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British Standard

Cores for inductors and transformers for telecommunications

Part 1. Methods of measurement

Noyaux pour bobines d'inductance et transformateurs destinés aux télécommunications
Partie 1. Méthodes de mesure

Kerne für Induktoren und Transformatoren der Fernmeldtechnik
Teil 1. Messverfahren

National foreword

This Part of this British Standard has been prepared under the direction of the Electronic Components Standards Committee. It is identical with the second edition of IEC Publication 367-1 'Cores for inductors and transformers for telecommunications' Part 1 'Measuring methods', published in 1982 by the International Electrotechnical Commission (IEC). The international text embodies IEC 367-1 of 1971, and its supplements 1A to 1F inclusive, which were incorporated in the first edition of the British Standard, together with the new measuring methods of clause 16 'Magnetic properties under pulse conditions', and clause 17 '(Effective) Amplitude permeability'. BS 5938 : Part 1 : 1980 is withdrawn.

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.

Wherever page numbers are quoted, they are IEC page numbers.

Clause 1, 'Scope' and clause 2, 'Object' are not presented in a manner that is customary in British Standards. For the purposes of this British Standard, the text of clause 1, together with paragraph 1 of clause 2, should be read as the following, which makes no change in the technical meaning.

'Scope

This Part of this British Standard gives guidance on the drafting of those parts of specifications for magnetic cores that are concerned with measuring methods for magnetic and electric core properties.

The cores covered by this standard are made primarily of magnetic oxides or metallic powders and used in inductors and transformers for telecommunication equipment and electronic devices employing similar techniques.

This standard is limited to the general principles to be followed for various possible test methods, and it sets out the factors to be taken into account when deciding on the description of the test method to be included in the specification.'

Cross-references

International standards	Corresponding British Standards
IEC 51 : 1973	BS 89 : 1977 Specification for direct acting electrical measuring instruments and their accessories (Identical)
IEC 68	BS 2011 Basic environmental testing procedures
IEC 68-2-1 : 1974	Part 2.1A : 1977 Tests A. Cold (Identical)
IEC 68-2-2 : 1974	Part 2.1B : 1977 Tests B. Dry heat (Identical)
IEC 205 : 1966	BS 6454 : 1983 Method for calculation of the effective parameters of magnetic piece parts (Identical)

The Technical Committee has reviewed the provisions of IEC 317-2 : 1970, to which reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard.

The related British Standard for IEC 317-2 : 1970 is BS 4738 : Part 1 : 1971.

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

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British Standard

Cores for inductors and transformers for telecommunications

Part 1. Methods of measurement

1. Scope

This standard applies to magnetic cores, mainly made of magnetic oxides or metallic powders, used in inductors and transformers for telecommunication equipment and electronic devices employing similar techniques.

Some of the methods described in this standard may also be suitable for magnetic cores used in other components.

2. Object

To give guidance for the drafting of those parts of specifications for magnetic cores that are concerned with measuring methods for magnetic and electric core properties. This standard is limited to the general principles to be followed for various possible test methods and it sets out the factors to be taken into account when deciding on the description of the test method to be included in the specification.

In accordance with the use made of the measuring methods, this Part 1 has been sub-divided into three sections as follows:

- Section One: General, including general stipulations and methods generally used in combination with measuring methods included in Sections Two and Three;
- Section Two: Common measuring methods, including those methods which are used for important parts of inductor and transformer core measurements;
- Section Three: Specialized measuring methods, including methods intended for information purposes and used only in special cases for specification purposes.

Note. – All formulae in this standard use basic SI units. When multiples or sub-multiples are used, the appropriate power of 10 shall be introduced.

The following standard symbols are used in these formulae:

t	= time
θ	= temperature
L	= self inductance
μ_0	= magnetic constant, $0.4 \pi \times 10^{-6}$ H/m
μ_r	= relative permeability*
μ_i	= initial permeability
μ_e	= effective permeability = $L C_1 / \mu_0 N^2$
μ_{rev}	= reversible permeability
N	= number of turns of measuring coil
C_1 and C_2	= core factors defined in IEC Publication 205: Calculation of the Effective Parameters of Magnetic Piece Parts
A_e	= effective cross-sectional area
ω	= angular frequency = $2 \pi \times$ frequency of measuring current

*In the case of qualified versions of permeability, such as initial permeability μ_i , the relative quantity is meant, unless otherwise stated.

3. Environmental conditions

3.1 General

Normally, the cores are magnetically conditioned in accordance with Clause 6, not less than 24 h before the measurements start.

During the whole procedure, the core shall be protected against mechanical shock and vibration and against magnetic disturbances. Condensation on measuring windings, which may occur at changing temperature, should be avoided.

3.2 Ambient temperature

Unless otherwise specified, the whole measurement procedure shall take place at a temperature within the range of standard atmospheric conditions for testing according to IEC Publication 68: Basic Environmental Testing Procedures. During the whole period of the measurement, however, the temperature shall not vary to such an extent as to have an appreciable effect on its results. In some cases, this may necessitate the use of a temperature controlled chamber.

The assembled cores with measuring coil and clamping devices shall be kept in this environment for a sufficient time to reach thermal equilibrium. The temperature during measurement shall be stated.

Note. – This clause means that the measurements may be made at any temperature within the range of 15 °C to 35 °C but that, if the specified limits are exceeded, it is allowed to repeat the measurements, preferably at $25 \pm 1^\circ\text{C}$ or at one of the other standard temperatures for referee tests: $20 \pm 1^\circ\text{C}$, $23 \pm 1^\circ\text{C}$, or $27 \pm 1^\circ\text{C}$.

