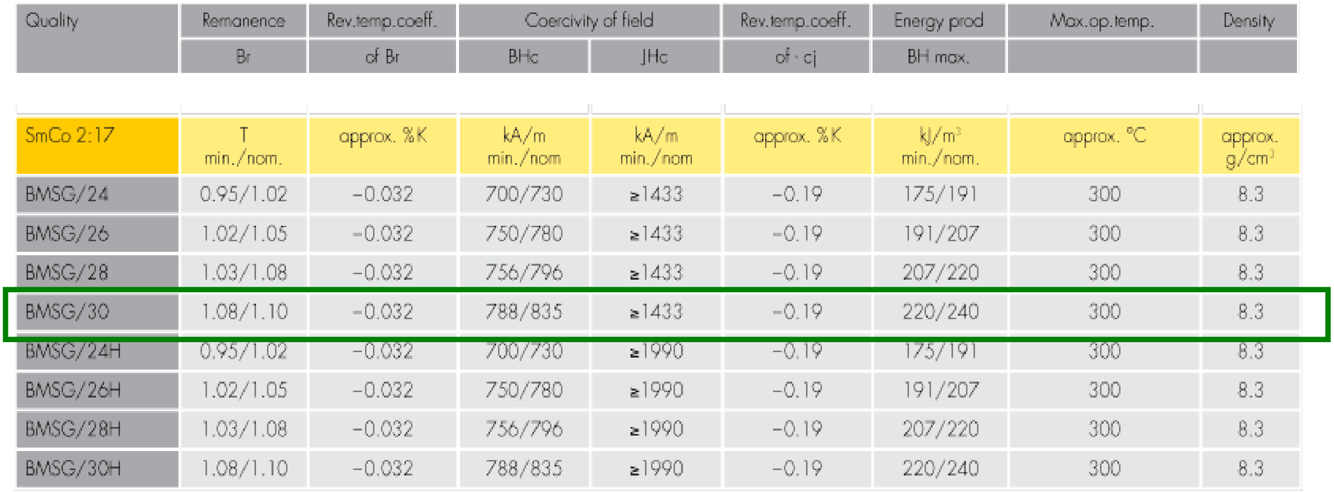
Property	NdFeB magnets	SmCo magnets
Temperature coefficient	-0.09 …. -0.12 %/K	-0.032….-0.04 %/K
Max. operating temperature	80…180°C	250…300°C
Remanence (strength)	1.02 - 1.46 T	0.86 - 1.18 T
Curie temperature	310 – 380°C	< 720 °C
Corrosion protection	Yes, typ. Nickel	Not required
Cost	$$	$$$

Table 1: NdFeB versus SmCo magnets

Table 1 shows a comparison between Neodymium-Iron-Boron (NdFeB) and Samarium-Cobalt (SmCo) magnets. Advantages over the other type are shown with green background, disadvantages are shown with red background. SmCo-magnets have a temperature stability that is about 3 times better than NdFeB (-0.035 to -0.04 %/°C) and can be operated at much higher temperatures (typ. 250 to 300°C operating, 720°C Curie temperature).
They are also less corrosive than NdFeB magnets and need no protective coating. However, they are also more expensive and not as strong as NdFeB magnets.
It is therefore strongly recommended to ensure that the protective coating of NdFeB magnets is not scratched during the process of inserting the magnet in a shaft or other rotating medium. The exposed NdFeB area may corrode quickly and eventually cause the magnet to break.

4.1 Magnetic Material Grades

Both SmCo and NdFeB magnets are available in different grades, mainly determined by the Remanence, essentially the strength of the magnet.
The recommended magnet grade for the AS5000-series when used for on-axis angle measurement is N35H for NdFeB magnets (austriamicrosystems part nbr. M1 and M2) and SG-30 for Sm_2Co_{17} magnets.
Note that NdFeB magnets have a lower operating temperature than SmCo magnets. A grade N35H has a maximum operating temperature of 120°C. If the magnet is to be operated at higher ambient temperatures, it is recommended to use a N35SH grade, which can operate up to 150°C (austriamicrosystems part nbr: AS5000-MH1).



Quality	Remanence	Rev.temp.coeff.	Coercivity of field		Rev.temp.coeff.	Energy prod	Max.op.temp.	Density
	Br	of Br	BHc	JHc	of · cj	BH max.		
SmCo 2:17	T min./nom.	approx. %K	kA/m min./nom	kA/m min./nom	approx. %K	kJ/m^3 min./nom.	approx. °C	approx. g/cm^3
BMSG/24	0.95/1.02	-0.032	700/730	≥1433	-0.19	175/191	300	8.3
BMSG/26	1.02/1.05	-0.032	750/780	≥1433	-0.19	191/207	300	8.3
BMSG/28	1.03/1.08	-0.032	756/796	≥1433	-0.19	207/220	300	8.3
BMSG/30	1.08/1.10	-0.032	788/835	≥1433	-0.19	220/240	300	8.3
BMSG/24H	0.95/1.02	-0.032	700/730	≥1990	-0.19	175/191	300	8.3
BMSG/26H	1.02/1.05	-0.032	750/780	≥1990	-0.19	191/207	300	8.3
BMSG/28H	1.03/1.08	-0.032	756/796	≥1990	-0.19	207/220	300	8.3
BMSG/30H	1.08/1.10	-0.032	788/835	≥1990	-0.19	220/240	300	8.3

Table 2: SmCo magnet grades (www.bomatec.ch)

