IEC 60404-17

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Magnetic materials –
Part 17: Methods of measurement of the magnetostriction characteristics of grain-oriented electrical steel strip and sheet by means of a single sheet tester and an optical sensor

Matériaux magnétiques –
Partie 17: Méthodes de mesure des caractéristiques de magnétostriction des bandes et tôles magnétiques en acier à grains orientés au moyen d'un essai sur tôle unique et d'un capteur optique

IEC 60404-17:2021-11(en-fr)

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MAGNETIC MATERIALS –

Part 17: Methods of measurement of the magnetostriction characteristics of grain-oriented electrical steel strip and sheet by means of a single sheet tester and an optical sensor

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Draft	Report on voting
68/685/CDV	68/692/RVC

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available

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- withdrawn,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

INTRODUCTION

This document provides standard methods to measure the magnetostriction characteristics of grain-oriented electrical steel strip and sheet under an applied AC magnetic field at 50 Hz or 60 Hz. The technical details are specified after intense considerations among magnetostriction experts, so that a satisfactory reproducibility of the measurement can be expected. The measurement requires detections of tiny vibrations of the test specimen at a resolution of 0,01 µm or better. In order to meet this challenging condition, not only the magnetic aspects, but also mechanical aspects of the test apparatus, e.g. the influence of friction, Maxwell forces, resonance and external vibrations, had to be specified.

The methods to determine magnetostriction characteristics of the butterfly loop, the peak-to-peak and zero-to-peak values of magnetostriction strain are specified in this document. Subsidiary characteristics of the velocity levels and the acceleration levels are described in Annex E.

The technical report IEC TR 62581:2010 [1][1] reviewed the methods of measurement of the magnetostriction characteristics of grain-oriented electrical steel by means of a single sheet tester. Various methods have been used for the measurement of the change in length of the various test specimens. However, for methods using sensors in contact with the test specimen, it is difficult to avoid measurement offsets associated with the contact methods. Moreover, the methods require special skills to be used in order to carry out the measurements. Therefore, this document provides methods using an optical sensor, namely a laser Doppler vibrometer, which fulfils the requirements of non-contact, high resolution and high reproducibility of measurements.

It is well known that mechanical stress in grain-oriented electrical steel has a strong influence on magnetostriction [1]. Grain-oriented electrical steel has a particular behaviour with regards to its sensitivity to compressive stress along the rolling direction compared to other kinds of electrical steels. It depends on the degree of grain-orientation of the material and the level of tensile stress in the material applied by surface coatings. Methods of measurement under an externally applied compressive stress are described in Annex B.

International round robin comparisons of the magnetostriction measurements have been carried out repeatedly by reducing the range of methods [2], [3], [4]. The reproducibility of the measurement was characterized by a relative standard deviation of more than 20 % when various methods were allowed. It became less than 2 % when test apparatuses following the principles described in this document were used for the assessment of grain-oriented electrical steel sheets cut along the rolling direction under the condition of a peak magnetic polarization of 1,7 T and a magnetizing frequency of 50 Hz.

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

MAGNETIC MATERIALS –

Part 17: Methods of measurement of the magnetostriction characteristics of grain-oriented electrical steel strip and sheet by means of a single sheet tester and an optical sensor

1 Scope

This part of IEC 60404 is applicable to grain-oriented electrical steel strip and sheet specified in IEC 60404-8-7 for the measurement of magnetostriction characteristics under an applied AC magnetic field at 50 Hz or 60 Hz.

This document defines the general principles and technical details of the measurement of magnetostriction characteristics of grain-oriented electrical steel strip and sheet by means of a single sheet tester and an optical sensor.

NOTE 1 The accelerometer method [5] is also an established method for the measurement of magnetostriction. However, it is more suited to the measurement of magnetostriction under an externally applied tensile or compressive stress, not zero stress, because it places a weight on the test specimen to prevent a deformation of the test specimen. Since this document includes the measurement at zero stress, the optical sensor method is provided as the optimum method.

