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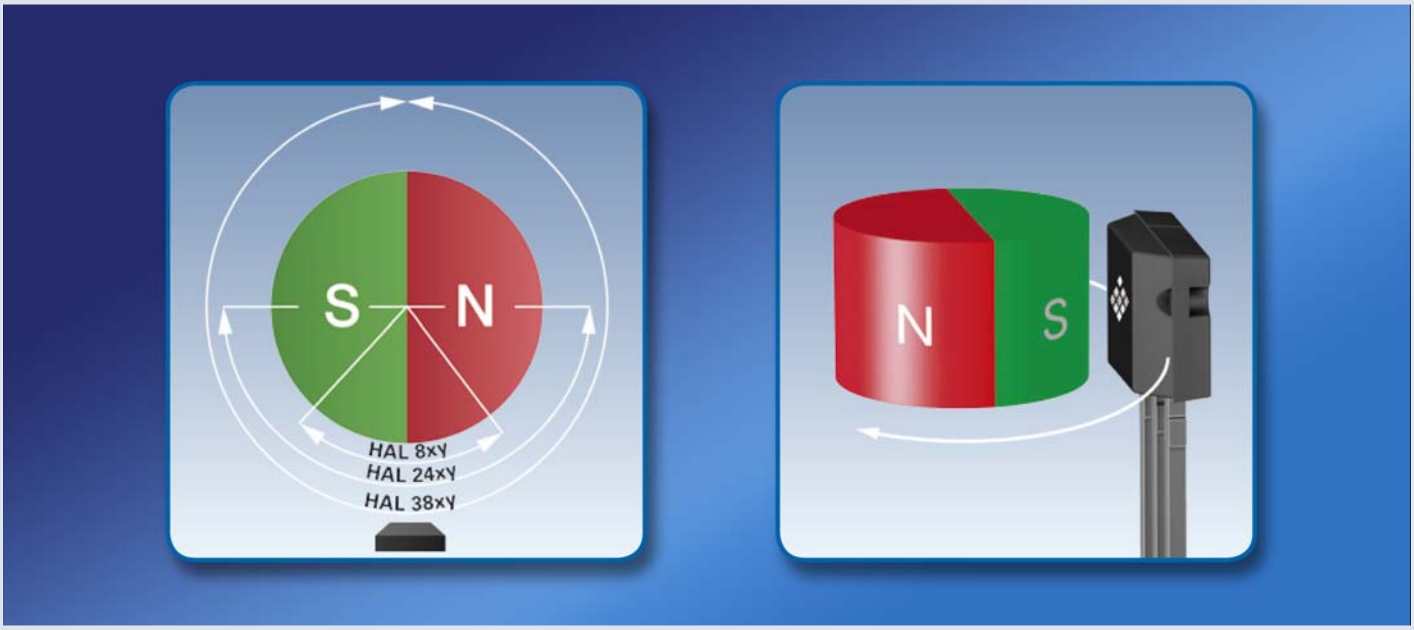

Hall Sensors for Small-Angle Detection

Angular Measurement with Hall Sensors

- A modern approach for measuring angles in a rotating system is by using magnetic systems. Compared to alternative technologies or different types of magnetic sensors Hall-effect sensors can bring advantages in terms of mechanical size, cost, resolution, accuracy, robustness, and operation in harsh environments.
- While both direct angle sensors and, to a certain extent, conventional linear Hall sensors can measure angles in a rotating system, they do so in different ways and at different costs. This directly affects their successful use in applications targeting small-angle detection. Choosing which of the two fits the application better may require better consideration of the sensor characteristics and the application requirements.
- This document is aimed to describe to which extent conventional linear Hall sensors can measure angles more conveniently than direct angle sensors, starting from a review of the two types of sensors.

