PD IEC/TR 62797:2013

BSI Standards Publication

International comparison of measurements of the magnetic moment using vibrating sample magnetometers (VSM) and superconducting quantum interference device (SQUID) magnetometers

bsi.

...making excellence a habit.™

National foreword

This Published Document is the UK implementation of IEC/TR 62797:2013.

The UK participation in its preparation was entrusted to Technical Committee ISE/108, Magnetic Alloys and Steels.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2013

ISBN 978 0 580 79772 9
ICS 29.030

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2013.

Amendments/corrigenda issued since publication

Date	Text affected

IEC/TR 62797

Edition 1.0 2013-08

TECHNICAL REPORT

colour inside

International comparison of measurements of the magnetic moment using vibrating sample magnetometers (VSM) and superconducting quantum interference device (SQUID) magnetometers

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRICE CODE V

ICS 29.030

ISBN 978-2-8322-1018-5

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

INTERNATIONAL COMPARISON OF MEASUREMENTS OF THE MAGNETIC MOMENT USING VIBRATING SAMPLE MAGNETOMETERS (VSM) AND SUPERCONDUCTING QUANTUM INTERFERENCE DEVICE (SQUID) MAGNETOMETERS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 62797, which is a technical report, has been prepared by IEC technical committee 68: Magnetic alloys and steels.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
68/448/DTR	68/454/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Following a proposal made at the meeting of IEC TC 68 Working Group 2 (Magnetic alloys and steels – Measuring methods) in Braunschweig (PTB, 13-14 November 2006), an intercomparison exercise was started regarding the measurement of the magnetic moment by means of the vibrating sample magnetometer (VSM) method. The VSM finds widespread use in industrial and research laboratories, because of its sensitivity, ruggedness, and relative simplicity of use [1][1]. It is not an absolute method and requires calibration by means of a reference sample. This is typically represented by a very pure Ni sphere, calibrated by means of an independent method [2]. The VSM is generally applied for the characterization of hard magnetic materials, but, depending on the specific sensitivity of the apparatus, can also be used to test paramagnetic and diamagnetic materials. Its application to magnetically soft materials is generally restricted to the determination of the saturation magnetization. In fact, being an open circuit method, the VSM is not suited to the measurement of the magnetization curve of soft magnetic materials.

The basic aim of this comparison is to verify the degree of reproducibility of the method, a prerequisite for the prospective development of a related IEC measuring standard. The existing ASTM Standard A894/894M-00 [3] is devoted to the determination of the saturation magnetization of nonmetallic magnetic materials. Ten different research laboratories, listed in Annex B, agreed to participate in the comparison exercise. Each laboratory was assumed to have appropriate traceability of measurements and was required to determine the measurement uncertainty according to the ISO/IEC Guide to the expression of uncertainty in measurement [4]. Two laboratories used superconducting quantum interference device (SQUID) magnetometers.

The comparison was coordinated by INRIM (Istituto Nazionale di Ricerca Metrologica, Torino, Italy) and the Hannam University (Taejon, Korea). A summarizing paper on these experiments was presented at the International Workshop on One- and Two-Dimensional Measurement and Testing (Vienna, September 2012) and is to be published on the Int. J. Appl. Electromagnetics and Mechanics [8].

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

INTERNATIONAL COMPARISON OF MEASUREMENTS OF THE MAGNETIC MOMENT USING VIBRATING SAMPLE MAGNETOMETERS (VSM) AND SUPERCONDUCTING QUANTUM INTERFERENCE DEVICE (SQUID) MAGNETOMETERS

1 Scope

This Technical Report provides the results of an international comparison of measurements of the magnetic moment, using vibrating sample magnetometers (VSM) and superconducting quantum interference device (SQUID) magnetometers.

The basic object of this comparison is to verify the degree of reproducibility of the method employed as a prerequisite for the prospective development of a related IEC measuring standard.

2 Overview

In this report an intercomparison exercise on the measurement of the magnetic moment by means of the vibrating sample magnetometer (VSM) and superconducting quantum interference device (SQUID) magnetometer is presented. The VSM finds widespread use in industrial and research laboratories, because of its sensitivity, ruggedness, and relative simplicity of use. The basic aim of this comparison was to verify the degree of reproducibility of the VSM method, as a prerequisite for the prospective development of a related IEC measuring standard. At present time, the VSM method is invoked in the ASTM Standard A984, which is devoted, however, exclusively to the determination of the saturation magnetization of nonmetallic magnetic materials. An exercise was carried out by ten different laboratories regarding the measurement of the hysteresis loop parameters in hard ferrites and the magnetic moment in tape samples by means of the VSM (SI units). Each laboratory was assumed to have appropriate traceability of measurements and was required to determine the measurement uncertainty according to the ISO/IEC Guide to the expression of uncertainty in measurement. The comparison was coordinated by INRIM. The results were analyzed according to standard rules (e.g. ISO and EURAMET guidelines).

The following relative standard deviations of the laboratories best estimates around the unweighted mean were found:

a) Anisotropic hard ferrites: coercive field H_{cJ} ~ 1,0 %; coercive field H_{cB} ~ 0,9 %; polarization at applied field H_a ~ 800 kA/m J_{800k} ~ 0,80 %; remanent polarization J_r ~ 1,8 %; maximum energy product $(BH)_{max}$ ~ 1,2 %.

b) Isotropic hard ferrites: coercive field H_{cJ} ~ 1,0 %; coercive field H_{cB} ~ 3,5 %; polarization at applied field H_a = 800 kA/m J_{800k} ~ 1,2 %; remanent polarization J_r ~ 3,2 %; maximum energy product $(BH)_{max}$ ~ 6,2 %.

c) Magnetic tape samples: magnetic moment at H_a = 400 kA/m m_{400k} ~ 1,8 % - 2,8 %; remanent magnetic moment m_r ~ 1,3 % - 1,6 %; squareness S ~ 2,0 %; coercive field H_{cJ} ~ 1,1 % - 2,2 %.

3 Samples

3.1 Hard ferrites

Two different types of hard ferrite spherical samples (isotropic and anisotropic) were prepared at INRIM by grinding commercial sintered ferrite specimens. Two samples for each type were circulated.

- Isotropic hard ferrite spherical sample. Label: HF_iso1. Mass m = 74,50 mg. Density δ = 4 950 kg/m^3. Volume V = 15,05 mm^3.
- Isotropic hard ferrite spherical sample. Label: HF_iso2. Mass m = 77,15 mg. Density δ = 4 950 kg/m^3. Volume V = 15,59 mm^3.
- Anisotropic hard ferrite spherical sample. Label: HF_anis1. Mass m = 73,33 mg. Density δ = 4 870 kg/m^3. Volume V = 15,06 mm^3.
- Anisotropic hard ferrite spherical sample. Label: HF_anis2. Mass m = 73,31 mg. Density δ = 4 870 kg/m^3. Volume V = 15,06 mm^3.

The circulation of the samples started with measurements made at INRIM. After completion of the measurements by all the other laboratories, INRIM measured the sample mass again and repeated the magnetic measurements. A slight decrease of the mass, which ranged from 0,2 % to 0,3% in all samples, was eventually found. No attempt was made, however, to correct for this loss of mass, which presumably took place gradually along the exercise. Its effect has been assumed to be incorporated in the overall measuring uncertainty.

3.2 Magnetic tapes

Disk samples were cut from two different types of magnetic tape at Hannam University and dispatched to INRIM before starting the circulation. Two samples for each type were tested.

- Tape 1A. Mass m = 1,258 mg. Diameter d = 3 mm.
- Tape 1B. Mass m = 1,248 mg. Diameter d = 3 mm.
- Tape 2A. Mass m = 1,246 mg. Diameter d = 3 mm.
- Tape 2B. Mass m = 1,205 mg. Diameter d = 3 mm.

Again, INRIM tested the samples at the beginning and at the end of the exercise. It was found that Tape 1B and Tape 2B samples were damaged. The measurements concerning Tape 1A and Tape 2A only were therefore retained for analysis.

4 Measuring quantities and measuring conditions

4.1 General

A demagnetization procedure before starting the measurements was recommended. The suggested maximum peak value of the magnetic field strength to be progressively and cyclically decreased, was $H_{a,peak,max} \geq 800$ kA/m.

4.2 Hard ferrite spheres

Before starting the measurement, the demagnetized spherical samples were oriented with their macroscopic easy axis aligned with the applied field direction. A simple way to achieve alignment is to let the sample free to orient itself in a weak field. Fine adjustments may possibly be done on site by looking for maximum VSM response. Notice that the nominally isotropic sample is endowed with slight macroscopic anisotropy. Previous experiments showed that a $\pm$ 5° misalignment in anisotropic samples can lead to a decrease of the measured remanence around 1 %. A similar decrease occurs in the typical isotropic ferrites for a misalignment as high as 30° - 40°. The measurement in this material is therefore negligibly affected by imperfect orientation of the easy axis along the applied field direction.

The applied field was then increased up to $H_{a,peak}$ = 800 kA/m and the return magnetization curve was recorded, after correction for the demagnetizing effect. The effective field was obtained as $H = H_a - \frac{N_d}{\mu_0} J$, with H_a the applied field, J the magnetic polarization, μ_0 = $4\pi \cdot 10^{-7}$ Vs/Am, and the demagnetizing coefficient, under the assumption of a perfectly spherical sample, N_d = 1/3. The following quantities were measured:

- Magnetic polarization J_{800k} at H_a = $H_{a,peak}$ = 800 kA/m;
- Remanent polarization J_r for H = 0;
- Coercive fields H_{cB} and H_{cJ};
- Maximum energy product $(BH)_{max}$.

4.3 Magnetic tape samples

Before starting the measurement, the demagnetized disk-shaped samples were oriented with their macroscopic easy axis aligned with the applied field direction. A faint mark on the disk surface indicated the easy axis. The applied field was increased up to $H_{a,peak}$ = 400 kA/m and subsequently decreased down to the symmetric value $-H_{a,peak}$ = -400 kA/m. No correction for the demagnetizing field was made.

The following quantities were determined:

- Magnetic moment m_{400k} for H_a = $H_{a,peak}$ = 400 kA/m;
- Remanent moment m_r for H_a = 0;
- Squareness $S = m_r / m_{400k}$;
- Coercive field H_{cJ}.

While the intercomparison was specifically directed at evaluating the reproducibility of the VSM method, two of the laboratories (PTB and NPL) performed their measurements by means of a SQUID magnetometer. SI units were used all along the experiments.

4.4 Role of the measuring temperature

The prescribed measuring temperature was 23 °C ± 1 °C. This temperature refers to the region occupied by the sample and the sensing coils, which, due to possible heating of the electromagnet, may be slightly different from the room temperature.

INRIM performed specific measurements by changing the sample temperature between 19 °C and 26 °C, in order to determine the temperature coefficient of the measured quantities. Laboratories making the measurements at temperatures different from 23 °C could correct their results according to value and sign of these coefficients.

