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Supporting World Development through Advanced Magnetic Measurement Applications in Industry and Physics Laboratories

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***Abstract* – This paper presents several applications of advanced magnetic field measurement that include among others condition monitoring of electrical machines; magnetic field mapping of undulators, quadrupoles and sixtupoles at national lightsources, radiation centers, synchrotron centers; quality control of permanent magnets.**

***Keywords* – magnetic measurement, magnetic field mapping, teslameter, monitoring of electrical machines**

I. INTRODUCTION

World Development is a process of improving the quality of human life. This includes, improving reliability and increasing efficiency of electrical machines; vehicle safety in the automotive and transportation industry; more accurate medical equipment; improved research infrastructures. The development and operation of these and many other machines is supported in a way or another also by advanced magnetic measurement applications.

Magnetic measurement instruments are typically applied for quality control and monitoring of permanent magnets, electro magnets and magnet systems; for the development of magnet systems and process control; for magnetic field mapping and in general for magnetic field measurement applications in production lines and in laboratories.

Driven by „Necessity is the mother of invention" our company SENIS, specialized in advanced magnetic and current measurement instrumentation, is supporting the industry and physics laboratories that contribute to the world development process, both through novel measurement principles and equipment as well as through new applications of known measurement techniques. In this sense, this paper presents several applications of advanced magnetic field measurement that support the world development.

Following this introduction, in Section IIwe give some examplesof magnetic field measurement applications: condition monitoring of electrical machines; magnetic field mapping of undulators, quadrupoles and sixtupoles at national lightsources, radiation centers, and synchrotron centers; quality control of permanent magnets; and AMR-based Nanoteslameterthat is applied in active cancelation of environmental magnetic fields and for measuring stray magnetic fields of electrical machines.These applications will illustrate how SENIS 3D Hall- and AMR-based magnetometers and mappers support the applications where magnetic field measurement is required.In Section III we will present our future developments: a nano-scale magnetic field mapper; and in SectionIV we shall briefly discuss and conclude why the SENIS equipment could be adapted for applications needed in advanced magnetic field measurements.

II. ADVANCED MAGNETIC FIELD MEASUREMENT APPLICATIONS IN INDUSTRY AND PHYSICS LABORATORIES

This section describes several advanced magnetic field measurement applications in industry and physics laboratories: condition monitoring of electrical machines, magnetic field mapping of undulators, quality control of permanent magnets, rotors and motors, active cancelation of zero magnetic fields and others.

A. Condition monitoring of electrical machines

Condition monitoring techniques are applied in order to identify a change in operation of an electrical machine, which is indicative of developing a failure of the machine. The use of condition monitoring requires maintenance to be scheduled, or other actions to be taken to prevent failure in electrical machines and avoid its consequences. There is a requirement to measure the magnetic flux density in or around stators and rotors of electrical machines, e.g. electrical generators or motors.

Fig. 1: SENIS Hall probe mounted on the stator of a generator. The Hall probe is packaged in ceramic package, applicable for temperature up to 160°C.

This can be done by a Hall-effect magnetic field transducer. Hall-effect devices have the advantage of being able to measure both DC and AC magnetic fields in a broad range, and can be made in extremely small sizes. Figure 1 shows a Hall probe mounted on a stator of a generator. The Hall probe needs to be thin, robust and resist high temperature to up to 160°C.The use of such an air-gap magnetic field probe has proven effective in the detection of generator rotor winding shorted turns and has helped to improve the quality of predictive maintenance decisions, concerning when or if to perform rotor re-work.

B. Magnetic field mapping of undulators, quadrupoles and sixtupoles at light sources, radiation centers, synchrotron centers

The arrays of magnets in the undulators for light sources, as for instance that atSwissFEL (Switzerland's X-ray free-electron laser) has to be precisely tested and adjusted [1].For example, an ultrathin 3-axis Hall probe is used to measure the magnetic field profile along or parallel to the undulator axis, see figures 2-4.