This document is applicable to the measurement of:

– the butterfly loop;

– the peak-to-peak value $\lambda_{p\text{-}p}$;

– the zero-to-peak value $\lambda_{0\text{-}p}$.

The magnetostriction characteristics are determined for a sinusoidal induced secondary voltage, for a specified peak value of the magnetic polarization and at a specified magnetizing frequency.

NOTE 2 Throughout this document the term “magnetic polarization” is used as described in IEC 60050-121:1998, 121-11-54. In some standards of the IEC 60404 series, the term “magnetic flux density” is used.

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 60050-103, *International Electrotechnical Vocabulary – Part 103: Mathematics – Functions* (available at www.electropedia.org)

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

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

IEC 60050-801, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electroacoustics* (available at www.electropedia.org)

IEC 60404-8-7, *Magnetic materials – Part 8-7: Specifications for individual materials – Cold-rolled grain-oriented electrical steel strip and sheet delivered in the fully-processed state*

IEC 61672-1:2013, *Electroacoustics – Sound level meters – Part 1: Specifications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-103, IEC 60050-121, IEC 60050-221, IEC 60050-801, IEC 61672-1 and the following apply.

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

- ISO Online browsing platform: available at http://www.iso.org/obp
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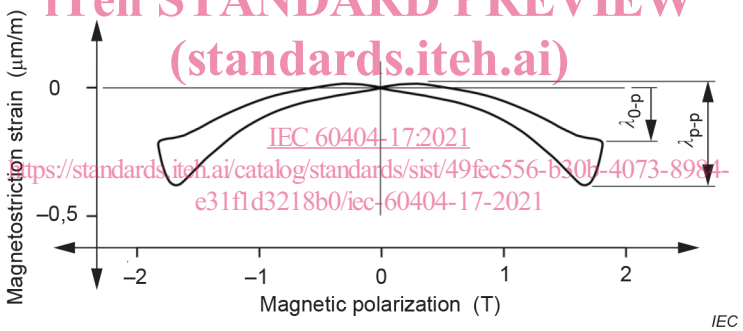
3.1
butterfly loop
butterfly curve
hysteresis loop of magnetostriction strain versus magnetic polarization along the direction of applied AC magnetic field for a period of magnetization, as illustrated in Figure 1

EXAMPLE



Key

$\lambda_{p\text{-}p}$ peak-to-peak value

$\lambda_{0\text{-}p}$ zero-to-peak value

Figure 1 – Illustrations of butterfly loop, peak-to-peak value and zero-to-peak value

3.2
$\lambda_{p\text{-}p}$
peak-to-peak value
peak-to-peak amplitude of magnetostriction strain along the direction of applied AC magnetic field, taking an absolute value, expressed in µm/m

Note 1 to entry: The peak-to-peak value can be read from the butterfly loop as shown in Figure 1.

3.3
$\lambda_{0\text{-}p}$
zero-to-peak value
difference in magnetostriction strain along the direction of applied AC magnetic field between the values at the prescribed peak magnetic polarization and at the zero value of the magnetic polarization, taking a positive or negative value, expressed in µm/m

Note 1 to entry: The zero-to-peak value can be read from the butterfly loop as shown in Figure 1.

3.4
L_v
velocity level
indicator of magnetostriction velocity comprising all harmonic components of magnetostriction strain of interest, expressed in dB

Note 1 to entry: The frequency weighting filter "A" defined in IEC 61672-1:2013 can be applied to the velocity level resulting as A-weighted velocity level, L_{vA}, expressed in dB(A).

3.5
L_a
acceleration level
indicator of magnetostriction acceleration comprising all harmonic components of magnetostriction strain of interest, expressed in dB

Note 1 to entry: The frequency weighting filter "A" defined in IEC 61672-1:2013 can be applied to the acceleration level resulting as A-weighted acceleration level, L_{aA}, expressed in dB(A).