Linear Hall Sensors

- Linear Hall-effect sensors measure the flux density of the magnetic field perpendicular to their surface, providing an output signal proportional to the strength of the applied field. They can be used as high-resolution angle sensors when placed near a diametrically magnetized magnet.
- The rotating magnet generates a sinusoidal waveform, one full wave per revolution. The corresponding signal out of the sensor is of the form $V_{OUT}=k\ \sin(\alpha)$. Although not linear, this function is monotonic over a range of $\pm 90°$ of rotation. It is hence possible to determine the angle over this angular range by taking the $\sin^{-1}$ function of the sensor's output signal. In practice, for smaller angular ranges, the nonlinearity of the sinusoidal response can be ignored. Within the nearly linear range up to $\pm 45°$ angle measurements can be accurate without any $\sin^{-1}$ correction. For increased sensitivity and better measurement accuracy a higher level of flux in the magnetic circuit is required. This can be achieved either by using a bigger magnet, by reducing the sensor-to-magnet distance, or by using a magnet made of a material with a better performance but at a higher cost.
- The high-precision / programmable HAL 2425 sensor features 16 programmable setpoints with 16 bit accuracy for improved output linearization. This enables reducing the magnet size or to extend the angle measurement nearly up to 180° range ($\pm 90°$) while keeping a high level of accuracy.
- The setup based on conventional linear sensors is, however, sensitive to the position of the sensor, the absolute magnetic field strength, and to the temperature. Dynamic variation of sensor-to-magnet distance will produce a variation of the sensor output despite there is no change in the magnet angle. A similar effect will be caused by changes in temperature. The temperature affects the strength of a magnet in a way that the generated field increases at colder temperatures and decreases at higher temperatures. The sensor's output will reflect changes of the magnet strength caused by temperature with an undesirable output voltage change, which can be minimized by using temperature-compensated devices, for instance by correcting the output signal according to the temperature coefficient of the magnet and the mechanical system.

SYSTEM SOLUTION

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- Angular measurements over a more extended angular range, from ±45° (±90° for HAL 2425) up to a full revolution, will require either a different setup (two Hall sensors, placed perpendicular to each other) or a different sensor type (e.g. a direct angle sensor).
- In the first case, the two sensors provide outputs that are proportional to sin(α) and cos(α) (being α the rotation angle), and by processing the outputs separately, looking at the relative polarity and magnitude, angle can be determined over the entire 360° range. On the other hand the solution based on two separate devices is not trivial (bigger amount of space, reduced reliability, and more difficult process due to a larger number of components), and advanced treatment of signals is required beside the sensor for an accurate real-time computation of the angle information.

Direct Angle Sensors

- A new generation of direct angle sensors, made with the use of advanced vertical Hall plate technology, enables concurrent measurement of two magnetic field components in the chip. Depending on the pair of sensitive axis, they can be used as high-resolution 360° angle sensors when placed beneath (X/Y configuration – see Fig. 3 (a)) or near (Z/X or Z/Y configuration – see Fig. 3 (b)) a diametrically magnetized rotating magnet.
- Looking at the configuration depicted in Fig. 3 (a), the diametrically magnetized magnet generates a magnetic field vector that rotates in a plane perpendicular to the shaft as the shaft rotates. The 2-axis Hall device placed beneath the magnet measures the two components in the chip plane of the rotating magnetic field. As the shaft rotates, the two field components vary as the sine and the cosine of the rotation angle. The shaft rotation angle is simply computed as the $\tan^{-1}(B_Y/B_X)$, thus becoming a function of the ratio of the two magnetic field components. For this reason, angle measurement via direct angle sensors is independent from the signal amplitude and consequently from both temperature and vertical air-gap variations of the magnet (in the homogeneous field area), as well as from magnet aging. Transducer offset error is still an issue and needs to be minimized. Operation over the full 360° boosts setups for angle measurement based on direct angle sensors.

Linear vs. Direct Angle Sensors for Small-Angle Measurements

Which sensor type and which setup are better suitable for angle measurements? There is not a simple decision matrix, the trade-off between achievable performance and cost of the whole system based on linear or direct angle sensors must be found by taking into consideration magnet cost, magnetic circuit complexity, sensor cost and calibration time versus the required performance.
However, some general rules can apply:

- Due to the measurement principle direct angle sensors are the unique choice for measuring angles beyond 180° (i.e.±90°), but for measuring smaller angles linear sensors can provide better performance to a certain extent.
- For a direct angle sensor the digital angle error is independent from the measured angular range, while for a linear sensor the error is dependent. For this last the dominant part of the total error is, at small angles, mainly due to offset error. As the magnetic field becomes stronger with increasing angle, the sensitivity error becomes then dominant.
- The technology of direct angle sensors is intrinsically independent from mechanical tolerances, temperature variation and magnet aging. To make a pertinent error comparison between direct and linear sensors some assumptions are therefore needed: the charts in Fig. 4 were obtained by assuming a ±1% error contribution to the sensitivity error due to magnet aging (orange curves) and an additional ±5% variation of the magnetic field due air gap variation (green curves). Depending on the type of linear sensor and inherent performance there is a different crossing point for the angular error between direct (HAL 3625) and conventional sensors.
- For HAL182x, entry level of the linear family, the crossing point is around 30° (±15°). So this sensor will provide better performance than direct angle sensors in that configuration for angles <30°. For the high-performance HAL 82x the crossing point increases to about 45° (±22°). Thanks to the 16 set-points, providing optimized output linearity over a more extended angular range, HAL 2425 can conveniently reach 50° (±25°). In summary, for reduced angular measurements conventional sensors can provide more precise results at a lower price although direct angle sensors can offer several advantages, including immunity to mechanical tolerances, temperature, and magnet aging. As with many technical solutions, there are always advantages and disadvantages that ultimately each user must weight for his application.

