



TECHNICAL REPORT



Studies and comparisons of magnetic measurements on grain-oriented electrical steelsheet determined by the single sheet test method and Epstein test method

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.030

ISBN 978-2-8322-4332-9

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	4
1 Scope.....	6
2 Normative references	6
3 Terms and definitions	6
4 Background	7
4.1 Historical background and former concepts of the SST-Epstein relationship.....	7
4.2 Establishing reference values for grain-oriented electrical steels determined by independent SSTs – A new approach to the purpose.....	8
5 Preliminary comparisons and experiments	9
5.1 General.....	9
5.2 Comparison of the relative difference $\delta P_{SE} = (P_{SST} - P_{eps})/P_{Eps}$ measured by steel manufacturers on their own products using own set-ups	10
5.3 Preliminary comparisons and experiments made by four Chinese laboratories using six SSTs with stacked yokes	11
5.4 Necessity of comparing independent SST results.....	13
6 International comparison of SST measurements on grain-oriented electrical steel and accompanying Epstein measurements	15
6.1 General conditions, samples, participants	15
6.2 Circulation of the samples and measurement procedure	16
6.3 Results and analysis of the measured quantities.....	17
6.4 Conclusions of the international comparison	30
7 Summary and conclusions	31
Bibliography.....	32
Figure 1 – Epstein frame and single sheet tester, schematic view, windings partly omitted	7
Figure 2 – Relative difference $\delta P_{SE} = 100 (P_{SST} - P_{EP}) / P_{EP}$ versus peak magnetic polarization J measured by six contributors on samples of their own products.....	10
Figure 3 – Contact pattern for the measurement of lamination resistance in the air gap of SST yokes	11
Figure 4 – Ratio of the power loss P_{SST} to that of the SST with the best yokes, P_{SSTopt} , versus lamination conductivity factor C_Y of the yokes.....	12
Figure 5 – Ratio of the power loss at 100 Hz to that at 40 Hz, P_{100}/P_{40} , at 1,7 T, versus lamination conductivity factor C_Y of the yokes.....	13
Figure 6 – Relative difference $\delta P_{SE} = 100(P_{SST} - P_{EP}) / P_{EP}$ versus magnetic polarization	14
Figure 7 – Relative difference $\delta P_{SE} = 100(P_{SST} - P_{EP}) / P_{EP}$ at 1,7 T determined by three standard laboratories, IEN, NPL and PTB, on S- and P-type g.-o. sample pairs	14
Figure 8 – Dispersion of manufacturer’s grain-oriented material production in form of Epstein samples (PTB 1999).....	15
Figure 9 – Example of scattering of the laboratories’ best estimates around the reference value (CGO sample No. 2, unweighted average, dash-dotted line)	18
Figure 10 – Example of scattering of the laboratories’ best estimates around the reference value (HGO sample No. 4, unweighted average, dash-dotted line)	19
Figure 11 – Example of scattering of the laboratories’ best estimates around the reference value (HGO sample No. 5, unweighted average, dash-dotted line)	19
Figure 12 – Samples No. 1 to No. 5: ratio of SST to Epstein power loss reference values $\delta P_{SE}(J_p) = (\langle P_{SST} \rangle - \langle P_{Epst} \rangle) / \langle P_{Epst} \rangle$ at 50 Hz versus peak polarization.....	20

Figure 13 – Overall dispersion (all labs, J_p values, and samples) of the laboratories' best estimates P_i of the power loss at 50 Hz around their reference values	23
Figure 14 – Overall dispersion (all labs, J_p values, and samples) of the laboratories' best estimates S_i of the apparent power at 50 Hz around their reference values, with and without outliers	24
Figure 15 – Dispersion around the reference value of the laboratories' best values of the power loss P measured at 50 Hz by the Epstein and the SST methods at 1,7 T	25
Figure 16 – Dispersion around the reference value of the laboratories' best values of the apparent power S measured at 50 Hz by the Epstein and the SST methods at 1,7 T	26
Figure 17 – Overall dispersion (European metrological laboratories only, all J_p values and samples) of the laboratories' best estimates P_i of the power loss at 50 Hz around their reference values, with and without outliers	27
Figure 18 – Dispersion of the laboratories' best estimates of SST (a) and Epstein (b) power loss at 50 Hz	28
Figure 19 – Dispersion of the laboratories' best estimates of SST (a) and Epstein (b) power loss at 50 Hz	29
Figure 20 – Dispersion of the laboratories' best estimates, represented by the standard deviation σ of SST (red) and Epstein (blue) power loss (a) and apparent power (b) at 50 Hz, versus the peak value of the polarization, J_p , summarizing Figures 18 and 19	30
Table 1 – Participating laboratories	16
Table 2 – Circulated grain-oriented electrical steel test samples	17
Table 3 – Reference values at 50 Hz for the power loss P and the apparent power S	21
Table 4 – Standard deviations associated with the reference values at 50 Hz for the power loss P and the apparent power S (Table 3)	22
Table 5 – Reference values at 50 Hz of the polarization at $H = 800$ A/m J_{800} and standard deviation of the distribution of the laboratories' best estimates	22
Table 6 – Relative standard deviations of 50 Hz power loss P and apparent power S distributions around their reference values	27

INTERNATIONAL ELECTROTECHNICAL COMMISSION

STUDIES AND COMPARISONS OF MAGNETIC MEASUREMENTS ON GRAIN-ORIENTED ELECTRICAL STEELSHEET DETERMINED BY THE SINGLE SHEET TEST METHOD AND EPSTEIN TEST METHOD

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 TR 62981, 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
68/535/DTR	68/543/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.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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.

STUDIES AND COMPARISONS OF MAGNETIC MEASUREMENTS ON GRAIN-ORIENTED ELECTRICAL STEEL SHEET DETERMINED BY THE SINGLE SHEET TEST METHOD AND EPSTEIN TEST METHOD

1 Scope

This document, which is a Technical Report, provides the results of international exercises and comparisons focusing on achieving the knowledge of the statistical performance of single sheet tester (SST) measurements made on grain-oriented electrical steel. These experiments aim at specifying obligatory reference values, measured by the single sheet test method, for the grading of high permeability (P grades) grain-oriented (g.-o.) materials, independently from the Epstein classification as it is practiced today. Besides this, Epstein test measurements have been made in order to gain more up-to-date statistical performance for comparison with the SST statistical characteristics. A few experiments were carried out aiming at improved knowledge on the systematic error performance of the SST, i.e. they were to determine the correlation between the quality of insulation separating laminations in the SST yokes and the measured loss.

There are various designations for "non-oriented electrical sheet steel" and for "grain-oriented electrical sheet steel" in use, for example in the IEC 60404 classification and specification standards, and there are also abbreviations like CGOS (for conventional grain-oriented steel) often used in industry. In this report, the following designations and abbreviations are used:

- electrical steel as generic term;
- n.-o- electrical steel and g.-o. electrical steel as generic terms for these two types;
- S-type electrical steel or c. g.-o. electrical steel for "conventional grain-oriented electrical steel";
- P-type g.-o. electrical steel or high-permeability g.-o. electrical steel;
- DR g.-o. electrical steel for "domain refined grain-oriented electrical steel";
- where two terms are used, it can depend on the context;
- "electrical steel" can be replaced with "material", depending on the context.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-121, *International Electrotechnical Vocabulary – Part 121: Electromagnetism* (available at <http://www.electropedia.org>)

IEC 60050-221, *International Electrotechnical Vocabulary – Chapter 221: Magnetic materials and components* (available at <http://www.electropedia.org>)