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TECHNICAL REPORT

Electrical steel – Methods of measurement of the magnetostriction characteristics by means of single sheet and Epstein test specimens

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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ELECTRICAL STEEL – METHODS OF MEASUREMENT OF THE MAGNETOSTRICTION CHARACTERISTICS BY MEANS OF SINGLE SHEET AND EPSTEIN TEST SPECIMENS

FOREWORD

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IEC 62581, 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
68/411/DTR	68/414/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 web site 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- withdrawn,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.

INTRODUCTION

Magnetostriction is one of the magnetic properties that accompany ferromagnetism. It causes reversible deformations of a material body due to magnetization arising from an applied magnetic field.

Nowadays, the environmental problem of acoustic noise pollution caused by transformers and other applications of electrical steels (e.g. ballast, motors, etc.) is a concern of industry [31][1]. Magnetostriction of electrical steels is recognized as one of the causes of the problem and a standardization of methods of measurement of the magnetostriction is required to advance developments in materials to address this problem.

Historically, several methods have been used to measure magnetostriction including strain gauge, capacitance, differential transformer, piezoelectric pick-up and piezoelectric accelerometer methods. However, these methods require skill to set up the sensor accurately and to avoid vibrational noise that accompanies these contact methods. To solve these problems, optical methods that adopt optical vibrometers and optical displacement meters have been developed [1]-[8].

The optical method satisfies the following requirements for the measurement: non-contact, high resolution, high reproducibility and ease of operation without any special skill on the part of the operator. Several optical sensors can be used: laser Doppler vibrometers, heterodyne displacement meters and laser displacement meters with high resolution.

Magnetostriction is a magneto-mechanical phenomenon which accompanies the change of the volume fraction of magnetic domains which have a certain magnetic orientation with respect to the direction of the applied magnetic field, and which is intrinsically sensitive to stress [14],[15]. The stress sensitivity is dependent on material conditions such as grain orientation, residual stress and coating tension. The magnetostriction of electrical steel is increased by compressive stresses in the magnetizing direction rather than tensile stresses [9],[16]-[23]. Magnetic cores of electrical machines such as transformers often contain areas of increased stress. Therefore the stress sensitivity should be evaluated under a specified stress.

The acoustic noise emission from transformers and other machines is usually evaluated in terms of the A-weighted sound pressure level specified in IEC 61672-1. Vibration velocities caused by magnetostriction are transformed into sound pressure on the surface of the materials. Therefore, A-weighted characteristics of magnetostriction, such as A-weighted magnetostriction velocity level or A-weighted magnetostriction acceleration level, are necessary for the assessment of electrical steel sheets with respect to the acoustic noise [24]-[26].

This technical report is comprised of articles which review the optical and accelerometer methods of measurement of magnetostriction with the aim of producing a standard method of measurement of magnetostriction.

Two methods, by a single sheet tester and by a single strip tester, are described. The former should be applied to single sheet specimens with width of not less than 100 mm which have not been stress relief annealed. The latter method should be applied to Epstein test specimens, which may have been stress relief annealed to remove stresses imparted to the specimens during preparation.

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1 The figures in square brackets refer to the Bibliography.

ELECTRICAL STEEL –
METHODS OF MEASUREMENT OF
THE MAGNETOSTRICTION CHARACTERISTICS
BY MEANS OF SINGLE SHEET AND EPSTEIN TEST SPECIMENS

1 Scope

This technical report describes the general principles and technical details of the measurement of the magnetostriction of single sheet specimens preferably 500 mm long and 100 mm wide and Epstein strip specimens, specified in IEC 60404-2, of electrical steel by means of optical sensors and accelerometers.

These methods are applicable to test specimens obtained from electrical steel sheets and strips of any grade. The characteristics of magnetostriction are determined for a sinusoidal induced voltage, for specified peak values of magnetic polarization and for a specified frequency.

The measurements are made at an ambient temperature of 23 °C ± 5 °C on test specimens which have first been demagnetized.

2 Normative references

The following referenced documents are indispensable for the application 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*

IEC 60050-221, *International Electrotechnical Vocabulary – Chapter 221: Magnetic materials and components*

IEC 60404-2, *Magnetic materials – Part 2: Methods of measurement of the magnetic properties of electrical steel sheet and strip by means of an Epstein frame*

IEC 60404-3:1992, *Magnetic materials – Part 3: Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester*
Amendment 1 (2002)
Amendment 2 (2009)

IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

3 Terms and definitions

For the purpose of this document, the definitions of the principal terms relating to magnetic properties given in IEC 60050-121 and IEC 60050-221 apply, as well as the following terms and definitions:

3.1
butterfly loop
hysteresis loop of the strain measured in the direction of applied field versus the magnetic polarization for a period of an alternating magnetization

3.2
zero-to-peak magnetostriction
λ_{o-p}
net strain measured in the direction of applied field from the zero magnetic polarization to a given magnetic polarization

3.3
peak-to-peak magnetostriction
λ_{p-p}
amplitude of the strain measured in the direction of the applied field under alternating magnetization

4 Method of measurement of the magnetostriction characteristics of electrical steel sheets under applied stress by means of a single sheet tester

4.1 Principle of the method

Measurement systems for magnetostriction are shown in Figure 1 and Figure 2. A block diagram of the measurement system is shown in Figure 3.

