Vol 57, No 4—November 2023

Magnet Design for Giant Magnetoresistance Multiturn Position Sensors

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Abstract

True power-on multiturn sensors based on giant magnetoresistance (GMR) sensing technology are set to revolutionize the position sensing market in both industrial and automotive use cases due to reduced system complexity and maintenance requirements compared to existing solutions. This article describes some of the key factors that must be considered when designing a magnetic system to ensure reliable operation even in the most demanding applications. It also introduces a magnetic reference design that is available for early adoption of the technology. In a previous article, we introduced the multiturn sensing technology and some of the key application areas such as robotics, encoders, and steer-by-wire systems.

Introduction

The multiturn sensor is essentially a magnetic write and electronic read memory combined with a conventional magnetic angle sensor to provide a highly accurate absolute position. The magnetic write process described in "Multiturn Position Sensor Provides True Power-On Capabilities with Zero Power" requires the incident magnetic field to be maintained with a specific operating window. Magnetic write errors may occur if the magnetic field is either too high or too low. It is essential to design the system magnet carefully and to consider any stray magnetic fields that might interfere with the sensor as well as mechanical tolerances over the life of the product. Small stray magnetic fields could cause an error in the measured angle while larger stray magnetic fields could cause a magnetic write error leading to a gross turn count error.

Magnetic Reference Design Goals

A careful understanding of the system requirements is necessary to design the optimum magnet and shielding. Generally, the looser the system requirements, the larger and more expensive the magnet solution required to achieve the target specifications. Analog Devices is developing a series of magnetic reference designs addressing various mechanical, stray field, and temperature requirements that can be adopted by customers of the ADMT4000 true power-on multiturn sensor. The first design developed by ADI covers systems with relatively loose tolerances: sensor to magnet placement of 2.45 mm ± 1 mm, a total displacement of the sensor to the axis of rotation of ±0.6 mm, operating temperature range of –40°C to +150°C, and stray magnetic field shield attenuation of greater than 90%.

Magnetic Considerations

When designing the magnet, there are some key considerations to take into account and the following section provides a high level view of the main aspects to consider when designing for the GMR sensor.

Magnet Material

The GMR sensor operates in a defined magnetic window (16 mT to 31 mT)[1]; in addition, the maximum and minimum operating range has a thermal coefficient (TC) as can be seen by the red traces in Figure 1. Selecting a magnet material with a TC that matches that of the GMR sensor will maximize the allowed variation of the operating magnetic field. This allows for greater variation in the strength of the magnet and/or the placement tolerance of the magnet with respect to the sensor. Low cost magnetic materials such as ferrites have a much higher TC than the GMR sensor, which would limit the operating temperature range compared with materials such as samarium-cobalt (SmCo) or neodymium-iron-boron (NeFeB).

Understanding the TC of the chosen magnetic material as well as the variation in the magnetic field strength due to manufacturing variations allows the required magnetic field strength at room temperature (25°C) to be determined. Design simulations may then be carried out at room temperature with a high degree of confidence that the system will operate as expected over the full temperature range. In Figure 1, the solid green traces represent a window of the magnetic field strength that the magnet should be designed to produce over the active area of the GMR sensor. This window is reduced from the maximum and minimum operating window of the GMR sensor due to variations in the manufacturing process of the magnetic material. The green dotted lines show the maximum and minimum expected magnetic field due to a typical manufacturing variation of >5%.

[1] The operating window is subject to change pending the release of the ADMT4000.

Magnet Simulation

The simulation of the magnet within the mechanical operating environment can take different forms. There are two types of simulation commonly used to design the magnet: an analytic simulation or finite element analysis (FEA). The analytic simulation solves the magnetic field using the bulk parameters of the magnet being simulated (size, material) without considering the surroundings other than the assumption it is operating in air. This is a quick calculation and useful when there are no adjacent ferromagnetic materials. FEA can model the effects of ferrous material in a larger magnetic system, which is essential when combining the magnet with a stray magnetic field shield or ferromagnetic materials close to the magnet or sensor. FEA is a time consuming process, so usually a starting point for this would be a basic magnet design from an analytical analysis. FEA was used in the simulation of the reference design for the magnet and stray field shield.

Magnet Design Feature

The reference design magnet resulting from the simulation consists of an SmCo magnet with an integrated steel stray field shield, as shown in Figure 2. The magnet is designed to be injection molded so it is capable of being mass produced. Injection molding of SmCo magnets is common due to the ability for it to produce complex shapes and it is used widely in automotive and industrial applications. The assembly is designed to be an interference fit with a 9 mm diameter shaft; however, modifications to the bushing are possible to allow attachment to shafts of different sizes.

Magnet Characterization

Careful characterization of the magnet assemblies has been carried out to demonstrate the robust magnetic solution for the GMR sensor. The key to characterization is the ability to perform detailed maps of the magnetic field strength across an extended magnet to sensor placement window in a control environment. Key to the success of characterization is a good understanding and calibration of the magnetic field probes used. Figure 3 shows an example of the measured field strength at two different air gaps, repeating these measurements across the full operating temperature range and air gap range is time consuming but is essential to understanding the performance of the magnet to ensure it operates under the required conditions.