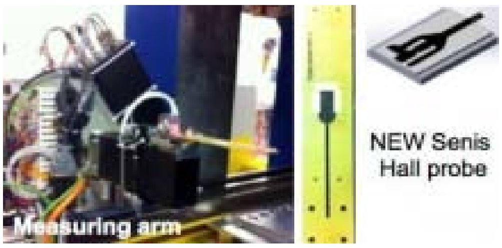

Fig. 2: The first prototype of the in-vacuum undulator (U15) for the SwissFEL project has been completed and tested with magnetic measurements using SENIS new thin Ceramic 3-axis Hall probe. (reprinted with permission of PSI [2], [3])

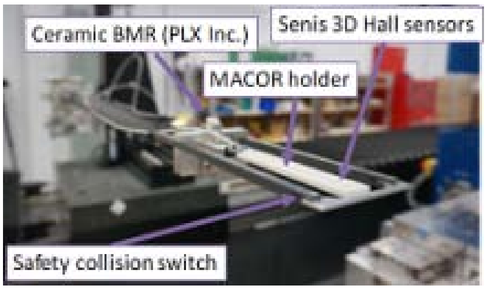

Fig. 3: SENIS 3D Hall probe magnetic field scanning at CLS - Canadian Light Source (reprinted with permission of CLS [4])

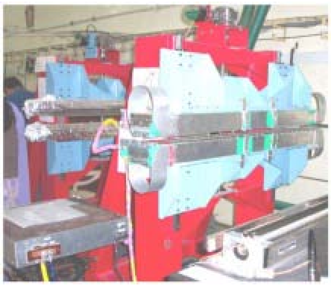

Fig. 4:Ultrafast TErahertz Free Electron Laser (CUTE-FEL) undulator at RRCAT - Department of Atomic Energy in India. Field measurement of the assembled undulator segments was done using a SENIS three-axis Hall probe, with a spatial resolution of 0.1 mm. (reprinted with permission of RRCAT [5])

Another example is the use of SENIS Hall probes for monitoring of beam control magnets e.g. in the Paul Scherrer Institute's proton therapy system for patient therapy [6].

C. Magnetic field mapping of magnets, rotors, motors

Magnetic field mapping for quality insurance in industry is typically performed with a magnetic field mapper, as shown in figure 5. The mapper contains a 3-achsis Hall probe that measures the magnetic field over an area or volume of interest near the magnetized parts.

Fig. 5: Quality control of permanent magnets using a state-of-the-art magnetic field mapper

a. Mapping of permanent magnets

Most of modern magnetic position and angle sensors consist of a combination of a permanent magnet and a magnetic field sensor. Billions of such sensors are built in automotive, industrial and consumer products each year. Also, rotors or segment permanent magnets are widely applied in actuators in the automotive industry.The characteristics of permanent magnets for such applications must be carefully controlled. The control of the magnets often includes measurement of the magnetic field over an area or volume of interest near the magnet, which is usually performed by a Magnetic Field Mapper[7].The above part of figure 6 shows some permanent magnets and formsused with linear and angular position sensors, multiple linear and rotary encoders, and multiple coded plates for automotive and consumer applications. The lower part of figure 6 shows the mapping analysis of three magnetic field components, min/max values, FFT, number of magnetic poles, pole disposition, etc.

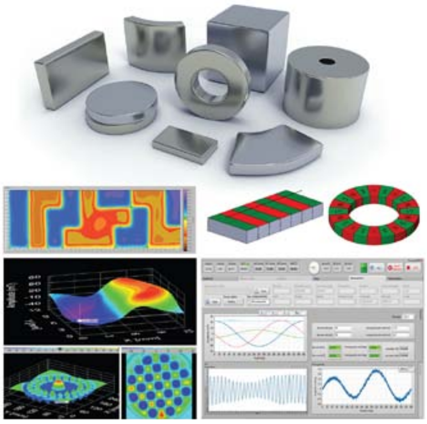

Fig. 6: Mapping of permanent magnets

Important in this application is the very compact magnetic field volume of the 3D hall probe. Moreover, the state-of-the-art mapper system, shown in Fig. 5, applies a calibration process for reducing the orthogonality error of the sensitivity vectors of the 3-axis Hall probe to less than 0.1°.