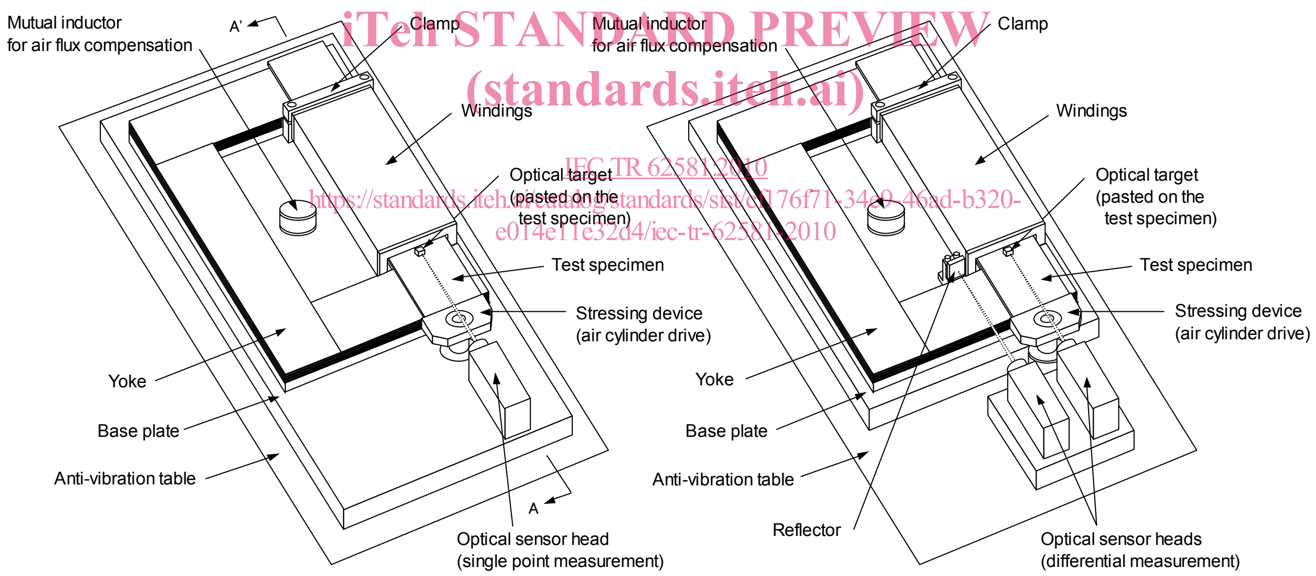

Figure 1a – Single point measurement **Figure 1b – Differential measurement**

Figure 1 – Measurement systems for magnetostriction

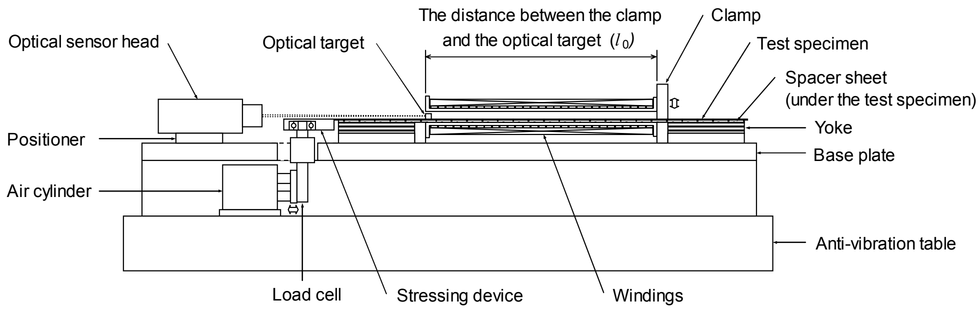

Figure 2 – Section of the test frame; A-A’ in Figure 1

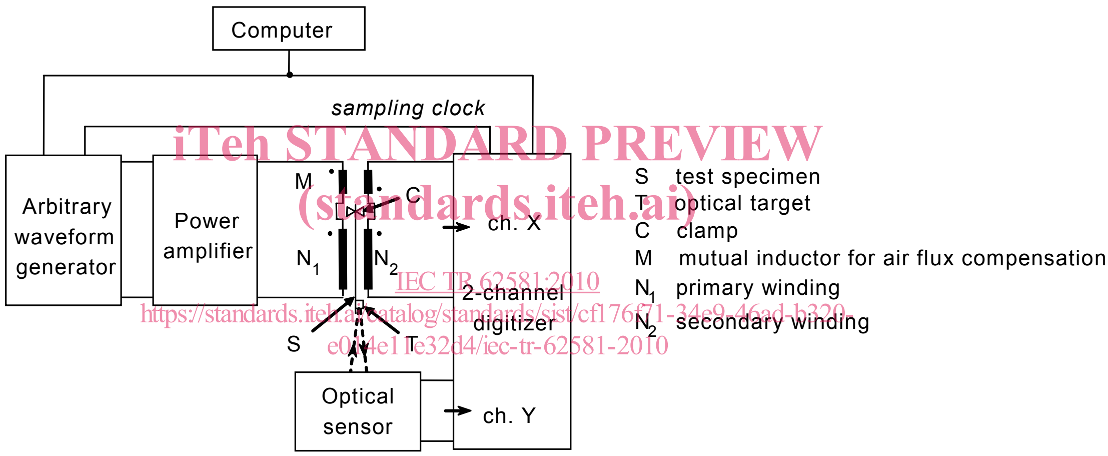

Figure 3 – Block diagram of the measurement system

The test specimen comprises a sample of electrical steel sheet and is placed inside two windings:

– an external primary winding;
– an interior secondary winding.

The flux closure is made by a magnetic circuit consisting of a yoke, the cross-section of which is large compared with that of the test specimen. There are narrow and homogeneous gaps between the test specimen and the pole faces of the yoke to weaken the electromagnetic force between them. The test frame that consists of the yoke, the windings and a clamp should be permanently fixed to a rigid base during the measurement.

The test specimen is fixed to the base at one end of the windings using the clamp shown in Figure 1. An optical target is pasted on the centerline of the surface of the test specimen at the other end of the windings. Changes in length between the clamping point and the optical target are measured using an optical sensor.

In order to reduce the effect of stray fields between the test specimen and the pole faces, the optical sensor should be at a sufficient working distance from the test frame.

Two measurement types of optical sensor can be used: a single point measurement and a differential measurement. The single point measurement uses a sensor head fixed on the base and measures vibration or displacement between the optical target and the sensor head. The differential measurement uses two sensor heads and measures vibration and displacement between the optical target and a reflector fixed on the base. The latter system has advantages of (a) cancellation of external noise and in (b) setting the sensors separately from the base.

Care shall be taken to minimize noise vibrations caused by resonances of the test frame and external vibrations. The test frame shall be placed on an anti-vibration table in order to isolate the test frame from external vibration.

