

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Transformers and inductors for use in electronic and telecommunication equipment – Measuring methods and test procedures

Transformateurs et inductances utilisés dans les équipements électroniques et de télécommunications – Méthodes de mesure et procédures d'essais



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

TRANSFORMERS AND INDUCTORS FOR USE IN ELECTRONIC AND TELECOMMUNICATION EQUIPMENT – MEASURING METHODS AND TEST PROCEDURES

FOREWORD

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International Standard IEC 61007 has been prepared by IEC technical committee 51: Magnetic components, ferrite and magnetic powder materials.

This third edition cancels and replaces the second edition published in 1994. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) scope: the application of the scope of IEC 61007 was extended;
- b) Clause 2: added new references and updated the references;
- c) Clause 3: new definitions were added in 3.3, and in 3.7 the voltage-time product was redefined;

d) test procedures were updated:

1) addition of test method:

AC resistance (in 4.4.1.2); short-circuit power test (in 4.4.3.4); efficiency (in 4.4.3.5); phase unbalance (in 4.4.5.7); amplitude unbalance (radio frequency) (in 4.4.5.8); transformation ratio by impedance (in 4.4.7.1); coefficient of coupling (in 4.4.7.2); cross-talk (in 4.4.10);

2) modification of test method:

Insulation resistance (an error range of the testing voltage, in 4.4.2.3);

3) deletion of test method:

Effective resistance;

e) environmental test procedures: new references were added;

f) Annexes A to G were added.

The text of this International Standard is based on the following documents:

CDV	Report on voting
51/1319/CDV	51/1339/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

TRANSFORMERS AND INDUCTORS FOR USE IN ELECTRONIC AND TELECOMMUNICATION EQUIPMENT – MEASURING METHODS AND TEST PROCEDURES

1 Scope

This document describes a number of tests for use in determining the significant parameters and performance characteristics of transformers and inductors for use in electronics and telecommunication equipment. These test methods are designed primarily for transformers and inductors used in all types of electronics applications that can be involved in any specification for such components. Even though these tests can be useful to the other types of transformers used in power distribution applications in utilities, industry, and others, the tests discussed in this document can supplement or complement the tests but are not intended to replace the tests in standards for transformers. Some of the tests described are intended for qualifying a product for a specific application, while others are test practices used for manufacturing and customer acceptance testing. The test methods described here include those parameters most commonly used in the electronics transformer and inductor industry: electric strength, resistance, power loss, inductance, impedance, balance, transformation ratio and many others used less frequently.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at www.electropedia.org)

IEC 60068-1: 2013, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-1, *Environmental testing – Part 2-1: Tests – Tests A: Cold*

IEC 60068-2-2, *Environmental testing – Part 2-2: Tests – Tests 8: Dry heat*

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-7, *Basic environmental testing procedures – Part 2-7: Tests – Test Ga and guidance: Acceleration, steady state*

IEC 60068-2-10, *Environmental testing – Part 2-10: Tests – Test J and guidance: Mould growth*

IEC 60068-2-13, *Basic environmental testing procedures – Part 2-13: Tests – Test M: Low air pressure*

IEC 60068-2-14, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60068-2-17, *Basic environmental testing procedure – Part 2-17: Tests – Test Q: Sealing*

IEC 60068-2-20, *Environmental testing – Part 2-20: Tests – Test T: Test methods for solderability and resistance to soldering heat of devices with leads*

IEC 60068-2-21, *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations and integral mounting devices*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-30, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60068-2-42, *Environmental testing – Part 2-42: Tests – Test Kc: Sulphur dioxide test for contacts and connections*

IEC 60068-2-45, *Basic environmental testing procedures – Part 2-45: Tests – Test XA and guidance: Immersion in cleaning solvents*

IEC 60068-2-52, *Environmental testing – Part 2-52: Tests – Test Kb: Salt mist, cyclic (sodium chloride solution)*

IEC 60068-2-78, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

IEC 60695-11-2, *Fire hazard testing – Part 11-2: Test flames – 1 kW pre-mixed flame – Apparatus, confirmatory test arrangement and guidance*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050 (all parts) and the following apply.

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

- IEC Electromedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

component

transformer or inductor

3.2

peak working voltage

maximum instantaneous voltage for which the winding insulation is rated under working circuit conditions

3.3 pulse wave form parameters (see Figure 1)

3.3.1 peak pulse amplitude

U_m
maximum value of an extrapolated smooth curve through the top of the pulse, excluding any initial "spike" or "overshoot", the duration of which is less than 10 % of the pulse duration

3.3.2 pulse duration

t_d
time interval between the first and last instant at which the pulse amplitude equals 50 % of the peak pulse amplitude

3.3.3 pulse rise time

t_r
interval between the first instant at which the pulse amplitude reaches 10 % of the peak pulse amplitude and the first instant at which the pulse amplitude reaches 90 % of the peak pulse amplitude, excluding an unwanted or irrelevant portion of the waveform

3.3.4 pulse fall time

t_f
interval between the last instant at which the pulse amplitude reaches 90 % of the peak pulse amplitude and the next instant at which the pulse amplitude reaches 10 % of the peak pulse amplitude excluding any unwanted or irrelevant portion of the waveform

Note 1 to entry: Where the value of the droop approaches 10 % of the peak pulse amplitude, the upper point defining fall time can be replaced by the last instant at which the pulse amplitude reaches 80 % of the peak pulse amplitude.

3.3.5 droop

difference between the peak pulse amplitude and the amplitude of the extrapolated smooth curve through the top of the pulse, excluding any initial "spike" or "overshoot", at its intersection with the straight line through the points defining the pulse fall time, expressed as a percentage of the peak pulse amplitude

3.3.6 pulse crest

maximum amplitude of the pulse

3.3.7 overshoot

amount by which the pulse crest exceeds the peak pulse amplitude, expressed as a percentage of the peak pulse amplitude

3.3.8 backswing

maximum amplitude of the reverse pulse, i.e. the portion of the pulse after the zero-crossing, expressed as a percentage of the peak pulse amplitude

3.3.9 return backswing

maximum amplitude of the swing that follows the backswing, expressed as a percentage of the peak pulse amplitude