Quality	Remanence	Rev.temp.coeff.	Coercivity of field		Rev.temp.coeff.	Energy prod	Max.op.temp.	Density
	Br	of Br	BHc	JHc	of · cj	BH max.		
NdFeB magnets	T min./nom.	approx. %K	kA/m min./nom.	kA/m min./nom.	approx. %K	kJ/m^3 min./nom.	approx. °C	approx. g/cm^3
BMN-30	1.08/1.12	-0.11	780/836	>955	-0.6	223/239	80	7.5
BMN-33	1.14/1.17	-0.11	820/876	>955	-0.6	247/263	80	7.5
BMN-35	1.17/1.22	-0.11	836/891	>955	-0.6	263/279	80	7.5
BMN-38	1.22/1.26	-0.11	836/891	>955	-0.6	279/302	80	7.5
BMN-40	1.26/1.3	-0.11	836/891	>955	-0.6	302/318	80	7.5
BMN-42	1.3/1.33	-0.11	836/891	>955	-0.6	318/334	80	7.5
BMN-45	1.33/1.37	-0.11	836/891	>955	-0.6	334/358	80	7.5
BMN-48	1.37/1.41	-0.11	812/859	>876	-0.6	358/382	80	7.5
BMN-50	1.4/1.44	-0.11	812/859	>876	-0.6	382/398	80	7.5
BMN-30M	1.08/1.1	-0.11	780/836	>1114	-0.6	223/239	100	7.5
BMN-33M	1.14/1.17	-0.11	812/859	>1114	-0.6	239/263	100	7.5
BMN-35M	1.17/1.22	-0.11	836/891	>1114	-0.6	263/279	100	7.5
BMN-38M	1.22/1.26	-0.11	859/915	>1114	-0.6	279/302	100	7.5
BMN-40M	1.26/1.3	-0.11	859/915	>1114	-0.6	302/318	100	7.5
BMN-42M	1.3/1.33	-0.11	859/915	>1114	-0.6	318/334	100	7.5
BMN-45M	1.33/1.37	-0.11	859/915	>1114	-0.6	334/358	100	7.5
BMN-48M	1.37/1.41	-0.11	859/915	>1114	-0.6	358/382	100	7.5
BMN-30H	1.08/1.14	-0.11	780/812	>1353	-0.6	223/239	120	7.5
BMN-33H	1.14/1.17	-0.11	812/875	>1353	-0.6	239/263	120	7.5
BMN-35H	1.17/1.21	-0.11	836/891	>1353	-0.6	263/279	120	7.5
BMN-38H*	1.22/1.26	-0.11	859/915	>1353	-0.6	279/302	120	7.5
BMN-40H*	1.26/1.3	-0.11	859/915	>1353	-0.6	302/318	120	7.5
BMN-42H*	1.3/1.33	-0.11	859/915	>1353	-0.6	318/334	120	7.5
BMN-45H*	1.33/1.37	-0.11	859/915	>1353	-0.6	334/358	120	7.5
BMN-46H*	1.35/1.38	-0.11	859/915	>1353	-0.6	350/366	120	7.5
BMN-48H*	1.37/1.41	-0.11	859/915	>1353	-0.6	358/382	120	7.5
BMN-27SH	1.02/1.06	-0.11	780/812	>1592	-0.6	199/215	150	7.5
BMN-30SH	1.08/1.14	-0.11	780/812	>1592	-0.6	223/239	150	7.5
BMN-33SH*	1.14/1.17	-0.11	812/875	>1592	-0.6	239/263	150	7.5
BMN-35SH*	1.17/1.22	-0.11	836/891	>1592	-0.6	263/279	150	7.5
BMN-38SH*	1.22/1.26	-0.11	859/915	>1592	-0.6	279/302	150	7.5
BMN-40SH*	1.26/1.3	-0.11	859/915	>1592	-0.6	302/318	150	7.5
BMN-42SH*	1.3/1.33	-0.11	859/915	>1592	-0.6	318/334	150	7.5
BMN-44SH*	1.33/1.36	-0.11	859/915	>1592	-0.6	334/350	150	7.5
BMN-28UH*	1.04/1.08	-0.11	780/812	>1989	-0.6	199/223	160	7.5
BMN-30UH*	1.08/1.14	-0.11	796/844	>1989	-0.6	223/239	160	7.5
BMN-33UH*	1.14/1.17	-0.11	812/875	>1989	-0.6	239/263	160	7.5
BMN-35UH*	1.17/1.22	-0.11	836/891	>1989	-0.6	263/279	160	7.5
BMN-38UH*	1.22/1.26	-0.11	836/915	>1989	-0.6	279/302	160	7.5
BMN-40UH*	1.26/1.30	-0.11	836/915	>1989	-0.6	302/318	160	7.5
BMN-28EH*	1.04/1.08	-0.11	780/812	>2387	-0.6	199/223	180	7.5
BMN-30EH*	1.08/1.14	-0.11	796/844	>2387	-0.6	223/239	180	7.5
BMN-33EH*	1.14/1.17	-0.11	812/875	>2387	-0.6	239/263	180	7.5
BMN-35EH*	1.17/1.22	-0.11	836/915	>2387	-0.6	263/279	180	7.5
BMN-38EH*	1.22/1.26	-0.11	836/915	>2387	-0.6	279/302	180	7.5

Table 3: NdFeB magnet grades (www.bomatec.ch)

5 Magnet Diameter and Vertical Distance

5.1 The Linear Range

As described in section 2, the Hall elements used in the AS5000-series sensor ICs are sensitive to the magnetic field component Bz, which is the magnetic field vertical to the chip surface. Fig. 9 shows a 3-dimensional graph of the Bz field across the surface of a 6mm diameter, cylindrical NdFeB N35H magnet at an axial distance of 1mm between magnet and IC.
The highest magnetic field occurs at the north and south poles, which are located close to the edge of the magnet, at ~2.8mm radius (see also Fig. 10). Following the poles towards the center of the magnet, the Bz field decreases very linearly within a radius of ~1.6mm. This linear range is the operating range of the magnet with respect to the Hall sensor array on the chip. For best performance, the Hall elements should always be within this linear range.

