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Quality Control of Permanent Magnets for Industrial Applications: Integrating Magnetic Field Mapping and Crack Detection

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***Abstract* – The characteristics of permanent magnets must be carefully controlled when applied in automotive, industrial and consumer products. In this paper we present a novel measurement system for quality control of permanent magnets by integrating magnetic field mapping and crack detection. The novel system is introduced that combines in a single device the features of a magnetic field mapper, the eddy-current measurements and a touch stylus. The magnetic field sensitive area of the 3D Hall probe is 100x100um; the selectable measurement range is 50mT-2T; the probe positioning accuracy is 2µm / 0.02°; and the measurement accuracy is 0.1%. The angular error of the sensitivity vectors of the 3D Hall probe are less than 0.1°. The system integrates various tools for in-situ automatic calibration, e.g. the precise determination of the magnetic field sensitive volume. The mapping system allows a smart and easy interchangeability of various measurement probes. Further in this paper we present several industrial applications that apply the novel measurement system for quality control of their permanent magnets and magnetized and non-magnetized parts: one application is the quality control of segment magnets for rotors; another application is crack detection in magnetized and non-magnetized parts; further applications include high-resolution magnetic field mapping of an area around permanent magnets in the form of a disc, block or electronic circuit PCB's such as smartphones or tablets.**

***Keywords* – Magnetic Field Mapping, Crack Detection, Permanent Magnets, 3D Hall Probe, Teslameter**

I. INTRODUCTION

In modern applications permanent magnets are used in various forms. For example, a permanent magnet may be used in combination with a magnetic field sensor to build a magnetic position and angle sensor. Billions of such sensors are built each year. Permanent magnets may be also used in electric motors, transformers, generators and electric pumps, where they can be applied for example as segment magnets for rotors.

In order to achieve an optimal performance in any of the above mentioned applications, the characteristics of permanent magnets must be carefully controlled; and this is usually done by using a magnetic field mapper.

A good overview of the published magnetic field mappers is given in a PhD thesis [1]. A particular problem reported in this work is the angular tolerances of the 3 sensitivity vectors of the probe that even in a CMOS integrated 3-axis Hall probe can be larger than 1°; and assembling a small probe in a mapper is subject to additional angular tolerances.

In the present paper we describe a 3D magnetic field mapper system with one 3D Hall probe that integrates both vertical and horizontal Hall elements in an area of 100x100um. The novel mapper system applies a calibration process for reducing the error of the sensitivity vectors of the 3-axis Hall probe to less than 0.1°. This calibration process has been partially described in [2].

The Hall probe is easily exchangeable in the mapper system with an Eddy-current probe, a touch stylus and other specialized probes. This allows a complete quality control of permanent magnets applied in modern industrial applications by providing accurate mapping of the magnetic field around the magnet under test, combined with crack detection and the material inhomogeneity test. Such tests require not only to measuring all three components of the magnetic field in one spot; but they also require an accurate positioning of the measurement probes with respect to the magnet coordinate system. A specialized tool integrated in the mapper allows the exact determination of the magnetic field sensitive area.

The novel Magnetic Field Mapper features the following characteristics:

o A high spatial resolution 3-axis Hall probe for 3D magnetic field measurement
o 3D mapping, homogeneity, angle error measurement
o No. of magnetic poles, pole width, pole max/min
o Selectable measurement ranges: 50mT – 2T
o Probe positioning accuracy: 2µm / 0.02°
o Measurement accuracy: 0.1%
o Eddy-current probe for crack detection
o In-situ, automatic calibration
o Customizable, user-friendly mapper software
o Easy and smart interchangeability of measurement probes.

The paper is organized in the following way: In Section II, the magnetic field mapper is described. Section III gives some examples of various applications of the magnetic field mapper. In Section IV we shortly emphasize the novelties of the system. The last Section V concludes the paper.

II. MAGNETIC FIELD MAPPING SYSTEM WITH SMART INTERCHANGEABLE MEASUREMENT PROBES: 3D HALL PROBES, EDDY CURRENT PROBES, STYLUS, SLIDING PROBES

Often there is a need to measure all three components of the magnetic field vector at many points in space and to build a map of the magnetic field. Instruments suitable for such measurements are known as magnetic field mappers, as shown in Fig. 1. The new magnetic field mapper system consists of four main parts: (a) the mechanical part, (b) the 3-axis Hall Probe (or any other probe – as shown in Fig. 2), (c) an electronic box with digital signal processing, motor drives, encoder control, and power supply; (d) and a PC and Software for measured data acquisition, visualization, and analysis.