4 General principles

4.1 Principle of the method

A length change of a test specimen for a base length under an AC magnetic field is measured by means of a single sheet tester and an optical sensor. Magnetostriction characteristics of the material are determined from the length change of the base length of the test specimen for prescribed peak values of the magnetic polarization and at a specified magnetizing frequency.

A schematic diagram of a test apparatus is illustrated in Figure 2. The test apparatus consisting of windings, a winding former, a bridge, a yoke, a clamp block, a weight, an end stop, an optical sensor and auxiliary support structures shall be fixed to a vibration-free table. The test apparatus may be assembled on a rigid base plate which is non-magnetic and fixed to the vibration-free table.

NOTE 1 Methods of measurement under an externally applied compressive stress are described in Annex B.

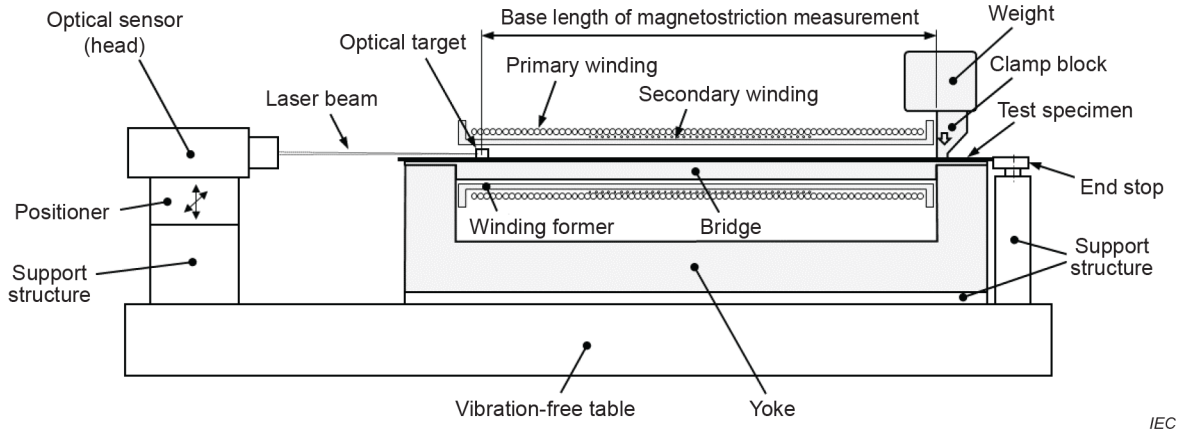


Figure 2 – Schematic diagram of a test apparatus (cross-sectional)

The test specimen shall be placed on the bridge inside the following two windings wound on the winding former (see 4.3.3):

– an exterior primary winding (magnetizing winding);
– an interior secondary winding (induced voltage winding).

A flux closure shall be made by the yoke placed under the test specimen. The two pole faces shall be in a horizontal plane. The cross-section of the yoke shall be sufficiently large compared to that of the test specimen. Several types of yoke may be used (see 4.3.2).

The winding former shall be placed symmetrically between the two pole faces so that the magnetic field is symmetrically distributed within the winding former. The length of the winding former shall be as long as possible.

The bridge between the two pole faces shall be placed inside the winding former without touching the winding former. The bridge shall be sufficiently rigid to keep the test specimen on it flat, and the surface on which the test specimen is placed shall be flat and smooth with a low friction film adhered to the surface (see 4.3.4).

Both end parts of the bridge shall be held in close contact with the pole faces. The remaining space between the end parts of the bridge and the pole faces shall be filled with a small amount of high vacuum silicone grease whilst keeping the top surface of the bridge strip flat. In order to prevent a formation of large cavities, the grease should be spotted on the pole face in a grid pattern, the bridge is placed, and pressed firmly from the top of a flat glass plate placed on the bridge. Care shall be taken not to stain the surface of the low friction film with grease. The bridge shall be replaceable in order to maintain the smooth surface condition (see 4.3.4 and Clause A.8).