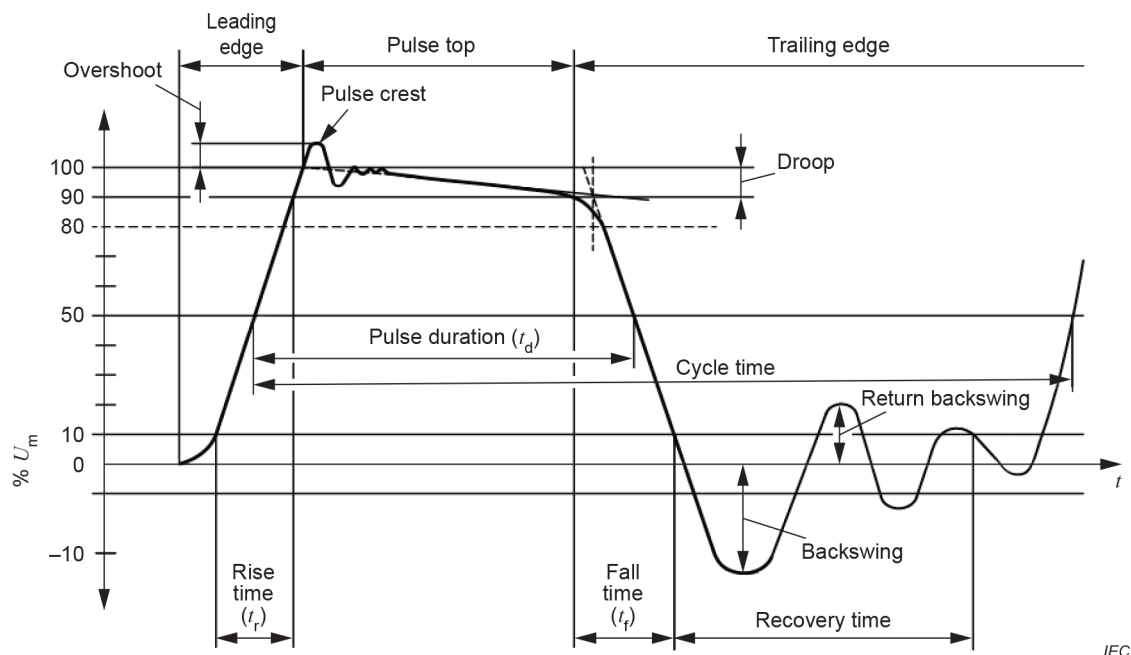
3.3.10 recovery time

time interval between the end of the pulse fall time and the time at which the pulse amplitude last reaches 10 % of the peak pulse amplitude

Note 1 to entry: Exceptionally, a value of less than 10 % may be used, in which case the interval is termed "the X % recovery time".

3.3.11 pulse repetition frequency

average number of pulses in unit time independent of the period over which it is measured



Leading edge: the interval between the first instant at which the pulse amplitude begins and the first instant at which the pulse amplitude reaches the peak pulse amplitude.

Pulse top: the interval between the first instants at which the pulse amplitude equals the peak pulse amplitude and the last instants at which the pulse amplitude equals 90 % of the peak pulse amplitude.

Trailing edge: the interval between the last instants at which the pulse amplitude equals 90 % of the peak pulse amplitude and the first instants at which the pulse amplitude of the second cycle begins.

For clarity in illustrating droop, the 80 % and 10 % points have been used in constructing the line which determines the border between the pulse top and the trailing edge.

Figure 1 – Pulse waveform parameters

3.4 quality factor

Q factor

ratio of the energy stored to the energy dissipated during one cycle at a particular frequency in a specified winding

Note 1 to entry: The Q factor is expressed in terms of either the series or the parallel components of reactance and loss resistance.

3.5 harmonic distortion

square root of the sum of the square of all harmonic voltages up to and including the seventh harmonic (excluding the fundamental) expressed as a percentage or as a ratio in decibels of the fundamental

3.6**maximum winding temperature**

mean temperature rise of any winding of the component under full load at maximum ambient temperature, when thermal stability has been achieved, added to the specified maximum ambient temperature

3.7**voltage-time product rating**

voltage pulse amplitude multiplied by the time interval between the first and last instants at which the pulse amplitude equals 50 % of the peak pulse amplitude

Note 1 to entry: The start of the pulse within which the non-linearity of the magnetizing current does not exceed a specified value.

3.8**background noise****acoustic noise**

noise measured at a measuring point with the component under test not electrically excited

3.9**compass safe distance**

distance from the pivot of the test magnetometer of a compass to the nearest on the surface of the component under test, at which the magnetic deviation is limited to a stated value

3.10**duty ratio**

ratio of pulse duration t_d to the cycle time

3.11**current transformer parameters****3.11.1****burden**

property of the circuit connected to the secondary winding of a current transformer which determines the real and reactive power at the secondary terminals

Note 1 to entry: Burden is expressed as total impedance with effective resistive and reactive components or as the total volt amperes and power factor at the specified values of current and frequency.

3.11.2**current transformation ratio**

k

ratio of the RMS value of the primary current to the RMS value of the secondary current under specified conditions

3.11.3**phase angle**

angular displacement of the fundamental frequency between the vector representing the primary and secondary currents of the transformer

Note 1 to entry: The phase angle is positive when the secondary current leads the primary current.

3.11.4**ratio error**

difference between the measured current transformation ratio k and its nominal value k_n , divided by the measured value k , and expressed as a percentage

$$\frac{k_n - k}{k} \cdot 100 \%$$

3.12**electrostatic screen**

conducting screen inserted between windings that, when it is connected to earth or the points where the voltage potentials are constant, considerably reduces the transference of unwanted signals from one winding to the other via inter-winding capacitance

3.13**safety screen**

conducting screen inserted between windings that, when it is connected to earth, effectively prevents fault currents flowing between those windings, in the event of an insulation failure

3.14**polarity**

<single-phase windings> property of a single-phase winding such that a terminal on one winding has the same polarity as a terminal on another winding if, when the other ends of the windings are connected to form a common terminal and the transformer/inductor is energized with a sinusoidal voltage, the induced voltage appearing between each of the two terminals and the common terminal rise positively through zero at the same instant of time

3.15**uniformly-insulated winding**

winding in which the insulation to earth is, at all points, designed to withstand an electric strength test of a value appropriate to the maximum voltage potential to be applied at the high voltage end

3.16**graded-insulated winding**

winding in which insulation to earth is graded from the amount at the high-voltage end to a smaller amount at the low-voltage end

Note 1 to entry: Such a winding should withstand an electric strength test of a value appropriate to the insulation of the low-voltage end.

