

A new generation of contactless magnetic position sensors

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Abstract

Magnetic position sensors have several advantages which make them attractive for automotive applications: they are contactless (there is no mechanical wear-out), insensitive to dirt, low cost and MMT has been a leader in the development of solutions based on measurement of magnetic field amplitude using Hall effect. In this paper, we will present a new generation of sensors using recently developed angular position sensors which measure the angle of the magnetic field generated by a diametrically or sinusoidally magnetized magnet [1], with a focus on through shaft 360° angular sensors and linear sensors adapted to large displacements [10...200 mm]

Key words: Hall Position sensor, diametrical magnetization, sinusoidal magnetization...

1- Introduction

Measurement of angular position using variation of magnetic field amplitude induced by the displacement of a moving magnet has been intensively developed over the last fifteen years. However, these solutions have limits in terms of angular range and temperature influence. Recently, new solutions based on the determination of the angle of a rotating magnetic field have been developed. They allow for a measurement of angles up to 360° with limited temperature influence using sine and cosine signals generated in a plane by a rotating magnet. Typical set-up of these solutions is to use a permanent magnet with a bipolar magnetization placed at one end of a shaft and facing a dedicated Hall ASIC. However, several applications require a through shaft, which prevents from using the basic principle described hereabove.

For this reason, MMT has developed and patented innovative solutions for through shaft magnetic position sensors using measurement of the angle of a rotating magnetic field, with a probe put next to the magnet. The principle is also valid for linear sensors.

2- New generation of Field Direction Sensor

2.1 Diametrical magnetization: Principle

In the proposed sensor solution [2] the ASIC for magnetic field measurement is put next to a diametrically magnetized magnet ring (Figure1), and, in this case, the angle of the magnetic field does not follow the rotational angle of the shaft. In this case, we should consider the magnetic field components separately. Theoretically, the solution for magnetic induction outside a diametrically magnetized infinitely long cylinder can be found in literature [4]. The following analytical solution for radial and tangential field component is obtained:

$$B_{\text{rad}} = B_{\text{max}} \cos \varphi \quad B_{\text{tan}} = B_{\text{max}} \sin \varphi \quad (1), \text{ where } B_{\text{max}} \text{ depends on radius as } \frac{1}{r^2}.$$

Two sinusoidal signals with 90° phase shift are obtained. For diametrically magnetized cylinders with finite length, one must solve the field equations numerically. The obtained solutions are, again, two sine signals with 90° phase shift between them, and their amplitude ratio depend on the magnet dimensions.

Ring magnet can be represented as a difference between two disk magnets, so the solution for its magnetic field will have the same form. An example is given in figure 2, the results are obtained by boundary element software [5]. In most cases, practical measurement with a diametrically magnetized ring magnet shows significant non-linearity in the computed angle. The reason for this is found in the magnetizing process: the magnetizing field is refracted on a magnet surface, due to boundary conditions [4].

In order to compute the angle of rotation, two different gains are applied to signal components, before the angle computation. Then it is possible to obtain the rotational angle by computing the arc tangent.

Another possibility is to use axial and tangential field components. It could be useful for some embodiments needing the probe close to the magnet. Magnetic flux sensor can be a multi-axis Hall effect device that is commercially available from Melexis [6] for instance.

2.2 Diametrical magnetization: Practical realization

The 360° through shaft technology can be used in a lot of automotive applications. At the beginning it was designed for the steering angle measurement. Indeed the steering angle sensor must deliver an absolute position signal over 360°, must be through shaft, and requires a very good accuracy. A typical design for this application is shown in the figure 3 and the measurement results of this sensor can also be seen in this figure 3.

The Non Linearity obtained is about $NL = \pm 0.5\%$ (of 360° → $NL = \pm 1.8^\circ$) over the complete range of temperature [-40°C 125°C]. With this sensor, we have tested successfully the influence of some geometric defaults that can occur during the life of the sensor. By design, this new generation of sensor is not sensitive to radial and axial shift since we measure only the direction of the field, not the amplitude of the field. Of course one can use this sensor in different embodiments and for different applications. For example a miniature prototype has been made, to potentially replace small size potentiometers in some applications. Magnet dimensions are: OD = 7 mm, ID = 5.5 mm, h = 3 mm. A Non Linearity of 0.33% on 359.5° stroke has been obtained.

