SCALE BASED MAGNETORESISTIVE SENSOR SYSTEMS

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Abstract

Position sensors based on the magneto resistance effect combine high precision with cost effectiveness for linear displacement measurements. The contactless measurement principle offers clear advantages versus optical encoder systems in harsh environments. Coming from applications with medium accuracy demands but high mechanical tolerances, the whole spectrum of displacement tasks down to nanoscale measurements can be solved with scale based magneto resistive sensor systems. Embedded in a small, modern DFN package for standard, flat or perpendicular mounting, the linear magneto resistive sensors can now easily be applied to a wide range of applications with small design space using standard SMT assembly processes.

Magneto resistive sensor systems – what´s behind

Among the variety of technologies for position sensing, solutions based on the anisotropic magneto resistance (AMR) effect [1,2] combine high precision and cost efficiency. As the measurement is contactless, AMR based devices work free from wear over a wide temperature range in harsh environments [3]. Its components may also be protected against chemicals and dirt, without affecting the precision of the measurement.

In case of linear position measurements, the magnetic field can be provided either by a magnetic scale [4] or by a magnetic pole wheel,both consisting of periodically alternating poles with a pole length p_0.

The sensor matches to the unique field distribution of a certain pole length (typically 1mm, 2mm or 5mm). The special chip design delivers sinusoidal outputs as a function of the position over the pole, almost independently on homogenous disturbing fields over a wide range of disturbing field strength. . The sensor chip often integrates the magnetic field over more than one pole to enable

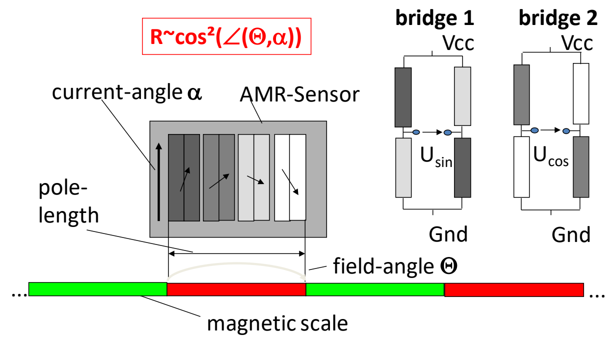

Figure 1 AMR-Sensor with two Wheatstone bridges

high accurate measurements. This compact measurement system provides the transformation of an angular magnetic measurement to a position information as shown in figure 1. For pole lengths greater than 1mm, the magnetic field from the scale is strong enough tofully magnetize the internal structures of the sensor. . The sensor contains two Wheatstone bridges which are designed to deliver two signals which are shifted by 90°, two signals Ua_{sin} and Ua_{cos} are obtained. Therefore, the field angle is a function of the sensor position x and the AMR sensor output signals U_a will become in first order:

$$U_{a,sin} = \frac{\Delta R}{R} \sin\left(\pi \cdot \frac{x}{p_0}\right)$$

and

$$U_{a,cos} = \frac{\Delta R}{R} \cos\left(\pi \cdot \frac{x}{p_0}\right)$$

where p_0 describes the pole pitch and x the position over the pole. The amplitude coefficient ΔR/R is a material constant and is typically 2.5%.

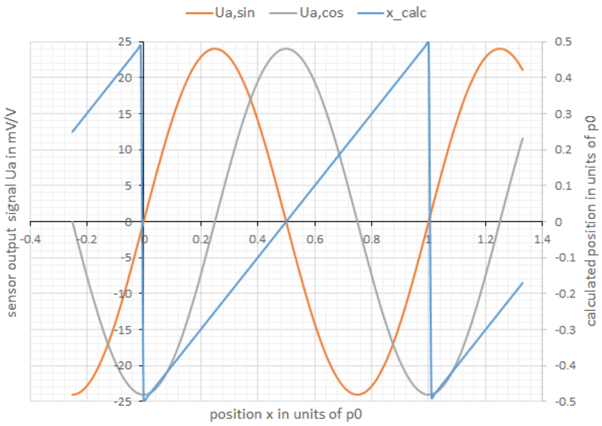

Figure 2: Signal output and calculated position

To extract the position x from the measured signals, both the sine and cosine signals are used to calculate the arctan, which represents a linear function for the position x.