3.17**frequency weighting characteristic**

A

most commonly used frequency curve in the measurement of sound pressure level

4 Test procedures**4.1 Test and measurement conditions****4.1.1 General**

Unless otherwise specified, all tests shall be carried out under standard atmospheric conditions for testing as specified in IEC 60068-1. Where there is a requirement for components to attain temperature stability this shall be in accordance with IEC 60068-1:2013, 4.4.

Unless otherwise stated in the detail specification, all voltages and currents shall be sinusoidal; values shall be taken as RMS, and polyphase supplies shall be assumed to be balanced.

The "information to be stated" that is required to complete the descriptions of test methods in Clause 4 shall be specified in the relevant detail specification for the component. The detail specification shall also specify the test fixture to be used in association with a component, where this is intended for use at frequencies high enough for the length of test leads to become significant.

Recommended tests and specifications for specific transformer groups are listed in Table 1.

Table 1 – Recommended tests and specifications for specific transformer and inductor groups

Test procedures	Filament	Isolating	Current limiting	Rectifier	Combination	Ferroresonance	Converter	Polyphase	Switch mode	Large rectifier	Voltage stepdown	Voltage stepup	Low ratio inverting	Impedance matching	DC isolating	Common-mode rejection	Potential transformers	Current transformers	Filter inductors	Charge inductors	Hybrid transformers	RF transformers	Network transformers
Winding resistance (4.4.1)																							
DC winding resistance (4.4.1.1)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AC resistance (4.4.1.2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Continuity (4.4.1.3)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Insulation tests (4.4.2)																							
Dielectric voltage withstand test (4.4.2.1)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x
Induced voltage test (4.4.2.2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
Insulation resistance (4.4.2.3)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Losses (4.4.3)																							
No-load current (4.4.3.1)	x	x	x	x	x	x	x	x	x	x	x	x	x										
No-load loss (4.4.3.2)	x	x	x	x	x	x	x	x	x	x	x	x	x										
Losses (4.4.3)																							
Quality factor, Q (4.4.3.3)																			x	x			
Short-circuit power test 4.4.3.4)	x	x	x	x	x	x	x	x	x	x	x	x	x										
Efficiency (4.4.3.5)	x	x	x	x	x	x	x	x	x	x	x	x	x										
Inductance (4.4.4)																							
Effective inductance (4.4.4.1)							x		x						x				x	x	x		x
Leakage inductance, L_1 (4.4.4.2)	x	x	x						x		x	x	x	x	x	x					x		x
Unbalance (4.4.5)																							
Capacitance unbalance (4.4.5.1)											x		x	x	x	x					x		
Common mode rejection ratio (4.4.5.2)																							x
Impedance unbalance (4.4.5.3)																						x	
Cross-talk attenuation (4.4.5.4)													x										
Voltage unbalance (4.4.5.5)															x								
Resistance unbalance (4.4.5.6)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Phase unbalance (4.4.5.7)																	x					x	
Amplitude unbalance (radio frequency) (4.4.5.8)																						x	
Capacitance (4.4.6)																							
Self-capacitance (distributed capacitance) (4.4.6.1)									x		x			x	x	x					x		
Inter-winding capacitance (4.4.6.2)												x	x	x	x	x							
Capacitance (4.4.6)																							
Inter-element capacitance (4.4.6.3)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x			x		
Transformation ratios (4.4.7)																							

Test procedures	Filament	Isolating	Current limiting	Rectifier	Combination	Ferroresonance	Converter	Polyphase	Switch mode	Large rectifier	Voltage stepdown	Voltage stepup	Low ratio inverting	Impedance matching	DC isolating	Common-mode rejection	Potential transformers	Current transformers	Filter inductors	Charge inductors	Hybrid transformers	RF transformers	Network transformers
Transformation ratio by impedance (4.4.7.1)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Coefficient of coupling (4.4.7.2)									x		x	x		x	x	x							
Voltage transformation ratio (4.4.7.3)																	x						
Current transformation ratio (4.4.7.4)																		x					
Resonant frequency (4.4.8)																							
Inherent self-resonance (4.4.8.2)						x	x							x		x					x		
Resonant assemblies (4.4.8.3)					x	x	x							x		x					x		
Signal transfer characteristics (4.4.9)																							
Insertion loss (4.4.9.1)											x	x	x	x								x	x
Return loss (4.4.9.2)											x	x	x	x									x
Cross-talk (4.4.10)																							x
Frequency response (4.4.11)														x	x	x					x		
Pulse characteristics (4.4.12)									x		x	x	x										
Voltage-time product rating (4.4.13)											x	x	x										
Total harmonic distortion (4.4.14)														x	x	x							
Voltage regulation (4.4.15)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Temperature rise (4.4.16)																							
Method utilizing the change in DC resistance of a winding (4.4.16.1)	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x			
Method using an additional series-opposing bifilar winding (4.4.16.2)	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x			
Surface temperature (4.4.17)	x	x	x	x	x	x	x	x	x	x									x	x			
Polarity (4.4.18)		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x
Screens (4.4.19)																							
Capacitance test for screens (4.4.19.1)		x		x	x				x	x	x			x	x	x	x	x			x		
Safety screens (4.4.19.2)															x		x						
Acoustic noise (4.4.20)																							
Acoustic noise (4.4.20.1)	x	x	x	x	x	x		x	x	x					x								
Electromagnetic noise (4.4.20.2)	x	x	x	x	x	x		x	x	x					x								
Corona tests (4.4.21)	x	x	x	x	x	x	x	x	x	x							x	x	x	x			
Magnetic fields (4.4.22)																							
Magnetic shielding (4.4.22.1)									x														
Magnetic influence (compass safe distance) (4.4.22.2)														x		x							
Magnetic radiation (4.4.22.3)		x		x	x			x	x	x				x	x	x	x						
Inrush current (4.4.23)			x															x					

4.1.2 Measurement uncertainty

The limits quoted in the detail specifications shall be absolute. The tolerance values applying to the actual measurement system shall be taken into account when the measurements are assessed against specification limits. Where tolerances with respect to set conditions or instrument error have been specified these shall be regarded as additional minimum requirements.

4.1.3 Alternative test methods

The test and measurement methods given in the relevant specification shall not be regarded as the only methods to be used. Special test equipment and automatic test sets are available, which may also be used. However, the tester shall satisfy the customer or relevant authority¹ that any alternative methods which the tester uses will give results equivalent² to those obtained by standard methods. In the case of dispute, for referee and reference purposes the specified methods only shall be used.