4. General precautions for methods involving permeability measurements

4.1 Parameters involved

The effective permeability of a core depends upon many factors, among which are the magnetic history, time, temperature, field strength, mechanical pressure, frequency of measuring current, core geometry and geometry and position of the measuring coil. Various methods described in this standard single out one of these factors at a time, e.g. time or temperature, and the precautions during these measurements should be directed towards eliminating the influence of all other factors. For example, a clamping device should be such that the pressure remains constant in time and with temperature, so that the measuring result is not influenced by changing pressure.

4.2 Relation to practice

The measuring conditions shall be so chosen that the measured results are suitable for predicting the performance of the core under practical circumstances. This does not imply that all conditions have to correspond to those prevailing in practice.

4.3 Mounting of cores consisting of more than one part

For cores consisting of more than one part and which are assembled around the measuring coil, a clamping device shall be used throughout the measurements. This clamping device shall be able to:

- distribute the clamping force uniformly over the contact surfaces, without introducing bending stresses in the core;
- hold the core parts rigidly in position relative to each other;
- give a transient overforce of about 10% when being closed, in order to break down fine irregularities between the cleaned contact surfaces;

- exert a specified clamping force $\pm 5\%$;
- keep the force constant within $\pm 1\%$ during the total period of the measurement.

Note. – Keeping the force within $\pm 1\%$ is considered sufficient when the specified clamping force is chosen in the flat portion of the curve of permeability versus force. Otherwise closer tolerances may be required.

The mounting of such cores shall be done in accordance with the following instructions:

The contact surfaces shall be inspected for damage and cleanliness. Damaged cores shall not be used. When necessary, the contact surfaces shall be cleaned by non-abrasive means, e.g. by rubbing gently on a dry wash-leather.

Dust particles shall be blown off with clean dry compressed gas. The contact surfaces shall never be touched with the bare fingers. The core parts shall then be assembled around the measuring coil, the latter being locked in position with respect to the core by suitable means, e.g. a foam washer. The core parts are centred and the core placed in the clamping device. The clamping force specified in the relevant specification shall then be applied. The clamped cores shall be kept under the specified environmental conditions (see Clause 3) for a time sufficient to allow any variation of effective permeability with time due to clamping to become negligible.

5. General precautions for loss measurement at low flux density

5.1 Contributory losses

At low flux density (i.e. within the Rayleigh region), the loss measured on a core by means of a coil or other coupling device is due to a number of causes; some may be inherent in the core itself, some in the coupling device and some in the connection between the coupling device and the measuring instrument. For measurements with coils, the following contributory losses can be distinguished:

core loss; d.c. coil loss; losses due to skin effect and proximity effect; dielectric loss in the coil; loss in connecting wires and loss in any associated component (e.g. resonating capacitor).

An attempt should be made to isolate the core loss from the total loss measured, either by correction or by choosing the conditions so as to make the other contributory losses negligible. The d.c. coil loss and the loss in any associated component can be measured separately; the other contributory losses may be either calculated or determined experimentally.

The determination of the core loss does not present undue difficulties for ferrite cores without an air-gap or with a very small air-gap (e.g. toroids and pot cores without intentional air-gap) because, with a suitably designed coil, the core loss then is appreciably higher than any other of the contributory losses.

This may not be the case for loss measurement on gapped cores for which it may be difficult to obtain a sufficiently accurate result for the core loss alone.

Two methods may then be followed:

- 1) Measure the loss factor before the air-gap is ground and calculate the loss in the gapped core.

Note. – It is not permissible to measure the loss factor on an ungapped core having a geometry different from that of the gapped core, for example, on a toroid of the same material, since the eddy current core loss strongly depends upon the core geometry.

- 2) Make no attempt to separate core and coil loss but compare the combined loss of the core and the measuring coil with the results obtained from similar measurements of other cores using a coil of identical construction and having the same d.c. resistance.

The best policy is to obtain these measuring coils from the same source and from time to time compare the results of measurements with various coils on the same cores. Furthermore, the measuring results should be accompanied by the d.c. resistance value of the coil; when comparing the results obtained with different coils, the measurements shall be corrected to allow for the difference in coil resistance.

5.2 *Mounting*

Coupling between the stray field of the core and extraneous objects shall be avoided. Connections between the measuring coil or other coupling device and the measuring instrument shall be short, direct and so fixed that movement of the specimen cannot cause additional error.

Cores of more than one part which assemble around the measuring coil shall in general be clamped as specified in Sub-clause 4.3 but the force is not so critical as in the case of inductance measurement.

The positioning of the measuring coil on the core shall be as described in Sub-clause 7.2.

6. **Magnetic conditioning**

6.1 *Object*

To arrive at a well defined and reproducible magnetic state of a core before the measurements are made.

6.2 *Principles of the methods*

There are two main methods:

- 1) the electrical method in which the specimen is subjected to an alternating magnetic field of sufficient magnitude, of which the amplitude is gradually reduced to zero;
- 2) the thermal method in which the specimen is taken above the Curie point.

6.3 *Procedure for the electrical method*

The initial peak of the field strength shall take the core well above the knee of the magnetization curve and during the reduction of amplitude there shall be two flux reversals in the core for each complete cycle.

There are two possibilities:

- 1) A decreasing alternating current is passed through the measuring coil on the specimen. The current decrease may be:
 - a) linear, e.g. by a potentiometer. The amplitude reduction shall then extend over not less than 50 cycles;
 - b) exponential, e.g. by a capacitor discharge. The ratio of two consecutive current peaks in the same direction shall be not less than 0.78 in that case.

The coil shall not be appreciably heated by the current during conditioning.

Further details on these methods are given in Appendices A and B.

- 2) The specimen is passed through the alternating field in the air-gap of an electromagnet.

Further details on this method are given in Appendix C.

6.4 *Procedure for the thermal method*

The core shall be heated at a specified rate of temperature change and maintained for about 40 min at a temperature approximately 25°C in excess of the Curie point. Cooling shall also take place at a specified rate. For further details, see Appendix D.

