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Nanomanufacturing – Key control characteristics –
Part 9-1: Traceable spatially resolved nano-scale stray magnetic field measurements – Magnetic force microscopy

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NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 9-1: Traceable spatially resolved nano-scale stray magnetic field measurements – Magnetic force microscopy

FOREWORD

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IEC TS 62607-9-1 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
113/584/DTS	113/606/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/standardsdev/publications.

A list of all parts of the IEC TS 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- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

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

However, many important industrial applications such as magneto-resistive position, angle, or motion control rely on precision sensing of spatially varying magnetic fields. Such spatially varying magnetic fields can, for example, be generated by a magnetic bit pattern of a magnetic encoder scale. Today, magnetic encoder bit patterns have typically a lateral periodicity above 100 µm. Based on stray field interpolation, such encoders are applied, for example, for precision positioning systems with sub-micrometre resolution. However, such precision positioning requires reliable local field measurements which are not yet underpinned by any suitable standards.

Today, local magnetic stray field measurements with resolutions from above 50 µm down to below 500 nm can be realized by scanning magnetic field detection (SMF) methods with different field sensors such as Hall sensors, magneto-resistive (MR) sensors and magnetically coated tips on an oscillating cantilever (magnetic force microscopy (MFM)), or with imaging techniques like Kerr and magneto-optical indicator film (MOIF) microscopy. Achievable spatial resolution and typical scanning area are compared in Figure 1.

MFM provides a significantly higher resolution than other SMF techniques and MOIF (see Figure 1) and can therefore be considered as the standard tool for nano-scale investigations of the local magnetic properties of magnetic nanostructures, thin films and devices [1][1]. However, despite its wide use, MFM measurements per se only deliver purely qualitative stray field images that cannot be applied for quantitative data analysis. This results from the fact that the measured signal strongly depends on the properties of the magnetic tip, the mechanical properties of the cantilever and the sensitivity of the detection device. Hence a calibration that includes the characterization of the magnetic tip and the microscope is needed if the MFM method is to be used to provide values of key control characteristics (KCCs) which are ultimately traceable to national calibration standards.

This document aims to provide industry end users, instrument manufactures and calibration laboratories with a description of traceable calibration procedures based on reference materials with well-defined local stray field distributions. This document includes the description of suitable reference samples, the evaluation of MFM key parameters required for the method, and the determination of the instrument calibration function (ICF). Due to the finite dimension of the tip, a spatial broadening of the MFM signal is unavoidable. Mathematically this broadening can be described by the convolution of the ICF and the real magnetic field structure of the sample to be measured. Vice versa, a quantitative analysis of the measured data is achieved by a deconvolution of the MFM measurement data using the ICF. The description of this process is the key part of this document.

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

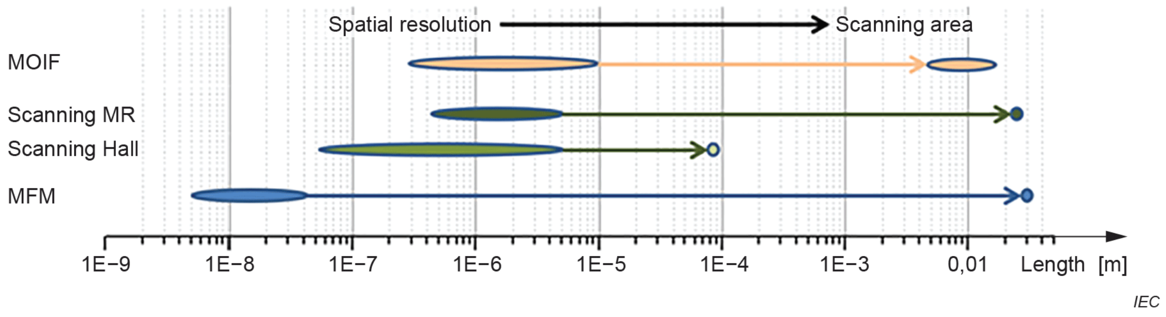

Figure 1 – Spatial resolution of magnetic stray field characterization techniques and their possible maximum scan area

The MFM technique as described in this document has a resolution down to about 10 nm to 20 nm (depending on the signal-to-noise ratio of the instrument), which is at least one order of magnitude superior to other common characterization techniques for spatially varying magnetic fields. MFM systems operated at ambient conditions typically can achieve a resolution of around 50 nm [1]. With optimized tips, a resolution down to below 20 nm is possible [2]. The highest resolution in MFM is achieved in vacuum. With very precise tip–sample distance control [3] and high-resolution tips [4], a resolution down to 10 nm could be demonstrated.

While the MFM technique has the best precision and accuracy of the test methods (see Figure 1), as a scanning technique it is comparatively slow, requires specific ambient conditions such as stable temperatures and can only be used for samples which are flat and smooth on a micrometre scale (depending on the scanning unit). For routine statistical process control (SPC) of the manufacturing process, it may not be suitable in many use cases. Therefore, it is anticipated that the MFM technique needs to be complemented, for example, by:

- the magneto-optical indicator film technique (MOIF), which, as an imaging process, allows high throughput;
- scanning Hall or MR test methods, which can easily be calibrated in homogeneous external fields. In CMOS technique, arrays of parallel Hall sensors can be prepared and thus a high throughput can be achieved in a scanning process.

Wherever possible, existing relevant scanning probe microscopy (SPM) standards are referred to, especially those developed by ISO/TC 201 like ISO 18115-2 [5] and ISO 11952 [6].

In summary, this document provides a traceable method for nanometre-resolution measurements of magnetic field patterns, which is the basis for precise control of fabrication processes and final product qualification. The key control characteristics for those products are very product specific (see, for example, IEC TS 62622:2012 [7]).

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 9-1: Traceable spatially resolved nano-scale stray magnetic field measurements – Magnetic force microscopy

1 Scope

This part of IEC 62607 establishes a standardized method to characterize spatially varying magnetic fields with a spatial resolution down to 10 nm for flat magnetic specimens by magnetic force microscopy (MFM). MFM primarily detects the stray field component perpendicular to the sample surface. The resolution is achieved by the calibration of the MFM tip using magnetically nanostructured reference materials.

The objective of this document is to define and describe:

- reference materials for traceable high resolution magnetic stray field measurements;
- the calibration procedures to determine the instrument calibration function (ICF) and, if required, MFM key parameters entering the deconvolution process;
- the deconvolution process which allows to calculate quantitative stray field data from the measured MFM data using the ICF;
- the evaluation of the measurement uncertainty, including the prevention of potential artefacts which can occur during the measurement leading to a misinterpretation of the results.

2 Normative references

There are no normative references in this document.