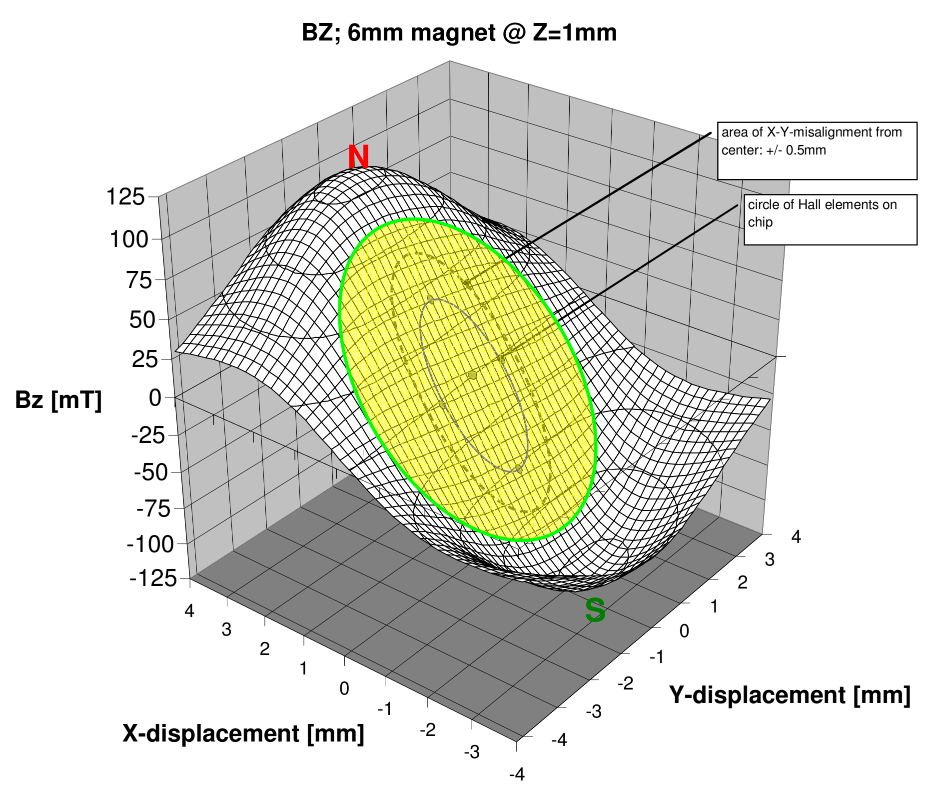


Fig. 9: 3D-graph of vertical magnetic field of a 6mm cylindrical magnet

As shown in Fig. 10 (grey zone), the Hall elements are located on the chip at a circle with a radius of 1.1mm. Since the difference between two opposite Hall sensors is measured, there will be no difference in signal amplitude when the magnet is perfectly centered or if the magnet is misaligned in any direction **as long as all Hall elements stay within the linear range** ! For the 6mm magnet shown in Fig. 10, the linear range has a radius of 1.6mm, so this magnet allows a radial misalignment of 0.5mm (1.6mm linear range radius – 1.1mm Hall array radius).

Consequently, the larger the linear range, the more radial misalignment can be tolerated. By contrast, the slope of the linear range decreases with increasing magnet diameter, as the poles are further apart. A smaller slope results in a smaller differential signal, which means that the magnet must be moved closer to the IC (smaller airgap) or the amplification gain must be increased which leads to a poorer signal – to – noise ratio. More noise results in more jitter at the angle output. A good compromise is a magnet diameter in the range of 5…8mm.

Small diameter magnet (<6mm):	Large diameter magnet (>6mm):
+++ stronger differential signal = good signal / noise ratio, larger airgaps	**+++** wider linear range = larger horizontal misalignment area
--- shorter linear range = smaller horizontal misalignment area	**--** weaker differential signal = poorer signal / noise ratio, smaller airgaps

