magnetfabrik bonn

Magnet Technology Compact

Current Applications and Technologies with Permanent Magnets

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Robust angle measurement with an in-shaft solution

Since sustainable electricity is increasingly being used in many automotive and industrial applications, solutions with interference immunity are required. The precisions needed from magnetic angle measurement systems require high magnetic field homogeneity. To respond to these requirements, Magnetfabrik Bonn has developed a ring magnet with magnetisation based on the Halbach[1] principle and a measuring device for rapid inline evaluation of field homogeneity.

The measurement setup is inserted into a steel shaft ("in-shaft measurement"), making it resistant to interference fields — particularly stray fields — and does not require differential measurement.

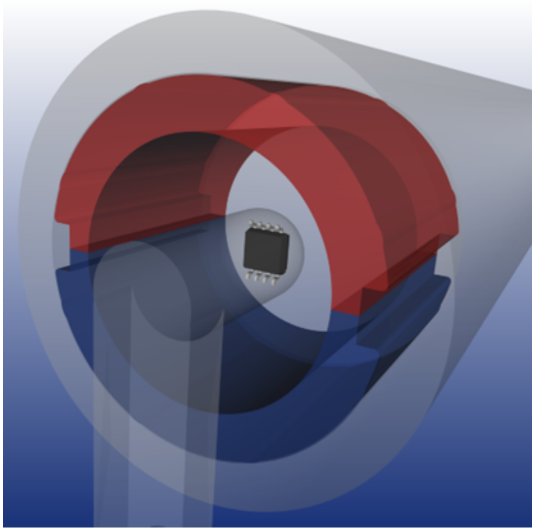

Figure 1: Shaft — Magnet — Sensor

The high level of field homogeneity allows compensation for higher assembly and dynamic tolerances/vibration. The magnet is injection-moulded from a plastic-bonded hard ferrite, which makes it extremely cost-effective.

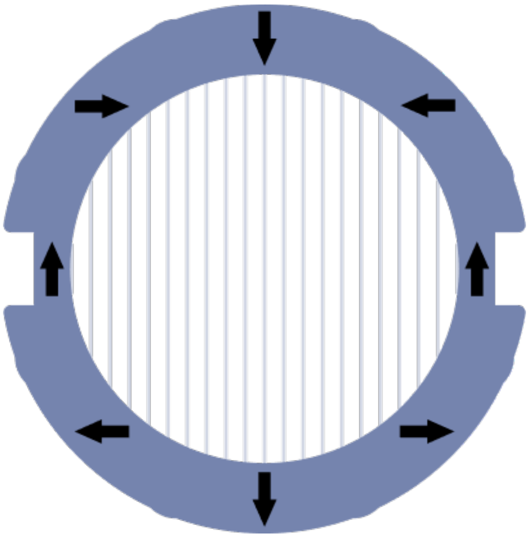

Figure 2: Halbach principle

Magnetfabrik Bonn can supply small quantities of three experimental tool variants for tests and evaluations. The properties of the

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[1] Named after Klaus Halbach, German physicist, 1925—2000.

three systems are summarised in the table below. These properties can be used to assess which is the best solution for your application.

Typ	D_a [(a)]	D_i [(a)]	h [(a)]	B_v [(b)]	φ [(c)]
Small	14,7	10	15	68 ±5 %	<0,35°
Medium	16,8	12,5	15	57 ±5 %	<0,2°
Large	21,8	16	16	54 ±5 %	<0,15°
[(a)] Diemensions in [mm] [(b)] Flux density in [mT] in the diametrical direction [(c)] Angle error at r < 1 mm					
→ See also “Details”					

Table 1: Experimental tool variants

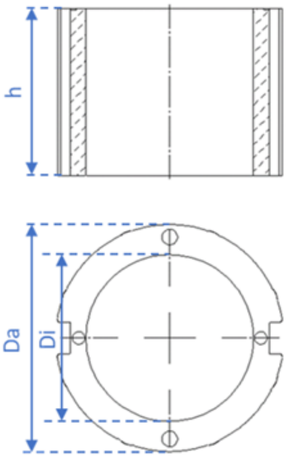

Figure 3: Dimensions

Details:

Angle measurement in a homogeneous magnetic field allows greater installation tolerances and behaves robustly towards dynamic tolerances. The system is suitable for both magnetoresistive and Hall[2] sensors.

Homogeneous magnetic fields can be generated around the sensor element by various ring-shaped magnet arrays. The disadvantage of diametrically magnetised rings is that the homogeneity of the field can be affected by the presence of magnetisable components in the surrounding area.

Halbach configurations, however, generate a closed field pattern around the sensor area without stray fields outside the sensor range.

Multi-layer Halbach configurations have been used for years in other areas. They are used to generate extremely homogeneous fields in medical applications and analysis apparatus, e.g. for magnetic resonance imaging. They are constructed from a large number of shaped magnets which are arranged very precisely in the Halbach array.

In magnetic angle measurement, measurement error depends on the tilt and eccentricity of the sensor with regard to the magnet. The quality of the field homogeneity can be described mathematically by field derivations (shape functions). In literature[3], the following tilt and eccentricity functions $\widetilde{T}$ and $\widetilde{E}$ at the sensor position x_0, y_0, z_0, enable a first-order calculation of angle errors:

$$\widetilde{T}=\frac{1}{B_{y_0}}\cdot\left(\frac{\partial B_y}{\partial z}\right) \tag{1}$$

$$\widetilde{E}=\frac{1}{B_{y_0}}\cdot\left(\frac{\partial^2 B_y}{\partial x^2}\right) \tag{2}$$

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[2] Named after Edwin Hall, US physicist, 1855—1938.