1) Isotropic and anisotropic hard-ferrites (HF_iso1, HF_iso2, HF_anis1, HF_anis2).

   a) Coercive field H_{cJ} $\quad \alpha_{hcJ} = \frac{1}{H_{cJ}} \cdot \frac{dH_{cJ}}{dT} = +0{,}2\ \%/C^o$

   b) Coercive field H_{cB} $\quad \alpha_{hcB} = \frac{1}{H_{cB}} \cdot \frac{dH_{cB}}{dT} = +5 \cdot 10^{-2}\ \%/C^o$

   c) Remanence and peak polarization values J $\quad \alpha_J = \frac{1}{J} \cdot \frac{dJ}{dT} = -0{,}12\ \%/C^o$

2) Magnetic tapes (1A, 1B, 2A, 2B)

   a) Coercive field H_c $\quad \alpha_{hc} = \frac{1}{H_c} \cdot \frac{dH_c}{dT} = -8 \cdot 10^{-2}\ \%/C^o$

b) Magnetic moment *m*

$$\alpha_{\mathrm{m}} = \frac{1}{m} \cdot \frac{dm}{dT} = -0{,}2\ \%/C^{o}$$

5 Analysis of the measured quantities

The figures provided by the participating laboratories were collected and analyzed according to standard rules [4]. For each measured quantity y_i and each sample, two types of reference values were determined. The first is the unweighted mean value $< y >= \sum_{i=1}^{N} y_i / N$ of the *N* laboratories best estimates. The second is the weighted mean value $\bar{\bar{y}}$, which is generally preferred when dealing with a range of individual measuring uncertainties, as is usually the case with intercomparisons. It is defined as

$$\bar{\bar{y}} = \frac{\sum_{i=1}^{N} \frac{y_i}{u_c^2(y_i)}}{\sum_{i=1}^{N} \frac{1}{u_c^2(y_i)}} \tag{1}$$

where $u_c^2(y_i)$ is the combined (*1σ*) variance of the i-th best estimate. The weighted variance is in turn given by the equation

$$\frac{1}{u_c^2(\bar{\bar{y}})} = \sum_{i=1}^{N} \frac{1}{u_c^2(y_i)} \tag{2}$$

One important point in analyzing and comparing the results from different sources regards the identification of outliers, which could lead to invalid conclusions regarding the reference values and the related uncertainty. An objective rule can be devised for their identification, which consists in calculating the normalized error

$$E_{\mathrm{ni}} = \frac{\left| y_{\mathrm{i}} - y_{\mathrm{ref}} \right|}{\sqrt{U_{\mathrm{i}}^2 + U_{\mathrm{ref}}^2}} \tag{3}$$

where $y_{\mathrm{ref}} \equiv \bar{\bar{y}}$, $U_{\mathrm{i}} = k u_{\mathrm{ci}}$ is the expanded uncertainty of the individual best estimate (with *k* the coverage factor), and U_{ref} is the expanded weighted uncertainty. When the dispersion of the individual estimates is in a correct relationship with the correspondingly provided uncertainties, it is expected that $E_{\mathrm{ni}} < 1$ [5]. We have loosely applied this rule to the present collection of data, by discarding those individual estimates for which $E_{\mathrm{ni}} > 2$.

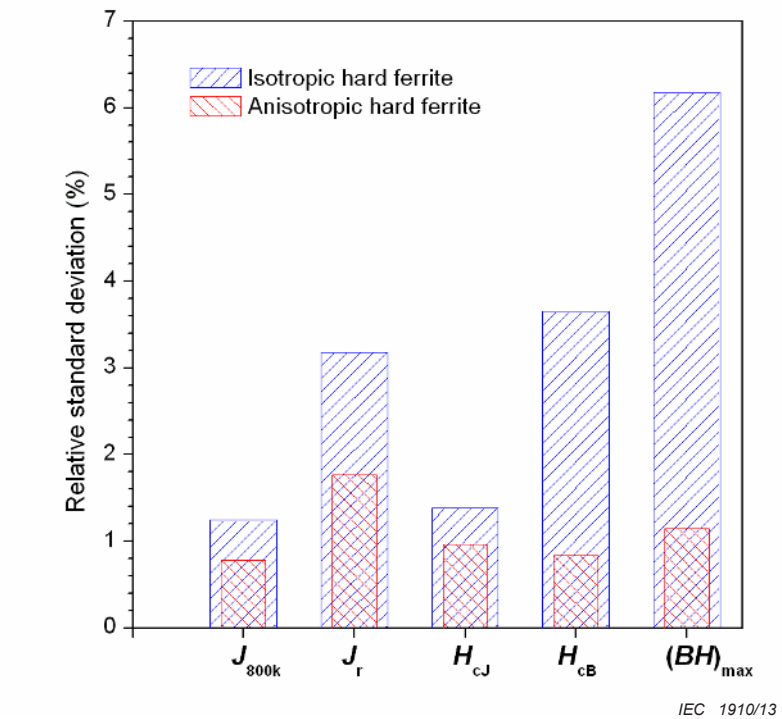
The detailed analysis of the above-mentioned quantities measured in the isotropic and anisotropic hard ferrites and in the magnetic tape samples is provided in Annex A. For each quantity, the following data are given:

a) The individual laboratories best estimates y_i and the related combined uncertainties u_{ci};
b) The unweighted mean <*y*> and the standard deviation of the individual values around it $s(y_i)$;
c) The weighted mean y_{ref} and the expanded weighted uncertainty (confidence interval) $U(y_{\mathrm{ref}}.))$.

Figures 1 and 2 summarize the dispersion of the laboratories best estimates around <*y*> in the different materials. It is noted that the measurements on anisotropic ferrites show the best

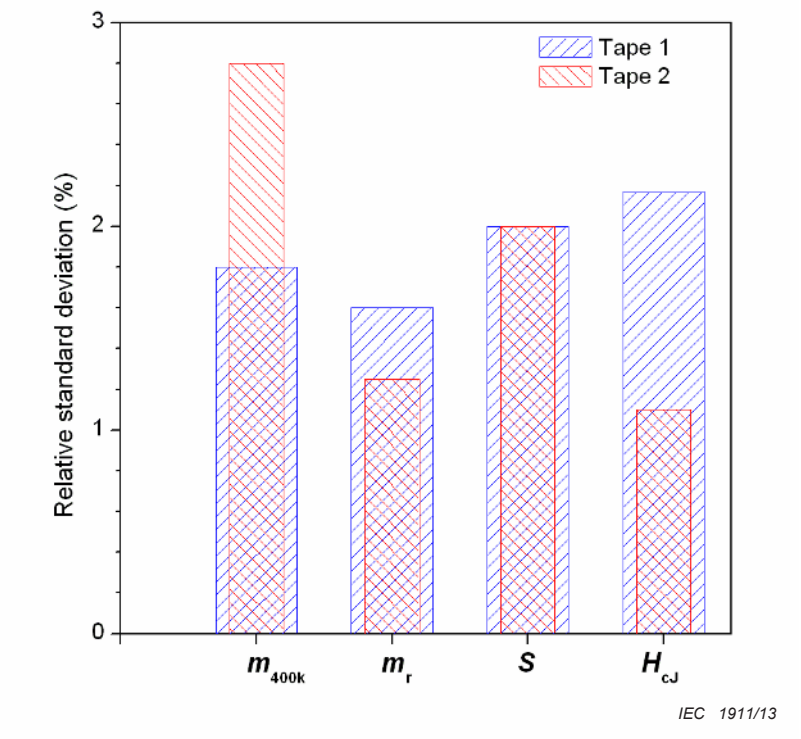
reproducibility. The standard deviation of coercive field H_{cJ} and polarization J_{800} is slightly larger than 1 % in both isotropic and anisotropic ferrites. The dispersion of the measured energy product values $(BH)_{max}$ is substantial (around 6 %) in isotropic ferrites, much larger than in the anisotropic counterpart. The quantities measured in the magnetic tapes show a standard deviation oscillating around 2 %. Comparing the behaviour of the return curves in anisotropic and isotropic materials, it is understood that the smoother shape of the latter is conducive to greater uncertainty in the determination of H_{cB}, J_r, and $(BH)_{max}$. Figures 3 and 4 provide the expanded weighted uncertainty $U(y_{ref})$ for the reference value y_{ref} of the different measured quantities. It is recalled here that the true value of the measured quantity is expected to lie in the interval $y = y_{ref} \pm U(y_{ref})$ with a confidence level $p \sim 95$ %.

It is interesting to recall the conclusions of a similar exercise carried out in the nineties [7], where the comparison, involving 12 laboratories, regarded both the closed magnetic circuit method (IEC 60404-5 [9]) and the VSM method. Anisotropic Nd-Fe-B magnet specimens were tested. The standard deviation around the unweighted mean was found to be 4,7 % for H_{cJ} and 3,6 % for $(BH)_{max}$ using the closed circuit method. With the VSM open circuit method these quantities became 3,6 % and 2,3 %, respectively. As sketched in Figure 5, the dispersion of the present experiments on the ferrite anisotropic samples favourably compares with these results. It is fair to say that reproducibility of results could be affected to some extent by the very high coercivity of the extra-hard rare-earth magnets.



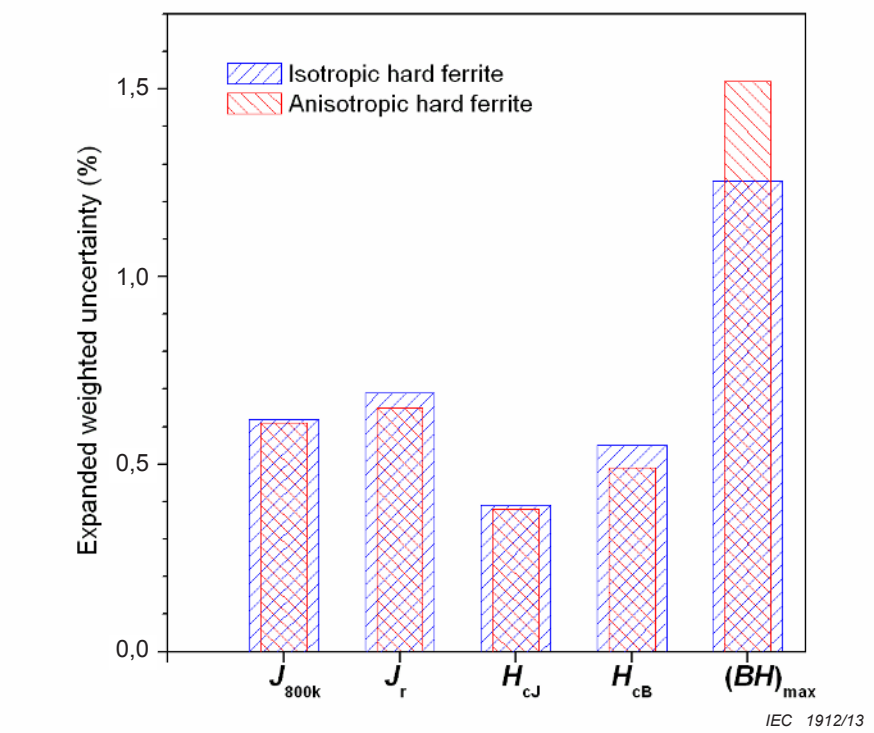
Relative standard deviation of the laboratories best estimates of the magnetic polarization J_{800k} at 800 kA/m, remanent polarization J_r, coercive fields H_{cJ} and H_{cB}, and maximum energy product $(BH)_{max}$ around their unweighted mean.