NOTE 2 High vacuum silicone grease has the appropriate properties being chemically inert, having low vapour pressure, and being difficult to solidify for a long time. However, if the grease stains the surface of the low friction film and/or the back surface of the test specimen, the frictional force acting on the test specimen increases and the magnetostriction value decreases. Grease stains can be removed with acetone.

NOTE 3 An H coil with the same length as the secondary coil can be embedded in the bridge inside the secondary winding in order to detect the magnetic field strength $H(t)$ applied to the test specimen. This is useful to investigate magnetostriction characteristics of grain-oriented electrical steel.

The test specimen shall be placed on the bridge so that the axis of the test specimen is coincident with the horizontal axis of symmetry of the winding former (hereafter, simply called “the axis of the winding former”).

NOTE 4 Misalignments of the test specimen can cause lateral vibrations of the test specimen by the Maxwell force, which works to align the axes of the test specimen and the winding former, causing measurement offsets.

Both ends of the test specimen shall overhang the bridge (see Clause A.6). The parts of the test specimen situated outside the pole faces shall be no longer than a few mm (see Clause A.7). The end of the test specimen opposite to the clamp shall be free to move. Nothing shall be connected to this end (see Clause A.7). The other end of the test specimen shall make contact with the end stop over the full width.

During the measurement, the test specimen shall be fixed to the test apparatus by means of the clamp block and the weight (see 4.3.7). The side of the clamp block facing the optical sensor shall be in plane with the inner edge of the pole face (see Figure 2 and Clause A.2).

No weight, except the optical target, shall be placed on the test specimen between the end of the test specimen opposite the clamp and the clamp block (see Clause A.5) [12].

The optical target shall be placed on the test specimen inside the winding former so that the distance between the optical target centre and the inner edge of the pole face is 10 mm ± 1 mm when the test specimen is placed on the bridge (see Figure 2 and 4.3.5).

NOTE 5 If the optical target is located close to the pole face, out-of-plane vibrations of the test specimen on the pole face can cause measurement offsets (see Clause A.2).

The optical sensor shall be placed in the optimum position so as to maximize the signal to noise ratio of the output signal. The laser beam shall be parallel to the axis of the winding former within ±0,1° in order to prevent measurement offsets due to vertical and lateral vibrations of the test specimen.

NOTE 6 The optical sensor has optimum distances from the optical target to maximize the signal to noise ratio of the output signal. The optimum distances are usually specified in the instruction manual of the optical sensor.

NOTE 7 The inclination of the laser beam can be adjusted so that the displacements of the laser beam from the axis of the winding former at both ends of the winding former are the same within ±0,7 mm.

The laser beam position on the optical target should be adjusted to maximize the intensity level of the reflected laser beam detected by the optical sensor in order to increase the signal to noise ratio of the output signal. The optical sensor should be mounted on an external positioner in order to make it easier to adjust the laser beam position (see Figure 2).

The base length of the magnetostriction measurement is the distance along the axis of the winding former between the optical target centre and the side of the clamp block facing the optical sensor (see Figure 2).

The auxiliary support structures close to the magnetic circuit shall be non-magnetic. Care shall be taken to avoid an electrical short circuit around the magnetic flux through the magnetic circuit.

All items placed on the vibration-free table should be stabilized to the table in order to prevent unexpected resonance generation and vibration transmission to the test apparatus.

The test apparatus should be located away from external noise. The test apparatus shall not be touched by hand or tools during the measurement, otherwise it induces vibration of the test apparatus causing, in turn, measurement offsets. The test apparatus should be placed so that the axis of the winding former is approximately at right angles to the direction of the earth's magnetic field (see Clause A.4).

NOTE 8 A simple magnetic shield and a windshield covering the test apparatus can weaken the influence of the external magnetic and acoustic noises respectively.

