PD IEC/TR 62981:2017

BSI Standards Publication

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

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

National foreword

This Published Document is the UK implementation of IEC TR 62981:2017.

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.

© The British Standards Institution 2017
Published by BSI Standards Limited 2017

ISBN 978 0 580 89689 7

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 2017.

Amendments/corrigenda issued since publication

Date	Text affected

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

IEC TR 62981

Edition 1.0 2017-05

TECHNICAL REPORT

colour inside

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

IEC TR 62981:2017-05(en)

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2017 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

IEC TR 62981

Edition 1.0 2017-05

TECHNICAL REPORT

colour inside

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.

® Registered trademark of the International Electrotechnical Commission

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

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

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62981:2017

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

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

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.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

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.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62981:2017

STUDIES AND COMPARISONS OF MAGNETIC MEASUREMENTS ON GRAIN-ORIENTED ELECTRICAL STEELSHEET 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 streel 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)

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-221 and IEC 60050-121 apply.

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

AVA Documents
Document Sharing Hub

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

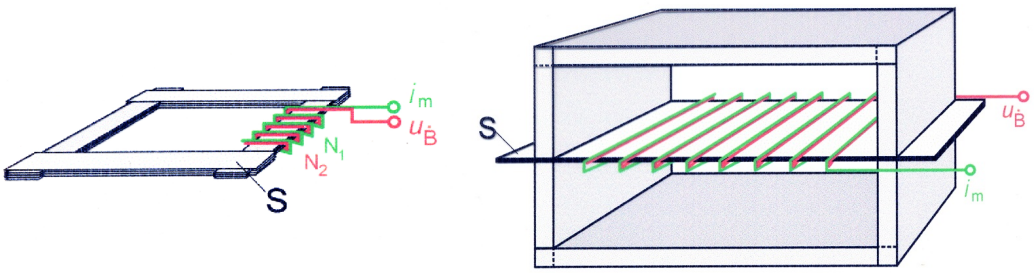
4 Background

4.1 Historical background and former concepts of the SST-Epstein relationship

The magnetic characteristics of electrical steel are significant in two regards. Firstly, they are decisive for the possible applications of the material. Secondly, the magnetic loss performance is essential for the material grading and for the efficiency of the energy transformation, i.e. for the energy costs and the economic and environmental aspects.

The Epstein method [1][1] and the single sheet tester (SST) method [2] are the two standardized methods for measuring the magnetic properties of electrical steel. Whilst the Epstein method, based on the 25-cm-frame, was designed about 60 years ago, the first edition of the single sheet tester standard was published in 1982 after intense discussions at IEC meetings (see Figure 1). This SST(82) standard comprised 500 mm x 500 mm sheet samples forming the closed magnetic circuit together with two symmetrical flux closure yokes made of grain-oriented electrical steel or nickel iron alloy. This first 1982-version was characterized by reference to the Epstein test method, i. e. it had to be calibrated using Epstein strips, 50 cm long and 30 mm wide, measured in the Epstein square and then, inserted side by side, in the SST. This method turned out to be considerably dispersive for reasons which are mentioned in 4.2 and 5.4.

Therefore, 10 years later, IEC published the independent single sheet test method in the IEC SST(92) standard [2] that includes the use of a conventional effective magnetic path length of l_m = 45 cm. However, due to the different designs of their magnetic circuits, SST(92) and Epstein methods show, in particular with high grade GOES materials, significant differences of their results when applied to the same material (for details, see 4.2).



Key

N_1 magnetizing winding

N_2 secondary winding

Figure 1 – Epstein frame and single sheet tester, schematic view, windings partly omitted

The Epstein method has been in use continuously, from its beginning to the present time, defined as the only reference method determining the quality reference in the specification standard. Correspondingly, the grade designations are directly related to the Epstein loss values, for instance the designation M150-35S5 designates a conventional (S-type) grain-oriented steel of 0,35 mm thickness with a maximum specific loss value of 1,50 W/kg measured by the Epstein method at 1,7 T and at 50 Hz. Thus, Epstein loss values have been the reference values for trade and application purposes, laid down in the lists of the

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

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62981:2017

specification standards, for about 60 years. For this reason, the Epstein to SST relationship was the subject of intense studies during the last two decades [3] [4] [6]. These studies are described in detail in Clause 5.

It is not easy to change this situation although the SST method is superior when applied to grain-oriented electrical steel because of its practical simplicity (no stress-relief annealing of sample needed) and also its suitability to the highest grade materials (e.g. domain refined grades which do not withstand stress relief annealing without deterioration of their properties). Therefore, an increasing part of the industry involved requests that SST reference values be included in the specification standards for these material grades [5].

4.2 Establishing reference values for grain-oriented electrical steels determined by independent SSTs – A new approach to the purpose

Earlier studies always based their considerations of the Epstein to SST relationship on the following formula:

$\delta P_{SE} = (P_{SST} - P_{Ep}) / P_{Ep}$ (or on the equivalent ratio P_{SST} / P_{Ep}).