7. Inductance measurement

7.1 *Object*

To provide general instructions for the measurement of inductance of inductor and transformer windings, without going into details of the method, which depend upon the electrical instrument used for the measurement.

Two measurement purposes should be distinguished:

- 1) to obtain a measurement of the absolute value of the inductance parameter of the core;
- 2) to obtain a measurement of the dependence of the inductance parameter under certain conditions.

7.2 *Means of coupling*

Normally, a measuring coil will be used, but in principle any coaxial line, cavity or other suitable device providing the necessary interaction between the magnetic material and the electromagnetic signal, may also be used.

For measurement on toroids using coils, the turns of the measuring coil shall be distributed in such a way as to keep both the stray capacitance and the stray field as low as necessary for sufficiently accurate measurement.

For measurements on cores which assemble around a coil, the shape of the measuring coil shall correspond to that of the coils used for normal application of the core and its influence on the variation of the inductance to be measured shall be negligible.

Unless otherwise specified, the test coil complete with coil former or encapsulation, or both, shall be positioned coaxial to the limb which it embraces, and the side of the coil at which the start of the winding is located shall be lightly pressed into contact with the core at one end of this limb as follows:

- for a symmetrical core, the coil assembly shall contact the core at either one end or the other;
- for a core that is symmetrical except for an air-gap, the coil assembly shall make end contact to that half of the core that contains the least proportion of the air-gap.

One of the coil faces shall be marked so as to define its orientation. The coil shall be kept in the defined position during the whole measurement in order to obtain the maximum reproducibility of the measurement.

Full details of the coil construction and position shall be given in the relevant specification. Guidance for the design of inductance measuring cores is given in Appendix E.

7.3 Absolute measurement

Any suitable measuring apparatus may be used provided the accuracy is compatible with the specified tolerance, taking into account the reproducibility of other parts of the measuring method.

The frequency of the measuring current shall be low enough to avoid the influence of the capacitance of the measuring coil on the measured result. Doubling the frequency shall not have an appreciable effect. For measurement of inductance corresponding to initial permeability, the flux density shall be vanishingly low, i.e. of such level that doubling its value causes negligible change in the measured value. If necessary, the result may be corrected by linear extrapolation from measurements at low flux densities.

The frequency of the measuring current and the peak effective flux density shall be stated.

Note. – The peak effective flux density $\hat{B}_e$ in a core is calculated from:

$$\hat{B}_e = \frac{U\sqrt{2}}{\omega N A_e}$$

where:

U = r.m.s. value of the sinusoidal voltage applied to the coil

7.4 Relative measurement

The same details apply as for the absolute measurement, except that the absolute accuracy of the measuring instrument is not important as long as the relative inductance variation $\Delta L/L$ can be determined with the required accuracy over the part of the measuring range(s) used. A practical upper limit for the peak flux density in any core part is 0.25 mT and it shall be applied for not more than 1 min for each measurement.

Where a frequency variation method is used, it shall be ensured that the frequencies are low enough to correspond to the flat portion of the permeability-frequency characteristic of the material, and that appreciable influence of the current distribution due to eddy currents in the measuring coil is avoided.

The (approximate) measuring frequency and the flux density shall be stated.

SECTION TWO – COMMON MEASURING METHODS

8. Disaccommodation

8.1 Object

To evaluate the change of the permeability of a core with time.

Notes 1. – Both components of the complex permeability will show disaccommodation but in this standard only the real component is considered.

2. – Either the disaccommodation or the disaccommodation factor may be used to describe the variation with time. See also Sub-clause 8.6.

8.2 Principle of the method

The core is magnetically conditioned; the inductance or other quantity corresponding to initial permeability is measured at two specified times after magnetic conditioning. The disaccommodation factor (or the disaccommodation) is calculated from the difference in the measured values.

Note. – The disaccommodation normally decreases with increasing flux density so that it is generally given for low values of flux density.

8.3 Specimens

Cores taken from normal production shall be used for the measurement.

When the complete core consists of more than one part, e.g. a pot core, and the disaccommodation is to be measured with a normal winding, it is preferable that the only air-gap in the flux path shall be the residual air-gap at the contact surfaces. However, when there is a series of cores each with a different air-gap cut into the flux path it may be permissible to make the measurement on cores with the smallest available air-gap.

Notes 1. – In some cases, such as pot cores with centre hole, the core parts can be wound as a toroid. The disaccommodation may be measured in that way after it has been established that the results are reasonably equal to or correlate with the results obtained with a normal winding and, moreover, the initial permeability along the toroidal flux path is not appreciably different from the initial permeability in the direction of the normal flux path. This method should be used with extreme caution. When a slotted pot core is toroidally wound, the outside walls make negligible contribution to the flux path.

2. – For certain materials, the disaccommodation changes appreciably in the period immediately after firing. Where this is the case, the article sheet may specify that disaccommodation measurement for acceptance testing shall not be made within a stated period after manufacture and it shall also state from what instant this period shall be measured.

8.4 Timing device

The inaccuracy of any time measurement shall not exceed 1 %. In the case where the timing device is started by the magnetic conditioning device, this figure shall include the inaccuracy of both the starting technique and the timing device.

Note. – In principle, for an electrical method the reference time shall be the moment when the field strength starts to decrease from the saturation value. For automatic conditioning systems, such as the capacitor discharge and power amplifier method, the whole magnetic conditioning process is so short as to fall within the tolerance of the time to the first measurement.