$$x = \frac{p_0}{\pi} \cdot \tan^{-1}\left(-\frac{U_{a,sin}}{U_{a,cos}}\right)$$

As for each magnetic pole the field angle turns for 180° the correlation between field angle and real position is known for a defined pole pitch p_0. To discover the measured position a last calculation step is needed, which maps the measured field angle to the linear position. As this measurement system represents an incremental application, each passed pole (n_{poles}) needs to be considered as full pole length p_0 added to the fine position, which is interpolated by the sensor over the actual pole.

$$x_{pos} = n_{poles} \cdot pole_{pitch} + \frac{pole\_pitch}{180°} \cdot \Theta$$

Magneto resistive sensor systems – what´s behind

An AMR sensor essentially consists of two Wheatstone bridges which are made of meander-formed parallel stripes (see figure 1). The vector between externally applied magnetization (Θ) and the direction of current (α) flowing through each meander strip, determines the signal component for each meander strip.

The signal is further affected by additional harmonics based on the following two reasons:

1. Internal, anisotropic fields act against external fields, arising from geometric form and material properties of the meander [5].

2. Pinning of domains in meander edges.

As a result, the user faces a deviation of the expected ideal change in resistance and hysteresis behavior [6]. Using stronger magnetic fields decrease both effects by forcing the alignment of the domains to the external field direction. However, a more suitable way of compensating harmonics even at lower field strengths is done by consciously creating inverted harmonic sub-signals, which interfere destructively [8].

Scale based sensors for high accuracy measurements

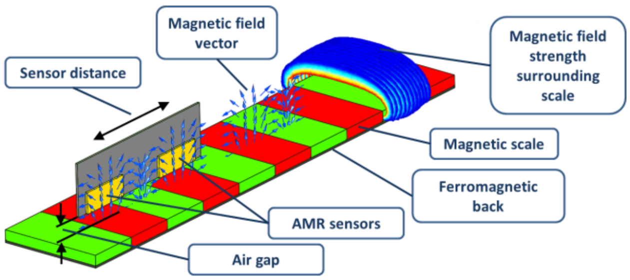

Figure 3: AMR sensor chip alignment to a magnetic scale

Magnetic linear sensors like the KMXP sensors contain special shaped AMR sensor chips which are adopted to the magnetic field distribution of ferrite bonded scales, in order to establish very accurate contactless linear measurements. For example, applications like microscope x-y alignment tables or wood resp. stone cutting machines have different requirements in terms of sensor-to-scale air gaps and measurement accuracy. These different requirements are covered by a range of different KMXP sensor types as shown in figure 4. The use of different pole pitches (see figure 5, from top to bottom, p = 5, 2 and 1mm) will result in improved achievable accuracies at the expense of smaller air gaps. The different sensor chip layouts integrate over n=1, 2 and 4 pole(s) for KMXP5000, 2000 and 1000 resp., averaging out possible scale inaccuracies for the smaller pole pitches. A good compromise for most applications is found with 2mm pole pitch as it combines the best of two worlds: practical 1mm air gap with 2 pole interpolation and excellent accuracy. As rule of thumb, achievable accuracies are less than p0/100.

A special case is shown in figure 5. to achieve a big air gap (for example in a harsh environment to establish an additional sensor and magnet protection with plastic housings) an angular sensor can be used. But as the angular sensor is not designed for a scale field distribution additional algorithmic calculation is needed to reduce parasitic signal effects and achieve an optimal system accuracy [4].