An essential part of the system used for magnetic field measurement is the unique 3-axis Hall probe in combination with the analogue and digital signal processing units. This part was partially described in the form of a high-accuracy Teslameter in a recent publication [3].

Fig. 1. The new Magnetic Field Mapper consists of four main parts: (a) the mechanical part, (b) the Hall Probe (or any other probe – as shown in Fig. 2), (c) an electronic box with digital signal processing, motor drives, encoder control, and power supply; (d) and a PC and Software for measured data acquisition, visualization, and analysis.

Accurate mapping of the magnetic field around permanent magnets and electromagnets requires both, accurate positioning of a magnetic field probe with respect to the magnet coordinate system and accurate measurement of the magnetic field vector with high spatial resolution. The requirement for accurate positioning is met by combining in a single machine the features of a magnetic field mapper and a touch stylus.

The high spatial resolution is achieved by applying a unique 3-axis Hall probe that measures all three components of a magnetic field in virtually the same spot [4].

The requirement on the flexibility in measuring different characteristics of permanent magnets has become an increasing importance in the recent years. This requirement can be solved with providing an easy way to interchange different measurement probes in the mapper, such as Hall probes, special probe geometries for rotor testing, eddy-current probes for crack detection, sliding probes for in-contact magnetic field measurement, touch stylus for coordinate measurements and further specialized probes. Fig. 2 shows some of the available probe options.

Fig. 2. Measuring different characteristics of permanent magnets is possible due to an easy way to interchange different measurement probes in the mapper. The photo shows some of the available probe options: Hall probe for rotor tests (special holder that allows the scanning of larger rotors); Standard Hall probe; Stylus; Eddy-current probe; Sliding probe; probe for Rotor air-gaps.

III. APPLICATIONS OF THE MAPPER

This Section gives some examples of the applications in Industry of the novel magnetic field mapping system. The mapper is used in quality control of permanent magnets; for magnetic field mapping around rotors of small motors; for the control of magnetized blocks e.g. smartphones; for crack detection of permanent magnets in the automotive industry, etc.

A. MAGNETIC FIELD MAPPING

The quality control of permanent magnets is performed by measuring all three components of the magnetic field at precisely defined points around the magnet. As shown in Fig. 3, the Mapper is applied for measuring magnetic field and the inhomogeneity, i.e. the magnetic angle error. It is also used as a quality assessment tool (good/bad analysis) in production lines for permanent magnets used in automotive industry.

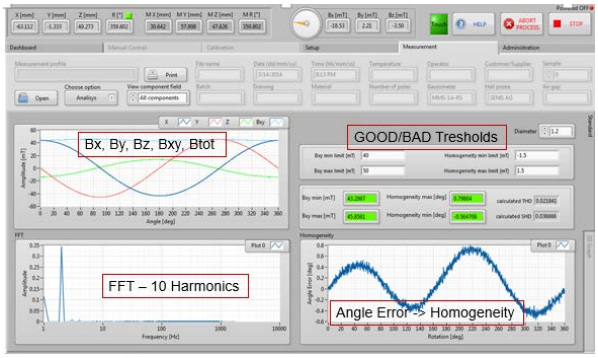

Fig. 3. The magnetic field mapper software showing the 3D magnetic field measurement, inhomogeneity measurement, harmonics analysis and pass/fails analysis.

B. ROTOR MEASUREMENT

For the magnetic field measurement around rotors, some specialized probes were developed, such as the one with a “knee” to approach larger rotors, or very long (90mm) and thin (0.25mm) Hall-Probe for magnetic field measurement in air gaps of large rotors-stators. The high-accuracy measurement allows magnetic pole counting, magnetic pole width determination, the magnetic field peak and zero value determination, etc. The scanning of the rotor is performed on different Z-distances (slices) in order to test the rotor’s longitudinal magnetization uniformity, i.e. the correct pole width on the full rotor length, see Fig. 4a); or to validate the number of poles, see Fig. 4b) and their distribution.