Figure 1 – Isotropic and anisotropic ferrites: standard deviations



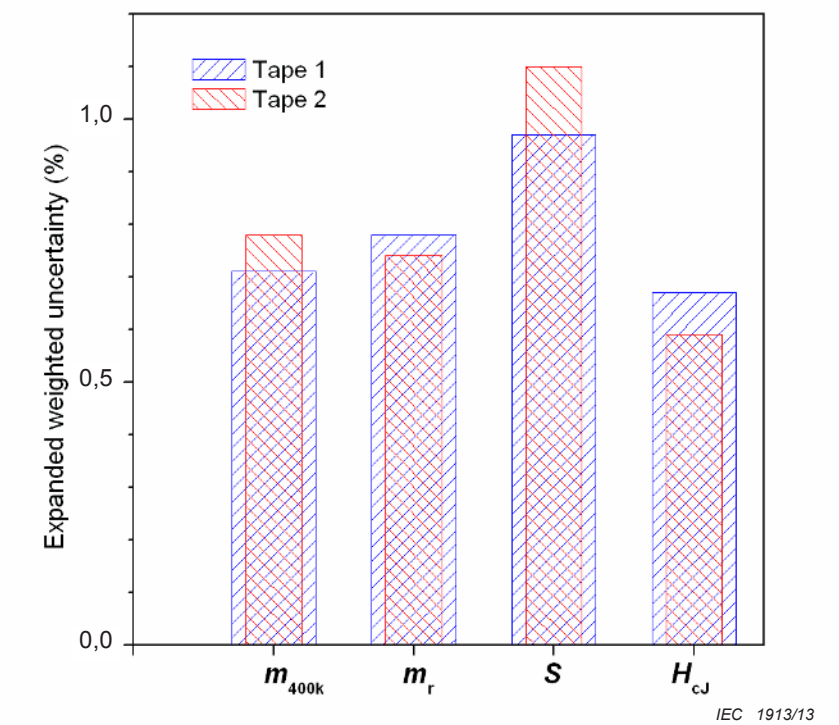
Relative standard deviation of the laboratories best estimates of the sample magnetic moment at 400 kA/m m_{400k}, remanent moment m_r, squareness ratio $S = m_r/m_{400k}$, and coercive field H_{cJ} around their unweighted mean.

Figure 2 – Magnetic tape samples: standard deviations



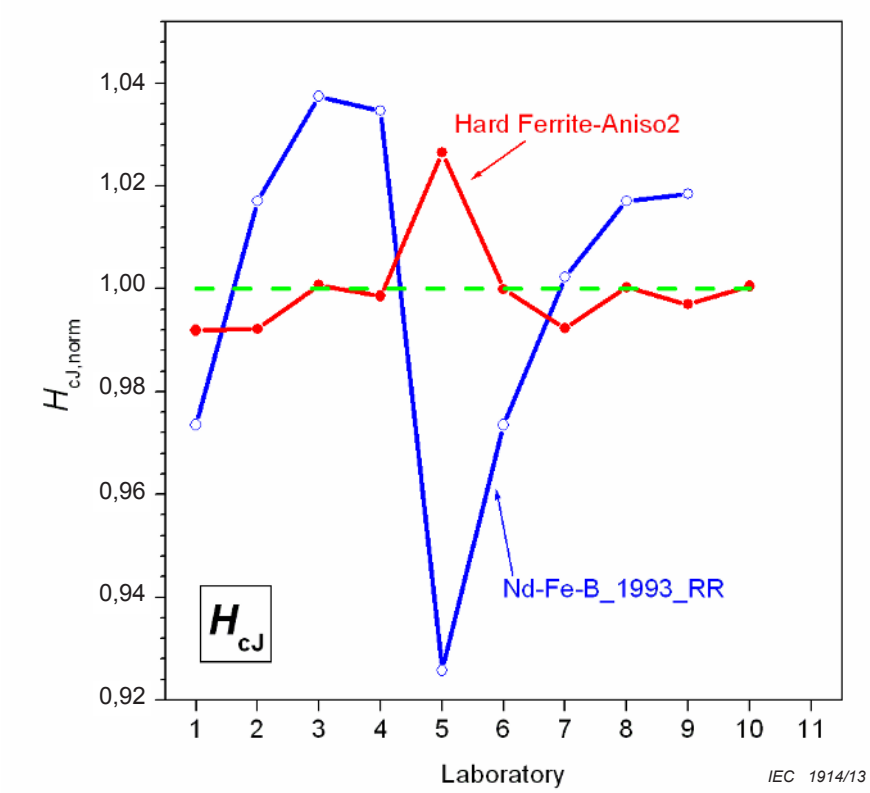
Relative expanded weighted uncertainty $U(y_{ref})$ for the polarization J_{800k}, remanent polarization J_r, coercive field strengths H_{cJ} and H_{cB}, and maximum energy product $(BH)_{max}$. The true value of the measured quantity is expected to lie in the interval $y = y_{ref} \pm U(y_{ref})$ with a confidence level $p \sim 95$ %.

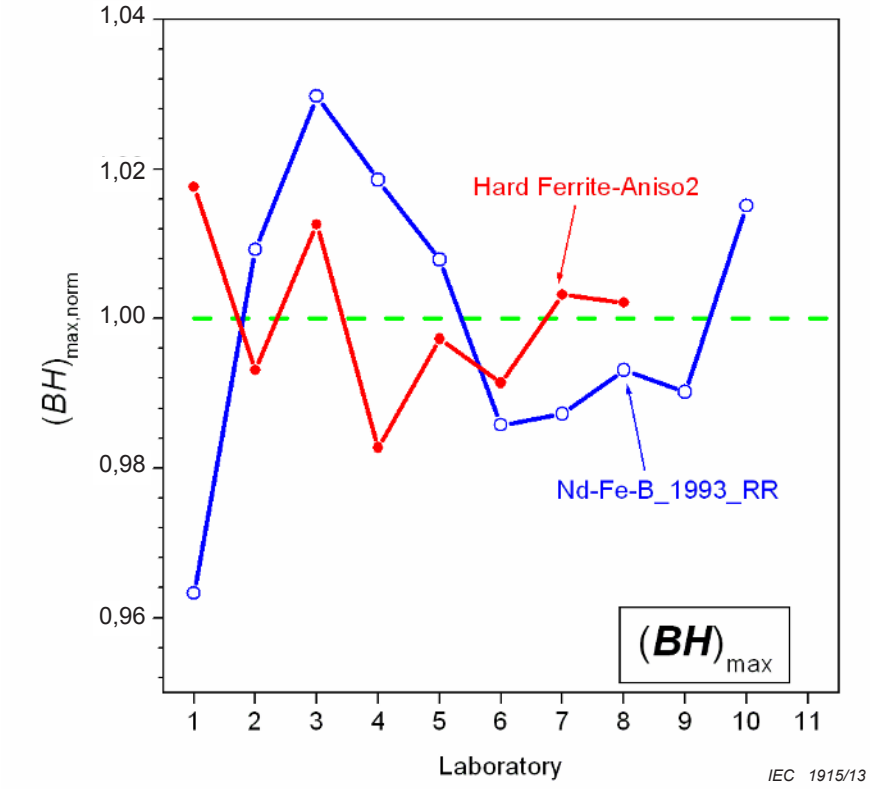
Figure 3 – Isotropic and anisotropic ferrites: weighted uncertainties



Relative expanded weighted uncertainty $U(y_{ref})$ for the sample magnetic moment m_{400k}, remanent moment m_r, squareness ratio $S = m_r/m_{400k}$, and coercive field strength H_{cJ}. The true value of the measured quantity is expected to lie in the interval $y = y_{ref} \pm U(y_{ref})$ with a confidence level $p \sim 95$ %.

Figure 4 – Magnetic tape samples: weighted uncertainties





Normalized best values $y_i / < y >$ of the coercive field strength H_{cJ} and maximum energy product $(BH)_{max}$ obtained by the participating laboratories in the present exercise (anisotropic hard ferrite sample) and in a previous VSM comparison [6] regarding anisotropic Nd-Fe-B samples.

Figure 5 – Normalized best values $y_i / < y >$ of the coercive field strength H_{cJ} and maximum energy product $(BH)_{max}$

Annex A
(informative)

International comparison of measurements of the magnetic moment using vibrating sample magnetometers and SQUID magnetometers

A.1 General

Material 1: Isotropic hard ferrite, anisotropic hard ferrite.

Measured quantities: J_{800k}, $J_{r,}$ H_{cJ}, H_{cB}. $(BH)_{max}$

Material 2: Magnetic tape (two types).

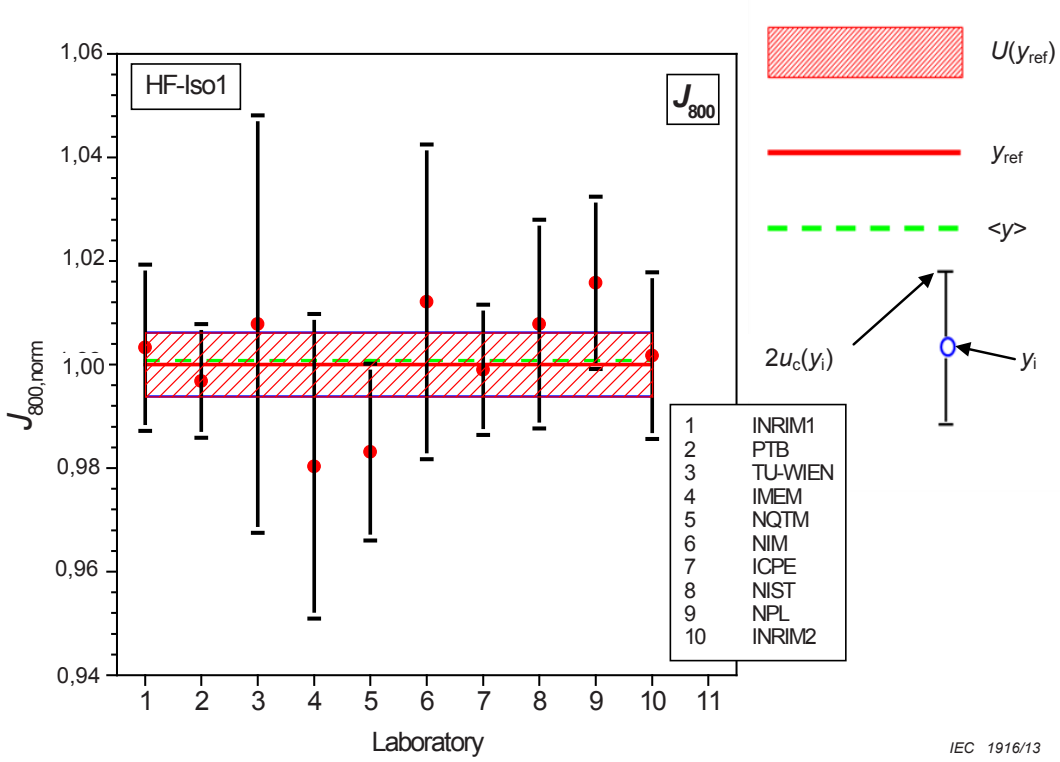
Measured quantities: m_{400k}, m_r, S, H_{cJ}

This annex provides in detail a few significant results regarding the measurements carried out by the participating laboratories in the isotropic and anisotropic hard ferrites and the magnetic tapes. It is an abridged version of a full length annex, reporting the complete statistical analysis of the measurements. Such a document was made available as a WG2 Document N210B at the TC 68 Working Group 2 Meeting, Ghent, 27/09/2011.