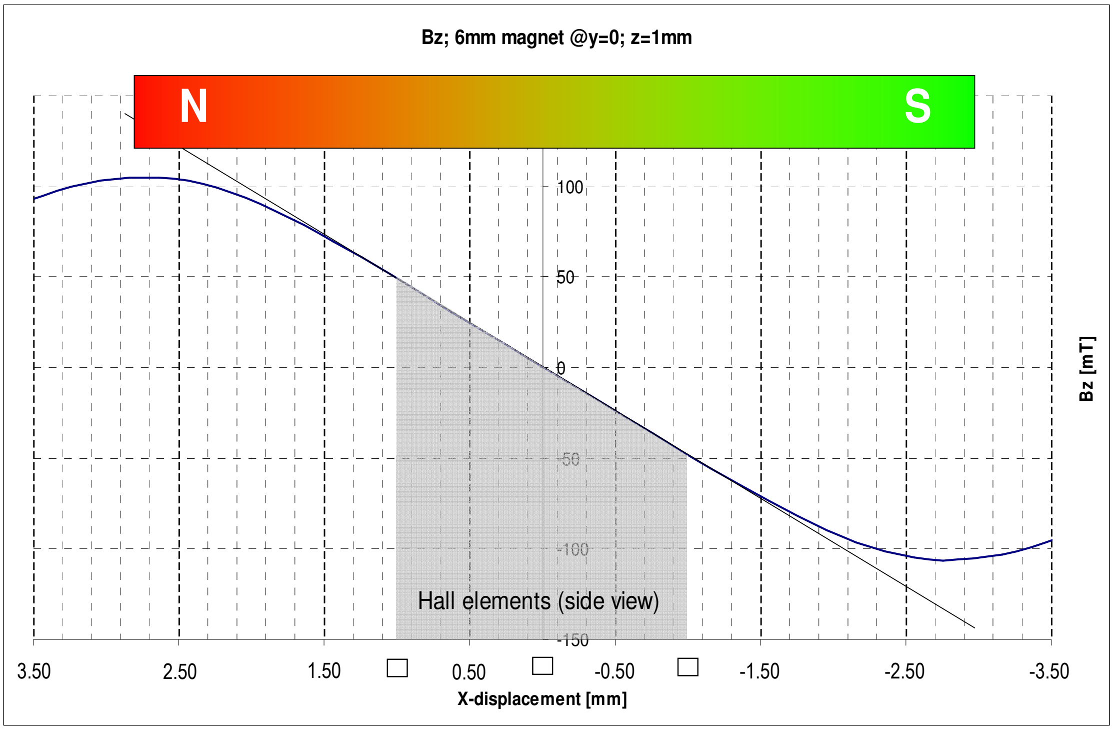


Fig. 10: Vertical magnetic field across the center of a cylindrical magnet

5.2 Magnet Thickness

Fig. 11 shows the relationship of the peak amplitude in a rotating system (essentially the magnetic field strength of the Bz field component) in relation to the thickness of the magnet. The X-axis shows the ratio of magnet thickness (or height) [h] to magnet diameter [d] and the Y-axis shows the relative peak amplitude with reference to the recommended magnet (d=6mm, h=2.5mm) . This results in an h/d ratio of 0.42.

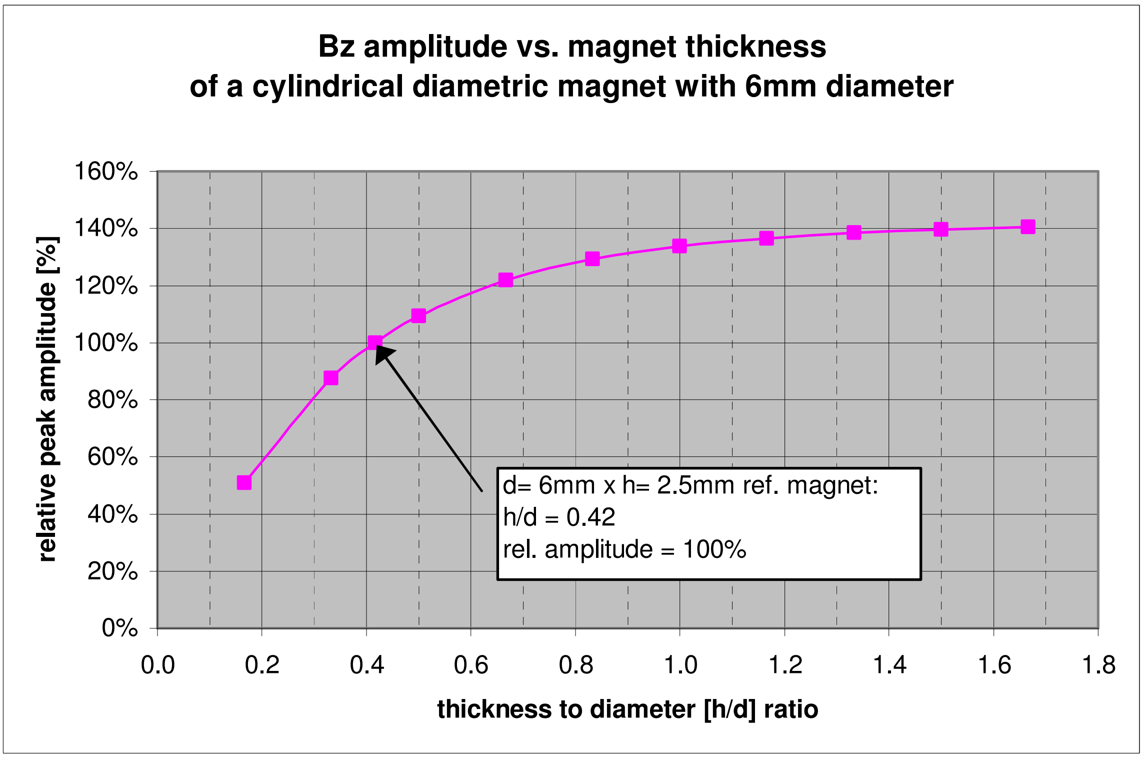
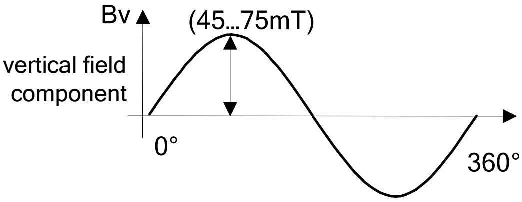


Fig. 11: Relationship of peak amplitude versus magnet thickness

As the graph shows, the amplitude drops significantly at h/d ratios below this value and remains relatively flat at ratios above 1.3. Therefore, the recommended thickness of 2.5mm (@6mm diameter) should be considered as the low limit with regards to magnet thickness.
It is possible to get 40% or more signal amplitude by using thicker magnets. However, the gain in signal amplitude becomes less significant for h/d ratios >~1.3. Therefore, the recommended magnet thickness for a 6mm diameter magnet is between 2.5 and ~8 mm.