4.2 Visual inspection

4.2.1 General

Visual inspection shall be performed under normal factory lighting without visual aids. The condition, workmanship, marking and finish shall be satisfactory.

NOTE If special lighting and/or visual aids are necessary for the acceptance of particular components (e.g. very small components such as 1812/4532 or smaller), these can be specified as additional tests in the relevant detail specification.

4.2.2 Safety screen position

NOTE 1 Sometimes the term "isolating screen" is used as an alternative to "safety screen".

Purpose: To determine the position of a safety screen in relation to adjacent windings.

Procedure: The fitted and positioned safety screen shall be inspected before being obscured by subsequent windings. The safety screen shall:

- a) totally cover the winding around which it is wrapped such that the "finish" end overlaps the "start" end by no less than the amount specified in the detail specification;
- b) be adequately insulated so as not to comprise a short-circuited winding.

NOTE 2 Screens fitted to toroidal transformers can consist of a number of turns of conductive strip provided that each turn overlaps the adjacent turn by not less than 5 % of the strip width.

Information to be stated:

- a) minimum overlap;
- b) minimum creepage distance.

4.2.3 Quality of joints

NOTE A good solder joint is one that has excellent electrical contact between the parts joined and good mechanical strength. Examples of good solder joints are shown in Figure 2. Figure 3 illustrates defective joints.

¹ For example, a National Supervising Inspectorate within the IECQ scheme or equivalent method.

² By "equivalent" it is meant that the value of the characteristic established by such other method and deemed acceptable in accordance with the limits ascribed to such other method will fall within the specified limits when measured by the specified method.

Purpose: To determine the quality of all solder joints.

Procedure: All solder joints shall be inspected to ensure that the following requirements are complied with.

Requirements: Soldered joints shall:

- a) exhibit good tinning as evidenced by the free flowing of solder with wetting of the termination;
- b) be smooth with no spikes;
- c) be bright and shiny;
- d) be without rough patches;
- e) have a concave surface and the outline of the wire shall be visible under the surface of the solder;
- f) not have been moved during soldering (such joints exhibit an "orange peel" effect, as shown in Figure 3(a));
- g) not be "dry" (that is, not exhibit a distinct line where the solder fillet joins the wire or have a high contact angle between the solder and the wire (see Figure 3(b));
- h) be wired at terminals in such a way as to leave no residual stress (see Figure 3(c));
- i) not exhibit "wicking" (that is, the joining wire shall not be overheated, leading to the movement of solder into multi-stranded wires (see Figure 3(d));
- j) not exhibit score and scratch at leading-out end before welding (see Figure 3(e));
- k) not exhibit solder cracking on the spot weld end (see Figure 3(f));
- l) not exhibit nonwetting (see Figure 3(g));
- m) not exhibit projection on the weld end (see Figure 3(h)).

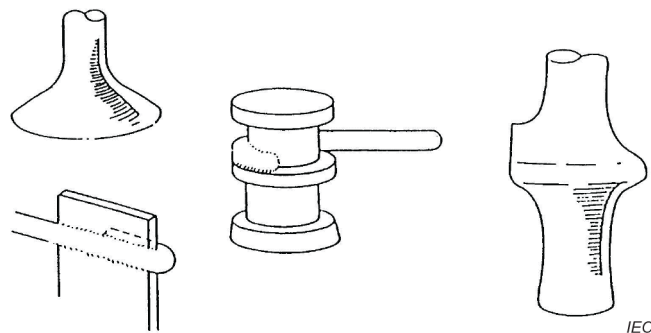
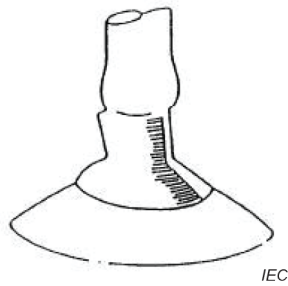
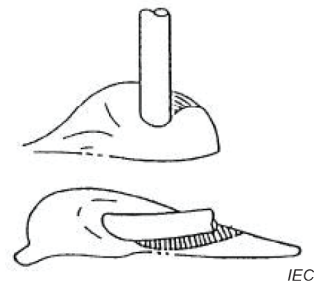


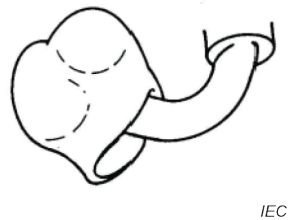
Figure 2 – Examples of good solder joints



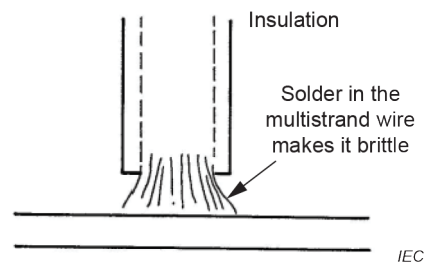
a) Moved joint



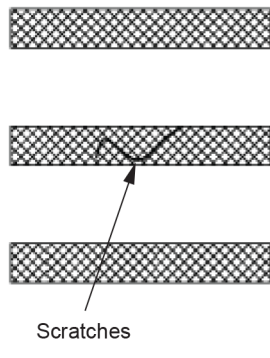
b) Dry joints



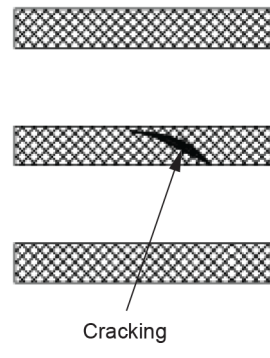
c) Mechanically stressed joint



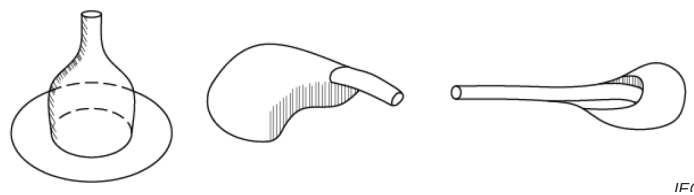
d) Wicking



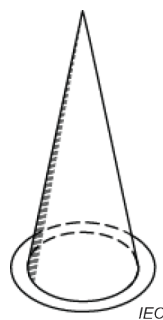
e) Scratches



f) Cracking



g) Nonwetting



h) Tip of welding end

Figure 3 – Examples of defective joints

4.3 Dimensioning and gauging procedure

The dimensions shall be verified as being in accordance with the relevant specification.

