
British Standard

Magnetic materials

Part 2. Methods of measurement of magnetic, electrical and physical properties of magnetic sheet and strip

Matériaux magnétiques

Partie 2. Méthodes de mesurage des propriétés magnétiques, électriques et physiques des tôles et bandes magnétiques

Magnetische Werkstoffe

Teil 2. Verfahren zur Messung der magnetischen, elektrischen und physikalischen Eigenschaften von magnetischen Blechen und Bändern

Foreword

This Part of BS 6404 has been prepared under the direction of the Iron and Steel and Non-Ferrous Metals Standards Committees and is technically equivalent to IEC 404-2 : 1978, published by the International Electrotechnical Commission (IEC). One additional test method is described in this British Standard. This test method is based on method A for the measurement of insulation characteristics which was previously described in BS 601 : Part 5 and is now mentioned in this British Standard in chapter 8 and described in appendix D under the heading of 'Dual electrode (double sided) method'.

This Part of BS 6404 supersedes BS 601 : Part 5 which is withdrawn. The essential differences between this British Standard and BS 601 : Part 5 are as follows.

- (a) The second method for the compensation of air flux when using the Epstein square for determining a.c. magnetic properties and used by all countries is described in this British Standard, the first method given previously in BS 601 : Part 5 and used only in the United Kingdom has been omitted.
- (b) Similarly, reference to the modified Heidweiller bridge used for measurement of specific total loss by bridge methods has been omitted.
- (c) A method for the determination of the density of magnetic sheet and strip and a method for the determination of the resistivity of magnetic sheet and strip have been included.

For ease of production the text of the IEC publication has been used; some terminology and certain conventions are not the same as those used in British Standards.

The following Parts of BS 6404 have been published.

Part 1 Classification

Part 2 Methods of measurement of magnetic, electrical and physical properties of magnetic sheet and strip

Part 3 Methods of measurement of specific total losses of magnetic sheet and strip by means of a single sheet tester (identical with IEC 404-3: 1982).

Additional Parts of IEC 404 will be published and are expected to provide a basis for additional Parts of this British Standard.

Compliance with a British Standard does not of itself confer immunity from legal obligations.



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Magnetic materials
Part 2. Methods of measurement of magnetic, electrical
and physical properties of magnetic sheet and strip

Revised text

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Clause D.3.1 Contact assembly

After paragraph 3, insert the following:

**Note—* The test specimens should be supported on a platform surrounding the lower electrode. The platform should be in the same plane as the top surface of the lower electrode when the electrode is subjected to the specified pressure.'

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British Standard

Magnetic materials

Part 2. Methods of measurement of magnetic, electrical
and physical properties of magnetic sheet and strip

1. Scope and object

This standard is applicable to magnetic steel sheet and strip for the construction of magnetic circuits.

Its object is to define terms and specify methods for the measurement of magnetic, electrical and physical properties of magnetic sheet and strip.

Note. — The titles of the publications referred to in this standard are listed on the inside back cover.

2. Accuracy and reproducibility

In the case of several of the test methods described in this standard it is not always possible to refer to fundamental principles.

The final accuracy of the test apparatus is a complex function dependent on the measuring instruments and other features of the measuring environment and equipment components; therefore it is not always possible to state the absolute accuracy which can be attained.

Moreover, experience in the use of a given method indicates the reproducibility which can be expected. Whenever the drafting technical committee has agreed upon reproducibility values, these have been given in this standard.

CHAPTER I: GENERAL CONDITIONS FOR A.C. MEASUREMENTS MADE WITH THE 25 CM EPSTEIN FRAME

3. Object

The object of this chapter is to define the general conditions for the determination of a.c. magnetic properties of sheet by means of the 25 cm Epstein frame.

4. Field of application

The use of the 25 cm Epstein frame is applicable to flat strip specimens obtained from magnetic sheets and strips of any quality.

The frequency of measurement is specified for each particular method. Magnetic characteristics must be determined for a sinusoidal induced voltage.

The measurements are made at an ambient temperature of $23 \pm 5^{\circ}\text{C}$ on test specimens which have first been demagnetized.

5. Principle of the 25 cm Epstein frame method

The 25 cm Epstein frame which comprises a primary winding, a secondary winding and the specimen to be tested as a core, forms an unloaded transformer whose characteristics are measured by one of the methods described in the following chapters.