5.3 Axial Distance (Airgap)



The recommended magnetic field, measured at the chip surface on a radius equal to the Hall sensor array radius (typ. 1.1mm) should be within a certain range. This range lies between 45 and 75mT or between 20 and 80mT, depending on the encoder product.
Linear position sensors are more sensitive as they use weaker magnets. The allowed magnetic range lies typically between 5 and 60mT.
Check the corresponding product datasheet for details.

Fig. 12: Sinusoidal magnetic field generated by the rotating magnet

5.4 Angle Error versus Radial and Axial Misalignment

The angle error is the deviation of the actual angle versus the angle measured by the encoder. There are several factors in the chip itself that contribute to this error, mainly offset and gain matching of the amplifiers in the analog signal path. On the other hand, there is the nonlinearity of the signals coming from the Hall sensors, caused by misalignment of the magnet and imperfections in the magnetic material.
Ideally, the Hall sensor signals should be sinusoidal, with equal peak amplitude of each signal. This can be maintained, as long as all Hall elements are within the linear range of the magnetic field Bz (see Fig. 10)

This is also reflected in graphs (Fig. 13 to Fig. 15):

Fig. 13 is a 3D-Plot of the angular error from a 5mm diameter magnet at an axial distance of 0.5mm. The X- and Y- axis of the plot is the radial misalignment of the magnet with respect to the IC. At X = 0, Y = 0 the magnet is perfectly centered over the chip. The maximum radial misalignment is +/-1mm in both axes. The grid size is 0.1mm.
The Z-axis is the maximum angle error over one full turn. The angle data is taken as it is read from the chip. No calibration or postprocessing is made. Same colors are same error ranges, in steps of 1°.

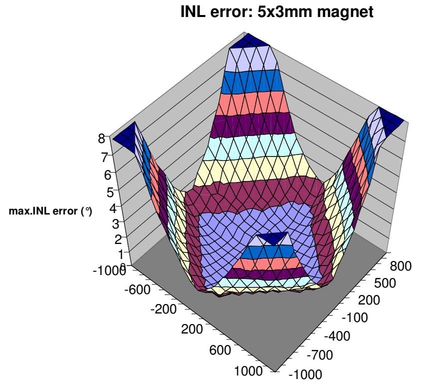


Fig. 13: Angle error of 5mm diameter magnet at 0.5mm airgap

The graph shows that the angle error remains below 1°, even if the magnet is out of center by ~0.4mm (~4 grid steps from the center). This is the area in which the Hall elements are within the linear range of the 5mm magnet. As soon as the Hall elements are shifted out of the linear range, as they are shifted towards the poles where the curve reaches its peak, the angle error increases fairly sharp.

Fig. 14 is measured with the same conditions as Fig. 13, except that the magnet diameter is increased from 5mm to 6mm. The Bz gradient of the 6mm magnet is also shown in Fig. 10. Since the diameter of the magnet has increased by 1mm, the linear range also increases by about the same amount. This increase gains also about +/-0.5mm of radial misalignment range, which is reflected in the graph. Even at ~ +/-0.9mm misalignment, the error is still better than 1°.

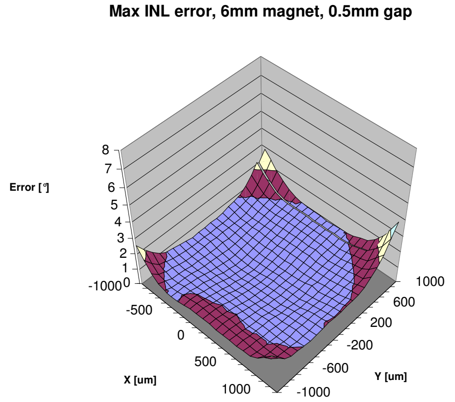


Fig. 14: Angle error of 6mm diameter magnet at 0.5 mm airgap

Fig. 15 is again using a 6mm magnet, this time the axial distance is increased from 0.5mm to 1.0mm. The misalignment range in this case drops to ~ +/- 0.5mm for better than 1° angle error. Fig. 10 shows the Bz curve under the same conditions. It also reflects that there is about 0.5mm misalignment range from the 1.1mm radius of the Hall sensor circle, before the curve becomes non-linear.

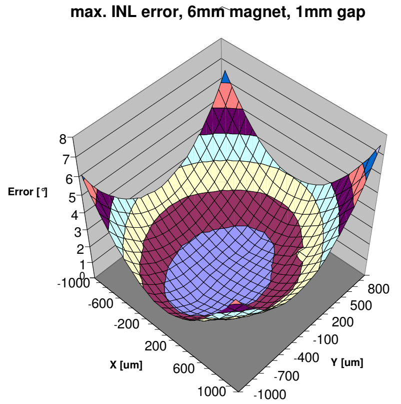


Fig. 15: Angle error of 6mm diameter magnet at 1 mm airgap

5.4.1 Summary

Small diameter magnets (<6mm Ø) have a shorter linear range and allow less lateral misalignment. The steeper slope allows larger axial distances.
Large diameter magnets (>6 mm Ø) have a wider linear range and allow a wider lateral misalignment. The flatter slope requires shorter axial distances.
The linear range decreases with airgap, Best performance is achieved at shorter airgaps.
The ideal vertical distance range can be determined by using magnetic range indicators provided by the encoder ICs. These indicators are named MagInc, MagDec, MagRngn, or similar, depending on product.