2.3 Sinusoidal Magnetization: Principle

MMT has tried and succeeded to extend the principle of the 360° through shaft technology to the measurement of distance. The idea is very simple and by consequence very smart. For the 360° sensor, the magnet is a complete ring, diametrically magnetized to get a rotating magnetic field vector. The original idea was to magnetize diametrically a flexible magnet wrapped around a ring and then unroll it for use in a linear sensor configuration. This principle is illustrated in Figure 5. From this process, we end up with a flat magnet and a rotating magnetic field with linear displacement illustrated Figure 6. Referring to Figure 6, a linear non contacting position sensor is shown. This Sensor is adapted for use in monitoring the linear position of an attached object that moves such as shaft. A shaft can be connected to any moving object such as an EGR valve, transmission gear... The linear position sensor includes a magnet and a magnetic flux sensor. The magnetic field generated varies sinusoidally with displacement and can be detected by a flux sensor to sense the position of an object. The original idea came from the use of a flexible magnet but it might lead to some industrialisation issues, since a flexible magnet is not easy to handle in a production process. Therefore MMT has developed some specific fixtures to avail magnetization of classical rigid bonded magnets (NdFeB, Ferrite). This specific tooling allows getting a perfect sinusoidally variation of the magnetic field with displacement.

In order to measure a small rotation, only a small part of a ring magnet could be used. A lot of automotive application does not require measuring the complete rotation of an object but only 50° to 90° of rotation (gear shift lever, Fuel sensor, EGR valve etc...). In this specific case it can be cost effective to save magnet volume and so to use only a tile magnet instead of a complete ring. From what have been seen up to now, there are two solutions to realize such sensor (table 1):

- To use a tile magnet diametrically magnetized and have a partial magnetic field rotation and

- to use a tile magnet sinusoidally magnetized to get a complete magnetic field rotation

Both solutions are valid, on one hand the first solution is very simple to magnetize but a little bit more sensitive to some defaults and on the other hand the second solution is more accurate in term of angle Resolution and insensitive but requires a specific magnetization tooling to be able to use a classical rigid magnet.

2.4 Sinusoidal Magnetization: Practical Realization

A linear sensor can be used in a lot of automotive applications, (to detect the position of the shifter or to monitor the position of the clutch, the position of an EGR valve. In this kind of applications the displacement of the object to monitor is about 15-20 mm (linear) or 45-90° (rotation). That's the reason why we have chosen to show an example of a 70° rotary sensor. But there are no constraints to use this kind of sensor for a larger stroke (>100°), the principle and the realization do not change. One can see the measured Radial and the tangential components on the figure 8, the output signal coming out from the MLX90316 chip and a linearity of +/- 0.26% of 70° is obtained.

3. Conclusions

A new generation of low cost magnetic sensors is proposed. Its performances are evaluated through simulation and measurement results. Several prototypes for different automotive applications are realized. Through the examples presented, one can see that the new generation of sensor can fit automotive applications having medium to large angular strokes (from several dozens up to 360 degrees and from a few to 200 millimeters), such as steering, fuel level, pedal, air control valves sensors, Gear & Shift travel sensor...

Literature

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Legends

Table 1: 2 different configurations for a rotary sensor (stroke $<360^\circ$)

Figure 1: Through shaft sensor overview

Figure 2: Radial and tangential induction component Measurement results

Figure 3: Overview of a Steering Angle sensor

Figure 4: measured non-linearity for Steering Angle sensor @ several temperatures

Figure 5: process to get a linear position sensor with a flexible magnet

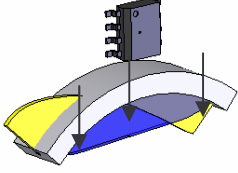
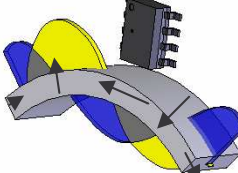
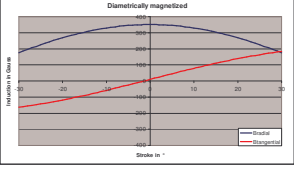
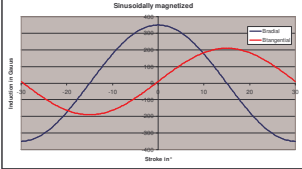
Figure 6: Sinusoidal Magnetization pattern

Figure 7: Process to get a short angle sensor with a flexible magnet

Figure 8: Measurement results: Radial(red) and Tangential (blue) induction component

Figure 9: Measurement results: Non Linearity in % of the stroke

Table 1

A tile magnet diametrically magnetized	A tile magnet with a complete magnetic field rotation
	
	