6. Test specimen

The magnetic circuit is made up of a core constructed with the strips to be tested, assembled in a square having double-lapped joints (see Figure 1) to form four branches of equal length and equal cross-sectional area.

The strips are sampled in accordance with product standards*.

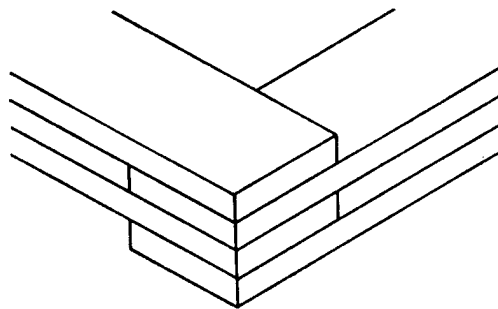


FIG. 1. — Double-lapped joints.

* Under consideration.

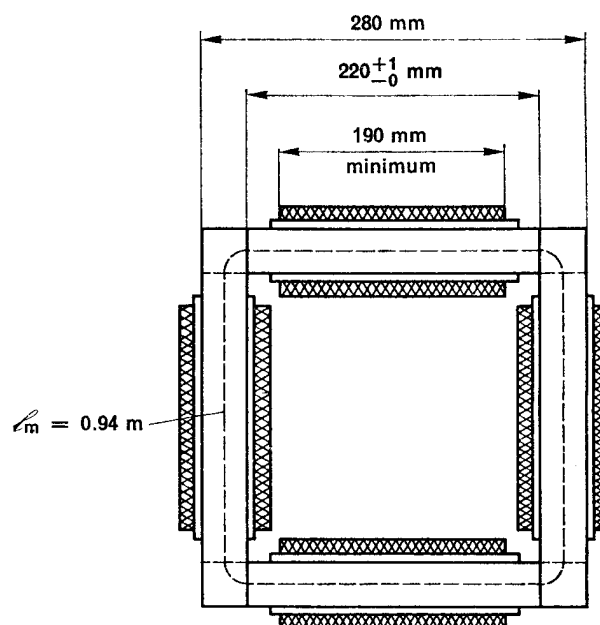


FIG. 2. — 25 cm Epstein frame.

They shall be cut by a method which will produce clean burr-free edges. They shall have the following dimensions:

- width $b = 30 \pm 0.2$ mm;
- length $280 \text{ mm} \leq l \leq 500 \text{ mm}$, the length of the strip is measured with a tolerance of ± 0.5 mm.

For strips of greater length than 305 mm, care shall be taken to avoid the bending of the strips during the test.

When the strips are cut parallel or normal to the direction of rolling, the edge of the parent sheet is taken as the reference direction.

The following tolerances will be allowed for the angle between the direction of rolling and that of cutting:

- $\pm 1^\circ$ for grain-oriented steel sheet;
- $\pm 5^\circ$ for non-oriented steel sheet.

Only flat strips shall be used. Measurements are to be made without additional insulation.

The number of strips forming a test specimen shall be not less than twelve and shall be a multiple of four. It is permissible to apply a force of about 1 N to each corner, normal to the plane of the overlapping strips.

7. 25 cm Epstein frame

The 25 cm Epstein frame (hereafter referred to as “Epstein frame”) consists of four solenoids into which the test specimen strips are introduced in such a manner that a closed magnetic circuit is formed (see Figure 2).

A mutual inductor for air flux compensation completes this test set-up (Appendix A).

The winding formers supporting the solenoids are made of hard insulating material, such as phenolic-paper, and have a rectangular cross-section of 32 mm inner width. A height of about 10 mm will be sufficient and is recommended.

The solenoids are mounted on a non-conductive and non-magnetic base plate in a square arrangement. Each side of the inner square formed by the test specimen strips shall have a length of $220 \pm \frac{1}{0}$ mm (Figure 2).

In order to avoid undue wear of the winding formers and especially of their inner surfaces, winding formers of larger cross section may be used into which replaceable liners of appropriate dimensions may be inserted.

Each solenoid comprises two windings:

- a primary outer winding (magnetising winding);
- a secondary inner winding (voltage winding).

An electrostatic screen may be provided between these windings.