4.4 Electrical test procedures

4.4.1 Winding resistance

4.4.1.1 DC winding resistance

Purpose: To determine the DC resistance of a winding or windings between specified terminations.

Procedure: The resistance shall be measured by a suitable method (refer to Annex A).

Where required by the detail specification, the ambient temperature θ (in °C) shall be measured and the result of the resistance measurement R_m (in Ω) corrected to the corresponding value at 20 °C, R_{20} (in Ω) by means of the following formulae:

$$R_{20} = \frac{k + 20}{k + \theta} R_m$$

$$k = \frac{1}{\alpha_{20}} - 20$$

where

k is a constant related to the thermal coefficient of resistivity. For the purposes of this document, the value for copper shall be taken as 234,5 and for aluminium as 228,1;

α_{20} is a temperature coefficient of resistivity of the winding conductor at 20 °C.

For safety reasons, care should be taken to avoid shock due to the risk of short-circuited windings generating high voltages at the moment of current interruption.

Information to be stated:

- a) terminations between which the measurement is to be made;
- b) whether the result of measurement should be corrected to 20 °C, and if so, the value of k is corrected by the temperature coefficient of resistivity.

The selected method should be determined by the ease of operating the test and the accuracy required. The accuracy of the equipment should be at least ten times better than the accuracy required of the test.

The measuring current should not be so large as to cause self-heating or to have a significant magnetizing effect on the component

4.4.1.2 AC resistance

Purpose: To determine the AC resistance under rated operating frequency.

Procedure: A suitable AC power source shall be adopted, and the test frequency and AC voltage shall be stipulated.

Information to be stated:

- winding to be tested.

Care should be taken in testing to avoid the risk of shock, especially in the case of components with high inductance, as a high voltage can be generated.

4.4.1.3 Continuity

Purpose: To verify the continuity of a specified winding.

Procedure: Continuity shall be established using a suitable DC or AC voltage or current source, and a suitable detector.

Information to be stated:

- winding to be tested.

The current should not be so large as to have a significant magnetizing effect on the component.

Care should be taken in testing a winding with a high inductance value as a high voltage may be generated.

NOTE Where there are parallel paths, as with multiple windings or in polyphase components, a DC resistance check can be necessary to ensure that the path under examination is not being influenced by shunt paths.

4.4.2 Insulation tests**4.4.2.1 Dielectric withstand voltage test**

Purpose: To ensure that the insulation of uniformly-insulated windings and the low-voltage end insulation of graded-insulated windings are adequate.

NOTE 1 This test is not suitable for the high-voltage end insulation of windings having graded insulation or designed to have one point earthed. The high-voltage end insulation of such windings can be tested only by the application of an appropriate induced voltage test of the special test conditions of 4.4.2.2 item b).

NOTE 2 In certain cases it can be appropriate to demonstrate the adequacy of the low-voltage end insulation of graded-insulated windings during the induced voltage test of the special test conditions of 4.4.2.2 item b).

Procedure: A test voltage whose value is from Table 2 unless otherwise specified. The test voltage shall be applied between specified pairs of isolated elements of the component. All windings shall be short-circuited. Windings and screens on one side of the insulation system shall be connected to the frame, core and earth while windings and screens on the other side shall be connected together. The test instrument should have sufficient output power (refer to Annex B).

Table 2 – Voltage of dielectric withstanding voltage test

Peak working voltage V_{pk}	AC test voltage, 45 Hz to 65 Hz (RMS) V_{RMS}	DC test voltage V
< 25	50	71
> 25 to 50	100	141
> 50 to 100	300	424
> 100 to 175	500	707
> 175 to 700	2,8 × peak working voltage	4 × peak working voltage
> 700	1,4 × peak working voltage + 1 000	2 × peak working voltage + 1 400

The test voltage shall be increased at a convenient rate not exceeding 2 kV/s, from zero to the specified value, maintained at this value for the specified time (unless breakdown occurs), then decreased to zero at the same rate.

For fluid-filled components, except for those designed for operation in one plane only and so marked, approximately half the test samples shall be tested with terminals uppermost and half with the terminals underneath.

If environmental conditioning is required in the detail specification for this test, the component shall be held in the specified conditions for a minimum of 6 h unless otherwise specified. (See IEC 60068 for information on environmental testing.)

There shall be no evidence of heating, breakdown or deterioration. Ionization shall not be regarded as a criterion of breakdown. The leakage current shall not exceed the specified value.

Information to be stated:

- a) terminations between which the test is to be made;
- b) test voltage (for a winding having graded-insulation, values shall be given for both ends of the winding);
- c) frequency of AC test voltage (if different from the values shown in Table 2);
- d) test duration;
- e) maximum leakage current, if specified.

NOTE If breakdown occurs during the test it can at first be detected by sporadic and intermittent increases in leakage current followed by a significant increase to a constant higher value which, on many electric strength test sets, is accompanied by a partial or complete collapse of the voltage. This type of breakdown can be caused by partial breakdown in ionized voids and weakened insulation which then avalanches to complete breakdown in the form of arc-over or arc-through.

Electric strength test voltages can be hazardous. Extreme care should be taken in performing this test.

4.4.2.2 Induced voltage test

Purpose: To verify the adequacy of inter-turn and inter-layer insulation of transformers and inductors, and to verify the adequacy of the high-voltage end insulation of windings having graded insulation.

Special conditions of test:

The following special conditions apply:

- a) Uniformly insulated windings are normally tested as in Procedure 1, 2 or 3, as appropriate. Any point of a winding may be earthed during the test as specified.
- b) Windings having graded insulation are normally tested as in Procedure 1, 2 or 3, as appropriate. A point on such a winding may be earthed or raised to a specified voltage above earth during the test. The induced voltage shall be such that, when added vectorially to any applied voltage, the high-voltage end of the winding is raised to the appropriate peak test voltage given in 4.4.2.1.

If the specified voltage above earth is alternating, it shall be of the same frequency as the induced voltage (refer to Annex C).

In general, during the execution of the induced voltage test, no winding should be permitted to "float", i.e. to remain unconnected at both ends.

Procedure 1: Applicable to transformers and inductors intended for exciting by sinusoidal waveforms.