8.5 Measuring procedure

- 1) The core is assembled with a measuring coil in accordance with Sub-clause 4.3.
- 2) The core shall be subjected to magnetic conditioning by one of the methods of Clause 6. The method used shall be stated together with the main characteristics of the conditioning device. In all cases, the instrument shall clearly and reproducibly indicate the moment of magnetic conditioning since this forms the starting point of time measurement and strongly influences the accuracy of disaccommodation measurement.
- 3) Two readings are taken in accordance with Sub-clause 7.4:
 - In the electrical method, the first one 10 min and the second one 100 min after magnetic conditioning.
 - In the thermal method, the first one 24 h and the second one 48 h after measurement reference time t_0 which is defined as the moment when, during the cooling period, the temperature reaches a point 10°C above the measurement temperature.

Other times may be used, but preferably the whole procedure shall not take more than 24 h for the electrical method. The measuring procedure and environmental conditions shall be identical at the two measurements.

8.6 Calculation

The disaccommodation D between t_1 and t_2 is calculated from the difference of the two readings relative to the first reading. In the case of inductance measurement, it is calculated from:

$$D = \frac{L_1 - L_2}{L_1}$$

The disaccommodation factor D_F may be calculated from:

$$D_F = \frac{\mu_0 N^2 (L_1 - L_2)}{C_1 L_1^2 \log_{10} \left(\frac{t_2}{t_1} \right)}$$

where:

L_1 = self-inductance measured at t_1 min after magnetic conditioning

L_2 = self-inductance measured at t_2 min after magnetic conditioning

Note. – The disaccommodation has been found to be approximately proportional to the logarithm of time, and for this reason the disaccommodation factor is normally used to express the variability with time. Within the limits of the approximation, the disaccommodation of a core with air-gap can be derived from the disaccommodation factor of the material:

$$D = \mu_r D_F \log_{10} \left(\frac{t_2}{t_1} \right)$$

Due to limitations of the manufacturing process, the properties of cores with different geometries made of the same material may differ.

9. Variation of permeability with temperature

9.1 Object

To evaluate the change of the permeability of a core with temperature.

Notes 1. – Both components of the complex permeability will show temperature variability but in this standard only the real component is considered.

2. – When permeability and temperature of a core are simultaneously recorded, a large band of measuring points is obtained. The variation of permeability with temperature may be characterized with absolute accuracy in a single figure only for an infinitely small temperature range.

The concept of a temperature coefficient or a temperature factor applying over a finite temperature range is still desirable. A practical value permitting calculations to be made, with adequate accuracy, can be obtained by a proper choice of the measuring conditions and temperature limits under which the temperature coefficient or factor applies.

9.2 Principle of the method

The required accuracy of the method has a bearing on its simplicity and duration and for this reason three different measurement principles are distinguished.

Method A: The assembled core with measuring coil is taken through a temperature cycle at a very low rate of variation of the temperature. After one or more stabilizing cycles, both the temperature and the inductance are continuously recorded.

Method B: The assembled core with measuring coil is taken through a temperature cycle at a moderate rate of variation of the temperature. After one or more stabilizing cycles, the cycle is interrupted at certain temperatures. During each interruption, the temperature is kept constant for a sufficient time to allow the core to attain temperature equilibrium before the measurement is made.

Method C: The assembled core with measuring coil is taken through a temperature cycle at a moderate rate of variation of the temperature. After one or more stabilizing cycles, the cycle is interrupted at certain temperatures. During each interruption, the temperature is kept constant. After the core has reached thermal equilibrium, it is magnetically conditioned and the measurement is made after a clearly defined time.

Note. – Since the disaccommodation varies with temperature, method C may give results which differ appreciably from those obtained with Method A or B, but, since it is more rapid, it is useful, provided the results reliably correlate with those of Method A or B.

9.3 Specimens

Cores taken from normal production shall be used for the measurement.

When the complete core consists of more than one part, e.g. a pot core, and the temperature variation is to be measured according to Method C with a normal winding, it is preferable that the only air-gap in the flux path shall be the residual air-gap due to the contact surfaces.

Note. – In some cases, such as pot cores with centre hole, the core parts can be wound as a toroid. The temperature variation may be measured in that way after it has been established that the results are reasonably equal to or correlate with the results obtained with a normal winding. This method should be used with extreme caution. When a slotted pot core is toroidally wound, the outside walls make negligible contribution to the flux path.

9.4 Temperature cycling device

1) Method A

A temperature controlled chamber shall be used in which the temperature change with time is practically linear and can be kept at 0.2°C/min.

2) Methods B and C

The chamber used for this test shall be capable of maintaining, in any region where the components are placed, the specified temperature within an overall tolerance of $\pm 1^\circ\text{C}$. The temperature shall be kept constant with time within $\pm 0.3^\circ\text{C}$.

The temperature in the chamber shall be so controlled that the cores are not subjected to any temperature ripple and overshoot exceeding this limit of $\pm 0.3^\circ\text{C}$.

3) Thermometers

The temperature measuring (or sensing) device shall have such sensitivity and accuracy that it is possible:

- to check that temperature is constant within $\pm 0.3^\circ\text{C}$;
- to measure within $\pm 1\%$, or $\pm 0.3^\circ\text{C}$, whichever is the greater, the total temperature difference over which the temperature dependence is to be measured.

9.5 Timing device (Method C only)

The inaccuracy of any time measurement shall not exceed 1%. In the case where the timing device is started by the magnetic conditioning device, this figure shall include the inaccuracy of both the starting technique and the timing device.

Note. – In principle, the reference time shall be the moment when the field strength starts to decrease from the saturation value. For automatic conditioning systems, such as the capacitor discharge and power amplifier method, the whole magnetic conditioning process is so short as to fall within the tolerance of the time of the measurement.

9.6 Measuring procedure

1) The core is assembled with a measuring coil in accordance with Sub-clause 4.3.

The tolerance of $\pm 1\%$ on the clamping force includes any force variation due to temperature change.

2) The core shall be subjected to a number of stabilizing cycles and one measuring cycle. Usually two stabilizing cycles are sufficient. They are identical to the measuring cycles described below as to temperature range and specified rate of temperature change, but the periods at constant temperature specific to the measuring cycles can be left out.