A.2 Isotropic hard ferrite

Table A.1 – Magnetic polarization value J_{800k} at $H_a = H_{peak}$ = 800 kA/m measured by the participating laboratories on the isotropic hard ferrite HF-Iso1

Isotropic hard ferrite Iso-1		
	J_{800k} (T)	combined uncertainty u_{ci} (%)
INRIM1	0,3285	0,8
PTB	0,3264	0,55
TU-WIEN	0,330	2,0
IMEM	0,321	1,5
NQTM	0,3219	0,87
NIM	0,3314	1,5
ICPE-CA	0,3271	0,63
NIST	0,33	1,0
NPL	0,3326	0,82
INRIM2	0,328	0,8
Unweighted average $<J_{800k}>$ = 0,3277 T		
Standard deviation $s(J_{800k})$ = 1,16 %		
Weighted average $J_{800k,ref}$ = 0,3274 T		
Expanded weighted uncertainty $U(J_{800k,ref})$ = 0,62 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

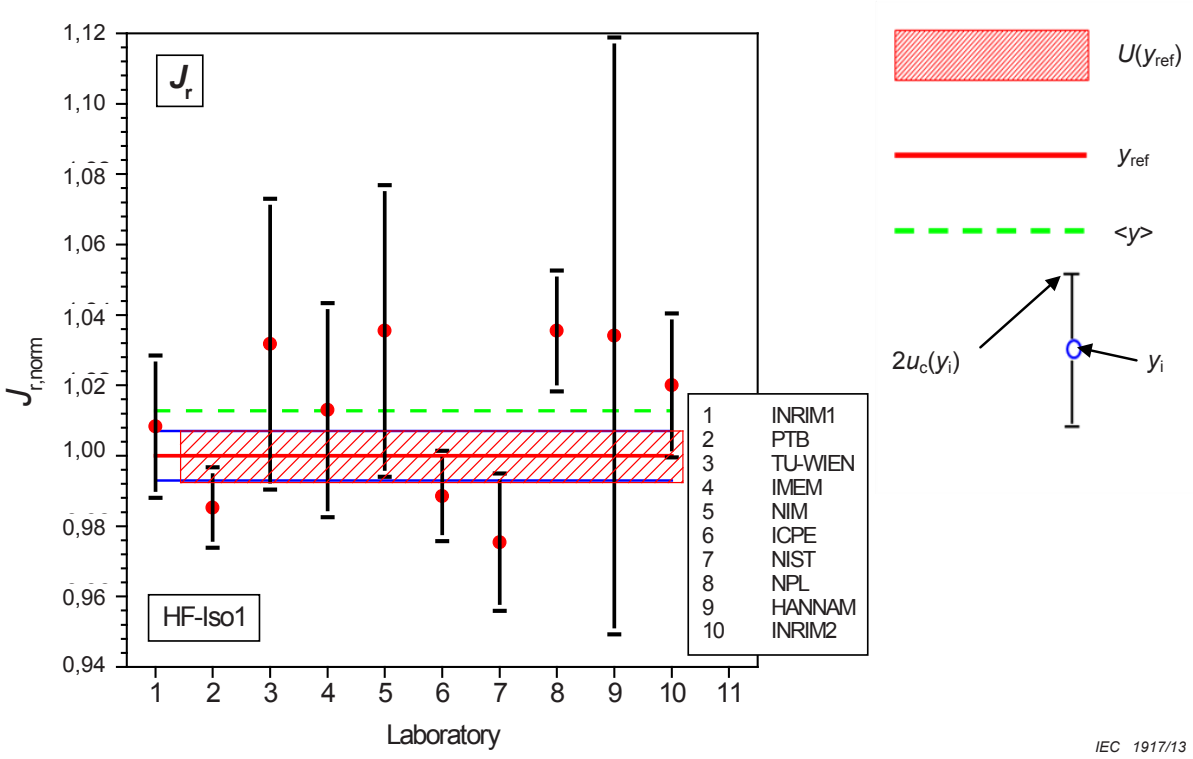
<y> unweighted average

These J_{800k} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.1 – Dispersion of the J_{800k} values measured by the participating laboratories on the isotropic ferrite sample HF-Iso1

Table A.2 – Remanent magnetic polarization J_r measured by the participating laboratories on the isotropic hard ferrite HF-Iso1

Isotropic hard ferrite Iso-1		
	J_r (T)	combined uncertainty u_{ci} (%)
INRIM1	0,215	1,0
PTB	0,2101	0.58
TU-WIEN	0,22	2,0
IMEM	0,216	1,5
NIM	0,2208	2,0
ICPE-CA	0,2108	0,65
NIST	0,208	1,0
NPL	0,2208	0,83
HANNAM	0,2205	4,1
INRIM2	0,2175	1,0
Unweighted average $<J_r>$ = 0,216 T		
Standard deviation $s(J_r)$ = 2,24 %		
Weighted average $J_{r\,ref}$ = 0,2132 T		
Expanded weighted uncertainty $U(J_{r\,ref})$ = 0, 69%		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

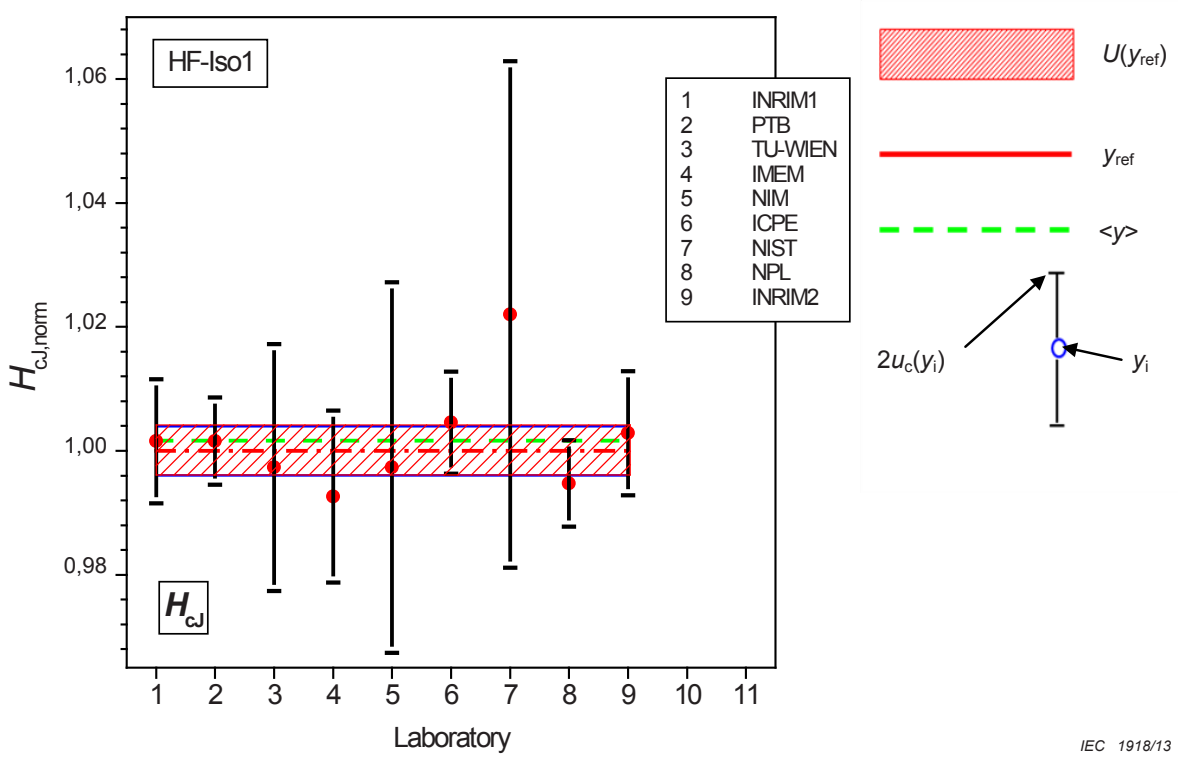
<y> unweighted average

These J_r values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.2 – Dispersion of the J_r values measured by the participating laboratories on the isotropic ferrite sample HF-Iso1

Table A.3 – Coercive field H_{cJ} measured by the participating laboratories on the isotropic hard ferrite HF-Iso1

Isotropic hard ferrite Iso-1		
	H_{cJ} (kA/m)	combined uncertainty u_{ci} (%)
INRIM1	235,2	0,5
PTB	235,2	0,35
TU-WIEN	234,2	1,0
IMEM	233,1	0,7
NIM	234,2	1,5
ICPE-CA	235,9	0,41
NIST	240,0	2,0
NPL	233,6	0,35
INRIM2	235,5	0,5
Unweighted average $<H_{cJ}>$ = 235,2 kA/m		
Standard deviation s(H_{cJ}) = 0,86 %		
Weighted average $H_{cJ,ref}$ = 234,8 kA/m		
Expanded weighted uncertainty $U(H_{cJ,ref})$ = 0,39 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

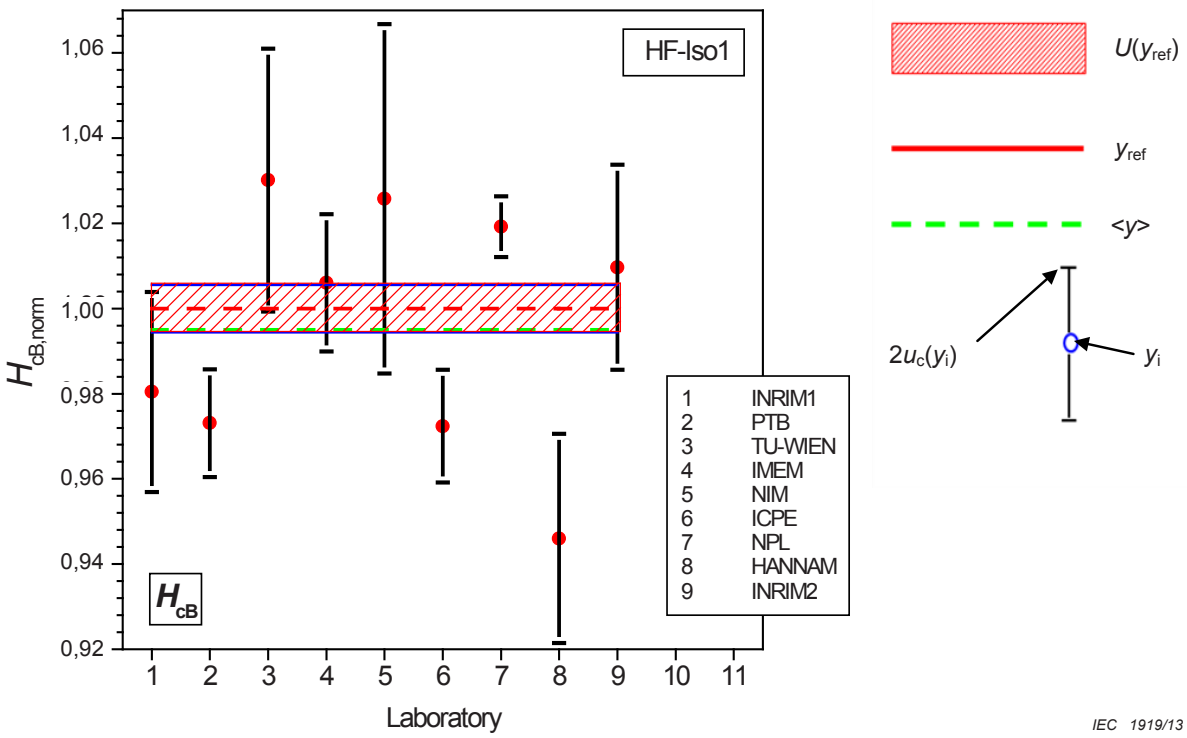
<y> unweighted average

These H_{cJ} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.3 – Dispersion of the H_{cJ} values measured by the participating laboratories on the isotropic ferrite sample HF-Iso1