A specified test voltage of not less than twice the rated supply voltage at a frequency of not less than twice the lowest rated frequency shall be applied across the specified winding. The duration and manner of application shall be as specified in the detail specification.

Procedure 2: Applicable to transformers and inductors intended for exciting by pulse waveforms.

Specified test voltage pulses of an amplitude not less than twice the rated pulse amplitude, at a specified pulse repetition frequency of not less than 25 % of the maximum rated pulse repetition frequency and with a specified pulse duration not less than 25 % of the rated maximum pulse duration and normally not greater than 50 %³ of the rated pulse duration shall be applied across the winding. The duration and manner of application shall be as specified in the detail specification.

Procedure 3: Applicable to transformers and inductors intended for exciting by non-sinusoidal periodic waveforms such as those in power supplies operating with semi-conductors in a switched mode.

A specified sinusoidal test voltage of peak value not less than twice the maximum rated peak value for the input voltage waveform and at a specified frequency, derived as follows, shall be applied across the specified winding. The duration and manner of application shall be as specified in the detail specification.

The test frequency shall be such that its cyclic period is normally⁴ not greater than the effective shortest half-cycle period of the operative waveform for which the component is intended, for example in the case of pulse width modulated symmetrical or asymmetrical waveforms.

The effective half-cycle shall be taken to be the effective minimum on-time of the electronic switch.

Duration for application of test voltage in Procedures 1, 2 and 3:

The duration of application of the test voltage shall be specified as one of the following:

- a) the applied voltage shall be raised from one-third of the specified voltage to the full value which shall then be maintained for 60 s $\pm$ 5 s before reducing the voltage to one-third of its value and thence to zero;
- b) 5 s to 10 s (value to be stated).

Requirements:

There shall be no evidence of heating, breakdown or deterioration. Ionization shall not be regarded as a criterion of breakdown.

³ Pulse durations greater than 50 % of the rated maximum value may be specified provided that they do not cause core flux saturation or other abnormalities.

⁴ A lower test frequency may be specified provided that it does not cause core flux saturation or other abnormalities.

Information to be stated in the detail specification:

- a) the test voltage (RMS or peak as applicable);
- b) the winding(s) to be excited (see the last paragraph in 4.4.2.1);
- c) the winding point intended to be connected to a known potential and the value of this potential (if applicable);
- d) the duration of application of test voltage;
- e) the test frequency or pulse repetition frequency (as applicable);
- f) the pulse duration (applicable to Procedure 2).

NOTE A source of test voltage can be connected to windings other than the normal input winding in order to obtain the necessary voltages.

4.4.2.3 Insulation resistance

Purpose: To measure the resistance of the insulation between the various parts of the component.

Procedure: Unless otherwise specified the insulation resistance shall be measured with a DC voltage of either:

100 V $\pm$ 10 V for windings with peak working voltage < 500 V, or

500 V $\pm$ 10 V for windings with peak working voltage $\geq$ 500 V.

The test voltage shall be applied until a steady reading is obtained or, failing that, for 60 s $\pm$ 5 s.

If environmental conditioning is required in the detail specification for this test, the component shall be held in the specified conditions for a minimum of 6 h unless otherwise specified. (See IEC 60068 (all parts) for information on environmental testing.)

Information to be stated:

- a) terminations between which the measurement is to be made;
- b) peak working voltage of each winding;
- c) environmental conditioning.

4.4.3 Losses**4.4.3.1 No-load current**

Purpose: To verify that the core is of the required quality and is correctly assembled and that there are no short-circuited parts of the windings.

Procedure: The specified voltage at the frequency or frequencies specified shall be applied from a low impedance source to the input winding with all other windings in open-circuit. The harmonic distortion of the applied voltage shall be less than 6 %. The input current shall be measured with a true RMS. instrument, whose impedance is sufficiently low not to affect the applied voltage by more than 1 %. The input current shall be measured when its value is stabilized. For polyphase components, all input currents shall be measured. The test schematic is shown in Figure 4.

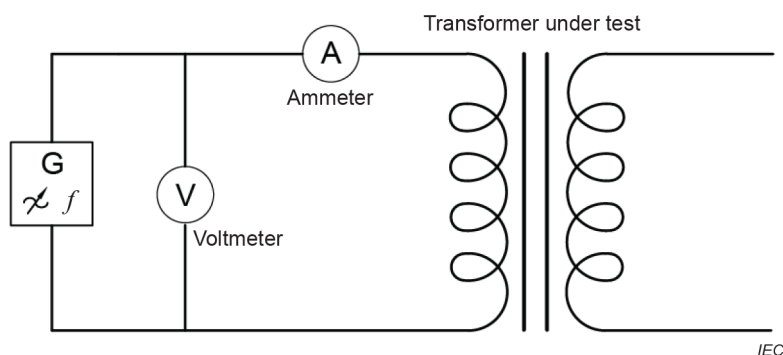


Figure 4 – No-load current test schematic

Information to be stated:

- a) AC voltage;
- b) test frequency;
- c) winding to be tested;
- d) maximum RMS value of input current.

4.4.3.2 No-load loss

Purpose: To verify that the transformer is of the required quality and is correctly assembled and that there are no short-circuited parts of the windings.

Procedure: The specified voltage at the specified frequency shall be applied to the input winding via a suitable wattmeter, all other windings being in open-circuit. The harmonic distortion of the voltage when applied to the winding shall be less than 6 % (refer to Annex D). The test schematic is shown in Figure 5.

The power loss shall be measured when its value has been stabilized, a correction being made for the wattmeter losses if these are significant.

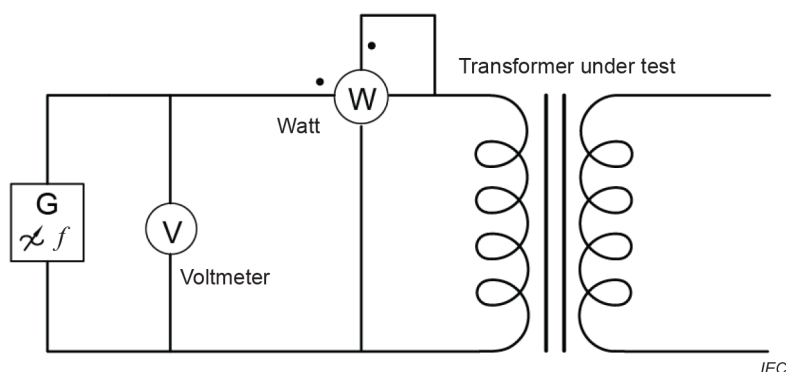


Figure 5 – No-load loss test schematic

Information to be stated:

- a) test voltage;
- b) test frequency;
- c) winding to be connected;
- d) maximum power loss.