Method A: The assembled core is placed in the chamber and after the specified number of stabilizing cycles, it is brought to the highest measuring temperature specified, then to the lowest measuring temperature specified and finally back to the temperature at which the cycle was started. The rate of temperature change shall be approximately 0.2 °C/min, and constant throughout the cycle. Temperature and inductance shall be recorded simultaneously during the measuring cycle at time intervals not exceeding 1 min. The time of starting the measurement shall also be recorded.

Method B: The assembled core is placed in the chamber and after the specified number of stabilizing cycles, it is kept at the temperature specified for the initial measurement for 30 min at least after temperature equilibrium has been attained, after which a measurement is made (reference value). The temperature is varied at a maximum rate of 1 °C/min to the lowest specified measuring temperature and kept constant as specified above, after which a measurement is made. The temperature is then raised at a maximum rate of 1 °C/min to the next higher specified measuring temperature and kept constant as specified, after which another measurement is made.

This procedure is continued up to the highest specified measuring temperature, after which the temperature is lowered at a maximum rate of 1 °C/min to the temperature for initial measurement, where the final measurement is made after a period of constant temperature as specified above.

Method C: The assembled core is placed in the chamber and brought to the lowest of the specified measuring temperatures at a rate sufficiently low as not to create an excessive temperature gradient in the material (normally, 1 °C/min will be a suitable value). The temperature is maintained for a sufficient time to allow the core assembly to reach thermal equilibrium with the atmosphere in the chamber. The core is then magnetically conditioned according to Sub-clause 6.3, Item 1) with a decreasing alternating current through the measuring coil, and the inductance of the measuring coil is measured 10 min after conditioning. The temperature is then raised to the next higher specified measuring temperature at the rate specified above. The maintaining of temperature, magnetic conditioning and inductance measurement are repeated at that temperature. This procedure is continued until the highest measuring temperature specified.

Note. – See note to Sub-clause 9.2, Method C.

- 3) The inductance readings are taken in accordance with Sub-clause 7.4. The measuring procedure and environmental conditions shall be identical throughout the measurement of one cycle, except for the temperature.

9.7 Calculation

The temperature coefficient α_μ for each measurement is calculated from the difference between the measured value and the reference value divided by the reference value and the corresponding temperature difference. In the case of inductance measurements it is calculated from:

$$\alpha_\mu = \frac{L_\theta - L_{\text{ref}}}{L_{\text{ref}} (\theta - \theta_{\text{ref}})}$$

where:

L_{ref} = self-inductance of measuring coil at reference temperature θ_{ref} (preferably 25 °C)
 L_θ = self-inductance of measuring coil at temperature θ

For Method A, the values are read from the recorded curve.

Notes 1. – The temperature coefficient is commonly used to calculate the limits of change of permeability of a core within a given temperature range. It can only be used to describe the behaviour within the temperature range, when the limits of linearity of the permeability versus temperature characteristic of the core are taken into account.

It should be noted that, because of the non-linearity of this characteristic, the temperature coefficient may be different for different temperature ranges. Further, the deviation from the straight line is not always reduced when a smaller temperature range is chosen.

Some methods of expressing temperature coefficient and non-linearity dependence are given in Appendix F.

2. – For series of cores with different air-gaps cut into the flux path (such as pot cores), the temperature coefficient α_μ may be calculated from the temperature factor α_F of the core in which the only air-gaps in the flux path are the residual air-gaps due to the contact surfaces. The required relation is:

$$\alpha_\mu = \frac{\alpha_F \mu_e}{1 - \alpha_F \mu_e (\theta - \theta_{ref})} \approx \alpha_F \mu_e$$

where:

μ_e = effective permeability of the core with air-gap at reference temperature θ_{ref}

α_F = temperature factor of the core without air-gap, over the range θ_{ref} to θ , calculated from measurements on that core according to:

$$\alpha_F = \frac{\mu_0 N^2}{C_1} \frac{L_\theta - L_{ref}}{L_\theta L_{ref} (\theta - \theta_{ref})}$$

The approximate formula holds true when the total variation of permeability of the core with air-gap over the temperature range is sufficiently small. It can also be written:

$$\alpha_\mu = \frac{C_1}{\mu_0} \alpha_F A_L$$

where:

A_L = inductance factor of the core with air-gap

3. – The temperature coefficient of an inductor may be totally different from that of the core, since various influences on the variability are introduced, e.g. by the clamping, by the copper winding.

10. Range of inductance adjustment

10.1 Object

To provide a method for the measurement of the range of adjustment of the inductance of magnetic cores having a separate adjusting device.

10.2 Terminology

For the purpose of this method, the following definitions apply:

- 1) *Adjusting device*: A device providing adjustment of the inductance of an inductor or tuned transformer, after its complete assembly, by changing the reluctance of the core.
- 2) *Fixed part (of an adjusting device)*: The part of an adjusting device which is mechanically attached to the core by such means as cement.
- 3) *Adjuster*: The part of an adjusting device which may assume different positions relative to the air-gap of the core.
- 4) *Adjustment range*: The difference in inductance of an inductor when the adjuster is placed in the maximum and minimum position respectively, expressed as a percentage of the inductance of that inductor without adjuster.

- 5) *Upper [lower] limit of the adjustment range*: The difference in inductance of an inductor when the adjuster is placed in the maximum [minimum] position and when the adjuster is removed, expressed as a percentage of that latter inductance:

$$a = \frac{L_{\min} - L_0}{L_0} \cdot 100\% \quad b = \frac{L_{\max} - L_0}{L_0} \cdot 100\%$$

where:

a = lower limit with inductance $L_{\min}$
 b = upper limit with inductance $L_{\max}$
 L_0 = inductance when adjuster is removed

- 6) *Maximum [minimum] position of the adjuster*: Position defined by mechanical requirements or other conditions and which corresponds to the upper [lower] limit of the adjustment range.
- 7) *Screw type adjusting device*: Adjusting device in which the adjuster screws into or onto the fixed part (stud or nut).