The windings on each solenoid shall be evenly distributed over a length of at least 190 mm, with each solenoid carrying one fourth of the total number of turns. The individual primary windings of the four solenoids are connected in series, and the secondary individual windings are connected in a similar fashion.

The number of turns of the primary and secondary windings may be chosen to suit the particular conditions of the power supply, instrumentation and measuring frequency. It is not advisable to use a small number of turns for either the primary or secondary winding. Totals of 700 or 1 000 turns are recommended and are commonly used for tests in the frequency range 50 Hz to 400 Hz. For testing at higher frequencies, a reduced number of turns is used.

In order to make the impedances of the windings sufficiently small to minimize waveform distortion and internal voltage drops, the following requirements should be met:

$$\begin{aligned} \frac{R_1}{N_1^2} &\leq 1.25 \cdot 10^{-6} \Omega & \frac{R_2}{N_2^2} &\leq 5 \cdot 10^{-6} \Omega \\ \frac{L_1}{N_1^2} &\leq 2.5 \cdot 10^{-9} \text{ H} & \frac{L_2}{N_2^2} &\leq 2.5 \cdot 10^{-9} \text{ H} \end{aligned}$$

R_1, R_2 = resistance values of the primary and secondary windings, respectively, in ohms

L_1, L_2 = inductance values of the primary and secondary windings, respectively, without the sample in place, in henrys

N_1, N_2 = total number of turns of the primary and secondary windings, respectively

These requirements are complied with, for instance, by the use of windings with the following characteristics:

Total number of turns: $N_1 = 700, N_2 = 700$.

Primary (outer) winding: Each solenoid wound with 175 turns of two copper wires of 1.8 mm² cross-sectional area, wound side by side in three layers and connected in parallel.

Secondary (inner) winding: Each solenoid wound with 175 turns of copper wire of 0.8 mm² cross-sectional area, wound in one layer.

The effective length ℓ_m of the magnetic path in this test equipment is conventionally taken as 0.94 m.

Consequently, the effective mass, i.e. the magnetically active mass of the test specimen, is given by the equation:

$$m_a = \frac{\ell_m}{4\ell} \cdot m \quad (1)$$

m_a = effective mass of test specimen, in kilogrammes

m = total mass of test specimen, in kilogrammes

ℓ_m = conventional effective magnetic path length, in metres

ℓ = length of a test specimen strip, in metres

8. Air flux compensation

The mutual inductor for air flux compensation (Appendix A) is located in the centre of the space enclosed by the four solenoids, its axis being directed normal to the plane of the latter. The windings of the mutual inductor shall be connected in series with the corresponding windings of the Epstein frame.

As described in Appendix A, the mutual inductance of the compensator shall be adjusted to be the same as that of the windings of the empty Epstein frame. Thus when the windings are properly connected, the voltage induced in the secondary winding of the mutual inductor by the primary current will compensate for the voltage induced in the secondary winding of the empty Epstein frame by the flux attributed to the primary current.

9. Power supply

The source shall be of low internal impedance and shall be highly stable in terms of voltage and frequency. During the measurement, the variation of voltage and the variation of frequency shall not exceed $\pm 0.2\%$ of the specified value. In addition, the waveform of the secondary induced voltage shall be maintained as sinusoidal as possible.

It is preferable to maintain the form factor of the secondary voltage within $\pm 1\%$ of 1.111 (this may be achieved by various means, e.g. electronic feedback amplifiers). If this condition cannot be maintained, it is permitted to make corrections to the loss measurement for deviation in form factor of up to a maximum of $\pm 5\%$. The formula for correcting watt loss is derived from the following equation:

$$P_t = P_h + P_p \left(\frac{F}{1.111} \right)^2 \quad (2)$$

P_t = measured loss, in watts per kilogramme

P_h = apparent hysteresis loss, in watts per kilogramme

P_p = apparent eddy loss for sine flux conditions, in watts per kilogramme

F = measured form factor

The corrected loss may be obtained most precisely with:

$$P_s = \frac{P_t}{P_h / P_s + (P_p / P_s) \cdot \left(\frac{F}{1.111} \right)^2} \quad (3)$$

but a result of sufficient accuracy can be obtained from the approximate formula:

$$\Delta P = 2 \left(\frac{P_p}{P_s} \right) \left(\frac{\Delta F}{1.111} \right) P_t \quad (4)$$

P_s = loss for sine flux conditions, in watts per kilogramme

P_t = measured loss, in watts per kilogramme

$\frac{P_h}{P_s}$ = proportion of hysteresis losses

$\frac{P_p}{P_s}$ = proportion of eddy losses

ΔP = change in watt loss due to waveform distortion, in watts per kilogramme

The conventional values of proportions of hysteresis and eddy losses are commonly derived for the various thicknesses and classes of commercial materials by the two form factor loss separation procedure.