Care shall be taken to prevent out-of-plane deformations of the test specimen. The test specimen shall be placed on a flat and smooth surface in the test frame and kept flat during the measurement (see Annex A).

4.2 Test specimen

The length of the test specimen should be not less than 500 mm. The part of the specimen situated outside the pole faces should not be longer than is necessary to facilitate insertion and removal of the test specimen and to apply an external stress to the test specimen in the longitudinal direction.

The width of the test specimen should be not less than 100 mm.

NOTE Since the average grain diameter for the high permeability grain-oriented electrical steel sheet is about 10-20 mm, a comparatively large sample size is required. The test specimen should be wide enough to take into account the affected region close to the cut edges. However, it may be difficult to produce a flux closure yoke with flat and coplanar faces for wider test specimens.

The test specimen should be cut without forming large burrs or mechanical distortion. The test specimen shall be flat. When a test specimen is cut, the edge of the parent strip is taken as the reference direction. The following tolerances are allowed for in the angle between the direction of rolling and that of cutting:

– ±1° for grain-oriented electrical steel sheet;
– ±5° for non-oriented electrical steel sheet.

4.3 Yokes

Several types of yoke can be used (see Figure 4):

– a horizontal single or double yoke;

– a vertical single or double yoke.

The horizontal yokes make a horizontal flux closure and the vertical yokes make a vertical flux closure. Each pole face is horizontal in both types of yoke.

Each yoke is made up of insulated sheets of grain-oriented electrical steel or nickel iron alloy. It should have a low reluctance and therefore stress relief annealing of the cut strips is required. The two pole faces of each yoke shall be coplanar within 0,03 mm (see Annex A). The yokes shall be constructed in accordance with the requirements of Annex A of IEC 60404-3.

In order to reduce the effect of eddy currents and give a more homogeneous distribution of the flux over the inside of the yokes, the yokes are made of a glued stack of laminations or C-cores. In the former case the corners have staggered butt joints. The overlap length of the test specimen and the pole faces shall be long enough and not less than 25 mm.