The different systematic error characteristics of the Epstein and SST methods with grain-oriented materials can result, for instance, in differences of 4 % to 10 % between the specific total loss values, P_S, measured by them at a peak magnetic polarisation of 1,7 T. The systematic errors were found to be caused by the different magnetic circuit designs of the two methods, i.e. the inhomogeneity of the Epstein circuit formed by the double-overlapping joints of the strips (decrease of value), and, on the other hand, by the loss contribution through the SST yokes (increase of value).

Above, the main sources of systematic errors of both, Epstein and SST, are mentioned. Whilst systematic errors might be partly explainable, the statistical errors (dispersion), which are almost of the same magnitude for Epstein and SST, can only partly be assigned to specific phenomena. However, the Epstein to SST ratio, showing pretty good agreement between laboratories when identical samples are circulated, shows significant higher dispersion when the comparison refers to varieties of samples of the same grade (see for example 5.1). The intrinsic properties of those sample individuals are supposed to vary to an extent which is determined by the complexity of the process of sample preparation. Thus, it is probable that there is a significantly larger dispersion with Epstein samples rather than with SST samples (see also Figure 8 and [11]).

Recently, initiated through experts from industry closely involved in practical metrology [5], the awareness has grown that the Epstein to SST relationship, comprising the systematic and statistical error performance of both, Epstein and SST method, is an improper quantity for upgrading the SST to a reference method for high grade g.-o. electrical steel. The main reason is a phenomenon which was ignored with the studies published earlier, including the empirical SST-Epstein relation curve shown in Annex C of [2] which was obtained predominantly for conventional grain-oriented material. This phenomenon is the uncertainty that has to be assigned to the preparation of the Epstein strip samples which necessitates a stress relief annealing operation. This suppresses eventual internal stress due to the production process and, thus, has a misleading impact on the Epstein to SST relationship. This effect is more pronounced with high permeability g.o. material. This uncertainty accounts for a dispersion component of the properties of individual Epstein strip samples caused by the difference in the preparation procedures between laboratories and the randomly arranged strips in the sample stack. Items causing this dispersion component are the following.

Firstly, cutting the plate into strips creates basically a specimen with different properties: the flux is constricted to the strips. High permeability grades partly have grain sizes larger than the Epstein strip width. Flux paths in legs and corners of the strip's stack then undergo drastic changes compared with the entire sheet, and they depend on the random stacking. Internal stress is introduced through the cutting which shall then be removed through suitable annealing. Variations in this procedure create further dispersion:

Documents
Document Sharing Hub

– the method of cutting and sharpness of the cutting tools;
– the shape of the annealed samples – single strip or stack, with or without weight;
– the annealing procedure – duration, temperature, atmospheres, type of furnace;
– the handling of the samples.

This dispersion is not reflected by comparisons based on circulation of identical Epstein samples to the participating laboratories as it was practiced in the past.

However, this consideration does not include the still more complicated situation with domain refined grades which do not withstand stress relief annealing without deterioration of properties (see below).

In the case of non-domain-refined grades, the cutting to Epstein strips and the process of annealing the strips can, as mentioned above, change the intrinsic properties of the original product; in particular, it can make an inferior quality product which includes severe internal stresses seemingly better by releasing the stresses. This might be tolerated where the building process of the transformer core involves an annealing stage (e.g. wound cores). For manufacturers of stacked transformer cores, this is unacceptable [4].

Whilst companies having stable production processes and applying constant sample preparation may achieve a reasonable in-house-reproducibility of the Epstein method, this is not sufficient for the grading metrology worldwide. Generally, it can be stated that the higher the grade, the stronger is the influence on the dispersion from the Epstein sample preparation.

Finally, with laser domain refined materials, the Epstein test is even not applicable without an expensive wire cutting of the strips to avoid stress. Also, in this case, a certain dispersion caused by the different variations of the process of the Epstein sample preparation may be assumed, however there is no information which allows to quantify this. What remains is the random flux path fluctuation when large-grain material is cut to strips as was mentioned above.

Thus, if single identical Epstein sample stacks are passed through various laboratories, a small dispersion of the measured specific total loss does not tell us the full story. This might also hold for SST samples, however to a smaller extent, because they are prepared in only one step, the cutting. The items listed above suggest that the sample preparation procedure makes the Epstein method results inappropriate as a reference for the conversion into nominal SST values to be listed as specification of grain-oriented material of higher grades. Thus, the independent SST method according to IEC 60404-3 [2] is needed as the more appropriate method for this purpose. This will become more evident by the results shown in Clauses 5 and 6.

5 Preliminary comparisons and experiments

5.1 General

In the first phase of this IEC project, a comparison of the relative difference $\delta P_{SE} = (P_{SST} - P_{Eps})/P_{Eps}$ measured by steel manufacturers on their own products using their own set-ups was performed. It turned out that the information was not sufficient for specifying reference values for SST sheet samples (see 5.2 and 5.4).

In order to assess the influence of the yokes on the SST measurement results, further preliminary comparisons and experiments were subsequently made in China. Four laboratories and six SST fixtures with yokes having stacked lamination were involved. These experiments were to improve, besides the knowledge about the dispersion, the knowledge of the systematic error performance of the SST which becomes more significant when SST results would be upgraded to independent reference values (see 5.3 and [18]).

Documents
Document Sharing Hub