

Magnetic materials —

Part 4: Methods of measurement of the d.c. magnetic properties of solid steels

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of the d.c. magnetic properties of solid steels]

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- Institute of Physics
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National foreword

This Part of BS 6404 has been prepared under the direction of the Iron and Steel and Non-ferrous Metals Standards Committees. It is identical with IEC Publication 404-4:1982 “*Magnetic materials. Part 4: Methods of measurement of the d.c. magnetic properties of solid steels*” published by the International Electrotechnical Commission (IEC).

The methods described in this Part of BS 6404 are, apart from some minor differences in detail, included in the current edition of BS 5884. The current edition of BS 5884 also describes methods of test for the measurement of the magnetic properties of magnetically hard (permanent magnet) materials and methods of test for the measurement of the coercivity of magnetic materials in an open magnetic circuit. These additional methods of test are now the subjects of BS 6404-5¹⁾ and BS 6404-7 respectively, which are identical with IEC Publications 404-5:1982 and 404-7:1982, respectively.

BS 5884 will be revised to include only the remaining methods described in the current edition, namely test methods for the determination of the relative magnetic permeability of feebly magnetic materials.

This Part of BS 6404 is the fourth Part of a series of British Standards based on the IEC series “Magnetic materials”.

The Part numbers of the British Standard follow the Parts of the IEC publication. The following Parts of BS 6404 have been published or are being prepared for publication.

- *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;*
- *Part 5: Methods of measurement of the magnetic properties of magnetically hard (permanent magnet) materials¹⁾;*
- *Part 7: Method of measurement of the coercivity of magnetic materials in an open magnetic circuit;*
- *Part 8: Individual materials;*
 - *Section 8.2: Specification for cold-rolled magnetic, non-oriented, alloyed steel strip delivered in the semi-processed state;*
 - *Section 8.3: Specification for cold-rolled magnetic, non-oriented, non-alloyed steel strip delivered in the semi-processed state.*

Additional Parts of IEC 404 will be published and are expected to provide the basis for additional Parts of BS 6404.

Terminology and conventions. The text of the International Standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards; attention is drawn especially to the following.

¹⁾ In preparation.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 21 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

1 Scope and object

The object of this standard is to describe the terminology and to specify the methods of measuring the d.c. magnetic properties of solid steels. Examples of solid steels are: bars of substantial thickness, cast or forged solid steels as defined under references C1 and D1 of the classification document.

Two methods are used:

- a) the ring method particularly for magnetic field strengths of less than 5 kA/m;
- b) the permeameter method. Different permeameters are used according to the range of the magnetic field strength;
 - the NPL (National Physical Laboratory) type permeameter for field strengths of between 2 kA/m and 200 kA/m;
 - the Iliovici permeameter for field strengths of between 2 kA/m and 40 kA/m;
 - the MH (Medium H) permeameter for field strengths of between 2 kA/m and 24 kA/m;
 - the Sanford-Bennett (High H) permeameter for field strengths of between 8 kA/m and 400 kA/m.

NOTE The methods described in this standard are test methods in which the test specimen is in a closed magnetic circuit. Methods in which the test specimen is in an open magnetic circuit are existing.

2 Reproducibility

The ultimate accuracy of test equipment is a complex function dependent upon measuring instruments and other characteristics of measuring conditions and equipment; it is therefore not always possible to state the absolute accuracy that is attainable. Particularly in the permeameter methods: shape parameters, end effects, corner effects, variations in path length and cross-section, as well as hysteresis characteristics of the yokes can cause substantially different test results to be obtained when specimens from an identical batch of material are prepared and tested in the various permeameters. The best use of any apparatus is where these error factors can be limited to tolerable values. Usually that occurs where coercivity is reasonably large (> 1 kA/m) or at inductions above those corresponding to maximum permeability in the test specimen.

As the result of the measurements is affected by changes in temperature, precautions must be taken to avoid heating the test specimen. The acceptable temperature shall be specified.