6 Extending the Vertical Range

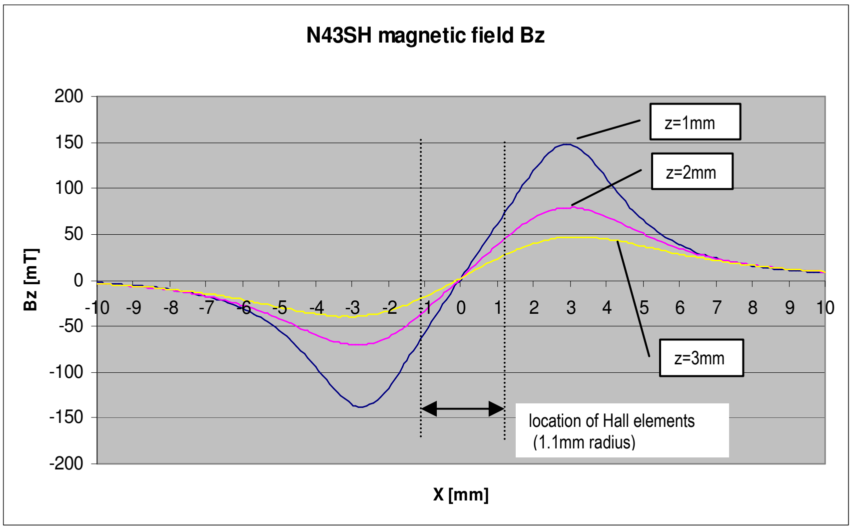


Fig. 16: Vertical field Bz of a N43SH magnet at different vertical distances

Similar to Fig. 10, which shows the Bz curve of a N35H magnet, Fig. 16 shows the Bz curve of a stronger, N43SH magnet with the same mechanical dimensions: 6mm diameter, 2.5mm height.
Measured at a distance of 1mm, the N35H magnet peaks at ~110mT (Fig. 10) and the N43SH magnet has a peak around 145mT. The critical spot is the magnetic field at the location of the Hall elements, at a radius of 1.1mm. This level should be in the range of 45…75mT (see Fig. 12).
While the N35H magnet has ~50mT at 1.1mm radius and 1mm air gap (Fig. 10), the N43SH magnet shows ~64mT at the same gap, ~40mT at 2mm distance and ~20mT at 3mm distance.

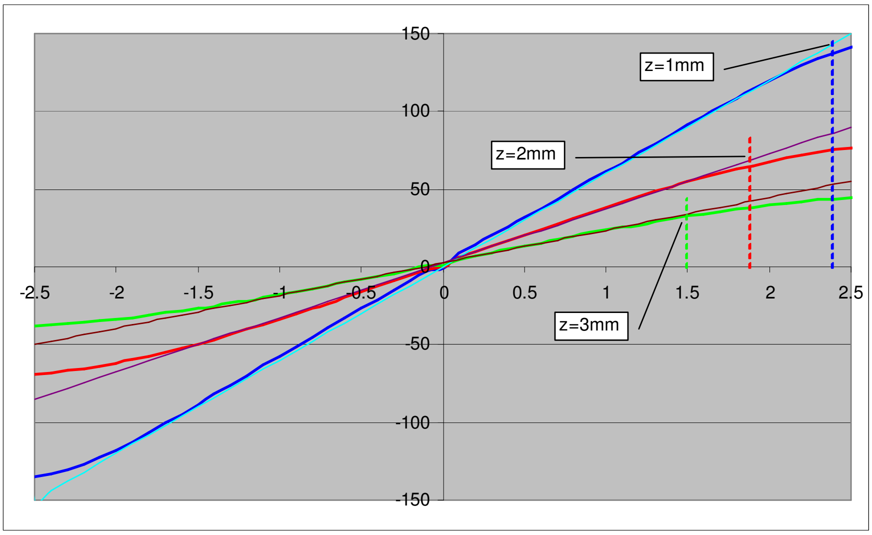


Fig. 17: Linear range at different vertical distances (magnified view of Fig. 16)

Fig. 17 shows an expanded view of Fig. 16 around the center of the magnet. Superimposed to each graph is a straight line which shows the ideal linear range, which is the ideal working point for best accuracy. It shows that the linear range decreases with airgap: While it is about +/-2.4mm at 1mm gap, it drops to +/-1.5mm at 3mm airgap, considering an allowed deviation of 5% (as shown in the encoder datasheets)
Given a Hall sensor radius of 1.1mm, the radial misalignment tolerance is ~ +/-1.3mm at 1mm distance, which drops to +/- 0.4mm at 3mm distance. The sensors will still operate satisfactorily at larger radial misalignment, but the accuracy will be slightly reduced. This is also reflected in graphs Fig. 14 and Fig. 15.

6.1 Field Non-Linearity

Magnetic Field Non-Linearity is the deviation of the measured linear range compared to an ideal straight line. Fig. 17 shows a straight line superimposed to each measured magnetic curve. The dotted vertical line marks the radial distance where the deviation is at the specified limit of 5%.