10.3 Principle of the measurement

The inductance of the core without adjuster is measured. The adjuster is then placed in the minimum position and the inductance measured at small steps of the adjuster until the maximum position has been reached. The relative change of inductance is plotted against the adjuster displacement.

10.4 Specimens

Adjusting devices taken from normal production shall be used for the measurement in combination with appropriate cores.

10.5 Measuring procedure

- 1) If the fixed part has not been attached to one of the core parts by the manufacturer, this shall be done according to the manufacturer's instructions.
- 2) The core is assembled with the measuring coil in accordance with Sub-clause 4.3.
- 3) The adjuster shall be introduced into the core and moved twice through the complete adjustment range and back. The adjuster is then removed from the core.

Note. – Too many movements through the adjustment range may result in deterioration of the stability and should therefore be avoided.

- 4) The inductance is measured in accordance with Sub-clause 7.4.
- 5) The adjuster is introduced into the core and placed in the minimum position. The inductance is measured in accordance with Sub-clause 7.4.
- 6) The adjuster is then successively displaced over a small distance and each time the inductance is measured till the maximum position is reached. The steps shall be small enough to detect irregularities in the adjustment characteristic (see Sub-clause 10.6); for example, for screw type adjusters, $\frac{1}{4}$ turn.

10.6 Calculation

The inductance change relative to the inductance measured with the adjuster removed shall be plotted against the mechanical position (displacement) of the adjuster. For screw type adjusters, the displacement shall be given in number of turns and for push types it shall be given in millimetres.

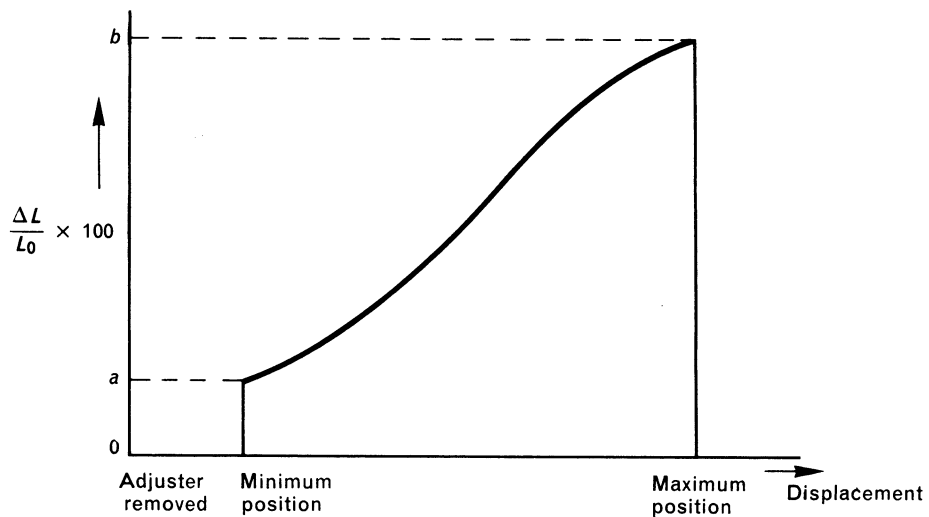


FIGURE 1

The maximum and minimum slopes of the curve shall be noted as required.

11. Losses

11.1 Losses at low flux density

11.1.1 Object

To provide general instructions for the measurement of loss, both in gapped and ungapped cores, and to establish reference methods for the calibration of loss measuring instruments.

11.1.2 Specimens

Cores taken from current production shall be used for the measurement.

For cores which are used with an air-gap in the flux path, such as pot cores for inductors, the loss may be measured before grinding that air-gap (see Sub-clause 11.1.4).

11.1.3 Means of coupling

Normally, a measuring coil will be used, but in principle any coaxial line, cavity or other suitable device providing the necessary interaction between the magnetic material and the electromagnetic signal may also be used.

Measuring coils sensitive to the influence of moisture should be stored under dry conditions and measurements should preferably take place under standard atmospheric conditions for referee tests (see Sub-clause 3.2).

Full details of the construction of the coil or other device shall be given in the relevant specification. The construction shall be based on the following considerations:

- a) Coils for cores consisting of more than one part shall, when possible, be designed so that the optimum frequency (where Q is maximum) for the core-coil combination is well below the measur-

ing frequency, so that the coil loss can be neglected. Where the above is not possible, an attempt should be made to keep the additional winding loss and the dielectric loss in the coil insulation as low as possible by using stranded wire, a low number of turns and/or subdivided coils, so that measuring results need only be corrected for the d.c. resistance loss of the coil.

Where correction for coil loss would result in an unacceptable inaccuracy, standard coils shall be used and the combined loss of core and coil shall be specified (see Sub-clause 5.1, Item 2)). For measurement on high- Q cores, such as gapped cores, the standard coils should be exchanged between parties making measurements on the same cores.

- b) Coils wound on toroids shall be evenly distributed. It is preferable that insulated solid copper wire be used and that it completely covers the toroid.

Note. – Solid copper wire is recommended because of the risk of breaking of wire strands when winding a toroid. For measurements at high frequencies, however, stranded wire may be necessary.

- c) In all cases, the self-capacitance of the coil on the core should preferably be less than 2% of the resonating capacitance to avoid both excessive dielectric loss and correction of the measured inductance (where measurement of the latter is required).

11.1.4 *Measurement of residual and eddy current loss*

Any suitable measuring apparatus may be used, provided the accuracy is compatible with the specified loss limit. It shall also allow the flux density in the core to be adjusted to the specified value. The flux density during measurement shall be stated. When no value of the flux density is specified, its value during measurement shall be equal to or lower than the value specified for the measurement of inductance on the same core according to Clause 7. The measuring frequency or frequencies shall be as specified in the relevant specification.