Before use, the yokes should be carefully demagnetized.

The electromagnetic force between the test specimen and the pole faces should be reduced by inserting narrow and uniform gaps between them. This can be achieved by inserting a sheet under the test specimen. The sheet shall be made of a non-compressible, non-conducting and non-magnetic material with flat and smooth surfaces. The thickness of the sheet should be uniform and between 0,1 mm and 1,0 mm.

NOTE 1 The electromagnetic force may increase out-of-plane vibrations of the test specimen and friction between the test specimen and the pole faces. These may reduce the accuracy and reproducibility of the measurement.

Each yoke is glued to the base plate. Resonances in each yoke that may affect the measurement shall be avoided.

In the case of the vertical double yoke, care should be taken to maintain a constant gap between the test specimen and the pole faces of the upper yoke.

NOTE 2 Because the upper yoke may block the optical beam from the sensor heads, the optical target may be outside the upper yoke in this case. Over the pole face region there will be perpendicular components of the magnetic flux in the test specimen and therefore over this region the magnetostriction behaviour may change. Verification of test results with the other test frame may be necessary.

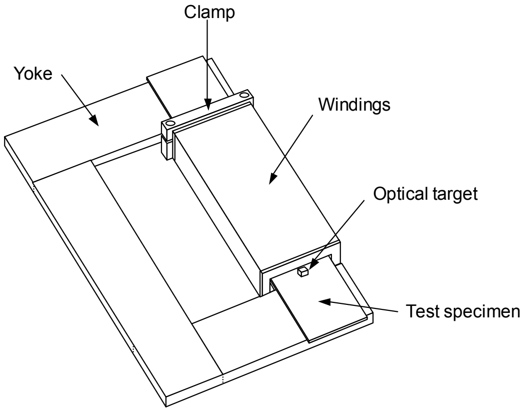

Figure 4a – Horizontal single yoke

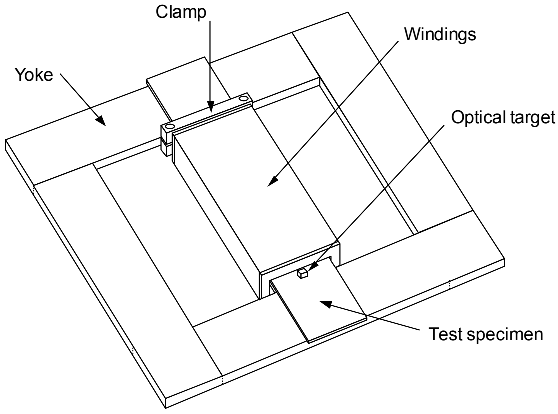

Figure 4b – Horizontal double yoke

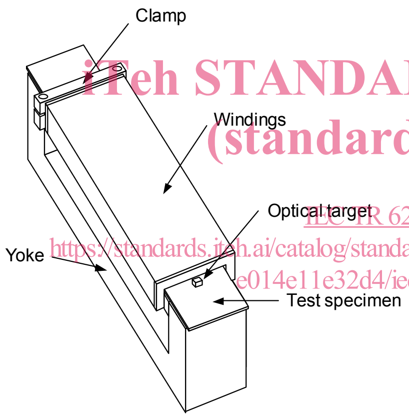

Figure 4c – Vertical single yoke

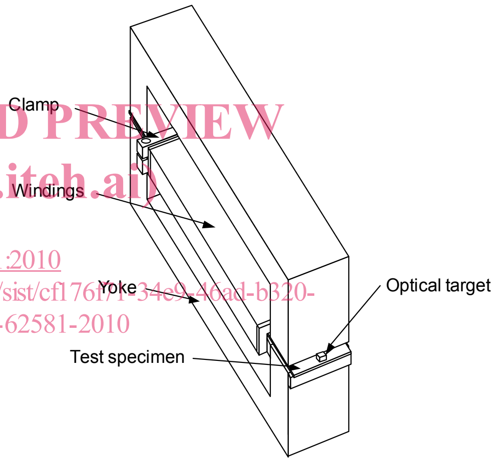

Figure 4d – Vertical double yoke

Figure 4 – Frames with various types of yoke

4.4 Windings

The primary and secondary windings are wound on a rectangular former made of non-conducting, non-magnetic material. The length of the former is shorter than the distance between the pole faces of the yokes to avoid the effect of stray fields between the test specimen and the pole faces.

The number of turns of the primary winding will depend on the characteristics of the power supply.

The number of turns of the secondary winding will depend on the characteristics of the measuring instruments.

The test specimen is inserted through the inside hollow of the former and supported on a plate of non-conducting and non-magnetic material. The surface of the plate in contact with the test specimen shall be flat and smooth with its surface coplanar with the pole faces within 0,03 mm (see Annex A).