[3] U. Ausserlechner, Progress In Electromagnetics Research B, Vol. 40, 79–99, 2012

whereby y denotes the field direction and B_{y_0} denotes the magnetic flux density at the sensor position. The axial direction z defines the distance between the sensor and the magnet for board sensors or the axial position of a sensor dome, so that x, as the 3rd direction, also lies on the plane.

Installation tolerances such as the tilt of the sensor and magnet and the eccentricity of both components determine the deviations in the application for precise angle measurement. The presence of a particularly homogeneous field in the vicinity of the sensor reduces this error and offers more flexibility. The angle error becomes smaller when the shape functions disappear but does not become zero!

A direct relationship between the angle error φ and the eccentricity shape function — without taking field and sensor tilt into account — can be approximated as:

$$\varphi \simeq \frac{r^2}{2} \cdot \widetilde{E} + \widetilde{\delta} \qquad (3)$$

whereby r denotes the measuring radius and $\widetilde{\delta}$ is caused by the sensor-to-magnet tilt and the dynamic tolerances.

The formulas (1—3) are practical simulation tools for magnet optimisation and prove helpful for qualification measurements since only the field component B_y and its derivations perpendicular to the field direction need to be investigated.

The magnet height in Table 1 was designed to optimise the relationship between field homogeneity and costs. To enable flexible mounting and alignment with the sensor, there are two lateral indentations on the outside of the magnet at a 180° angle. They can be given different forms to realise "Poka-Yoke" protection in order to define absolute alignment with the sensor.

The quality of the field angle mismatch for radial sensor tolerance can be assessed using the field shape function $\widetilde{E}$. Figure 4 shows the comparison between the measured angle error of the largest version using a 2D field scan and the calculation of the field shape function with $\widetilde{E} = 0{,}0031\,[1/m^2]$.

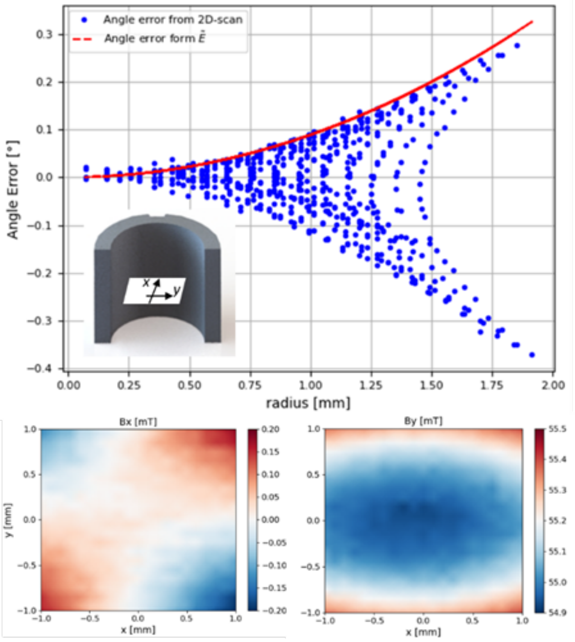

Figure 4: Measured angle error

The estimation of the angle error from $\widetilde{E}$ is a fast method for the qualification of magnets. Magnetfabrik Bonn has developed a "distortion meter" to determine the angle error in a measuring step using a three-point measurement. This enables in-line qualification for series production if required. The tilting of the sensor to the magnet is typically small due to the constructive design of the dome and ring; however, if necessary, an end-of-line calibration can take place to ensure the best possible system performance.

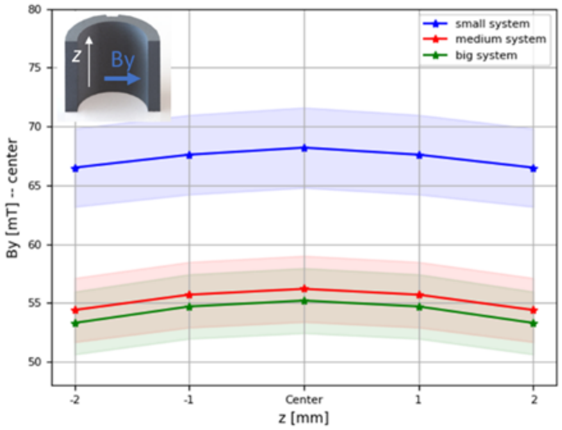

Figure 5: Axial field pattern, centred

Figure 5 shows the field pattern in the axial direction in the centre of the magnet. For all variants, the injection moulding process can be controlled to achieve a field tolerance of around ±5%. Any angle error influence on the axial position of the sensor is very small.

In the current design, the chosen magnetic material is a PA6-bonded hard ferrite — our Sprox® 11/21p — which can be used up to max. 160°C depending on the thermal and mechanical load. Other binding materials such as PA6-GF and PPS have already been successfully tested.

The sensor magnet is versatile. It is already used in the series production of electric cars for the control of the electric motor. It offers a new alternative to previous angle measurement methods, e.g. for steering wheel, actuator and motor control .

We'd be happy to work with you to develop your perfect magnet solution.

Reaching our goals together! Set us your challenge!