Corrections for coil loss or loss in the tuning capacitor or both may be required. The following method is recommended for the correction of the coil loss:

Measure the series resistance and inductance of the coil with core and subtract the equivalent resistance of the coil, i.e. the measured d.c. resistance of the coil increased by the equivalence of the estimated additional coil loss at the measuring frequency (see Sub-clause 11.1.3 a)). Finally, if necessary, convert the result to parallel resistance, quality factor or other quantity in which the core loss has to be expressed.

When the loss factor is measured before the grinding of the air-gap (see Sub-clause 5.1, Method 1), the loss in a core with air-gap can be calculated from:

$$(\tan \delta)_e = \left(\frac{\tan \delta}{\mu_i} \right) \times \mu_e$$

where:

$(\tan \delta)_e$ = tangent of loss angle in the gapped core with effective permeability μ_e

$\left(\frac{\tan \delta}{\mu_i} \right)$ = loss factor measured on the core (or on a core of the same lot or series) before the grinding of the air-gap

11.1.5 *Measurement of the hysteresis loss*

Any suitable measuring apparatus may be used which allows the variation of the core loss with amplitude to be determined with the required accuracy. The value of the hysteresis loss shall be derived from loss measurements at the two values of the peak voltage specified in the relevant specification (the number of turns of the test coil also being specified), which shall be so chosen that the peak effective

flux density in the core does not exceed 5 mT. When necessary, the inductance of the measuring coil with core shall be measured at the lower voltage value.

The measuring frequency or frequencies shall be as specified in the relevant specification.

The hysteresis loss shall be calculated on the basis of its proportionality to the ratio of the measured loss difference to the applied peak voltage difference. Correction for coil loss is not normally required.

For example:

- 1) For cores with given effective permeability, series measurement:

$$\tan \delta_h = \frac{\dot{U} \Delta R_s}{\omega L_s \Delta \dot{U}}$$

where:

$\tan \delta_h$ = tangent of the loss angle due to hysteresis loss
 $\dot{U}$ = higher applied measuring peak voltage
 ΔR_s = measured difference in series resistance
 $\Delta \dot{U}$ = difference in applied measuring peak voltage
 L_s = series inductance of the coil on the core at lower applied measuring voltage

- 2) For materials and for cores which may have different air-gaps, parallel measurement:

$$\eta_B = \frac{\omega^2 N^3 \mu_0}{C_2} \cdot \frac{\Delta G_p}{\Delta \dot{U}}$$

where:

η_B = hysteresis material constant
 ΔG_p = measured difference in parallel conductance
 $\Delta \dot{U}$ = difference in applied measuring peak voltage

Notes 1. – For an explanation of further symbols, see Clause 2.

2. – If it is assumed that η_B as a material constant is independent of μ_e and $\hat{B}$, then it follows that $\tan \delta_h$ for a core with given μ_e is proportional to $\hat{B}$ since $\tan \delta_h = \eta_B \cdot \mu_e \cdot \hat{B}$.

11.1.6 Reference methods

For loss measurements on gapped cores with high quality factor and on ungapped or toroidal cores with moderate quality factor, the measuring apparatus shall be calibrated by means of a reference method.

Two reference methods are recommended: a damped oscillation method (see Appendix G) and a transmission method (see Appendix H).

11.2 Losses at high flux density (total core loss)

11.2.1 Object

To provide measuring methods for total core loss of magnetic cores energized at high flux density with a periodic waveform.

11.2.2 Principles of measurement

One or more of the following three methods is suitable, according to the application:

- 1) *Multiplying voltmeter method*

This method is generally applicable provided the peak factor is within the limitations imposed by the instrument.

The voltage across a non-reactive resistor in series with a measuring coil on the core and the voltage across that coil are connected to the two channels respectively of a multiplying voltmeter. This instrument gives an average of the products of the instantaneous values of the two voltages and this is proportional to the total loss in the core.

2) *Bridge method*

This method is restricted to sinusoidal voltage or current.

The equivalent parallel resistance of a measuring coil on the core is determined by a bridge circuit suitable for handling the power required to generate the specified flux density in the core.

3) *Oscilloscope method*

This method can be used for either alternating or pulsating voltages and currents and for high peak factors as may occur for pulses having a small ratio of pulse duration to pulse repetition time. It is more appropriate for high powers and high voltages.

The voltage across a non-reactive resistor in series with a measuring coil on the core, and the voltage across that coil integrated over the time are fed to the horizontal and vertical deflection plates respectively of an oscilloscope. The surface area of the displayed loop is determined and this is a measure of the total loss in the core.

11.2.3 *Specimens*

Cores taken from normal production and forming complete magnetic circuits shall be used for the measurement.

11.2.4 *Measuring coil*

- 1) The number of turns should be specified in relation to the measuring conditions, the equipment used and the accuracy to be obtained. The resistance and self-capacitance of the measuring coil should be as low as is needed to make the error negligible.

The conductor should consist of insulated strands if this is necessary for measurements at high frequencies. In the case of a toroidal winding, the turns shall be evenly distributed around the circumference.

- 2) In the case of the multiplying voltmeter method and of the oscilloscope method, if the use of a single winding measuring coil would be incompatible with the accuracy to be obtained, a double wound coil, with separate current and voltage windings, should be used.

The voltage winding should have a resistance very much smaller than the impedance of the instrument and should be wound as close to the core as possible. The self-capacitance should be as low as is necessary to make the error negligible. The current winding shall completely cover the voltage winding.

Note. – When winding a coil on to a sharp-edged core, care should be taken to ensure that the wire insulation is not ruptured and, in the case of stranded wire, strands are not broken.