6.2 Magnetic Offset

A magnet may have a magnetic offset, which can be determined for example by finding the highest positive and highest negative magnetic field strength in a Bz field scan parallel to the poles of the magnet. If they do not match in magnitude, there is a magnetic offset in the magnetization of the magnet.
Fig. 16 shows an example of a magnetic offset: the maximum positive peak is about 10mT larger than the maximum negative peak. For example, the curve for 1mm distance shows a positive peak at +150mT, while the negative peak is at -140mT. This is an indication of a 5mT magnetic offset:

nominal magnetization = +/-145mT
offset = +5mT
result = +/-145mT + 5mT = -140mT / +150mT

This is acceptable in this case, the maximum magnetic offset should be less than +/-10mT.

6.3 Characteristic Scans of Diametric Magnets

For rotation angle measurements, diametric magnets are used. There are two key figures that relate to the quality of the magnet and hence the accuracy of the angle measurement results. Essentially, the Hall sensors on the IC are sensitive to the vertical magnetic field component Bz. So primarily, only this magnetic field is of interest. Magnetic fields, coming from the horizontal direction (= the plane of the IC surface), whether they are coming from the sensor magnet or from an external disturbing magnetic source, cannot be "seen" by the Hall sensors and are therefore of no value to the measurement result.

This reduces the characteristics of the sensor magnet to two essential curves:

- the rotational scan, which is the vertical magnetic field at the location of the Hall elements. It provides a feedback about the quality of the sinewave that is measured by the Hall elements as the magnet rotates.
- the linearity scan, which senses the linear range between the poles and provides a feedback about the expected horizontal misalignment tolerance of the magnet with respect to the IC

The rotational scan is a circular scan around the rotation axis of the magnet, measured at a radius of 1.1mm, which is the radius of the Hall sensor array on the IC. Note that some rotary sensors ICs, like the AS5030 have a slightly smaller radius of 1.0mm. It is recommended to check the parameter "Hall Array radius" in the datasheet of the rotary sensor IC intended for use; see also: 5.3.

The linearity scan is a straight scan across the poles of the magnet. Care should be taken to scan both over the poles (= location of maximum magnetic field) and over the rotation axis of the magnet (= zero magnetic field zone); see also: 5.1.

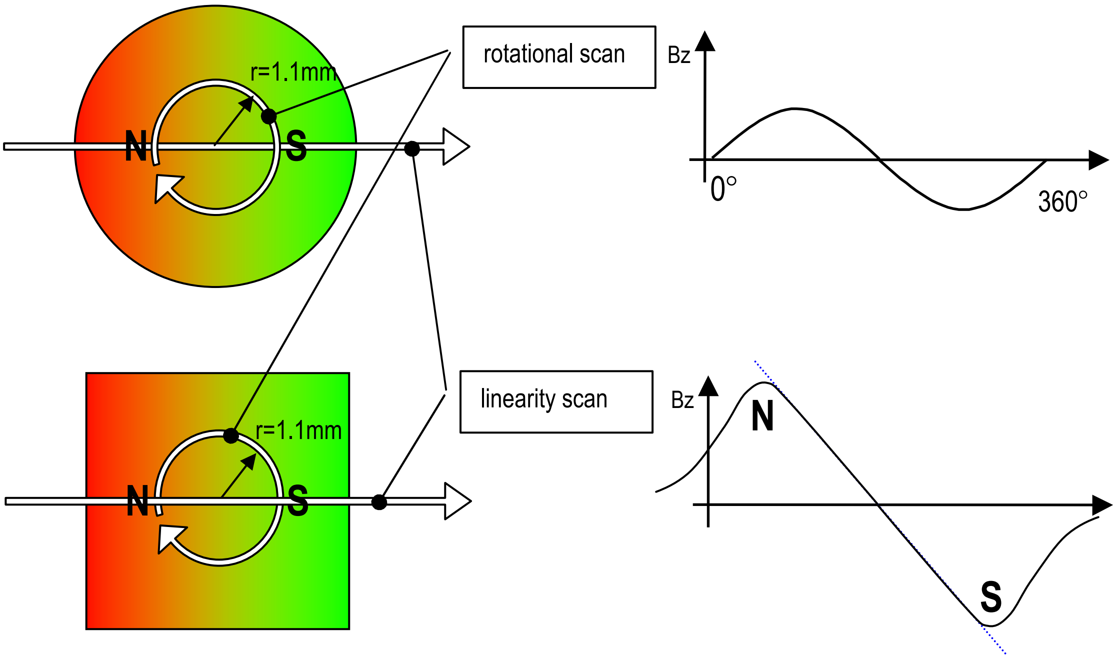


Fig. 18: Characteristic scan curves of diametric magnets for rotation angle measurements

7 Circular, Square or Rectangular Magnets?

As shown in Fig. 18, both round as well as square (or rectangular) magnets may be used. As a rule of thumb, a square or rectangular magnet is only as good as a round magnet with the same diameter as the width of the square or rectangle. The key parameters in each case (round or square) are an undistorted sinewave obtained by a rotational scan and a wide linear range obtained by a linearity scan.

Note that when using rectangular or square magnets, the orientation of the magnetic field is not always perfectly in line with the geometry of the magnet shape. The angular error is typically +/-3….+/-5°. Check with your magnet supplier for detailed specifications regarding DOM (Direction Of Magnetization).

8 Mounting the Magnet

Generally, for on-axis rotation angle measurement, the magnet must be mounted centered over the IC package (see 2.1). However, the material of the shaft into which the magnet is mounted, is also of big importance.
Magnetic materials in the vicinity of the magnet will distort or weaken the magnetic field being picked up by the Hall elements and cause additional errors in the angular output of the sensor.