4.4.3.3 Quality factor, Q

Purpose: To determine the quality factor of a component at a particular frequency.

Procedure: The quality factor, Q , shall be measured at the specified voltage and frequency using a suitable method, for example:

- a) a suitable inductance bridge;
- b) circuit magnification meter (Q -meter);
- c) insertion loss measurement;
- d) damped oscillation test method (refer to Annex E).

The relationships between the effective inductance L and resistance R of a component under test, according to whether a series (s) or parallel (p) circuit representation is used, and the measured value of Q at the frequency f are given by:

$$Q = \frac{2\pi \cdot f \cdot L_s}{R_s}$$

and

$$Q = \frac{R_p}{2\pi \cdot f \cdot L_p}$$

respectively.

Information to be stated:

- a) winding connections;
- b) AC voltage;
- c) measuring frequency;
- d) limits of Q value.

NOTE In tests of high Q components, corrections for the dissipation factor of the capacitor and terminating impedance can be necessary.

4.4.3.4 Short-circuit power test

Purpose: The purpose of the short-circuit power test is to determine the losses due to the effective AC resistance of the transformer, excluding the losses of the core, at rated current.

Procedure: The simplified diagram is shown in Figure 6. The circuit consists of a power source of specified frequency, an ammeter to monitor the primary current of the transformer, and a wattmeter to measure the losses in the transformer's primary circuit. The secondary winding is short-circuited with the least impedance practical.

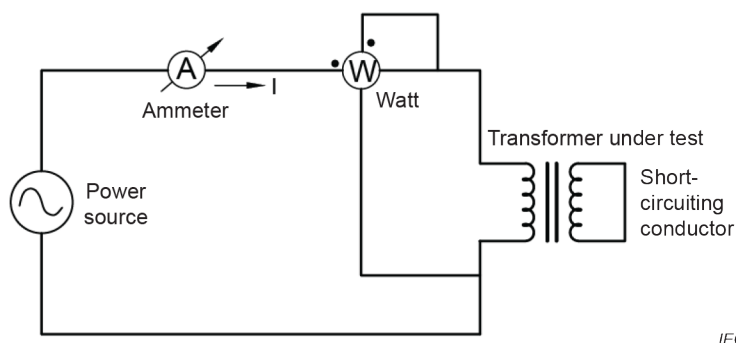


Figure 6 – Simplified diagram for short-circuit power test

Information to be stated:

- the power source shall furnish the required voltage and current with a specified limit on harmonic distortion;
- the wattmeter shall indicate the real power lost in the transformer under test with the specified accuracy;
- the ammeter shall indicate the RMS current in the primary winding with a specified accuracy;
- the short-circuiting conductor and its connections to the terminals of the secondary winding shall have negligible impedances with respect to the secondary winding.

The transformer is connected in the test circuit. The input voltage should be raised from 0 V until the rated current is achieved, as read on the ammeter. The power P indicated by the wattmeter is the short-circuit power, which is the sum of the losses in the test winding and all short-circuiting windings, as well as the power loss of the wattmeter.

NOTE The measurement is made as quickly as possible after excitation is applied to minimize the effects of self heating.

4.4.3.5 Efficiency

The efficiency of the transformer is the ratio of its total power output to the power input to the device, expressed in percent:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \cdot 100$$

where

P_{out} is the total power output;

P_{in} is the power input.

The efficiency of transformers can be more accurately calculated when P_{loss} , including the core and copper losses, is known from independent measurements or estimates:

$$\eta = \frac{P_{\text{in}} - P_{\text{loss}}}{P_{\text{in}}} \cdot 100 = \frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{loss}}} \cdot 100$$

where

P_{out} is the total power output;

P_{in} is the power input;

P_{loss} is the loss.

4.4.4 Inductance

4.4.4.1 Effective inductance

Purpose: To measure the effective inductance of a winding.

Procedure: The inductance of the specified winding shall be measured on a suitable bridge at the specified voltage and frequency with a polarizing DC applied if required.

Information to be stated:

- a) winding to be measured;
- b) form of measurement;

NOTE 1 In the case of low Q components, typically 10 or less, the series or parallel mode of measurement is specified.

NOTE 2 There is a difference between the true inductance L_0 measured at low frequencies and the effective inductance L_e measured at frequencies close enough to self-resonance that self-resonance affects the measured inductance.

- c) AC voltage on the measured winding;
- d) measuring frequency;
- e) polarizing DC.

4.4.4.2 Leakage inductance, L_1

Purpose: To determine the leakage inductance between the windings of a transformer.

Procedure: The series inductance of the specified winding shall be measured on a suitable bridge, the remaining windings or a specific winding being short-circuited as specified.

Information to be stated:

- a) test winding and other windings connections;
- b) AC voltage;
- c) measuring frequency.

4.4.5 Unbalance

4.4.5.1 Capacitance unbalance

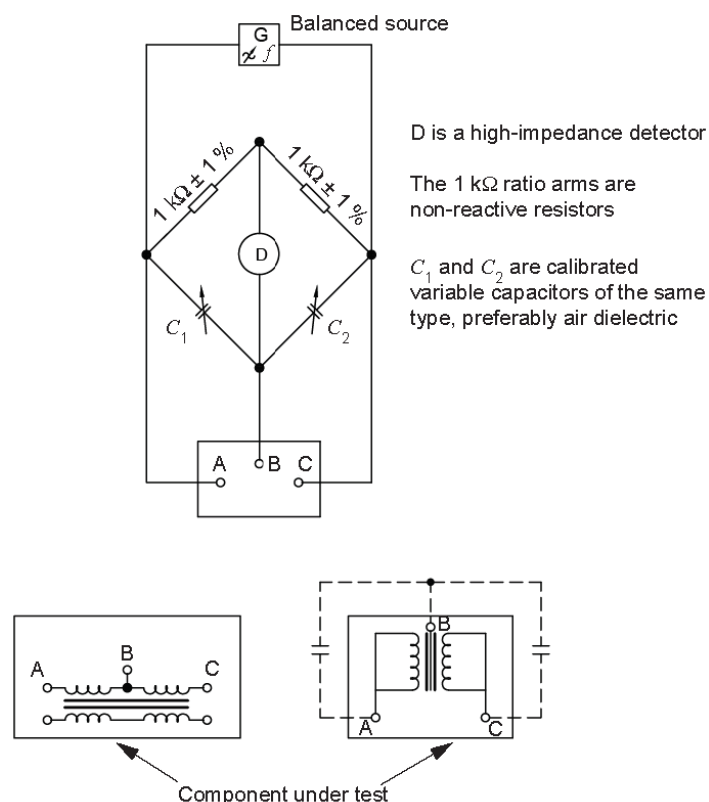
Purpose: To determine the capacitance unbalance between the specified terminations of a transformer.