11.2.5 *Measuring equipment*

Any suitable measuring equipment may be used. Examples of appropriate circuits are given in Appendix J. The following requirements shall be met:

- 1) The generator used shall be able to supply the specified voltage or current having the correct waveform within the specified tolerances when the measuring coil on the core is connected in the

circuit. When sinusoidal waveform is specified, the total harmonic content shall be less than 1%. When square pulses are specified, the relevant requirements of Clause 16 shall be met.

- 2) All connections between the circuit components shall be as short as possible. The connections of the two channels of the multiplying voltmeter with the circuit shall be of equal length and of the same type. The connecting cables to the oscilloscope shall be of a low capacitance type (e.g. air insulated cables).
- 3) The resistor in series with the measuring coil shall have a resistance tolerance not exceeding $\pm 0.5\%$. With non-sinusoidal currents this resistor shall be non-reactive to the extent that the phase angle between the current flowing through it and the voltage across it shall not exceed 0.002 rad over the frequency range defined in Item 4. With sinusoidal currents this resistor shall either be non-reactive as specified above, or in the case of a reactive component shall be compensated at the measuring frequency by a variable capacitor. This capacitor may at the same time be used to compensate any phase shift between the channels of the multiplying voltmeter.

Notes 1. – Instructions for making a non-reactive resistor are given in Clause J4 of Appendix J.

2. – Compensation of a reactive resistor is generally valid only for a single frequency.

- 4) The frequency range of the voltmeters and the oscilloscope shall include all harmonics of the applied voltages having amplitudes of 1% or more of their fundamentals. The frequency range shall be specified in the relevant specification.

Any phase error between the channels of the multiplying voltmeter shall not exceed 0.003 rad over the full frequency range required. The input impedance of both channels shall be high enough to have a negligible effect on the circuit.

- 5) The average-reading voltmeter and the r.m.s.-reading voltmeter shall be Class 1 or better, in accordance with IEC Publication 51: Recommendations for Direct Acting Indicating Electrical Measuring Instruments and their Accessories.

The inaccuracy inherent in each channel of the multiplying voltmeter shall not exceed 1% of its full scale reading; this applies, for example, when the multiplying voltmeter is used instead of a separate voltmeter for determining the average voltage across the measuring coil.

When used in the product mode, the multiplying voltmeter shall be capable of indicating, with known meter constant, the time average of the product of the instantaneous values of the two voltages measured by each channel, with an inaccuracy not exceeding 2% of the full scale reading.

Notes 1. – The limit on the peak factor for the multiplying voltmeter should be observed.

2. – If the quality factor Q of the assembled coil is greater than 10, the error in the indicated average product is increased.

- 6) Calibration facilities shall be provided for the oscilloscope method to obtain an accuracy for the displayed voltages of better than 3% of full deflection. Measures should be taken to ensure that the inaccuracy of the area measurement does not exceed 5%.
- 7) A temperature-controlled environment shall be provided, capable of maintaining the core at the specified temperature during the measurement.

11.2.6 *Measuring procedure*

- 1) The core to be measured is assembled with the measuring coil in accordance with Sub-clause 5.2.

- 2) When the temperature of the core is specified, it shall be placed in a temperature-controlled environment in accordance with Item 7 of Sub-clause 11.2.5. The measurement shall be made as quickly as possible to ensure that the self-heating of the coil and core is negligible.
- 3) The assembled coil is connected to the circuit and the generator is adjusted to give the specified voltage or current waveform at the specified frequency. The source voltage is adjusted so that the average voltage per half cycle, measured across the coil, is given by:

$$U_{av} = 2f \cdot N \cdot A \cdot \Delta B$$

where:

- f = measuring frequency
- N = number of turns of the measuring coil or of the voltage winding of the measuring coil
- ΔB = specified change in the flux density during the measurement. For flux density alternating in a symmetrical fashion with a peak value of $\hat{B}$, $\Delta B = 2\hat{B}$
- A = either the effective core area A_e or the nominal value of the smallest cross-section A_{min} , as required by the specification

All the dimensions used to calculate A_{min} shall be the mean values between the tolerance limits quoted on the appropriate piece part drawing

Notes 1. – When the oscilloscope method is used without an average-reading voltmeter, the maximum integrated voltage measured across the coil is:

$$(\int u dt)_{max} = N \cdot A \cdot \Delta B$$

2. – For pulse measurements, one of the circuits of Clause 16 of which a circuit diagram is given in Appendix M, may be used, with the addition of a multiplying voltmeter when appropriate.

- 4) For the multiplying voltmeter method, the voltmeter is switched for multiplication and its indication is read.

For the bridge method, the final balance is made, the bridge settings as compared with those before connection of the assembled core are noted and the r.m.s. voltage across the assembled coil is read.

For the oscilloscope method, the displayed loop is photographed, if possible in such a way that the calibration voltage pulses in both co-ordinates are included.

Note. – A better accuracy can be obtained when use is made of a digital processing method. In this case, the surface area can be derived directly.

11.2.7 Calculation

1) Multiplying voltmeter method

The total core loss in watts is given by:

$$P = (\overline{u \cdot i}) = \alpha \cdot K$$

where:

- $(\overline{u \cdot i})$ = time average of the product of the voltage across the assembled coil and the current through it
- α = meter reading
- K = meter constant derived from the sensitivity of both channels, the value of the current-measuring resistor R_i and the full scale deflection of the appropriate meter scale

In the case of pulse measurements the pulse repetition frequency f_p is chosen by consideration of recovery time. It is therefore preferable, in this case, to express the loss in terms of energy per cycle, $E = (\overline{u \cdot i})/f_p$. For a given pulse amplitude and pulse duration, E is independent of f_p and in general $P = E \cdot f_p$.

Reference should be made to the manufacturer's instructions accompanying the instrument for advice on the errors likely to occur, and their correction.