b. Rotors, motors and air gaps inspection

By using a long and ultra-thin 3-achsig Hall probe as a key component of the magnetic field mapper, the analysis of the magnetic field distribution of rotors, motors and in the air gap between the stator and rotorusing a long and ultra-thin 3-axis Hall probe can be performed, such as the 3D mapping, min/max values, number of magnetic poles, pole width, pole disposition, slope, skewing, etc., as shown in figure 7.

Fig. 7: Rotors, motors and air-gap inspection

c. AC magnetic field mapping and EMC applications

New applications of the magnetic field mapper, shown in figure 8, include the high frequency magnetic field mapping of inductive heaters, cookers and electromagnets with HF Hall probes (f-bandwidth of up to 75kHz and higher). Miniaturized pickup coils can be applied for the electromagnetic compatibility (EMC) of electronic components and devices.

Fig. 8: AC magnetic field mapping and EMC

d. Low magnetic field mapping

The measurement of magnetic field mapping around smartphones, tablets, demagnetized parts, magnetic strips, etc. is applicable by using the low-field Hall and AMR probes.

D. AMR-based Nanoteslameter for active cancelation of environmental magnetic field and for measuring stray magnetic fields of electrical machines

For the measurement of small magnetic fields usually flux gate sensors are applied. However, fluxgates can be very large in their dimensions. Some applications require the combination of very high-spatial resolution, high DC magnetic resolution and very well defined position of the sensitive area during the measurement[8], which is all solved by AMR-based Nanoteslameters. Figure 9 shows a histogram of the noise-equivalent magnetic field spectral density of the AMR probe. The standard deviation is about 0.6nT. That means that the smallest magnetic field that we can detect is about 600pT.

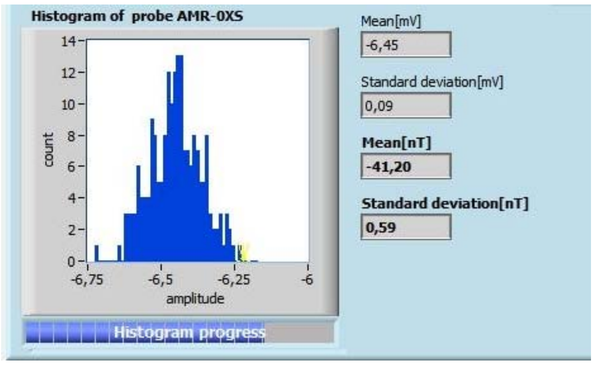

Fig. 9: Histogram of the noise-equivalent magnetic field spectral density of the SENIS Nanoteslameter used for applications where the combination of very high-spatial resolution, high DC magnetic resolution and very well-defined position of the sensitive area during the measurement is required.

III. FUTURE DEVELOPMENTS – NANO-SCALE MAGNETIC FIELD MAPPERS

The market is asking for smaller and higher performance electronic devices. Magnetic field measurements at the micro and nano level cannot yet be measured accurately and reliably traced back to magnetic reference standards – and this is hindering high-tech industries' ability to conduct the quantitative analysis and quality control.

In a consortium with the major European Metrology Institutes and some Industrial partners, the currentproject"Nano-scale traceable magnetic field measurements"[9]will develop European metrologycapabilities to extend the accurate and traceable measurement of magnetic fields to micrometre and nanometre scales.

Industrial users including computing, magnetic sensing and biomedicine will be able to develop new standards in quality control and product performance.

Our company SENIS, as the industry partnerof this big important consortium will contribute with its track record in magnetic field mapping and the world's smallest ultra-low-noise Hall cells[10]. The result of this project will be a "Nanomapper" that shall be able to measure the magnetic field of the micro- and nano structures, with a very high magnetic and spatial resolution.