The form factor of the secondary voltage is the quotient of the r.m.s. value and the average rectified value. The former is measured by an r.m.s. voltmeter, such as a moving iron instrument, and the latter by an average voltmeter, such as a rectifier-type instrument.

Note. — When a negative feedback amplifier is used for the supply it may be necessary to observe the waveform of the secondary induced voltage on an oscilloscope to ensure that fundamental frequency waveform is being produced.

10. Magnetic flux density limits

In each measuring method described in the following chapters, the magnetic flux density limits which typically have been found to ensure validity of test are specified. These limits depend upon the quality of the steel, the characteristics of the source, the instrumentation, the Epstein frame, and the mutual inductor used for air flux compensation, etc. To permit valid testing, it is essential that the induced voltage waveform shall be maintained sinusoidal (see Clause 9). In no case should the form factor of the induced voltage deviate from that of a sinusoidal voltage by more than $\pm 5\%$.

CHAPTER II: DETERMINATION OF SPECIFIC TOTAL LOSSES BY THE WATTMETER METHOD

11. Object

The object of this chapter is to define the wattmeter method for the determination of the specific total losses of magnetic sheet and strip.

12. Field of application

The specific total losses are determined, according to this method, for specified peak values of magnetic flux density and for a specified frequency.

In order to obtain comparable results, test values must be referred to magnetic flux density of sinusoidal waveform. Consequently, non-oriented sheet is generally measurable up to a magnetic flux density of $\hat{B} = 1.5$ T, and grain-oriented sheet up to $\hat{B} = 1.8$ T (see Clauses 9 and 10).

Measurements are made preferably within a frequency range of 15 Hz to 100 Hz. If suitable instruments are used, the upper limit may be raised.

13. Test specimen

Test specimen strips complying with the specifications of Clause 6 are used for the measurements.

14. Principle of measurement

The 25 cm Epstein frame with the test specimen represents an unloaded transformer whose total losses are measured by the wattmeter method in the circuit shown in Figure 3 which illustrates the principle.

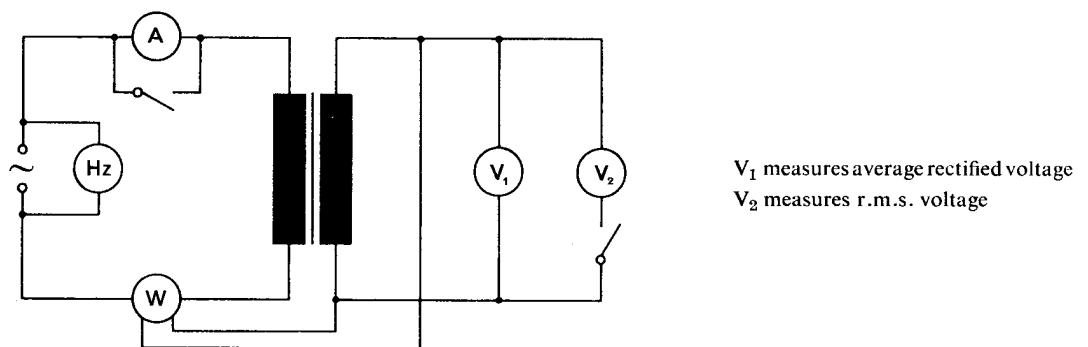


FIG. 3. — Circuit for the wattmeter method.

In order to prevent the Joule losses and the voltage drop in the primary winding from influencing the measurement, the voltmeter and the voltage circuit of the wattmeter are connected to the secondary winding.

Note. — For simplicity, the mutual inductor used for air flux compensation is not shown in Figure 3 and subsequent diagrams.

15. Power supply

The general specifications of power supply in Clause 9 should be followed.