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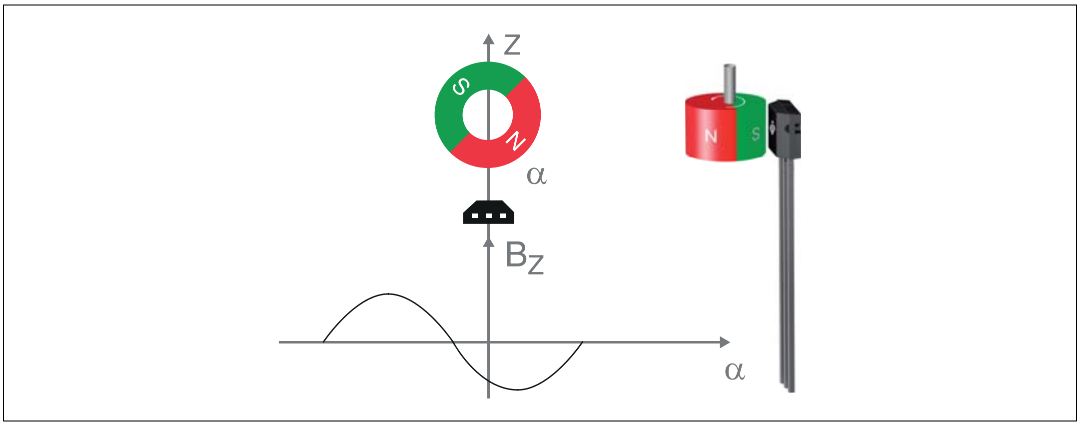

Fig. 1: Conventional linear sensor used for up to ±45° angle measurement, without linearization