Table A.4 – Coercive field H_{cB} measured by the participating laboratories on the isotropic hard ferrite HF-Iso1

Isotropic hard ferrite Iso-1		
	H_{cB} (kA/m)	combined uncertainty u_{ci} (%)
INRIM1	134,0	1,2
PTB	133,0	0,65
TU-WIEN	140,8	1,5
IMEM	137,5	0,8
NIM	140,2	2,0
ICPE-CA	132,9	0,68
NPL	139,3	0,35
HANNAM	129,3	1,3
INRIM2	137,0	1,2
Unweighted average $<H_{cB}>$ = 136,0 kA/m		
Standard deviation $s(H_{cB})$ = 2,9 %		
Weighted average $H_{cB,ref}$ = 136,7 kA/m		
Expanded weighted uncertainty $U(H_{cB,ref})$ = 0,55 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

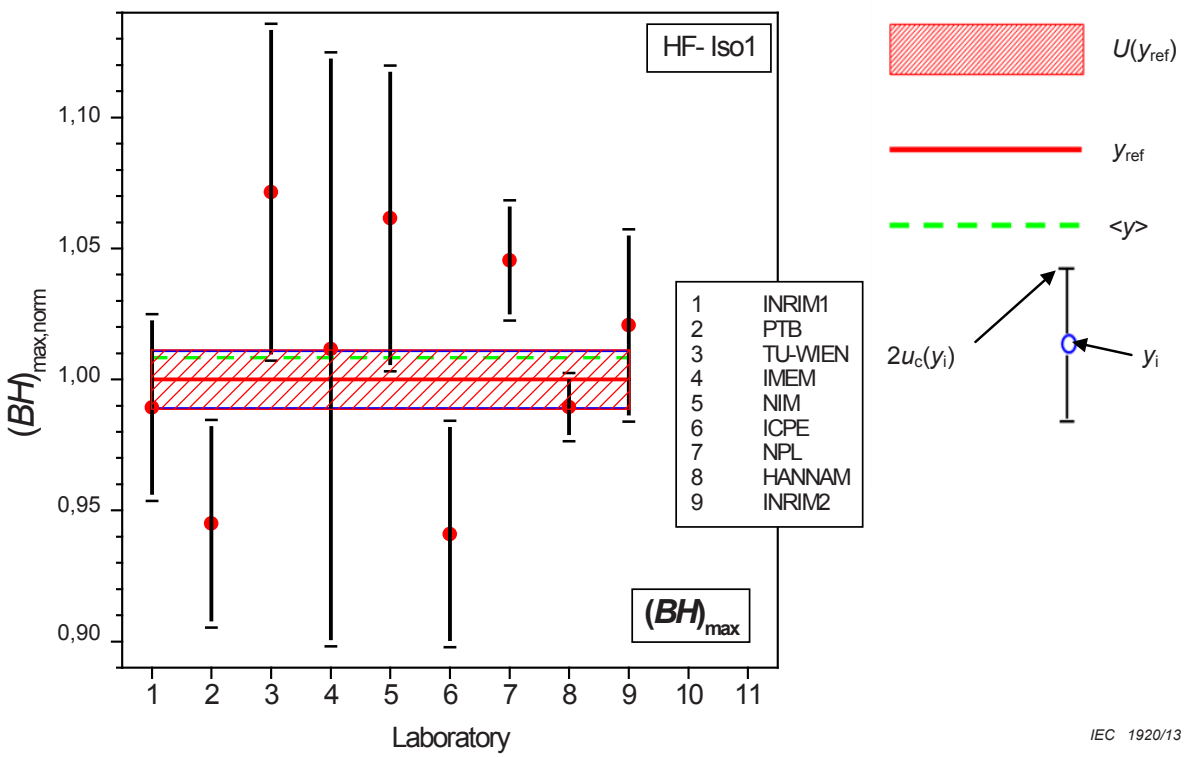
<y> unweighted average

These H_{cB} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.4 – Dispersion of the H_{cB} values measured by the participating laboratories on the isotropic ferrite sample HF-Iso1

Table A.5 – Maximum energy product $(BH)_{max}$ measured by the participating laboratories on the isotropic hard ferrite HF- Iso1

Isotropic hard ferrite Iso-1		
	$(BH)_{max}$ (J/m^3)	combined uncertainty u_{ci} (%)
INRIM1	7580	1,9
PTB	7240	2,1
TU-WIEN	8210	3,0
IMEM	7750	5,6
NIM	8133	2,75
ICPE-CA	7210	2,3
NPL	8010	1,1
HANNAM	7581	0,66
INRIM2	7820	1,9
Unweighted average $<(BH)_{max}>$ = 7726 J/m^3		
Standard deviation s($(BH)_{max}$) = 4,65 %		
Weighted average $(BH)_{max,ref}$ = 7662 J/m^3		
Expanded weighted uncertainty $U((BH)_{max,ref})$ = 1,1 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

<y> unweighted average

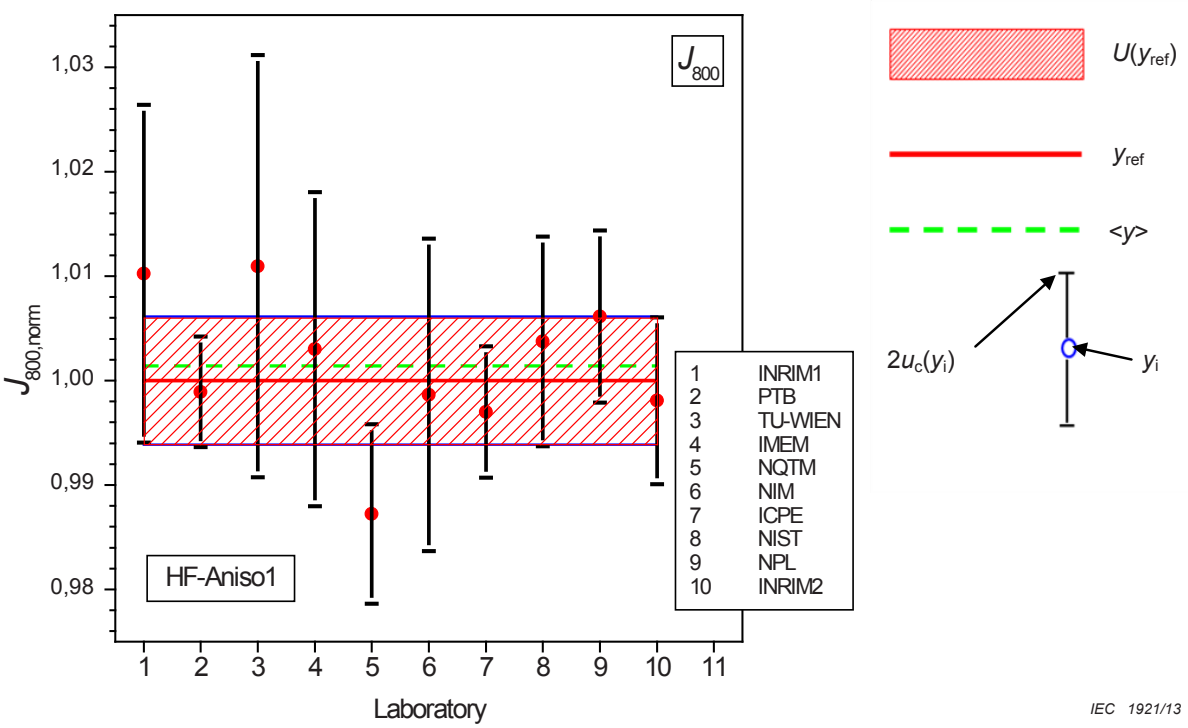
These $(BH)_{max}$ values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.5 – Dispersion of the $(BH)_{max}$ values measured by the participating laboratories on the isotropic ferrite sample HF-Iso1

A.3 Anisotropic hard ferrite

Table A.6 – Magnetic polarization value J_{800k} at $H_a = H_{peak}$ = 800 kA/m measured by the participating laboratories on the anisotropic hard ferrite HF-Aniso1

Anisotropic hard ferrite Aniso-1		
	J_{800k} (T)	combined uncertainty u_{ci} (%)
INRIM1	0,4197	0,80
PTB	0,415	0,53
TU-WIEN	0,42	2,0
IMEM	0,4167	1,5
NQTM	0,41015	0,87
NIM	0,41488	1,5
ICPE-CA	0,4142	0,63
NIST	0,417	1,0
NPL	0,418	0,82
INRIM2	0,41465	0,80
Unweighted average $<J_{800}>$ = 0,416 T		
Standard deviation s(J_{800}) = 0,70 %		
Weighted average $J_{800,ref}$ = 0,415 T		
Expanded weighted uncertainty $U(J_{800,ref})$ = 0,61 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

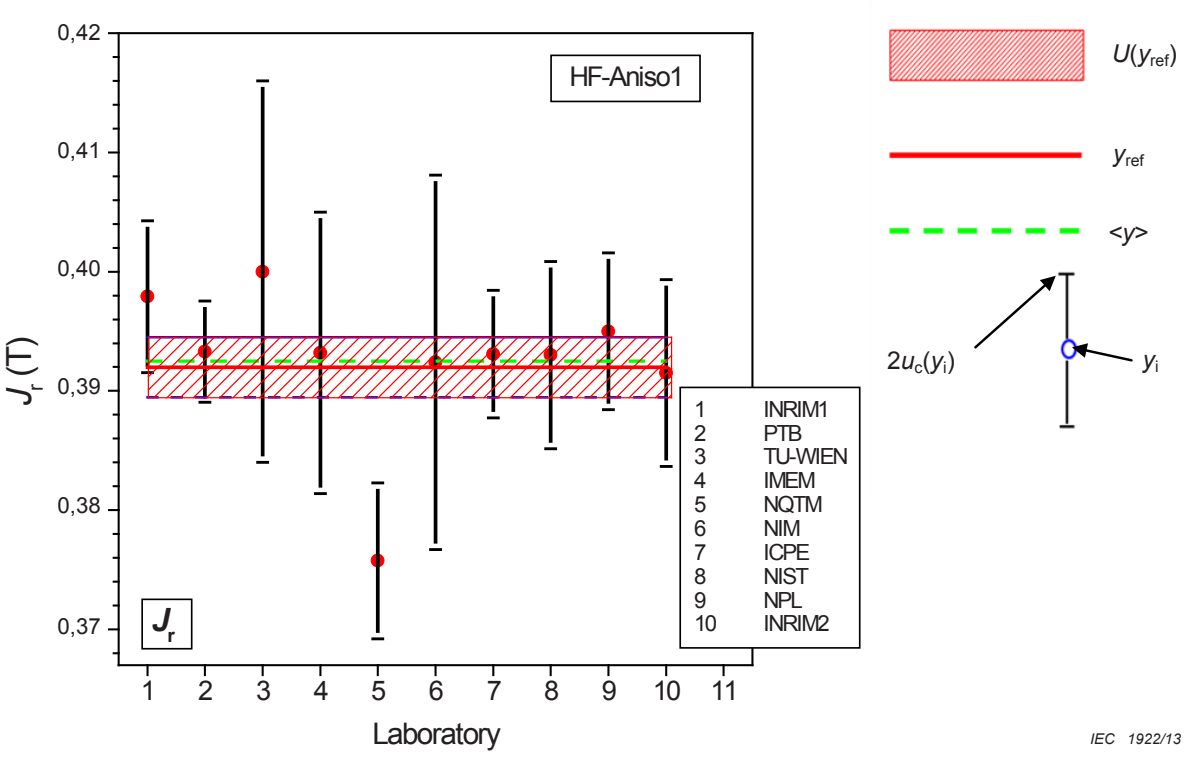
<y> unweighted average

These J_{800k} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.6 – Dispersion of the J_{800k} values measured by the participating laboratories on the anisotropic ferrite sample HF-Aniso1