IV. DISCUSSION AND CONCLUSIONS

In a recent presentation[11]we gave an overview of magnetic field sensors and explained why some magnetic sensors (such as Hall sensors and magnetic resistors) are more used in industrial applications than others.Hall-effect devices have the advantage of being able to measure both DC and AC magnetic fields in a broad range, and can be made in extremely small sizes. In addition to that and other standard requirements, such as high accuracy and resolution and high stability, some additional features required in modern applications are three-axis probes with very small overall dimensions. Other examples in industry require verysmall magnetic field sensitive volume of the 3-axis Hall probe and smallorthogonalityerror of the three sensitivity vectors of the 3D Hall probe.

In another recent study [12] we analysed several advanced magnetic field measurement applications and we compared commercially available Teslameters/Gaussmeters at the high-end performance level. The teslameters have been evaluated by following characteristics that are published by suppliers: probe dimensions, magnetic field sensitive volume, accuracy, magnetic resolution, measurement range, frequency bandwidth, temperature coefficient sensitivity, and price/performance ratio. The Teslameter that best matches the measurement needs in various application fields incorporates a 3-axis integrated Hall probe, analog electronics based on the spinning-current technique, an analog-to-digital converterand an embedded computer for high resolution measured data acquisition and visualization.

These previous analyses gave us the base for the present paper to better understand and illustrate how the SENIS 3-axis Hall- and AMR-based magnetometers and mappers could be adapted to support the world development throughapplications where advanced magnetic measurement is required. Several important magnetic field measurement applications in industry and physics laboratories are described in this paper. In addition to that we announced some future applications of Nanoscale magnetic field mappers.

V. ACKNOWLEDGMENT

We gratefully thank our customers for providing the magnetic measurement examples and results as a reference for this paper[13].

REFERENCES

[1] S. Sanfilippo, *"Hall probes: physics and application to magnetometry"*, PSI Switzerland, 2011.

[2] M. Calvi, *"Status of the undulator development at the SwissFEL"*, TE Magnet Seminar, CERN, 2014

[3] M. Calvi, M. Brügger, S. Danner, *A. Imhof and T. Schmidt "The magnetic assessment of the U15 prototype for the SwissFEL"*, 35th International Free-Electron Laser Conference, FEL 2013, Manhatten, USA, August 26-30, 2013

[4] Tor Pedersen, *"Building a Double APPLE-II Undulator"*, IMMW19, 27 October 2015, Taiwan

[5] S. Krishnagopal et al, *"FEL activities in India"*, Proceedings of FEL 2006, BESSY, Berlin, Germany

[6] *Center for Proton Therapy CPT at Paul Scherrer Institute*: https://www.psi.ch/protontherapy/

[7] S Spasic, *"Magnet Inspection Tool with High Magnetic and Mechanic Accuracy"*, Magnetics, Orlando FL, 2015

[8] D Popovic Renella, S Spasic, RS Popovic, *"Ultra-low noise Nanovolt-amplifier and 3-axis Nanoteslameter"*, International Magnetic Measurement Workhop (IMMW19), National Synchrotron Radiation Research Center, Hsinchu, Taiwan, 2015

[9] *EURAMET Research project: Nano-scale traceable magnetic field measurements*: https://www.euramet.org/research-innovation/search-

research-projects/details/?eurametCtcp_project_show%5Bproject%5D=1410

[10] Ultra low noise Hall cells: http://www.senis.ch/products/ic-chip-design

[11] D Popovic Renella, S Spasic, RS Popovic; *"Magnetic Sensors and Measurement"*, UK Magnetics Society, 30th Ewing Event: Magnetics Past, Present and Future, November 2016

[12] D Popovic Renella, S Spasic, S Dimitrijevic, M Blagojevic, RS Popovic, *"An overview of commercially available teslameters for applications in modern science and industry"*; ACTA IMEKO, Vo.6 No.1, April 2017

[13] SENIS reference customers' applications of magnetic field measurement: http://www.senis.ch/products/applications/references