Conclusion

In summary, the reference design magnet has been shown to meet the requirement for operation with a temperature of –40°C to +150°C, with an air gap of 2.45 mm ±1 mm, and an axial to sensor placement tolerance ±0.6 mm. Details of the magnetic stray field shielding will follow in subsequent articles.

The ADMT4000 is the first integrated true power-on multiturn position sensor and is set to significantly reduce system design complexity and effort, ultimately resulting in smaller, lighter, and lower cost solutions. The reference design will be available to ADI's customers to enable designers with and without magnetic design capability to add new and improved functionality to current applications and open the door to many new applications.

To find out more about the ADMT4000 and the magnetic reference design, please visit analog.com or contact your local ADI's sales team who will be happy to discuss your requirements and applications.

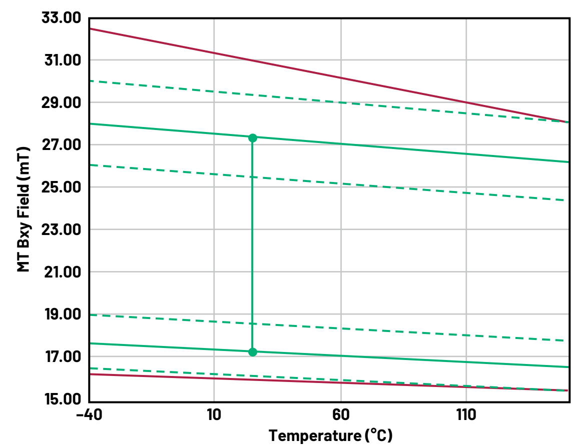


Figure 1. A thermal coefficient comparison of the operating window vs. a typical SmCo magnet.

Figure 2. The reference design magnet.

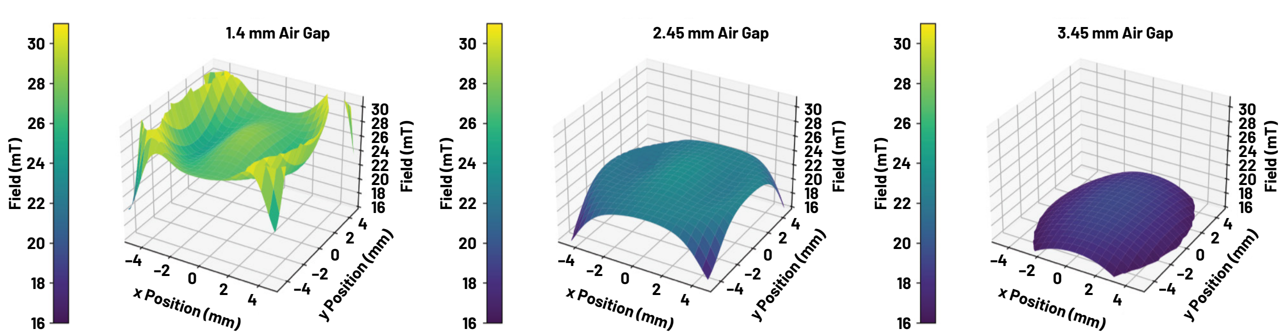
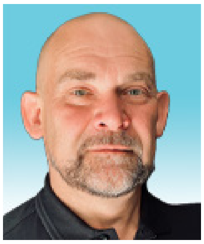


Figure 3. Magnetic field distribution with an air gap of 1.42 mm and 2.45 mm.



About the Author

Stephen Bradshaw has a B.Eng. in electrical engineering from the University of Leeds as well an M.Sc. and Ph.D. in optoelectronics from the University of Glasgow. During the early part of his career, Stephen was responsible for the design and characterization of the lens used in the first generation of mobile phone cameras with STMicroelectronics before working on Gbps optical transceivers at Maroni and most optical transceivers at Nanotech Semiconductor. Stephen has been with Analog Devices for over 10 years as an applications engineer supporting both LiFe and Pb-acid battery monitoring product lines and magnetic position sensors.

About the Author

Christian Nau is a product applications manager at Analog Devices and has a background in automotive electronics and sensors. He joined ADI in 2015 as a field applications engineer and subject matter expert supporting magnetic sensors in the EMEA region. Since 2019, Christian has been working in ADI's Magnetic Sensor Technology Group, supporting customer engagements on existing products and working on the future direction of the group covering multiple markets.

About the Author

Enda Nicholl is a strategic marketing manager for magnetic sensors at Analog Devices based in Limerick, Ireland. Enda was a mechanical engineer and joined ADI back in 2006. He has almost 30 years of experience in the field of sensors and sensor interface products across a broad range of applications and markets including automotive and industrial. Enda, throughout his career, has worked in product applications, field applications, and sales, as well as strategic business development and marketing.