Table A.7 – Remanent magnetic polarization J_r measured by the participating laboratories on the anisotropic hard ferrite HF-Aniso1

Anisotropic hard ferrite Aniso-1		
	J_r (T)	combined uncertainty u_{ci} (%)
INRIM1	0,3979	0,80
PTB	0,3933	0,54
TU-WIEN	0,4	2,0
IMEM	0,3932	1,5
NQTM	0,37576	0,87
NIM	0,3924	2,0
ICPE-CA	0,3931	0,68
NIST	0,393	1,0
NPL	0,395	0,83
INRIM2	0,3915	1,0
Unweighted average $<J_r>$ = 0,3925 T		
Standard deviation s(J_r) = 1,65 %		
Weighted average $J_{r\,ref}$ = 0,3920 T		
Expanded weighted uncertainty $U(J_{r\,ref})$ = 0,64 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

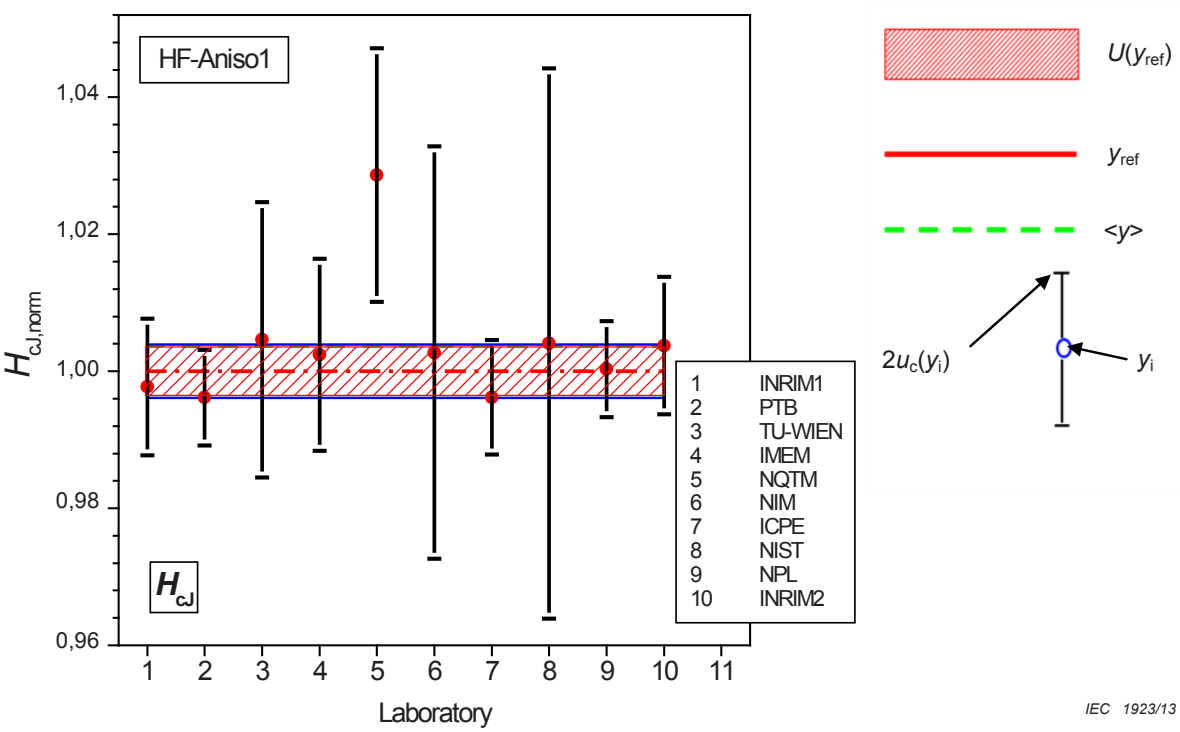
<y> unweighted average

These J_r values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.7 – Dispersion of the J_r values measured by the participating laboratories on the anisotropic ferrite sample HF-Aniso1

Table A.8 – Coercive field H_{cJ} measured by the participating laboratories on the anisotropic hard ferrite HF-Aniso1

Anisotropic hard ferrite Aniso-1		
	H_{cJ} (kA/m)	combined uncertainty u_{ci} (%)
INRIM1	238,48	0,50
PTB	238,11	0,35
TU-WIEN	240,13	1,0
IMEM	239,60	0,70
NQTM	245,87	0,90
NIM	239,67	1,5
ICPE-CA	238,12	0,42
NIST	240,00	2,0
NPL	239,10	0,35
INRIM2	239,92	0,50
Unweighted average $<H_{cJ}>$ = 239,9 kA/m		
Standard deviation s(H_{cJ}) = 0,93 %		
Weighted average $H_{cJ\,ref}$ = 239,0 kA/m		
Expanded weighted uncertainty $U(H_{cJ\,ref})$ = 0,37 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

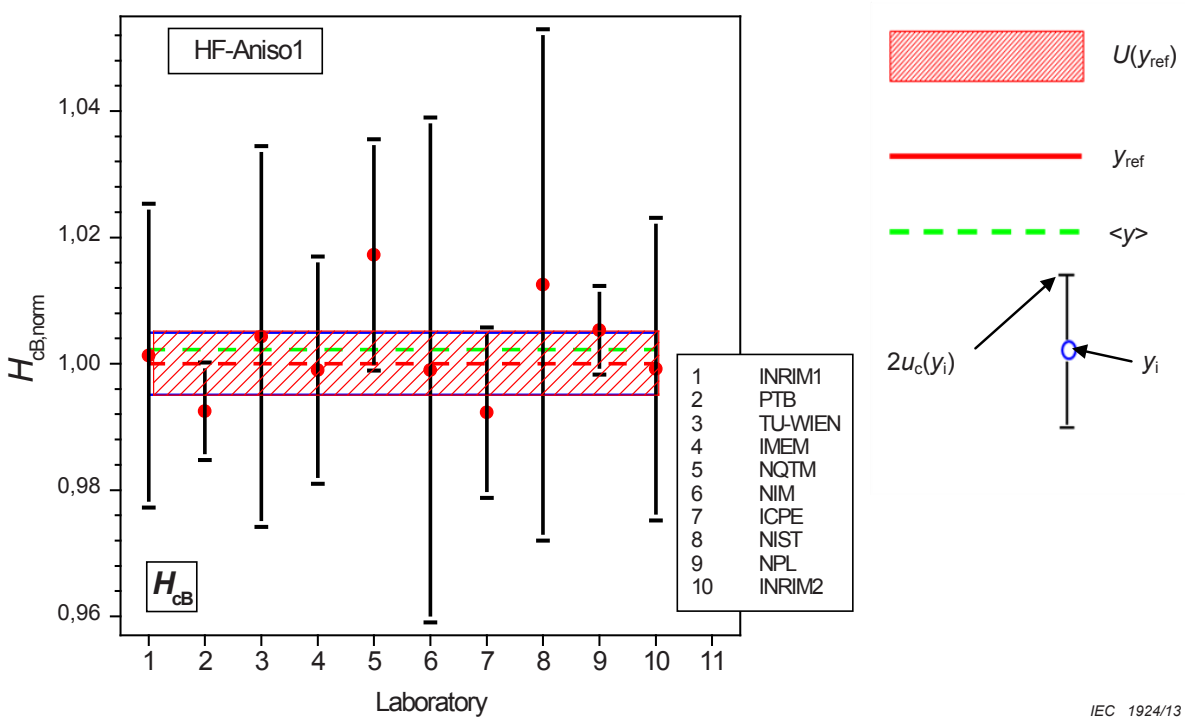
<y> unweighted average

These H_{cJ} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.8 – Dispersion of the H_{cJ} values measured by the participating laboratories on the anisotropic ferrite sample HF-Aniso1

Table A.9 – Coercive field H_{cB} measured by the participating laboratories on the anisotropic hard ferrite HF-Aniso1

Anisotropic hard ferrite Aniso-1		
	H_{cB} (kA/m)	combined uncertainty u_{ci} (%)
INRIM1	237,35	1,2
PTB	235,26	0,39
TU-WIEN	238,06	1,5
IMEM	236,80	0,90
NQTM	241,12	0,90
NIM	236,81	2,0
ICPE-CA	235,21	0,68
NIST	240,00	2,0
NPL	238,30	0,35
INRIM2	236,84	1,2
Unweighted average $<H_{cB}>$ = 237,6 kA/m		
Standard deviation s(H_{cB}) = 0,80 %		
Weighted average $H_{cB,ref}$ = 237,0 kA/m		
Expanded weighted uncertainty $U(H_{cB,ref})$ = 0,49 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