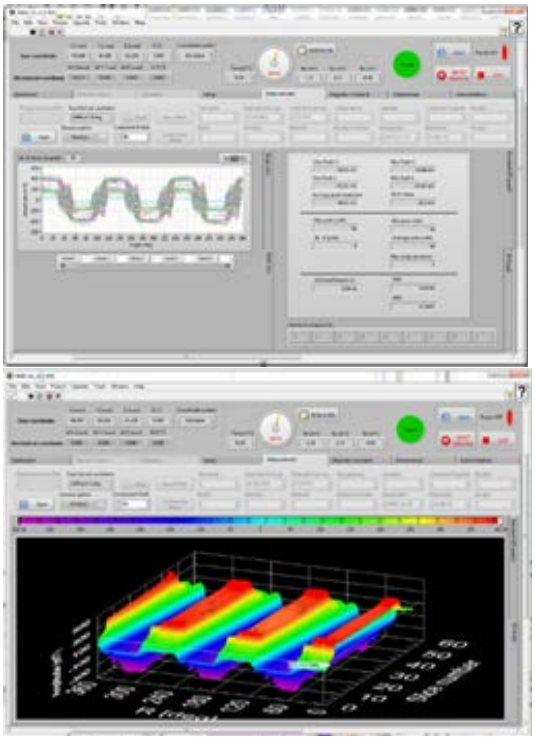

Fig. 4a). High-accuracy magnetic field measurements of rotors: multi-slice, multi-pole scanning, presented in 1D and 3D graphs.

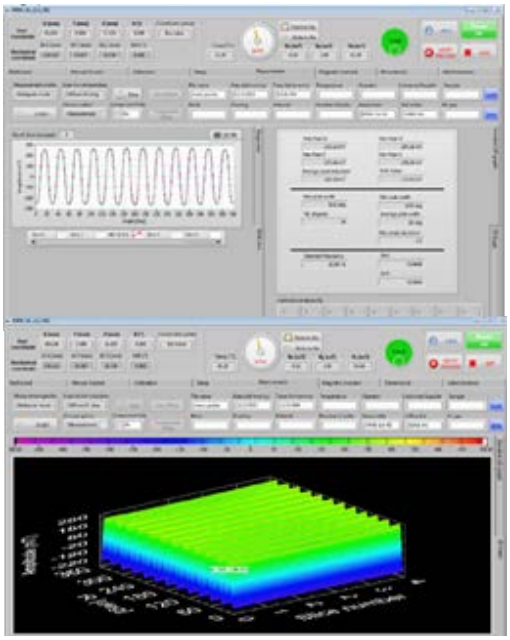

Fig. 4b). High-accuracy magnetic field measurements of rotors: number of poles, pole width, pole max/min.

C. EDDY-CURRENT PROBE FOR CRACK & INHOMOGENEITY DETECTION

Visible and invisible cracks (inside material or under material coating) and the inhomogeneity or anisotropy inside material (prior to magnetizing) can be detected by using specialized eddy-current probes.

Fig. 5a). Cracks and Inhomogeneity detection: a ring magnet with invisible inhomogeneity.

Fig. 5 shows several samples, in 5a) a ring magnet with invisible inhomogeneity; in 5b) a block magnet with the crack, and in 5c) a rotor segment magnet with the crack. The mapper software visualizes the crack or inhomogeneity on a 2D graph through the measured distribution of the eddy-current, as the differential voltage.

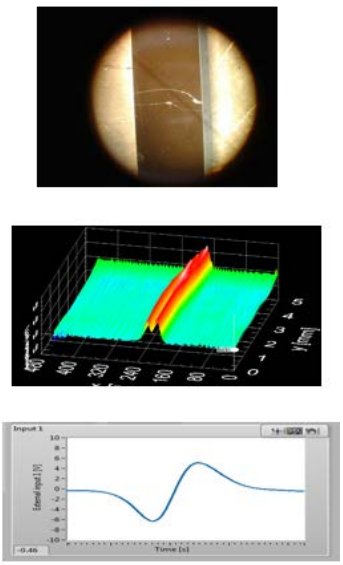

Fig. 5b). Cracks and Inhomogeneity detection: a block magnet with the crack.

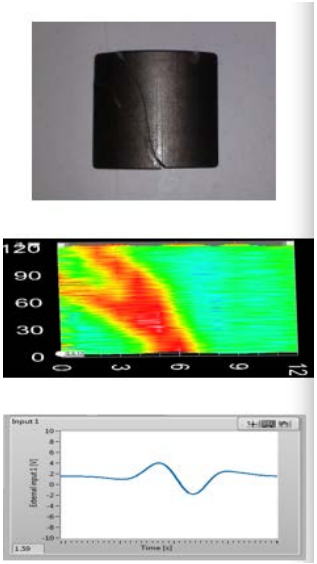

Fig. 5c). Cracks and Inhomogeneity detection: a rotor segment magnet with the crack.

D. SCANNING AN AREA AROUND PERMANENT MAGNETS (DISCS, BLOCK) OR AROUND THE PCBs OF SMARTPHONES, TABLETS

The SENIS Magnetic Field Mapper allows the 2D and 3D magnetic field mapping of electronic circuit PCB's (such as smartphones, tablets, etc.), Fig. 7; but also the mapping of coded-plates (multipole block magnets) and other complex magnetization structures, see Fig. 6.