16. Apparatus

16.1 Voltage measurement

16.1.1 Average type voltmeter

The average value of the secondary rectified voltage of the Epstein frame is measured by an average type voltmeter of class 0.5 or better (for instrument classes see BS 89 for Direct Acting Indicating Electrical Measuring Instruments and Their Accessories).

Note. — Instruments of this type are usually graduated in average rectified value multiplied by 1.111.

Electronic voltmeters can also be used.

The load on the secondary circuit of the network should be as small as possible. Consequently, the internal resistance of the average type voltmeter should be at least 1 000 Ω/V .

An amplifier with input impedance greater than or equal to 1 000 Ω/V may be used, if the total accuracy of the apparatus (including measuring instrument) is equivalent to that of a voltmeter of class 0.5 or better.

16.1.2 R.M.S. voltmeter

A voltmeter of accuracy class 0.5 or better, responsive to r.m.s. values shall be used.

16.2 Current measurement

The primary current may be measured by a class 1 ammeter or better of low impedance. In such a case the ammeter should be short-circuited when the secondary voltage is adjusted and the losses are measured.

16.3 Frequency measurement

A frequency meter of class 0.5 or better is required. An instrument of class 0.2 is indicated when the aim is high accuracy measurement.

16.4 Power measurement

Power is measured by a highly sensitive wattmeter of class 0.5 or better, suitable for circuits of low power factor ($\cos \varphi = 0.1$ or 0.2). Readings in the first quarter of the scale should be avoided as far as possible.

The resistance of the voltage circuit of the wattmeter should be greater than or equal to 100 Ω/V for all ranges. If necessary the losses in the secondary circuit should be subtracted from the indicated loss value. A suitable electronic wattmeter can be used.

Moreover, the ohmic resistance of the voltage circuit should be at least 5 000 times the reactance, unless the wattmeter is compensated for the latter. Thus, corrections of phase angle are avoided. Where appropriate, to meet the specification of the wattmeter in respect of the voltage between current and voltage coils, the primary and secondary windings of the square may be joined.

17. Measuring procedure

17.1 Preparation for measurement

The test specimen is weighed and its mass determined within $\pm 0.1\%$. After weighing, the strips are stacked into the solenoids of the Epstein frame with double-lapped joints at the corners. In the case of strips which are cut half in the direction of rolling and half normal to that direction, care shall be taken that all the strips cut in the direction of rolling are placed in two opposite arms of the frame and that those cut normal to that direction are placed in the two other opposite arms. The joints shall form a minimum gap between the strips. The strips shall be positioned so as to conform with the requirements of Clause 7. The number of strips shall be the same in each solenoid.

Before measurement, the test specimen should be demagnetized by a decreasing alternating magnetic field.

17.2 Source setting

The source is adjusted so that the average rectified value of the secondary voltage is:

$$\bar{U}_2 = 4fN_2 \left(\frac{R_1}{R_1 + R_t} \right) A \hat{B}_1 \quad (5)$$

$\bar{U}_2$ = average value of secondary rectified voltage, in volts

f = frequency, in hertz

R_1 = combined resistance of instruments in the secondary circuit, in ohms

R_t = series resistance of the secondary windings of Epstein frame and mutual inductor, in ohms

N_2 = number of turns of the secondary winding

A = cross-section of test specimen, in square metres

$\hat{B}_1$ = peak value of intrinsic magnetic flux density, in teslas

The cross-section A is obtained by the equation:

$$A = \frac{m}{4\ell \rho_m} \quad (6)$$

m = total mass of test specimen, in kilogrammes

ℓ = length of a test specimen strip, in metres

ρ_m = density of the test material, in kilogrammes per cubic metre

(some methods of determining density are detailed in Chapter VI).

17.3 Measurements

The ammeter in the primary circuit is observed to ensure that the current circuit of the wattmeter is not overloaded. Then the ammeter is short-circuited and the secondary voltage readjusted. After checking the waveform of the secondary voltage in compliance with Clause 9, the wattmeter is read.

18. Determination of specific total losses

The power P_m measured by the wattmeter includes the power consumed by the instruments in the secondary circuit, which to a *first approximation* is equal to $(1.111 |\bar{U}_2|^2)/R_1$ since the secondary voltage is essentially sinusoidal.