It is fundamentally important that the surface on which the test specimen is placed is flat and clean in order to stabilize the frictional force acting on the test specimen to low values (see Clause A.5). A flat glass plate shall be used to check and maintain the flatness (see 4.3.2, 4.3.4 and 4.3.9).

The test apparatus shall be verified so that there is no out-of-plane vibration of the test specimen and no effect of resonance causing measurement offsets (see Clause A.8).

4.2 Test specimen

The test specimen shall be rectangular and flat. The test specimen shall be free of fold marks, dents and scratches with residual stress. The back surface of the test specimen shall be free of substances that affect friction such as grease, adhesives, liquids, powders, etc. (see Clause A.5).

The length and width of the test specimen shall be 500 mm ± 0,5 mm and 100 mm ± 0,2 mm respectively.

The test specimen shall be cut parallel to the direction of rolling unless otherwise specified.

The test specimen shall be cut without forming excessive burrs and mechanical distortion. Stresses introduced into the test specimen by the cutting process shall be as low as possible. The test specimen shall be handled very carefully in order to avoid any further introduction of stresses.

NOTE 1 The stress introduced into the test specimen can create 90 degree magnetic domains in the material causing magnetostriction offsets.

NOTE 2 A laser cutting technique can be used provided that the comparability of the results is demonstrated. It can leave a considerable amount of stress along the cut edges [6].

When a test specimen is being cut, the edge of the parent strip is taken as the reference direction. The angle between the reference direction and the cutting direction shall be within ±1°.

4.3 Test apparatus

4.3.1 General

The components of the test apparatus shall be assembled with minimal misalignment in order to prevent measurement offsets. In particular, the flatness of the surface on which the test specimen is placed shall be ensured.

In order to prevent resonance with the harmonic components of magnetostriction strain, the test apparatus shall be free from natural frequencies between 50 Hz and 1 000 Hz (see Clause A.7).

4.3.2 Yoke

The yoke should have a low residual magnetization and a low reluctance. The yoke shall be fixed to the test apparatus so that the two pole faces are in the same horizontal plane.

NOTE 1 That the two pole faces are in the same horizontal plane can be confirmed by the fact that when a liquid such as alcohol is dropped on the pole faces and the glass plate is placed on top, a thin film of the liquid spreads uniformly over the entire pole faces. A difference in height and/or an inclination between the two pole faces can cause deformation of the bridge strip and measurement offsets (see Clause A.6).

NOTE 2 Due to the elastic deformability of the yoke, the two pole faces can be no longer in the same plane depending on how the yoke is fixed, even if the yoke alone was processed so that the two pole faces are in the same plane.

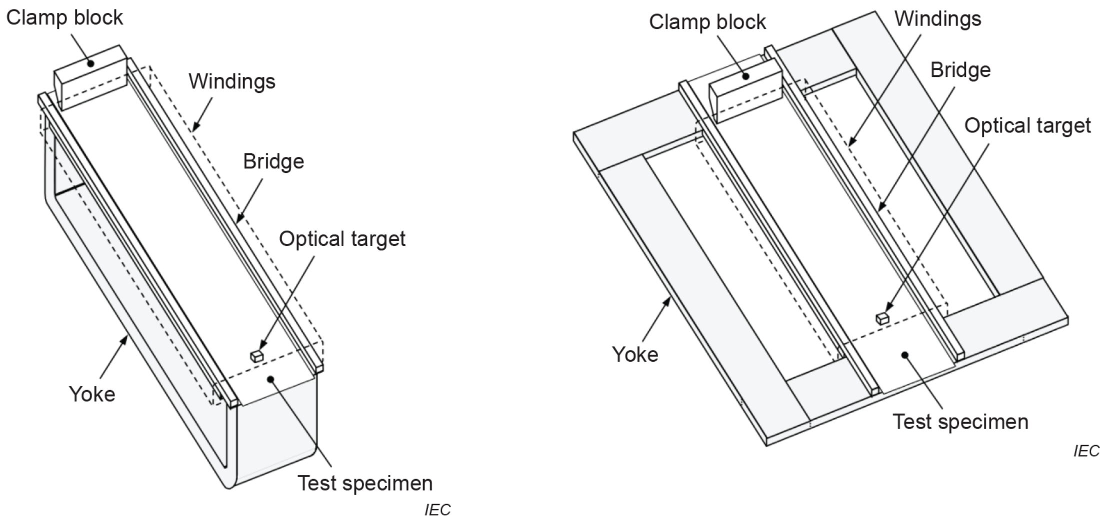
Care shall be taken to avoid a deterioration of the magnetic properties of the yoke due to excessive stress and to prevent vibration of the yoke during magnetization. The yoke should be fixed rigidly to the vibration-free table, or the rigid base plate, at points close to the pole faces so that it will not be displaced by the clamping force. The outside dimension of the yoke along the axis of the winding former shall be slightly shorter than 500 mm; between 494 mm and 496 mm is recommended.