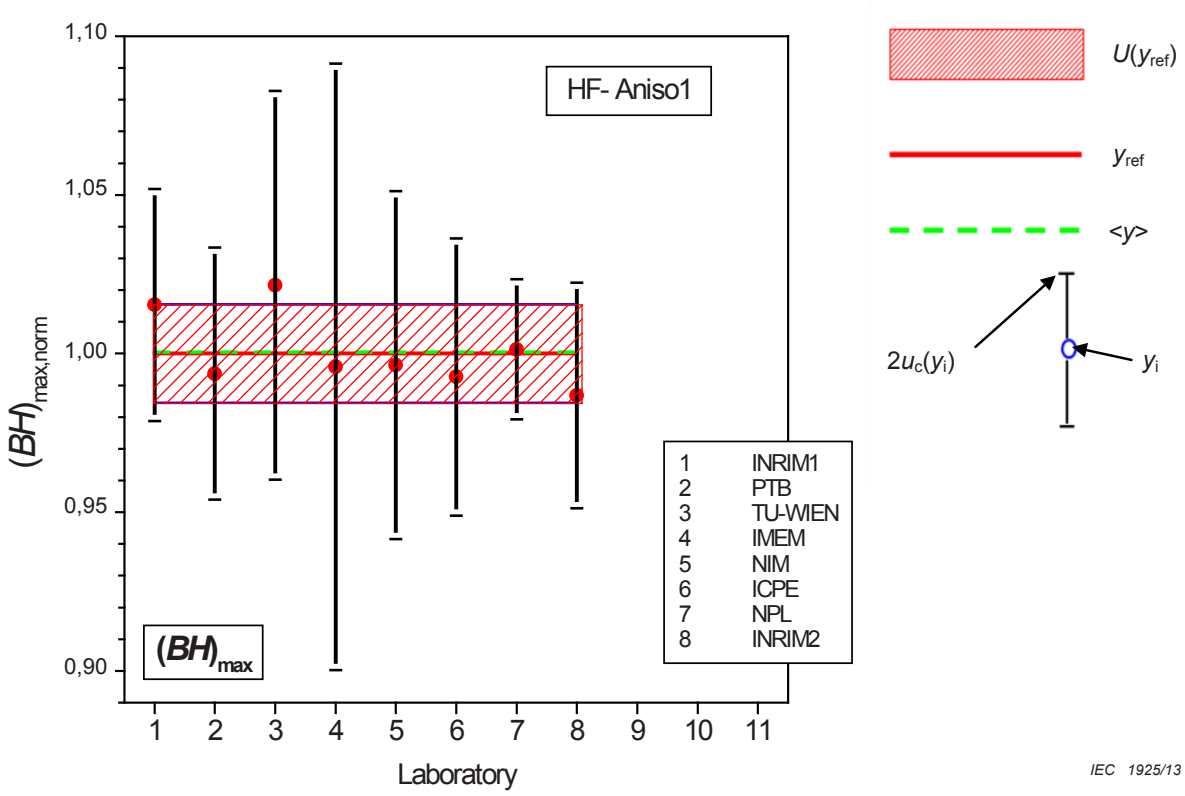
<y> unweighted average

These H_{cB} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.9 – Dispersion of the H_{cB} values measured by the participating laboratories on the anisotropic ferrite sample HF-Aniso1

Table A.10 – Maximum energy product $(BH)_{max}$ measured by the participating laboratories on the anisotropic hard ferrite HF- Aniso1

Anisotropic hard ferrite Aniso-1		
	$(BH)_{max}$ (J/m^3)	combined uncertainty u_{ci} (%)
INRIM1	29162	1,8
PTB	28540	2,0
TU-WIEN	29340	3,0
IMEM	28600	4,8
NIM	28616	2,75
ICPE-CA	28510	2,2
NPL	28760	1,1
INRIM2	28341	1,8
Unweighted average $<(BH)_{max}>$ = 28734 J/ m^3		
Standard deviation s($(BH)_{max}$) = 1,2 %		
Weighted average $(BH)_{max\ ref}$ = 28721 J/m^3		
Expanded weighted uncertainty $U((BH)_{max\ ref})$ = 1,54 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

<y> unweighted average

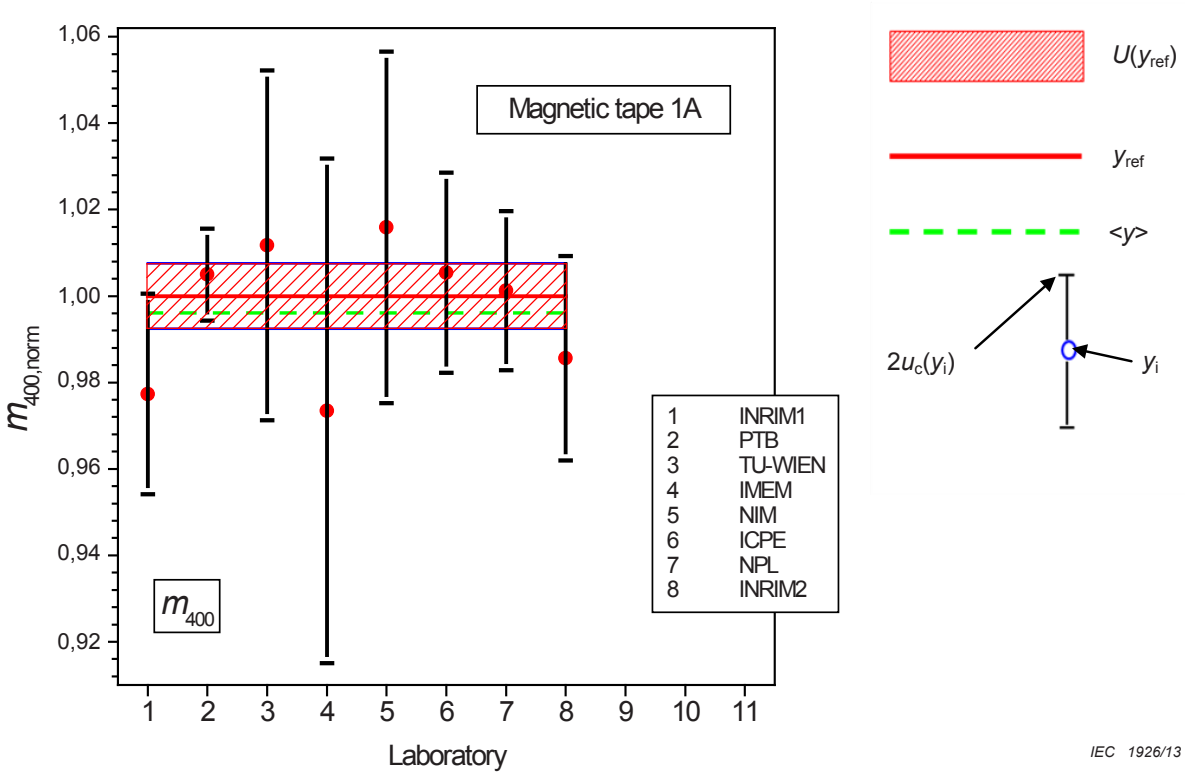
These $(BH)_{max}$ values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.10 – Dispersion of the $(BH)_{max}$ values measured by the participating laboratories on the anisotropic ferrite sample HF-Aniso1

A.4 Magnetic tape sample

Table A.11 – Magnetic moment m_{400k} measured at at $H_a = H_{peak}$ = 400 kA/m by the participating laboratories on the magnetic tape sample 1A

Magnetic tape sample 1A		
	m_{400k} (Am^2)	combined uncertainty u_{ci} (%)
INRIM1	$4{,}442 \cdot 10^{-6}$	0,90
PTB	$4{,}619 \cdot 10^{-6}$	0,53
TU-WIEN	$4{,}65 \cdot 10^{-6}$	2,0
IMEM	$4{,}474 \cdot 10^{-6}$	3,0
NIM	$4{,}6692 \cdot 10^{-6}$	2,0
ICPE-CA	$4{,}621 \cdot 10^{-6}$	0,65
NPL	$4{,}602 \cdot 10^{-6}$	0,92
INRIM2	$4{,}53 \cdot 10^{-6}$	0,90
Unweighted average $<m_{400k}>$ = $4{,}58 \cdot 10^{-6}$ Am^2		
Standard deviation s(m_{400k}) = 1,8 %		
Weighted average $m_{400k\,ref}$ = $4{,}60 \cdot 10^{-6}$ Am^2		
Expanded weighted uncertainty $U(m_{400k\,ref})$ = 0,71 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

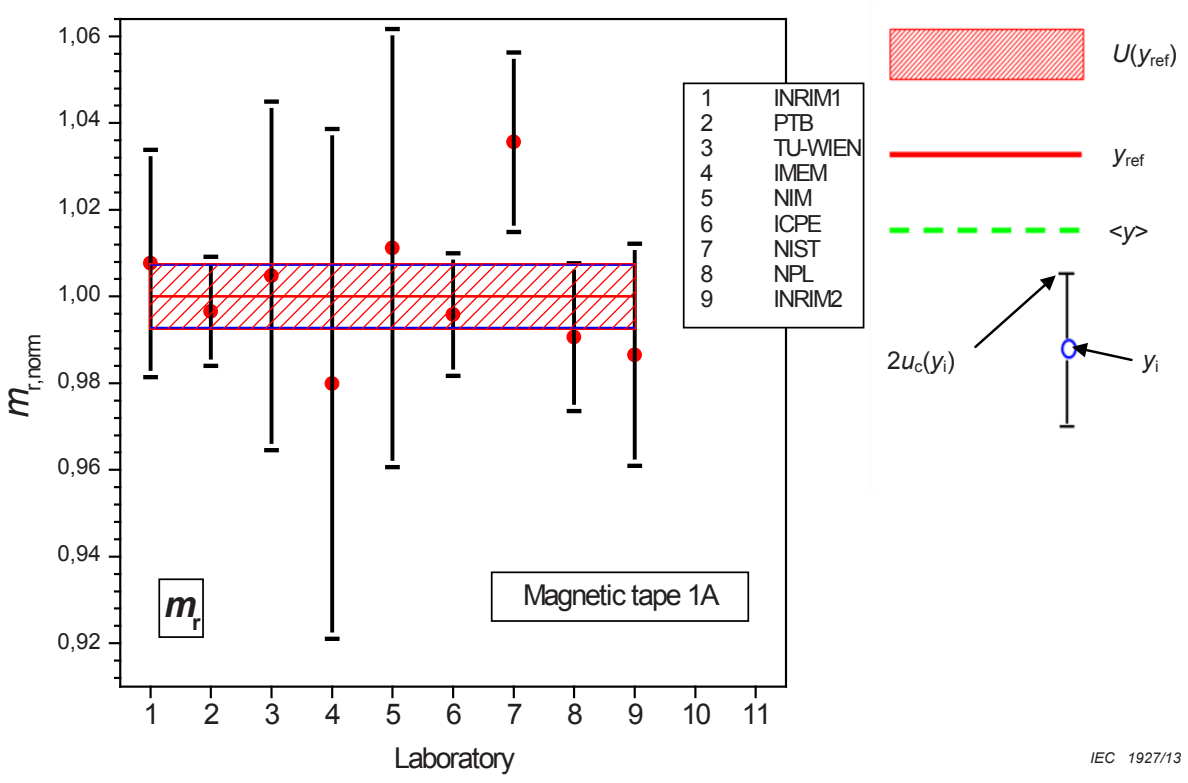
<y> unweighted average

These m_{400k} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.11 – Dispersion of the m_{400k} values measured by the participating laboratories on the magnetic tape sample A1

Table A.12 – Remanent magnetic moment m_r measured by the participating laboratories on the magnetic tape sample 1A

Magnetic tape sample 1A		
	m_r (Am^2)	combined uncertainty u_{ci} (%)
INRIM1	3,921E-6	1,3
PTB	3,878E-6	0,63
TU-WIEN	3,91E-6	2,0
IMEM	3,813E-6	3,0
NIM	3,9349E-6	2,5
ICPE-CA	3,875E-6	0,71
NIST	4,03E-6	1,0
NPL	3,855E-6	0,86
INRIM2	3,839E-6	1,3
Unweighted average $<m_r>$ = 3,90 E-6 Am^2		
Standard deviation s(m_r) = 1,6 %		
Weighted average $m_{r,ref}$ = 3,89 E-6 Am^2		
Expanded weighted uncertainty $U(m_{r,ref})$ = 0,78 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