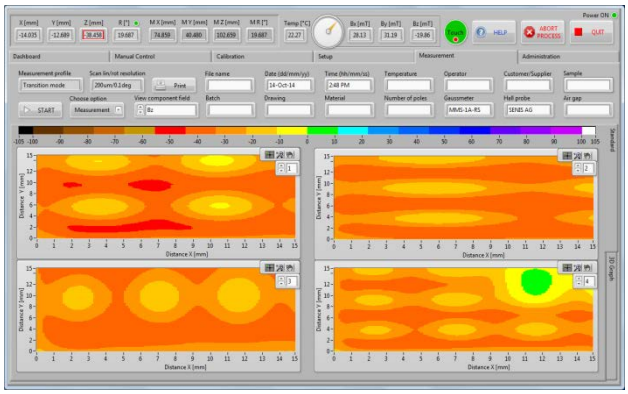

Fig. 6. a). 2D visualization of a scanned area around a permanent magnet.

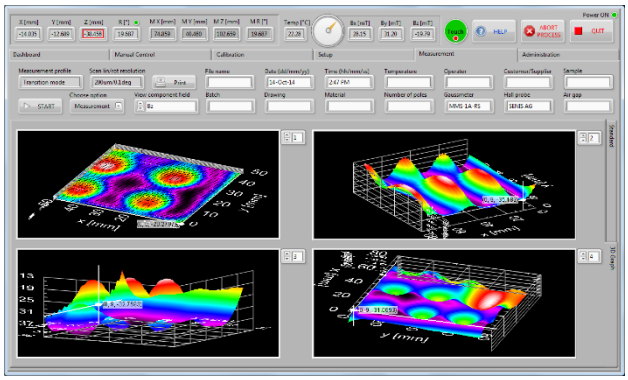

Fig. 6b). 3D visualization of a scanned area around a permanent magnet.

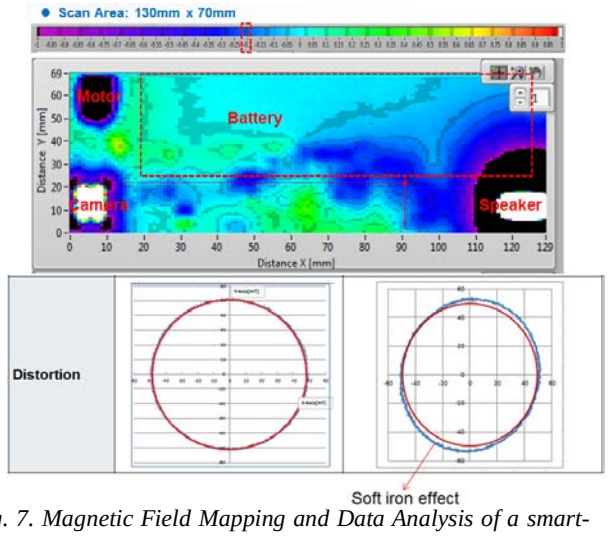

Fig. 7. Magnetic Field Mapping and Data Analysis of a smart-phone

IV. NOVELTIES IN THE PAPER

Commercially available magnetic field mappers are usually good enough for one particular application. In this paper we describe a general purpose Magnetic Field Mapping system that integrates several features important for various applications in industry and modern science. The novel measurement solutions propose the integration of a high resolution and high accuracy magnetic field measurement system with crack detection using an Eddy-current probe. The system allows an easy and smart interchangeability of various specialized measurement probes in combination with a touch stylus:
a high spatial resolution 3-axis Hall probe for 3D magnetic field measurement, 3D mapping, homogeneity, angle error measurement, no. of magnetic poles, pole width, and pole max/min determination; an Eddy-current probe for crack detection; and a touch stylus for dimensional measurement. The magnetic field sensitive area of the 3D Hall probe is 100x100um and its position can be precisely determined by using an automatic in-situ calibration tool. The calibration of the sensitivity vectors of the 3D Hall probe that reduces the angular error of the sensitivity vectors to less than 0.1° was partially described in [2].

V. CONCLUSIONS

The novel magnetic field mapper system with the easy and smart interchangeable measurement probes (high-spatial resolution 3D Hall probe, rotor probe, Eddy-current-probe, touch stylus) was presented. In a single device the features of a magnetic field mapper, the eddy-current measurements and dimensional measurements are

combined. This allows a high-quality control of permanent magnets in industrial applications such as e.g. the magnetic field measurement around rotors, crack and inhomogeneity detection, and it allows high-accuracy scanning around magnetized blocks such as e.g. smartphones, etc.

VI. ACKNOWLEDGMENT

We would like to thank our reference customers for providing us the information of their applications [5].

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