The yoke may be a vertical single yoke or a horizontal double yoke (see Figure 3). Other types of yoke may be used provided that no stress is applied to the test specimen due to the yoke, and that the comparability of the results is demonstrated.

The vertical yoke shall have two pole faces having a length of 25 mm ± 1 mm along the axis of the winding former and a width between 105 mm and 110 mm. The height of the yoke shall be between 80 mm and 90 mm.

The horizontal yoke shall have two pole faces having a length between 50 mm and 60 mm along the axis of the winding former and a width between 400 mm and 500 mm. The height of the yoke shall be around 10 mm.

Other dimensions of the yoke may be applicable provided that the comparability of the results is demonstrated.



(a) Vertical single yoke **(b) Horizontal double yoke**

Figure 3 – Schematic diagram of test frames with different types of yoke

NOTE 3 It was confirmed by experiments that the difference in measurement results when a vertical yoke is replaced with a horizontal yoke is sufficiently small in comparison to the reproducibility of the measurement required in this document [3].

The yoke may be made of a glued stack or a C-core of high permeability grain-oriented electrical steel sheets. In the case of the glued stack, the corners shall have staggered butt joints. In the case of horizontal yoke, the sheets should be laminated on a flat plate with sparsely distributed particles of glue on one side of each sheet to minimise stress introduction caused by the gluing.

The yoke shall be carefully demagnetized before use. For the demagnetization of the yoke, an exciting winding shall be wound around the yoke. The demagnetization shall be made without the test specimen in the test apparatus and by slowly decreasing an AC current flowing through the exciting winding to zero, starting from the current that produces a magnetic field in the yoke well above the knee of the magnetization curve of the yoke material. The demagnetized state can be verified by whether the positive and negative peak values of the magnetization current of the test specimen match at the measurement of magnetostriction (see Clause A.3). In the case of the vertical single yoke, a flux closure of the same dimensions as the yoke, e.g. the upper yoke, should be put on the two pole faces during the demagnetization.

NOTE 4 The residual magnetization of the yoke can cause asymmetrical butterfly loops and thus cause measuring offsets.

A vertical double yoke may be applicable provided that the upper yoke does not affect the length change of the test specimen and does not disturb the laser beam path between the optical sensor and the optical target.

NOTE 5 The vertical double yoke is suitable for general loss measurements by the magnetizing current method provided that the bridge is removed and the upper and lower yokes are in contact with the test specimen. The H coil method using an H coil embedded in the bridge inside the secondary winding enables simultaneous measurements of magnetostriction and loss regardless of the yoke type. For the H coil method, see IEC 60404-16:2018 [7].

4.3.3 Windings

The primary and secondary windings shall be wound around the winding former. The winding former shall be non-conducting and non-magnetic. The dimensions of the winding former shall be as follows (see Figure 4):

- length: as long as possible between the two pole faces;
- internal width: wider than the width of the bridge, 120 mm is recommended;
- internal height: higher than the height of the bridge, 15 mm is recommended;
- external height: ≤ 20 mm.