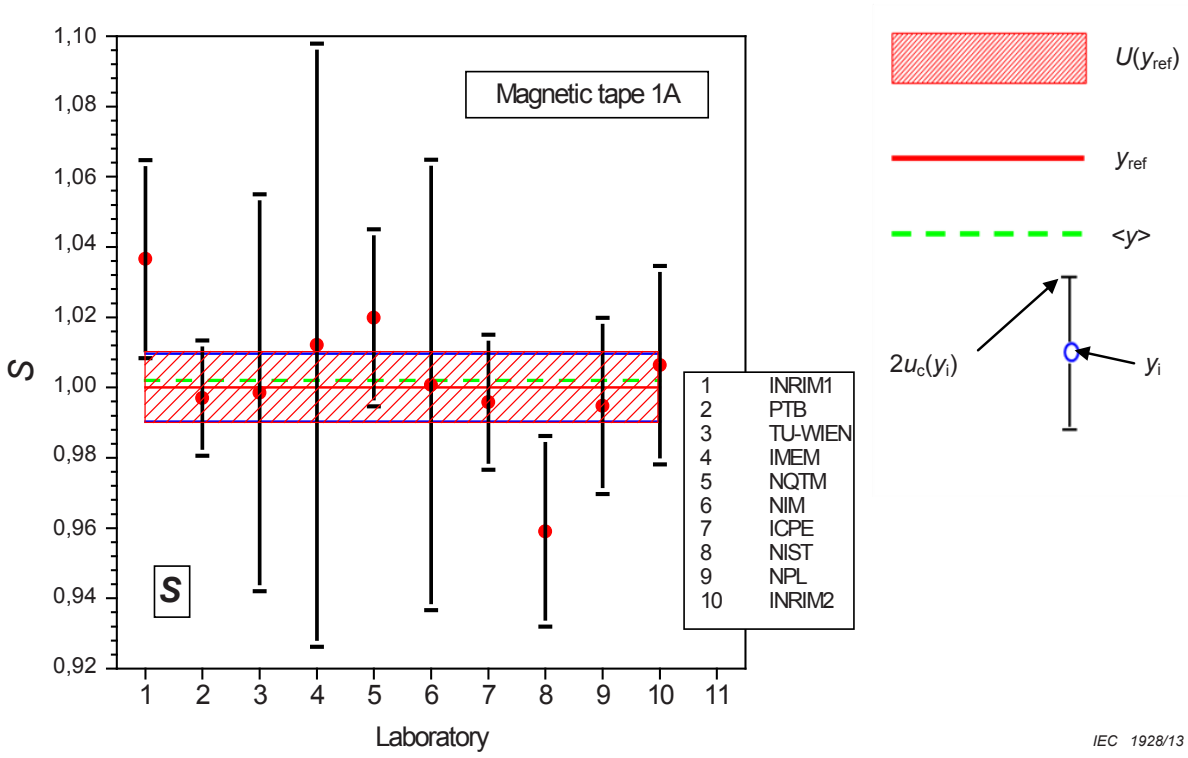
<y> unweighted average

These m_r values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.12 – Dispersion of the m_r values measured by the participating laboratories on the magnetic tape sample A1

Table A.13 – Squareness ratio $S = m_r/m_{400k}$ measured by the participating laboratories on the magnetic tape sample 1A

Magnetic tape sample 1A		
	S	combined uncertainty u_{ci} (%)
INRIM1	0,87289	1,35
PTB	0,83958	0,82
TU-WIEN	0,84086	2,83
IMEM	0,85226	4,24
NQTM	0,85879	1,24
NIM	0,84274	3,20
ICPE-CA	0,83856	0,96
NIST	0,80762	1,41
NPL	0,83768	1,26
INRIM2	0,84746	1,35
Unweighted average $<S>$ = 0,844		
Standard deviation s(S) = 2,0 %		
Weighted average S_{ref} = 0,842		
Expanded weighted uncertainty $U(S_{ref})$ = 0,97 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

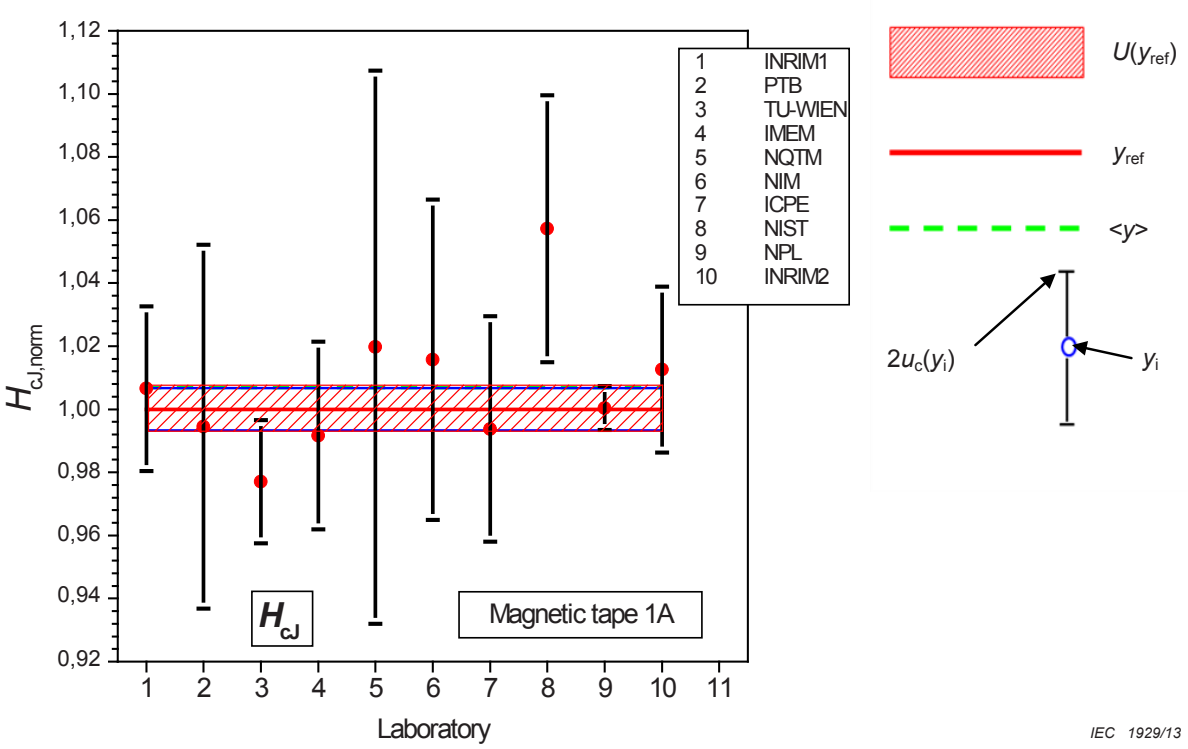
$<y>$ unweighted average

These $S = m_r/m_{400k}$ values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.13 – Dispersion of the $S = m_r/m_{400k}$ values measured by the participating laboratories on the magnetic tape sample A1

Table A.14 – Coercive field H_{cJ} measured by the participating laboratories on the magnetic tape sample 1A

Magnetic tape sample 1A		
	H_{cJ} (kA/m)	combined uncertainty u_{ci} (%)
INRIM1	28,85	1,3
PTB	28,50	2,9
TU-WIEN	28,00	1,0
IMEM	28,42	1,5
NQTM	29,22	4,3
NIM	29,11	2,5
ICPE-CA	28,48	1,8
NIST	30,30	2,0
NPL	28,67	0,35
INRIM2	29,02	1,3
Unweighted average $<H_{cJ}>$ = 28,86 kA/m		
Standard deviation s(H_{cJ}) = 2,17 %		
Weighted average $H_{cJ\,ref}$ = 28,66 kA/m		
Expanded weighted uncertainty $U(H_{cJ\,ref})$ = 0,67 %		



Key

y_i best estimate of the i-th laboratory

$u_c(y_i)$ combined uncertainty of the i-th laboratory

<y> unweighted average

These H_{cJ} values are normalized with respect to the reference value (weighted average) y_{ref}.

Figure A.14 – Dispersion of the H_{cJ} values measured by the participating laboratories on the magnetic tape sample A1

Annex B
(informative)

Participants

Pilot Laboratory 1: Istituto Nazionale di Ricerca Metrologica (INRIM), Strada delle Cacce 91 10135 Torino, Italy.

Pilot Laboratory 2: Dept. of Physics Hannam University, Ojung Dong 133 Taejon City, 300-791 Korea.

Physikalisch –Technische Bundesanstalt (PTB), Bundesallee 100 D-38116, Braunschweig, Germany.

Institut für Festkörperphysik, TU Wien, Wiedner Hauptstr. 8-10, A-1040 Vienna, Austria.

IMEM-CNR, Parco Area delle Scienze 37/A, 43010, Parma, Italy.

China Jiliang University, Xiasha Higher Education Zone, Hangzhou,Zhejiang, China, 310018 China.

National Institute of Metrology (NIM), No. 18, Bei San Huan Dong Lu, 100013 Beijing, P.R. of China.

INCDIE ICPE-CA, Splaiul Unirii, Nr. 313, Sector 3 74204, Bucuresti Romania.

National Institute of Standards and Technology (NIST), 100 Bureau Drive, Stop 8552, Gaithersburg, MD 20899-8552, USA.

National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW, UK.

PTB and NPL performed the measurements using a SQUID magnetometers. All the other laboratories used the VSM method. The value of including two laboratories making use of a SQUID magnetometer can be appreciated, since the related measurements can directly substantiate the results obtained with the VSM method.

Bibliography

[1] F. Fiorillo, Measurement and Characterization of Magnetic Materials, Amsterdam: Elsevier-Academic Press, 2004, p. 499.

[2] R.D. Shull, R.D. McMichael, L.J. Swartzendruber, and S. Leigh, *J. Appl. Phys*. 87 (2000) 717.

[3] ASTM Publication A894/A894M-00, "Standard test method for saturation magnetization or induction of non-metallic magnetic materials" (West Conshohocken, PA: ASTM International, 2000).

[4] ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)* .

[5] EUROMET, "Guidelines for the organization of comparisons", (EUROMET Guidance Document n°3).

[6] R. Thalmann, *Metrologia*, 37 (2000), 253-260.

[7] J. Sievert, H. Ahlers, J. Lüdke, S. Siebert, L. Pareti, and M. Solzi, "European intercomparison of measurements on permanent magnets," *IEEE Trans. Magn.* 29 (1993), 2887-2889.

[8] F, Fiorillo, C. Beatrice, D. Son, H. Ahlers, R. Groessinger, F. Albertini, Y.P. Liu, A. Lin, E. Patroi, R. Shull, O. Thomas, M.J. Hall: International comparison of measurements in hard magnets with vibrating sample magnetometer. XII. Int. Workshop on One- and Two-Dimensional Measurement and Testing, Vienna 3-.6 September 2012; accepted for publication in IJAEM, Tokyo.

[9] IEC 60404-5, *Magnetic materials – Part 5: Permanent magnet (magnetically hard) materials – Methods of measurement of magnetic properties*

———————

This page deliberately left blank

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

bsi.

...making excellence a habit.™