26th IMEKO TC4 International Symposium
24th International Workshop on ADC and DAC Modelling and Testing
IMEKO TC-4 2023
Pordenone, Italy / September 20-21, 2023

Magnetic stray field analysis over large areas using Hall- and magneto-optical sensors

Benjamin Wenzel[1], Matthias Schmidt[1]

[1] *Matesy GmbH*, Löbstedter Straße 101-103, 07749, Jena*
b.wenzel@matesy.de

Abstract **– In this paper, fast and large-area measurements using Hall sensors and magneto-optical sensors are presented, which are suitable for 100% in-line testing of magnetic assemblies in industry. The advantages of the two methods are explained and illustrated using real measurement examples. We show how identically designed magnetic components can be compared easily and quickly based on their stray fields. High-resolution measurements of miniaturized magnetic structures are carried out using magneto-optical measurement technology and the results are presented.**

I. INTRODUCTION

Permanent magnets and magnetic assemblies are used today in many areas of industry, aerospace, and medical technology. A strong increase in the use of permanent magnets is currently due to the rapidly increasing demand for electromobility [1]. The quality of the magnets used is becoming increasingly important to produce efficient products that save natural and energy resources. The quality check is often determined based on the stray field distribution of the permanent magnets. Some mapping methods are already very well-known and described [2], [3], [4]. Most of these methods work with single magnetic field sensors that are scanning over the surface. Hall-, XMR-, NV center-, magneto-optical sensors and sensor coils are typically used. In the laboratory use, this enables a very high geometric resolution to analyze the stray fields precisely. Unfortunately, the scan times for these methods are in the minutes, or even hours, timeframe. This paper describes a method that significantly accelerates the scanning process and thus enables 100% in-line testing of all components produced. Matesy uses a Hall sensor array that can simultaneously analyze a measuring length of up to 317.5 mm with one movement. For area scans with high resolution, Matesy uses so-called magneto-optical sensors with which lateral resolutions of up to 25 µm can be achieved.

II. HALL SENSOR MEASUREMENTS

A Hall sensor line called MHLS (Matesy Hall Line Sensor) was developed in order to be able to quickly and extensively examine stray fields from magnetic assemblies. This combines a compact and robust design with sensitive 3-axis Hall sensors that are arranged in the longitudinal direction of the measuring line with a pitch of 2.5 mm. The calibrated measuring standard range is ± 800 mT for each direction and it is temperature-compensated for use in industrial environments. The MHLS can be built up modularly, up to a measuring length of 317.5 mm. The maximum measuring rate is 200 S/s. The sensor line is calibrated in the homogeneous magnetic field volume of an electromagnet. The figure below shows an MHLS with the sensor ICs arranged:

Fig. 1: MHLS 320 measurement line with arrangement of the sensor ICs on the PCB

In principle, planar and rotary measurements can be carried out with the sensor line, depending on which positioning system is used [5].

A. Planar measurements

For the planar measurements, the MHLS was equipped to a PT15B_V3-120-500 gantry from iTK Dr. Kassen GmbH. This achieves a measuring area of 500 mm x 500 mm and a z-stroke of 100 mm in the current setup. The assembled magnetic field mapper and a measurement result are shown in the following figures:

26th IMEKO TC4 International Symposium
24th International Workshop on ADC and DAC Modelling and Testing
IMEKO TC-4 2023
Pordenone, Italy / September 20-21, 2023