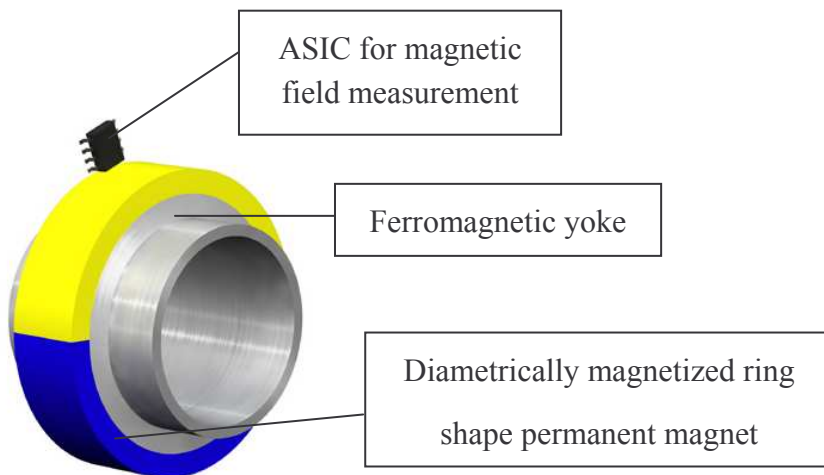


Figure 1: Masson et Al

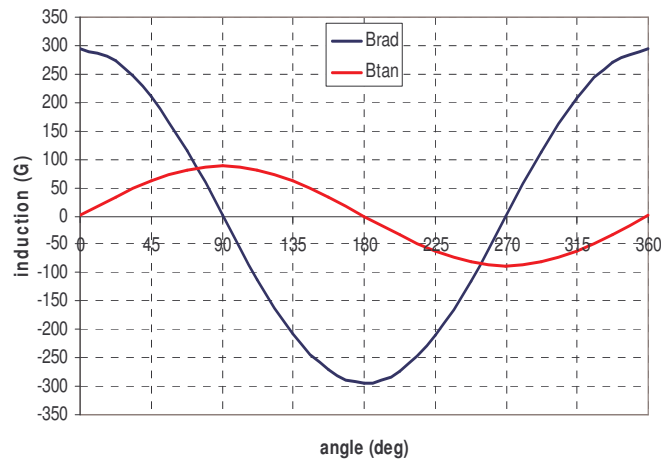


Figure 2: Masson et Al



Figure 3: Masson et Al

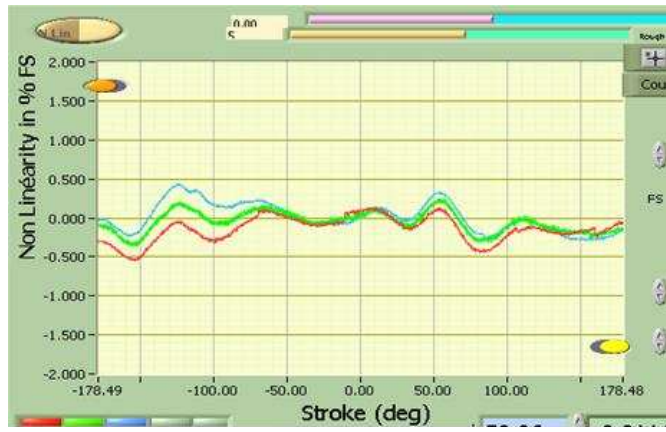


Figure 4: Masson et Al

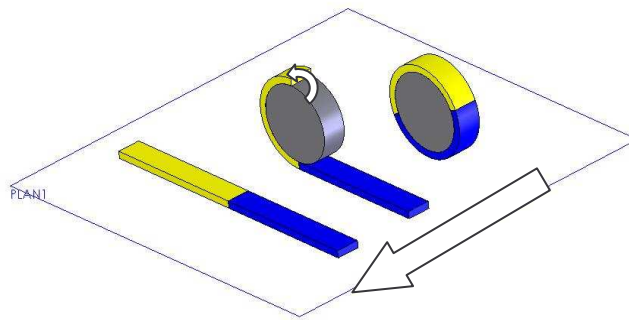