For a known method, experience shows the reproducibility or the size of the measurement error that can be expected. This error depends upon the estimated errors of the measuring instruments. The total measurement error of the measurement of the magnetic flux density or the magnetic field strength normally expected for the different methods is less than or equal to $\pm 2\%$ when using measuring instruments whose estimated measuring error is less than or equal to $\pm 1\%$.

Chapter I. Determination of the magnetic characteristics by the ring method

3 General

3.1 Object

This chapter describes the ring method used to obtain the normal magnetization curve and the hysteresis loop.

3.2 Field of application

This method is used particularly for magnetic field strengths of less than 5 kA/m. However if care is taken to avoid heating the test specimen, this method may be used at higher magnetic field strengths.

3.3 Test specimen

The test specimen is a homogeneous unwelded ring of rectangular or circular cross-section. The cross-sectional area of the ring will be determined by the product dimensions, uniformity of magnetic properties, instrumentation sensitivity and space required for the test windings. Usually the cross-sectional area will be in the range of 100 mm² to 500 mm².

Care shall be taken in the machining of the test specimen to avoid work hardening of the material and hence alteration of the magnetic characteristics. The test specimen may be prepared by turning and finished by light grinding with sufficient coolant to prevent heating the material. The edges of the ring shall be deburred.

To reduce the effect of the radial variation of the magnetic field strength, the following relationship shall apply:

$$D \leq 1.1 d \quad (1)$$

where:

D = outside diameter of test specimen, in metres

d = inside diameter of test specimen, in metres

The dimensions of the test specimen shall be determined by measuring the outside and inside diameters of the ring together with the height or diameter using a suitable micrometer or vernier gauge. The mean cross-sectional area shall be calculated with an uncertainty of $\pm 0.5\%$ or better.

The mean magnetic path length of the test specimen shall also be calculated with an uncertainty of $\pm 0.5\%$ or better from the relationship:

$$L = \pi \frac{D + d}{2} \quad (2)$$

where:

L = mean magnetic path length of test specimen, in metres

3.4 Windings

Before winding, a connection shall be made to the core in order to check the insulation of the windings and then the ring should be overlaid with a thin layer of insulating material.

Firstly, a secondary winding of insulated copper wire shall be wound evenly round the core. The dimensions of the secondary winding shall be measured with a micrometer and the mean cross-sectional area, A_s , of the secondary winding is calculated.

A magnetizing winding of wire capable of carrying the maximum magnetizing current and of a sufficient number of turns to produce the maximum required magnetic field strength shall be evenly wound in one or more layers on the core. The magnetizing winding may consist of:

- a large number of turns of a single conductor applied closely and uniformly round the whole ring, or
- a smaller number of turns of a multicore cable applied closely and uniformly round the whole ring, the ends of the conductors in the individual cores being interconnected to give the effect of one multilayer winding, or
- an arrangement of rigid, or part rigid and part flexible, conductors which can be opened to admit the ring (carrying the secondary winding and insulation) and then closed to form a uniformly wound toroid round the ring.

If necessary, the wound ring is immersed in an oil bath or subjected to an air blast in order to cool it.

NOTE If the above arrangements are used with an uniformly distributed secondary winding, an error, which may be present in any ring test, is liable to be magnified and to become of considerable importance. This error arises from the fact that, in winding a ring specimen toroidally, an effective circular turn of diameter equal to the mean diameter of the ring is produced.

The flux between the effective circular turns of the magnetizing winding and secondary winding, associated with flux parallel to the axis of the ring, is added to, or subtracted from the circumferential flux. When a multiconductor cable is used for the magnetizing winding, the number of turns in the primary of this supplementary mutual inductance is increased in proportion to the number of cores, and the error from this source, particularly at high field-strengths where the permeability of the iron is reduced, may amount to several percent. To eliminate this error a turn may be wound back on the secondary winding along the mean circumference of the ring, or, preferably, the magnetizing cable should be wound in pairs of layers, alternate layers being wound clockwise and anti-clockwise around the ring.

4 Methods of measurement

4.1 Magnetic field strength

The magnetizing current shall be measured with an ammeter.