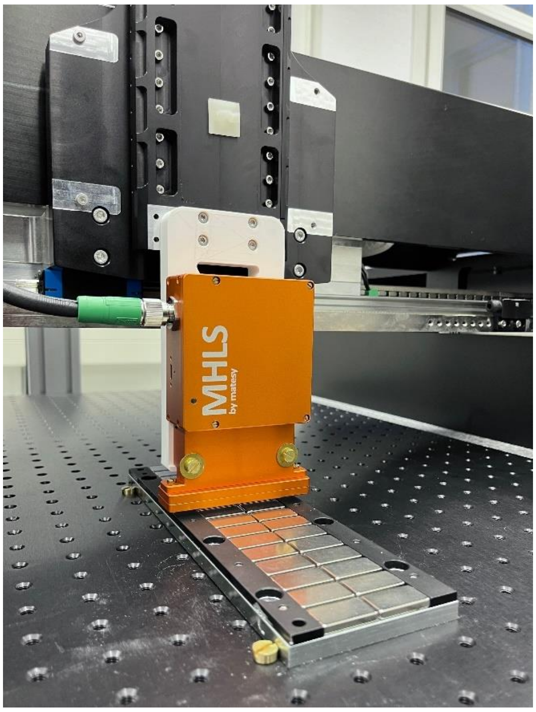

Fig. 2: Measurement setup for linear motor modules

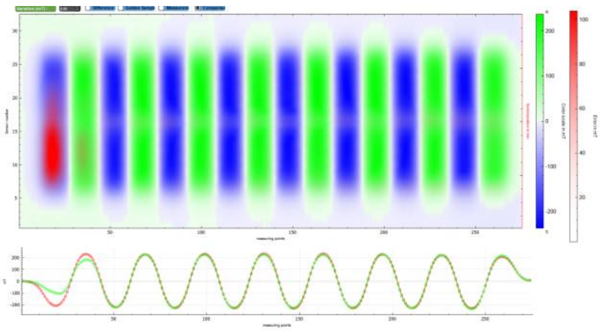

Fig. 3: Compared measurement results of two linear motor magnet modules, with red marking of error areas (top) and line diagram for both magnet modules in the region of the highest error (bottom)

For the stray field analysis, in 5 mm distance to the magnet surface, 2 magnet modules of linear motors were measured. The magnetic field image in Fig. 3 shows a comparison of the two magnet modules using the Golden Sample method. The deviations in the stray field of both modules are shown in red. It is very easy to see that the last two magnets compared of the magnet module deviate from the Golden Sample by up to 110 mT and are therefore significantly weaker. The scan was recorded with a resolution of 1 mm in the scanning direction, a speed of 100 mm/s and lasts 2.75 s for the whole magnet module shown. The recording of measured values is released by a trigger signal that is generated by the iTK gantry control. This means that each measured magnetic field value can be assigned an exact position on the scan area. Using the golden sample method, faulty magnet modules can be quickly found and sorted out, as shown here.

B. Measurements of rotating parts

To check the quality of the stray field of permanent magnet rotors, the MHLS was built into the RMP (Matesy Rotor Mapper) for these measurements and triggered using a high-resolution encoder on the axis of rotation. This results in an angular resolution of the measurement of 0.09°. The entire measurement took 20 seconds per rotor. It will take just 2 seconds if we change the angular resolution to 0.9°. An image of the measured rotor type in the measurement setup is shown in the following figure:

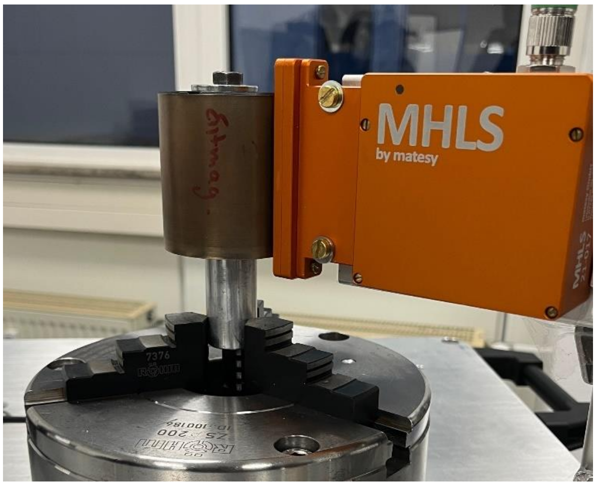

Fig. 4: Measurement setup for permanent magnet rotors

The measurement of 2 rotors was also evaluated here using the Golden Sample method and is shown in Fig. 5. It is again very easy to identify how the compared rotor deviates from the Golden Sample in the stray field. A field-weakening of up to 22 mT could be determined in the red marked areas. This process enables faulty rotors to be sorted out before they are assembled with the stator and thus also helps with quality testing in rotor production.

