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Magnetic field measurement as an essential part of quality control

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Summary:
There is an increasing demand for magnets, driven primarily by the move to electromobility and renewable energy. Magnets are needed for both sensors, such as encoders, as well as for electric motors. Magnetic encoder systems for precision applications depend greatly on the quality of the magnetic scale. While the magnetization process itself is often based on empirical data, the measurement processes and used measurement devices for the magnetic scales and pole rings are selected in a best-practice manner. This paper focuses on the design and development of the 3D magnetic mapper to describe a standardized protocol for measuring and quality control of magnetic scales, pole rings and magnet assemblies for motor applications.

Keywords: Magnets, magnetic field mapping, accuracy, precision, calibration

Introduction

The rise in the popularity of electromobility and renewable energy is resulting in increasing demand of magnets, which are used in both sensors and electric motors.

Magnets in the form of magnetic scales and pole rings, as part of encoder systems, are produced in-house on various levels within the supply chain. In some cases, even the Tier-1 within the B2B supply chain produces the scales. Due to the varied manufacturing processes and the fact that the magnetic measurement processes are based on best-practice methods, the quality control and characterization of magnetic scales and pole rings differs across the entire supply chain. Unifying the needs for more standardized measuring protocols led to the development of the DIN SPEC 91479 standard “Characterization of scales for magnetic length and angle measurement systems”, for which the consortium has just recently started. Both Matesy and ITK are members of the consortium.

Magnetic assemblies for motor applications are of similar focus, however the reason for magnetic measurements differ. It is common practice to perform functional tests with electric motors where magnetic errors of the rotor are likely to be identified. Sensors however are in many cases not tested together with the scale used in the application.

This increase in demand of magnets along with the varied manufacturing processes, is consequently leading to the need of accurate 3D magnetic mapping systems for quality control and characterization of magnetic systems and sub-assemblies. This paper will describe the design and development of a highly dynamic and accurate 3D magnetic mapper.

3D Magnetic Mapper

3D magnetic mappers (3DMM) serve several applications such as inspection of magnetic components, sub-assemblies and generation of magnetic stray field data used in calibration of finite element models and empirical models. The ever-increasing application of magnets also leads to making the requirements of 3DMM more complex and demanding. To match smaller and more complex magnetic applications, 3DMM must have high spatial resolution, high repeatability and absolute accuracy while maintaining high speed for improved productivity. To ensure high accuracy of the measured magnetic fields, the 3DMM must be designed to have a low stray field affecting the magnetic measurements.

Realization of 3DMM

In cooperation ITK Dr. Kassen GmbH and Matesy GmbH have jointly developed a highly dynamic and accurate 3DMM as seen in Fig 1. The developed 3DMM is based on the PT15 3-axis scanning platform, a high-speed scanning system utilized in the semiconductor and life science sectors, with a resolution in the nanometer range, an absolute accuracy of sub-micrometer

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level and a measurement range for any typical industrial motor design. The magnetic sensor is a calibrated Hall linear sensor array (MHLS – Matesy Hall Line Sensor) with 32 3-axis Hall sensors [1]. The sensor pitch is 2.5 mm in the longitudinal axis of the sensor line. Sample rate of the sensor is 200 S/s, the calibrated measurement range reaches between ±800mT within an accuracy of 0.5%.

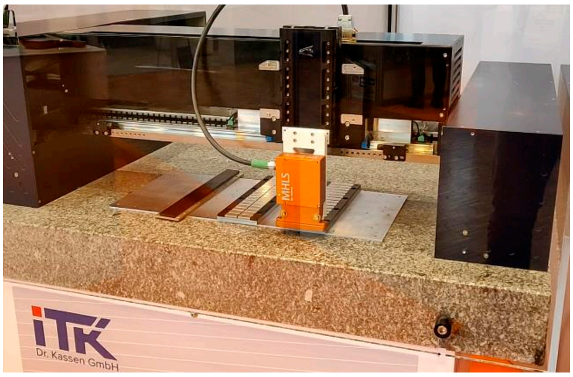

Figure 1: 3DMM

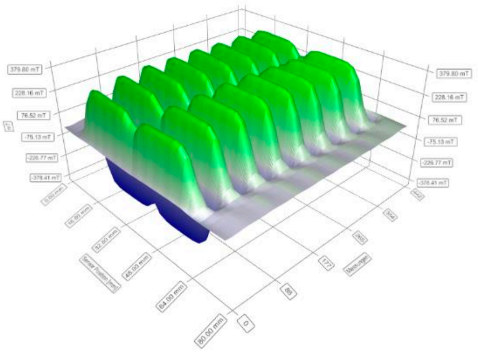

Figure 2: Measurement result magnetic stray field linear stator element

The development of this system consisted of 2 demanding design criteria:

- Optimization of the 3D scanner design to reduce the effect of stray fields of the scanner drive technology while being precise with high dynamic requirements
- Development and calibration of the magnetic sensor to enable fast measurements of the magnetic sub-assemblies

The presentation during SMSI will provide detailed information of stray field measurements in comparison to simulated stray fields. For this FE based simulations were compared to Magpylib, an analytical and therefore extremely fast magnetic simulation software.