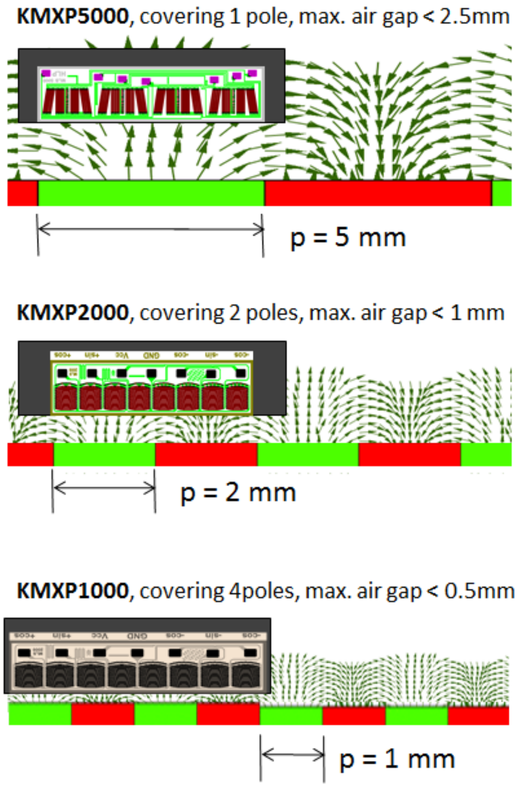

Figure 4: Different KMXP sensor layouts for different pole pitches and their maximum air gaps

Also, single dipole magnets may be taken into account for larger magnetic field distributions.

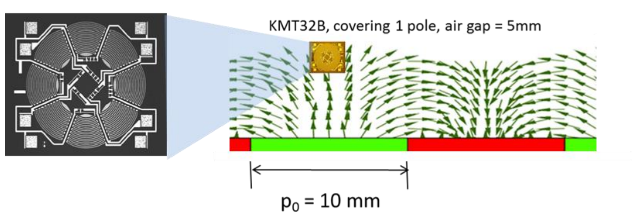

Figure 5: linear measurement at larger air gaps utilizing an AMR angular sensor KMT32B resp. KMT39

Modern DFN packages allow for new applications

The integration of a sensor head and a scale into a mechanical system is very often restricted by space constraints. The use of modern DFN packages in combination with new scale materials, which allow for much thinner scales, opens room for new applications, where precise linear displacement measurements in a limited space environment are needed.

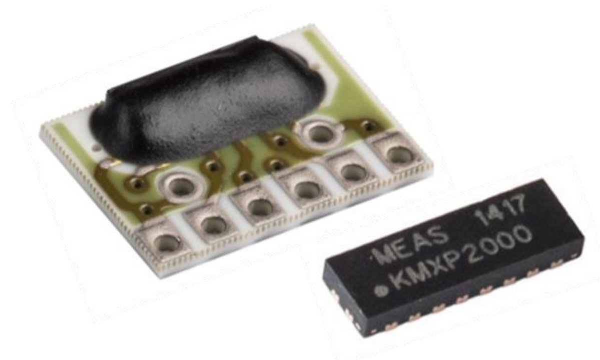

Figure 6: Comparison of KMXP's tiny DFN form factor with common Chip-on-board package size

As the sensor chip must be placed as close as possible to the scale, a typical assembly technology used so far has been chip-on-board (COB), which is a costly, non-standard assembly process. Modern DFN packages are tiny, robust and most importantly allow for standard SMT processes. They provide better defined mechanical tolerances as standard glob tops with much less internal mechanical stress, giving a robust protection to the sensor chip and a well-defined placement on the PCB (see figure 6).