The magnetic field strength shall be calculated from the following relationship:

$$H = \frac{N_1 I}{L} \quad (3)$$

where:

H = magnetic field strength, in amperes per metre

N_1 = number of turns of magnetizing winding of the ring

L = mean magnetic path length, in metres

I = magnetizing current, in amperes

4.2 Magnetic flux density

The secondary winding (B coil) shall be connected to a flux integrator²⁾, the calibration of which shall be established in accordance with one of the procedures given in Appendix A.

Provided that the secondary winding is wound closely on the test specimen, the air flux included in the secondary winding over the range of magnetic field strength 0 to 4 kA/m will be insignificant and no correction need be applied. At higher values of magnetic field strength, an air flux correction shall be applied in accordance with equation 8.

4.3 Connection apparatus

The apparatus is connected as shown in Figure 1, page 15.

A source of direct current E (battery or stabilized d.c. supply) is connected through ammeter A , reversing switch S_1 and changeover switch S_4 to the magnetizing winding N_1 on the ring specimen. With switch S_5 closed, the current in the magnetizing circuit is controlled by resistor R_1 . This is the arrangement of the magnetizing circuit for the determination of the normal induction curve and for the measurement of the tips of hysteresis loops. Switch S_5 , together with resistor R_5 , is used in the determination of the complete hysteresis loop.

The secondary circuit comprises the secondary winding N_2 (B coil) connected to the flux integrator F through resistor R_2 (sensitivity control). Resistor R_4 is a shunt control required with some types of flux integrator.

4.4 Determination of normal magnetization curve

The specimen shall be carefully demagnetized from a magnetic field strength of not less than 5 kA/m by the slow reversal of a gradually reducing direct current. Test specimens which have been subjected to a higher magnetic field strength shall be demagnetized from a suitably high field before test (for example when machined using a magnetic chuck).

NOTE In order that the magnetic field may completely penetrate the test specimen, the duration of reversal should be greater than 2 s for a cross-section 10 mm × 10 mm and 10 s for a cross-section 20 mm × 20 mm.

With switch S_5 closed and changeover switch S_4 in position 1, the flux integrator shall be calibrated as described in Appendix A. Then changeover switch S_4 shall be closed in position 2 and a small current corresponding to a small magnetic field strength (see equation 3) passed through the magnetizing winding N_1 . The current shall be reversed about 10 times by means of reversing switch S_1 to bring the material into a steady cyclic state. Switch S_2 may be closed during this operation to maintain the flux integrator at zero. With switch S_2 open the flux integrator reading corresponding to the reversal of the magnetizing field shall be recorded and the corresponding magnetic flux density shall be calculated.

By successively increasing the magnetizing current and repeating this procedure, corresponding values of magnetic field strength and magnetic flux density may be obtained from which a normal induction curve may be plotted.

NOTE The magnetizing current must never be decreased during the measurements otherwise the test specimen must be demagnetized before resuming measurements.

4.5 Determination of a complete hysteresis loop

The test specimen shall be demagnetized and the tip points of the hysteresis loop shall be determined by measuring the corresponding values of magnetic field strength and magnetic flux density in accordance with Sub-clause 4.4.

Portion PQ of the hysteresis loop (see Figure 2, page 15) is then determined with switch S_1 closed in position 1 by opening switch S_5 , and measuring the corresponding magnetic field strength and change in magnetic flux density. By adjusting resistor R_5 a number of points on the curve PQ can be obtained. The point Q is obtained with switch S_5 closed and measuring the change in magnetic flux density when opening switch S_1 .

The value of the magnetic field strength at each point is calculated from the corresponding measured value of current flowing (see equation 3).

The value of the magnetic flux density at each point is calculated from the following relationship:

$$B_{P'} = B_P - \Delta B \quad (4)$$

where:

$B_{P'}$ = magnetic flux density at the point P' on curve PQ, in teslas

B_P = magnetic flux density at tip of hysteresis loop, in teslas

²⁾ The flux integrator may be a ballistic galvanometer, fluxmeter or electronic charge integrator.