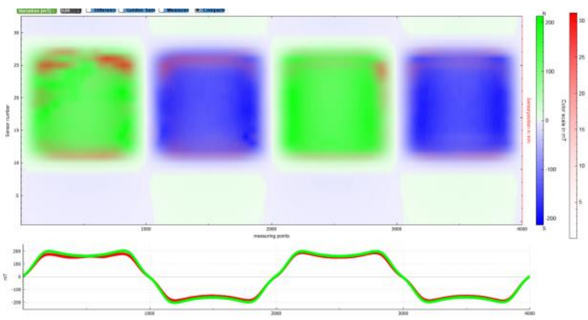

Fig. 5: Compared measurement results of two permanent magnet rotors with red marking of error areas (top) and line diagram from both rotors in the region of the highest error (bottom)

III. MAGNETO-OPTICAL MEASUREMENTS

The now shown results are made by magneto-optical principle which is based on the Faraday effect [6]. It describes the rotation of the polarization plane of linearly polarized light that passes through the magneto-optical sensor. The plane rotation is due to different refractive indices of the magneto-optical sensor for left- and right-circularly polarized wave parts of the polarized light. Viewed with help of another polarizer (analyzer) in nearly crossed orientation, one gets a highly resolved magneto-optical image of the different locally rotated light, which is a result of the applied or present magnetic stray fields. The following figure shows the Faraday effect in reflection mode which is used in cmos-magview technology by Matesy.

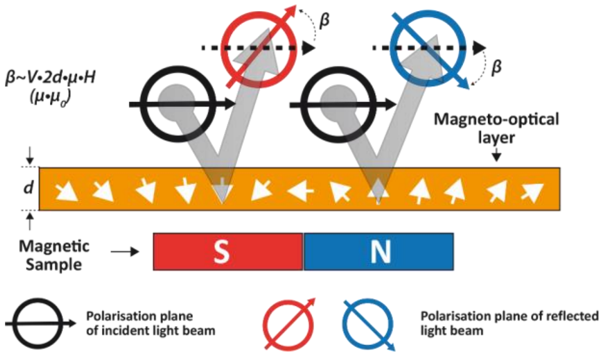

Fig. 1: Magneto-optical setup in reflection mode

A. Magnetic encoder testing

A magnetic scale with a diameter of 36 mm was investigated to determine zero crossings of the magnetic poles. The samples were positioned by hand directly on the magneto-optical sensor and different alignments were tested. Therefore, the measurement results show the real magnetic near field because the distance between the sample surface and the sensor plane is just a few microns. For the measurements, a cmos-magview XL with a calibrated measurement range of ± 125 mT and 60 µm lateral resolution was used. Additionally, a costumer specific software for automated detection of magnetic pole widths was developed. The repeatability of angular measurements was 0.02°. Due to the zero-crossing and circumference line detection the positioning between the outer and inner pole ring could be detected as well.

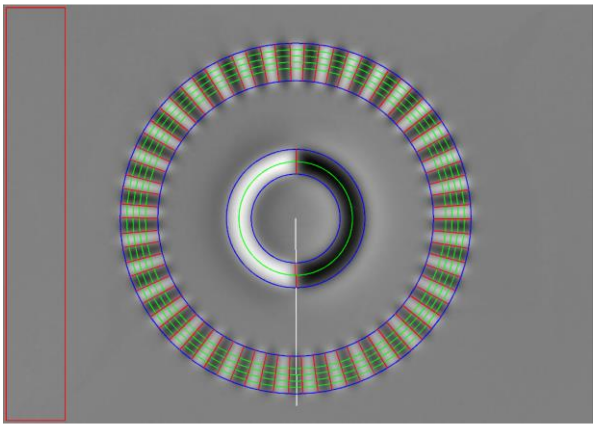

Fig. 7: Magneto-optical measurement result of a rotary encoder with 36 mm diameter