Alignment of perpendicular and flat sensors towards a scale

The following two examples illustrate where the benefits of DFN packages apply: Figure 6 shows the common application where a sensor is placed on the edge of a PCB. DFN packages also allow for perpendicular assembly, so that the PCB can now be placed parallel to the scale. The sensor chip's orientation itself stays

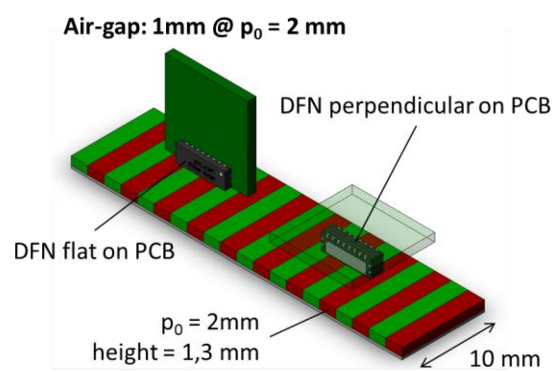

Figure 7: depicts a flat and perpendicular DFN packaged AMR sensor, chip alignment to scale remains perpendicular air gap: 1 mm @ p_0 = 2 mm

perpendicular to the scale.

For more precise measurements, very small pole pitches are needed which in turn require very small air gaps. Figure 7 depicts how this measurement task can be addressed utilizing an ultrathin DFN package.

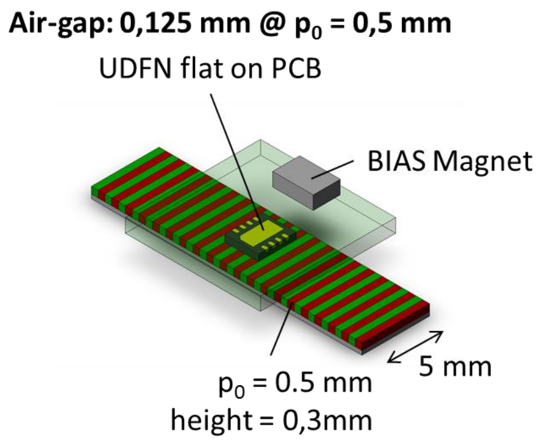

Figure 8 extra thin track (height = 0.3 mm) with a flat UDFN packaged AMR sensor, air gap: 0.125 mm @ p_0 = 0.5 mm, flat chip alignment to scale leads to very small air gaps.

Linear measurement systems based on DFN packaged linear AMR sensors

When designing a linear magnetic encoder, at least three parameters have to be taken into account:

1. Used sensor principle
2. Magnetic scale
3. Application

The overall system accuracy depends predominantly on the tolerance band of the air gap between sensor and scale as well as of the scale quality itself. Common scale qualities ensure accuracies of ±40 µm/m down to ±10 µm/m [7]. In praxis, measuring smaller lengths will yield much better accuracies, as the scale is much better defined for smaller lengths. Using DFN packaged linear AMR sensors, enables a maximum air gap between scale and sensor as the component is placed directly on the edge of the PCBA. The three-sided pad layout ensures exact alignment during the SMD soldering process. As a result, highly accurate linear encoders in the range of +/- 3 µm can be created in combination with a standard magnetic scale, as shown in figure 8.

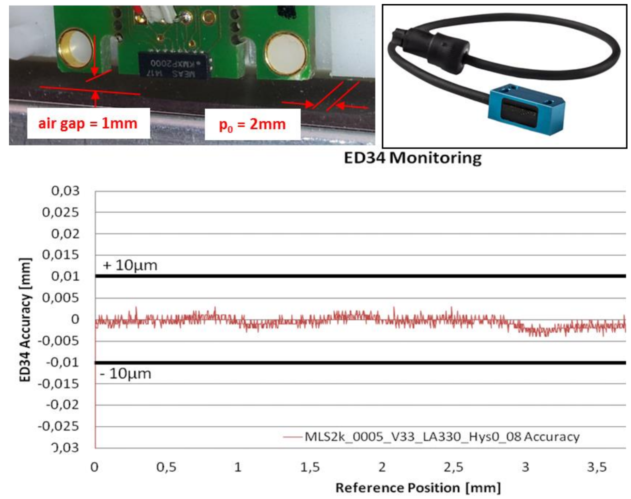

Figure 9: Accuracy plot of a KMXP2000 magnetic length sensor using a scale with pole pitch p0 = 2 mm and standard sine/cosine interpolator IC. The example was a housed linear encoder with dimensions 20 x 10 x 8 mm

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