Figure 5: Masson et Al

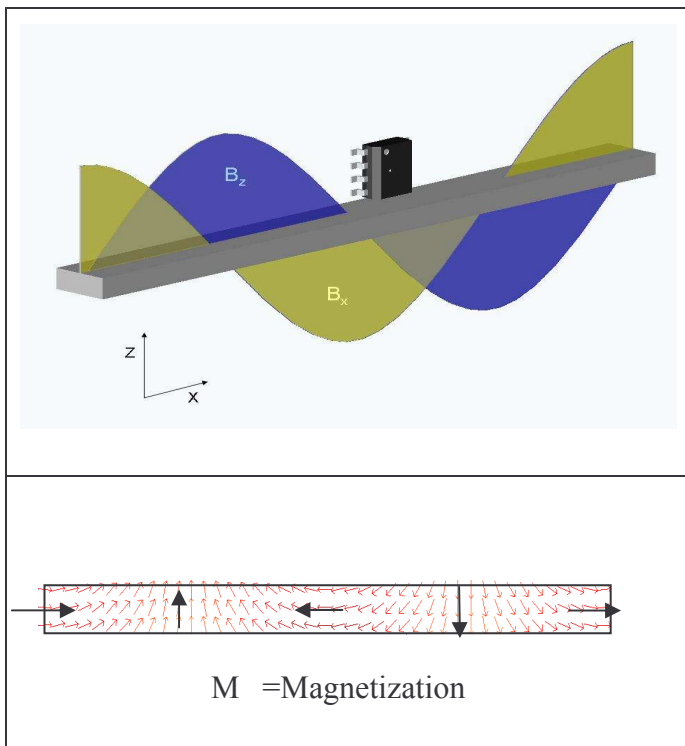


Figure 6: Masson et Al

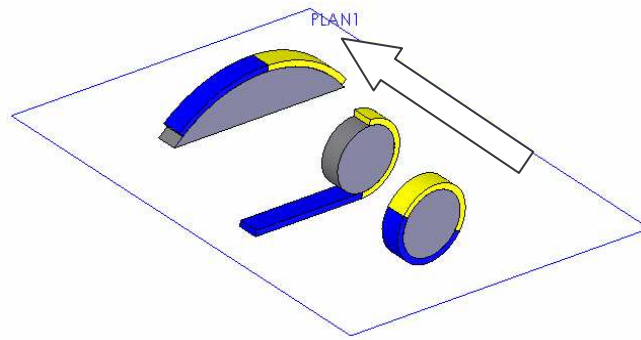


Figure 7 Masson et Al

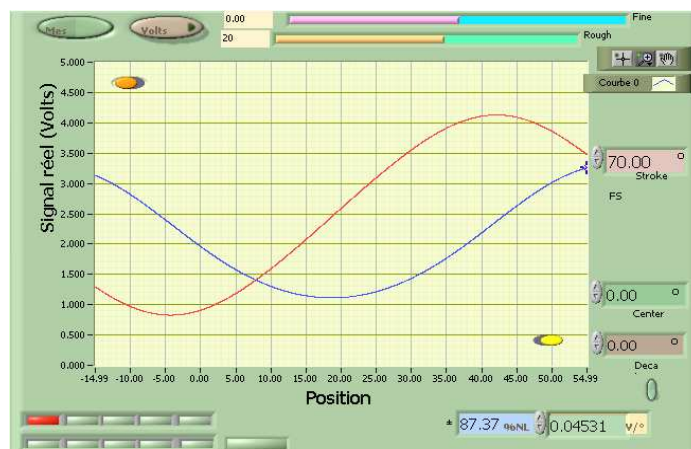


Figure 8 Masson et Al

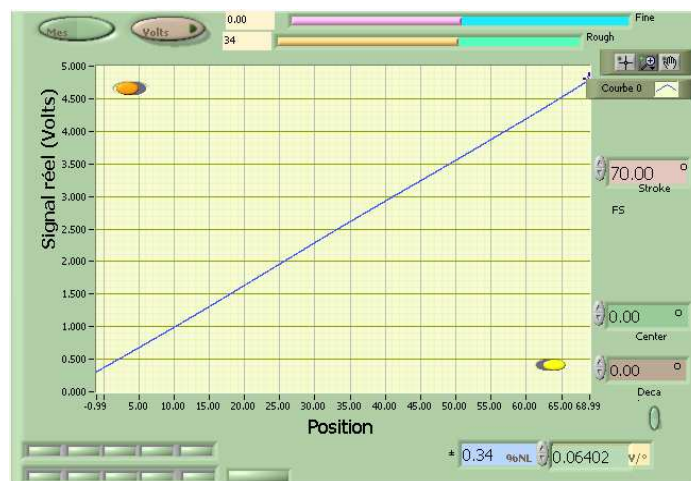


Figure 9 Masson et Al