Target applications will usually need different sizes and adapted 3DMM needs by each customer. Verification of stray field simulations is therefore the key to easily adapt system configurations.

Design Optimization of the 3DMM

The stray fields of the scanner drive system were simulated and verified against measurements. The sensor used to perform a magnetic mapping within the working of the scanner was a MMC5633NJL (3-axis AMR magnetic sensor) calibrated by Matesy. These stray field effects were taken into consideration and the 3D scanner system was adapted in order to optimize for low stray fields and high accuracy. The linear motors used within the 3DMM were a main point of concern, but experiments and simulation data (as shown in Fig 3 and 4) confirm that no significant influence on the magnetic measurement is given.

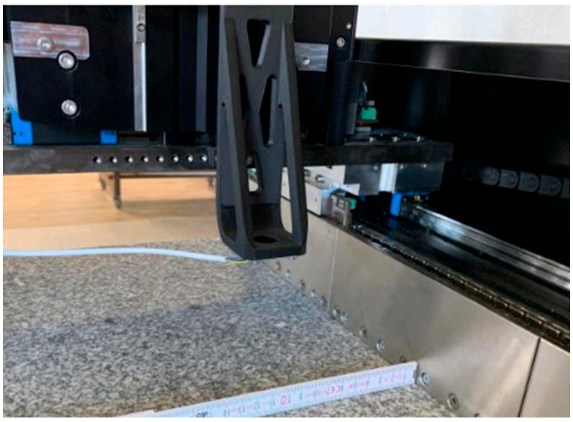

Figure 3: Experimental magnetic measurement

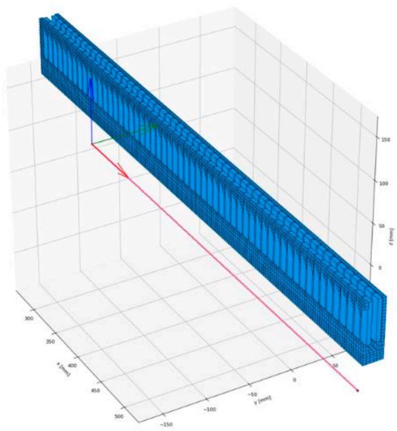

Figure 4: Simulation of linear motor

The magnetic field of the measuring area closest to the linear motor were measured and compared against simulation results. Both magnetic results were similar in trend and the magnitudes were determined to be too small to have a significant influence on the magnetic measurements (Fig 5 and 6).

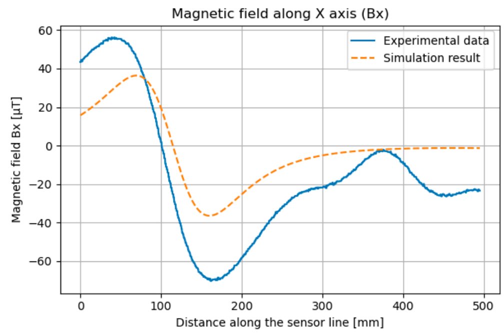

Figure 5: experimental vs. simulated magnetic field along x axis

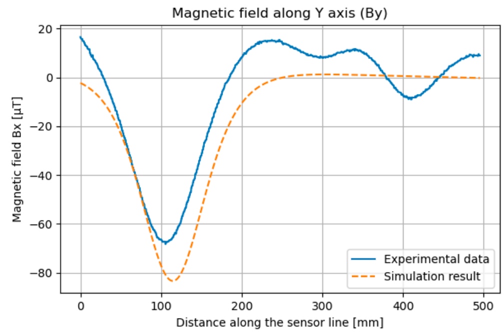

Figure 6:: experimental vs. simulated magnetic field along y axis

Calibration of the magnetic sensor

The Hall Line Sensor was calibrated at Matesy in all 3 directions in space. For this purpose, the system was positioned in a homogeneous area of an electromagnet and the corresponding magnetic fields were approached over the entire measuring range of ± 800 mT. The sensor alignment was previously referenced in a calibrated 3D Helmholtz coil to the reference surfaces on the housing. The correction function is stored directly in the sensor, so the sensor can be used immediately as a magnetometer.

Applications

The application examples of such a 3DMM are:

- Inspection of stator magnet sub-assemblies for linear motors: To avoid expensive replacement of defective magnet segments.
- Characterization of magnetic scales for magnetic linear encoders: Avoid unnecessary production delays that are caused due to late (or no-existent) magnetic field measurements.

By applying techniques such as MOIF (magneto-optical indicator film) in the future, the application of the 3DMM can be extended to gathering both the magnetic characteristics and the microstructure data using the same device.

Results

With the developed 3DMM end of line magnetic mapping has never been so fast and precise. With both partners being in the consortium of DIN SPEC 91479 the 3DMM will consequently be developed to be used as a calibrated measurement tool for and industrial company with magnetic assemblies. From material incoming inspection to sub-assembly testing, the 3DMM provides important data to make magnetic quality assurance more transparent and cost effective.

References

List and number all bibliographical references at the end of the paper. When referenced within the text, enclose the citation number in square brackets, i.e. [1]

[1] M. Schmidt, 100% Quality Control of Permanent Magnets for Industrial Applications, Magnetics Conference 2022, Orlando FL