B. Electrical steel sheet testing

The quality control requirements for electrical steel are constantly increasing. Domain structures can be made visible by means of magneto-optical investigations on electrical steel, which allow conclusions to be drawn about the material properties [7]. In the magneto-optical image shown here in Fig. 8, the domains of a grain-oriented laser-treated (LMDR) electrical steel sheet are shown. It is a stitched image of 6 x 6 mm individual exposures. The overall size of the recording is approx. 100 mm x 65 mm. The lateral resolution of the image is 25 µm. Up until now, it has not been possible to characterize electrical steel sheets with this resolution and image size. It is very easy to see how the domains of the electrical sheet are interrupted by the introduced laser lines. This leads to domain refinement in the vertical direction of the image. The zoom section (framed in blue) shows a more misaligned area of the electrical sheet, which can be recognized by the higher domain contrast.

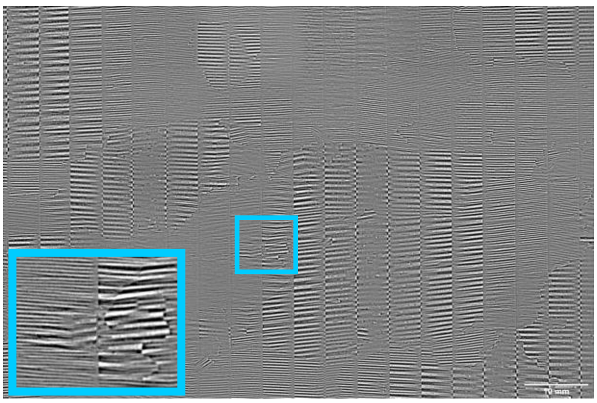

Fig. 8: Stitched magneto-optical domain image of a laser-treated, grain-oriented electrical steel sheet

IV. CONCLUSIONS AND ACKNOWLEDGMENT

Both hall scans with MHLS and large-area magneto-optical recordings using cmos-magview are efficient tools for 100% end-of-line control. In combination with the right evaluations in the software, the properties of the magnetic assemblies and test objects can be determined effectively, and defective parts can be sorted out quickly. As a further development, it is planned to combine the MHLS with a laser distance sensor to obtain a magneto-mechanical reference for the measurement. We thank the colleagues from INNOVENT e.V. for providing the magneto-optical recording and the Federal Ministry of Economics and Climate Protection, who supported the development of the MHLS as part of the ZIM program.

REFERENCES

[1] EV-Volumes - The Electric Vehicle World Sales Database.(o. D.). https://www.ev-volumes.com/evphev-forecast-example.png, 06-22-2023
[2] H. Husstedt, “Measurement of Magnetic Fields for the Testing of Automotive Sensors”, Dissertation March, 2014, AlpsAdriatic University Klagenfurt, Austria
[3] H. Husstedt, U. Ausserlechner, M. Kaltenbacher.: Accurate Scanning of Magnetic Fields. In book: Smart Sensors for Industrial Applications (Devices, Circuits, and Systems), pages 273-288, Chapter: 17, 2013.
[4] D. Popovic Renella, and S. Spasic. "Quality Control of Permanent Magnets for Industrial Applications: Integrating Magnetic Field Mapping and Crack Detection." 21st IMEKO TC-4 International Symposium on Understanding the World through Electrical and Electronic Measurement/19th International Workshop on ADC Modelling and Testing Conference Location Budapest, HUNGARY. IMEKO Location BUDAPEST, 2016.
[5] M. Schmidt, “100% Quality Control of Permanent Magnets for Industrial Applications”, Magnetics Conference 2022, Orlando FL.
[6] T. Hibiya, P. Görnert, in Liquid Phase Epitaxy of Electronic, Optical and Optoelectronic Materials (Eds: P. Capper, M. Mauk), John Wiley & Sons Ltd., pages 305 - 339, Chichester 2007.
[7] H. Richert, H. Schmidt, S. Lindner, M. Lindner, B. Wenzel, R. Holzhey, R. Schäfer.: “Dynamic Magneto-Optical Imaging of Domains in Grain-Oriented Electrical Steel”. In steel research international, Volume 87, Issue 2, pages 232-240, 2015.