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TECHNICAL SPECIFICATION

colour inside

Nanomanufacturing – Key control characteristics – Part 9-2: Nanomagnetic products – Magnetic field distribution: Magneto-optical indicator film technique

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IEC TS 62607-9-2 has been prepared by IEC technical committee 113: Nanotechnology for electrotechnical products and systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
113/817/DTS	113/830/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62607 series, published under the general title *Nanomanufacturing – Key control characteristics*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

Measurements of magnetic fields that are homogeneous over macroscopic volumes can be made traceable to the SI standards. Traceable calibration chains from national metrology institutes to the end users are well-established.

However, many important industrial applications rely on precision sensing of spatially varying magnetic fields. End-users need traceably quantitative characterization tools for magnetic materials on the micrometre to centimetre scale to perform quality management of their production processes.

IEC TS 62607-9-1 [1] [1] established high-resolution magnetic field measurements based on calibrated magnetic force microscopy. While qMFM can be regarded as the gold standard for nanoscale magnetic field measurements with highest spatial resolution, its technical application is often hindered by several drawbacks: qMFM does not provide a high time resolution and it has a limited scan range (typically up to 100 µm × 100 µm in commercial systems). Also, qMFM can only deal with samples that are flat on a 100 nm scale. On the other hand, nuclear magnetic resonance (NMR) based SI standards can only be applied to centimetre scale macroscopic objects. However, industrially relevant magnetic materials often combine micrometre scale magnetic features with sample dimensions in the millimetre or centimetre range and rough rather than flat surfaces.

Magneto-optical sensor technology is already used in the testing of magnetic materials and partly also for quality control of magnetic components. Prominent examples for such industrial samples with high economic relevance and high production numbers are:

– Magnetic scales for the fabrication of precise magnetic encoders for length measurement systems and rotary encoders, e.g. for automotive applications; relevant parameters to be metrologically assessed, like magnetic period, pole location, magnetic pole length, or pole width, are, for example, defined in the DIN SPEC 91411 [2].
– High-quality electrical steel sheets (grain-oriented SiFe alloys), which are used in rotating machinery and generators for efficient power generation and in transformers for low-loss electrical energy conversion. While the relevant metrological parameters are for example discussed in DIN EN 10107 [3], magneto-optical testing allows the magnetic and loss properties to be related to the underlying grain and domain structure.

This document closes the length scale gap for magnetic field measurements by establishing a quantitative magneto-optical indicator film measurement technique (qMOIF) for magnetic field distribution. qMOIF is a fast (sub second resolution) imaging technique, that allows a one-shot characterization of samples with areas of several square centimetres and with a resolution down to the micrometre range. It can be used under room temperature conditions and for direct sample testing without the need for costly and time-consuming surface treatments. qMOIF allows a near-field testing of the distribution of the stray magnetic field directly at the specimen surface. However, without magnetic and geometric calibration as well as proper adjustment of the setup geometry, qMOIF merely delivers qualitative stray field images. This results from the fact that the measured signal depends on the properties of magneto-optical indicator film used as well as on the setup geometry and the detector.

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[1] Numbers in square brackets refer to the Bibliography.

MOIF imaging can be used in two basic operation modes that enable feature analysis and the characterization of quantitative stray field distributions, respectively.

a) The first mode, the “geometrical feature detection mode”, allows the characterization of the density and characteristic dimension of certain magnetic features on the basis of a magneto-optical image. The contrast is adjusted to give maximum contrast of certain features compared to the background. It is for example used for a dichotomization of the surface into areas with two distinct characteristics, like up and down magnetized domains. This mode is, for example, used for a quantitative characterization of domain widths and areal percentage.
b) The second mode, the “quantitative stray field distribution analysis mode”, allows one to perform a spatially resolved analysis of the stray field distribution above the surface of a sample. This demands a magnetic calibration that includes the characterization of the sensor and the setup. Thereby quantitative values of key control characteristics (KCCs) like magnetic field amplitudes are made accessible and ultimately become traceable to national calibration standards.

This document aims at providing a description of the measurement approaches for both above defined modes. This includes the adjustment of the setup and the traceable calibration and thus feature analysis as well as traceably calibrated field distribution measurements.