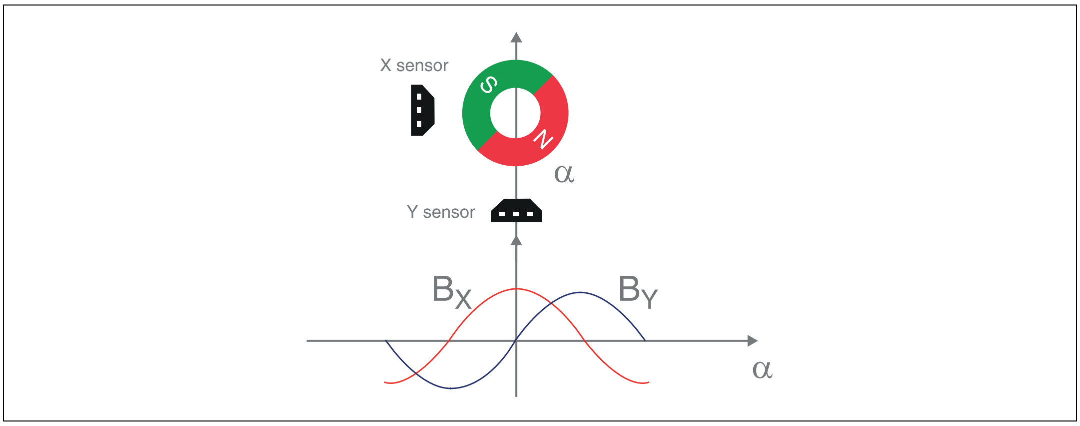

Fig. 2: Conventional linear sensors used for up to 360° angle measurement

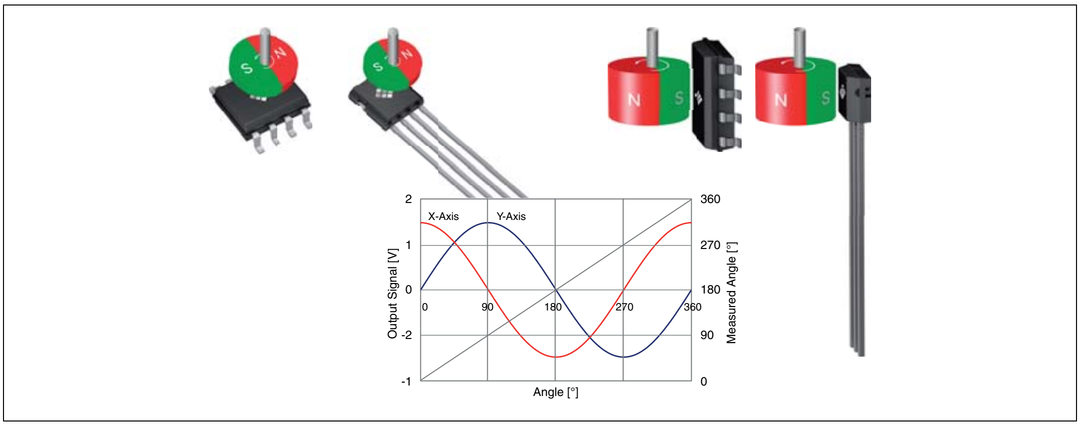

Fig. 3: Direct angle for end-of-shaft (a) or out-of-shaft (b) 360° rotation angle measurement

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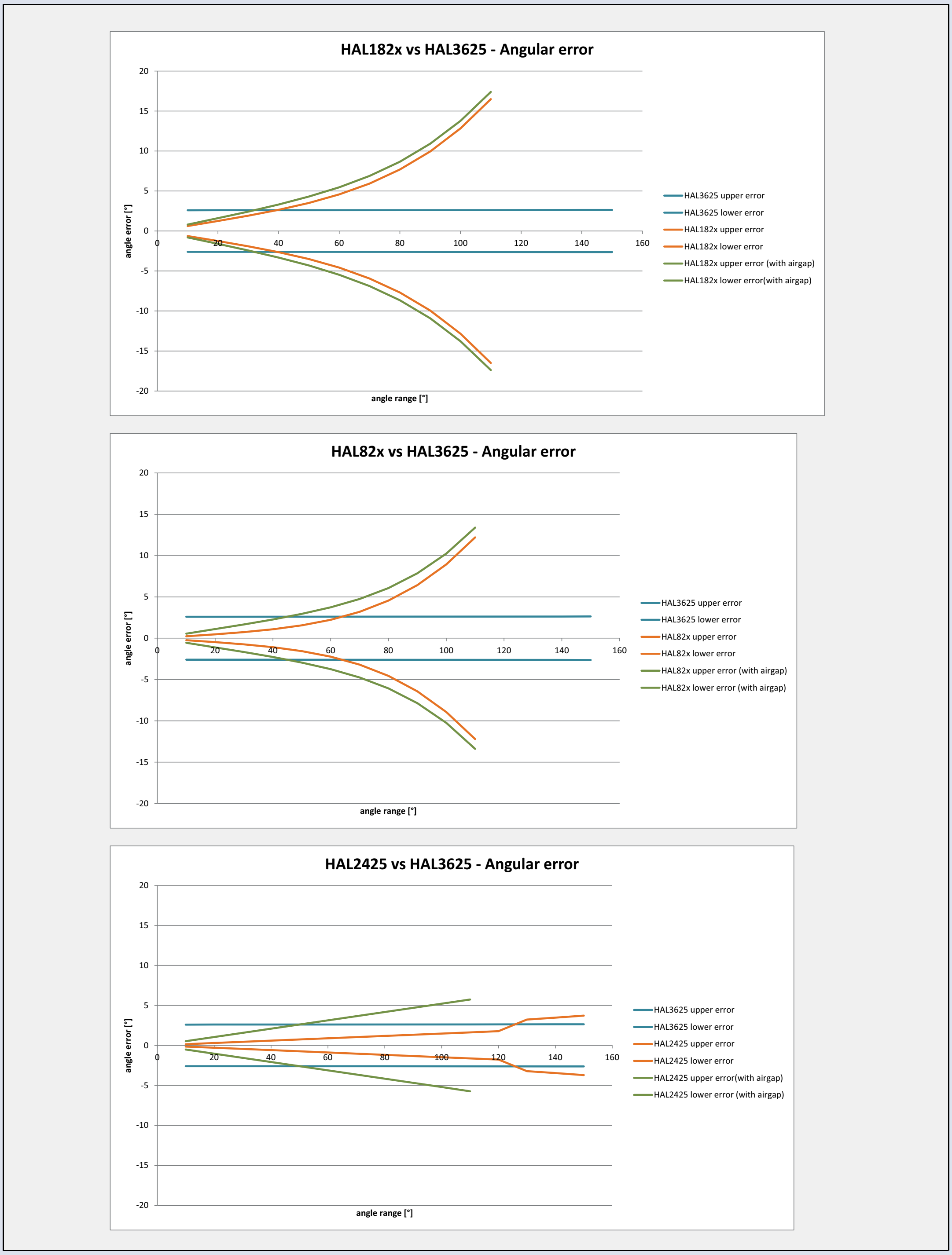

Fig. 4: Conventional linear sensors used for up to 150° angle measurement

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