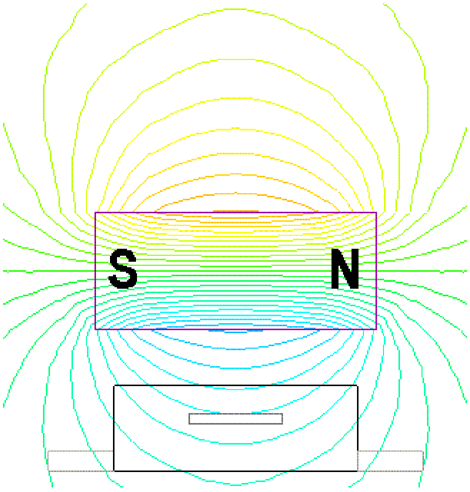


Fig. 19: Magnetic field lines in air

Fig. 19 shows the ideal case with the magnet in air. No magnetic materials are anywhere nearby.

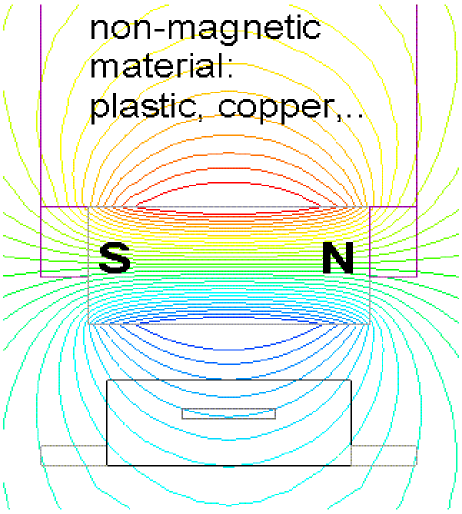


Fig. 20: Magnetic field lines in plastic or copper shaft

If the magnet is mounted in non-magnetic material, such as plastic or diamagnetic material, such as copper, the magnetic field distribution is not disturbed.

Even paramagnetic material, such as aluminum may be used. The magnet may be mounted directly in the shaft (see Fig. 20).

Note: stainless steel may also be used, but some grades are magnetic, they should be avoided.

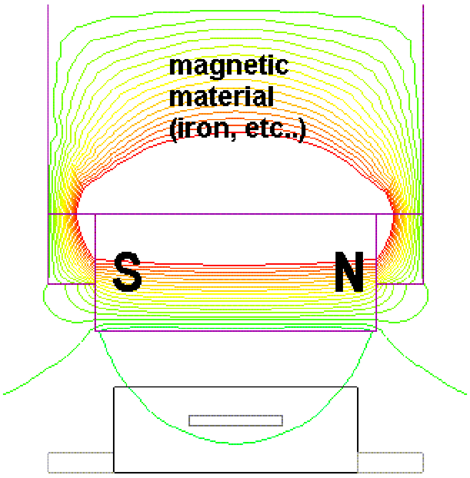


Fig. 21: Magnetic field lines in iron shaft

If the magnet is mounted in a ferromagnetic material, such as iron, most of the field lines are attracted by the iron and flow inside the metal shaft (see Fig. 21). The magnet is weakened substantially. This configuration should be avoided !!

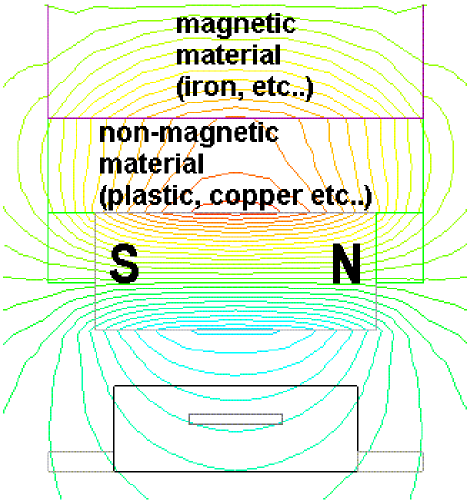


Fig. 22: Magnetic field lines with spacer between magnet and iron shaft

If the magnet has to be mounted inside a magnetic shaft, a possible solution is to place a non-magnetic spacer between shaft and magnet, as shown in Fig. 22. While the magnetic field is rather distorted towards the shaft, there are still adequate field lines available towards the sensor IC. The distortion remains reasonably low.

9 Magnets available at austriamicrosystems Online Shop

austriamicrosystems offers a number of magnet samples for the AS5000 encoder family at the online webshop.
See the "magnets" section of the Magnetic Encoder product pages of the austriamicrosystems website:
http://www.austriamicrosystems.com/eng/Products/Magnetic-Encoders

10 Which IC for which Magnet and Application?

Depending on the application, different magnet types must be used. These could include diametric or axial 2-pole magnets as well as multi-pole magnetic strips and rings.
See the "magnets" section of the Magnetic Encoder product pages of the austriamicrosystems website:
http://www.austriamicrosystems.com/eng/Products/Magnetic-Encoders

11 Recommended Magnet Suppliers

Proper magnets for the austriamicrosystems magnetic Encoder family are available from many vendors. The customer is free to select a magnet supplier of his preference. As a guideline, austriamicrosystems offers a list of recommended magnet suppliers in the Magnetic Encoder product pages of the austriamicrosystems website:
http://www.austriamicrosystems.com/eng/Products/Magnetic-Encoders

Note that austriamicrosystems does not assume responsibility on the quality of the magnets supplied by these companies.

12 Contact

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