In summary, this document provides a traceable method for spatially resolved and quantitative micrometre-resolution measurements of magnetic field patterns with centimetre image sizes which can be applied to technologically relevant materials with flat surfaces. Thereby, it will further advance the precise control of fabrication processes and final product qualification. The values of the key control characteristics for those products are very product specific (see, for example, IEC TS 62622:2012 [4]).

NANOMANUFACTURING –
KEY CONTROL CHARACTERISTICS –

Part 9-2: Nanomagnetic products – Magnetic field distribution: Magneto-optical indicator film technique

1 Scope

This part of IEC 62607 establishes a standardized method to determine the key control characteristic

- magnetic field distribution

of nanomagnetic materials, structures and devices by the

- magneto-optical indicator film technique.

The magnetic field distribution is derived by utilizing a magneto optical indicator film, which is a thin film of magneto-optic material that is placed on the surface of an object exhibiting a spatially varying magnetic field distribution. The Faraday effect is then employed to measure the magnetic field strength by analysing the rotation of the polarization plane of light passing through the magneto-optic film.

– The method is applicable for measuring the stray field distribution of flat nanomagnetic materials, structures and devices.
– The method can especially be used to perform fast quantitative measurements of stray field distributions at the surface of an object.
– The magneto-optic indicator film technique is a fast, non-destructive method, making it an attractive option for materials analysis and testing in the industry.

– MOIF measurements can be done without any sample preparation and do not rely on specific surface properties of the object. It can be applied to the characterization of rough samples as well as of samples with non-magnetic cover layers.
– MOIF can quantitatively measure magnetic field distributions.
  - with a one-shot measurement which typically takes a few seconds
  - over areas of several square centimetres (over diameters of up to 15 cm with special techniques)
  - in a field range from 1 mT to more than 100 mT
  - with down to 1 µm spatial resolution
– Although techniques with nano-scale resolution are suitable for analysing the details of magnetic field structure, their ability to characterize larger areas is limited by their scanning area. Therefore, the MOIF technique is an indispensable complementary method that can offer a more comprehensive understanding of material properties.

This document focuses on the calibration procedures, calibrated measurement process, and evaluation of measurement uncertainty to ensure the traceability of quantitative magnetic field measurements obtained through the magneto-optic indicator film technique.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1 General terms

3.1.1
key control characteristic
KCC
key performance indicator
measurement process characteristic which can affect compliance with regulations and quality, reliability or subsequent application of the measurement result

Note 1 to entry: The measurement of a key control characteristic is described in a standardized measurement procedure with known accuracy and precision.

Note 2 to entry: It is possible to define more than one measurement method for a key control characteristic, if the correlation of the results is well-defined and known.

Note 3 to entry: In IATF 16949 the term "special characteristic" is used for a KCC. The term key control characteristic is preferred since it signals directly the relevance of the parameter for the quality of the final product.

3.2 General terms related to magnetic stray field characterization

3.2.1
magnetic-force microscopy
MFM
atomic force microscopy mode employing a probe assembly that monitors both atomic forces and magnetic interactions between the probe tip and a surface

[SOURCE: ISO 18115-2:2021, 3.1.15]

3.2.2
magneto-optical indicator film technique
MOIF technique
method of mapping the magnetic field above a sample surface by a thin magneto-optical Faraday-active indicator film

Note 1 to entry: The magnetic fields induce a declination of the magnetization from equilibrium direction in the active layer of the sensor, which is recorded with the Faraday effect.

3.3 Terms related to the measurement method described in this document

3.3.1
MOIF raw data distribution
$S(Nx, Ny)$, $S(x,y)$
pixel position, $S(Nx, Ny)$, for array sensors in wide field microscopes, or spatially resolved, $S(x,y)$, for sample scanning measurements in confocal microscopes, detector signal data array of a MOIF measurement

Note 1 to entry: The signal data type depends on the applied analysis technique. For direct MOIF measurements, raw data depict sensor dependent converted intensity distribution data in appropriate units. For differential, lock-in based MOIF measurements, raw data depict lock-in amplitudes in units of volt.