Procedure: A suitable circuit for the measurement of this parameter is shown in Figure 7. The test frequency shall be high enough to make the effect of inductance unbalance negligible.

With no connections to the transformer under test, capacitor C_1 is set to a specified value (for example 50 pF) and a balance is obtained by varying C_2 . The transformer is then connected as shown in Figure 7 and the bridge is rebalanced by varying C_1 . The difference between the two values of C_1 is the capacitance unbalance.

Information to be stated:

- a) initial value of C_1 ;
- b) component connections;
- c) frequency.



NOTE Terminal letters are for reference only.

Figure 7 – Circuit for measuring capacitance unbalance

4.4.5.2 Common mode rejection ratio

Purpose: To determine the degree of rejection of the common mode input voltage.

Procedure: A suitable circuit for this test is shown in Figure 8.

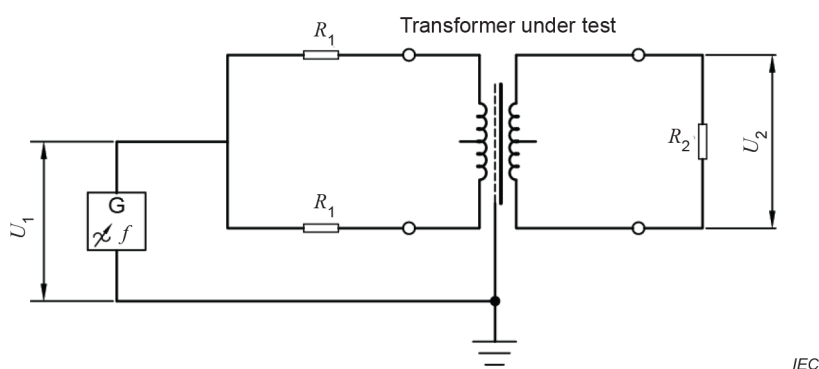


Figure 8 – Circuit for determining common mode rejection ratio

The input terminals of the transformer under test are connected to the high potential terminal of a voltage source through equal resistors R_1 , each equal to half the input impedance. The output terminals of the transformer under test are connected to a resistor R_2 whose value is specified in the detail specification.

The common mode rejection ratio (CMRR) in decibels is given by:

$$\text{CMRR} = -20\lg(U_2/U_1)$$

where

U_1 is the voltage of the common mode source, and

U_2 is the voltage of the common mode signal emerging from the component under test.

Information to be stated:

- a) transformer connections, including earth connections;
- b) test frequency;
- c) input impedance, $2R_1$;
- d) load resistor R_2 .

4.4.5.3 Impedance unbalance

Purpose: To determine the impedance unbalance between two windings of a transformer, intended to be equal.

Procedure: A suitable circuit for this test is shown in Figure 9.

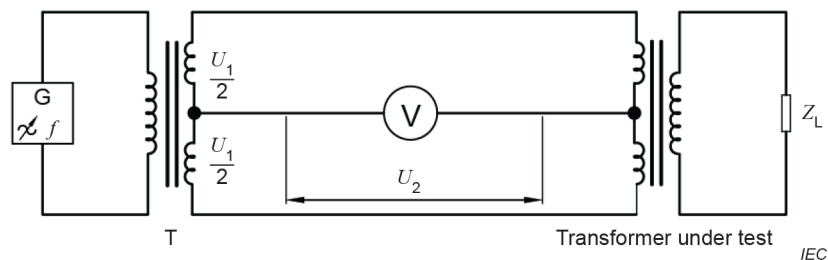


Figure 9 – Circuit for measuring impedance unbalance

A precision screened and balanced transformer shall be used as the input transformer T and its symmetry shall be at least 20 dB better than the expected reading for the transformer under test.

If the voltage caused by unbalance, as measured by the voltmeter V, is U_2 , then the impedance unbalance a_{uz} in decibels is given by the expression:

$$a_{uz} = 20 \lg(U_1/2U_2)$$

Information to be stated:

- a) component connections;
- b) input voltage U_1 ;
- c) load impedance Z_L ;
- d) test frequency.

It is recommended that V be a frequency selective voltmeter, tuned to the test frequency.

4.4.5.4 Cross-talk attenuation

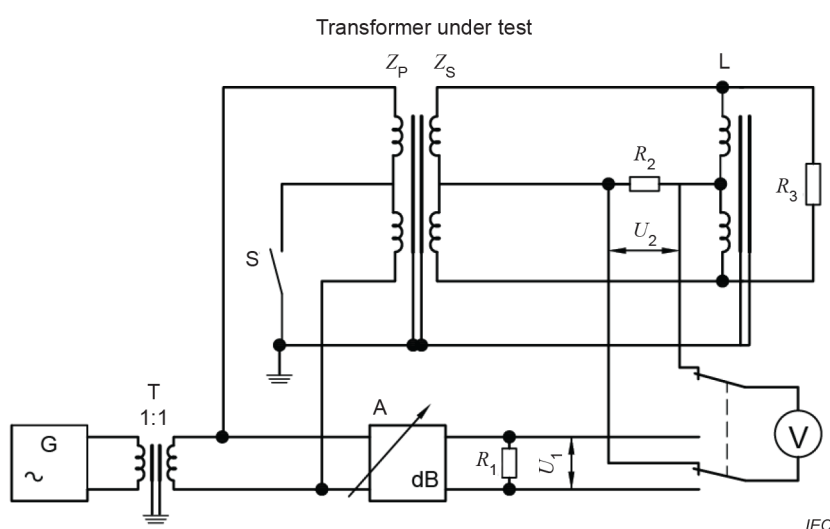
Purpose: To determine the cross-talk attenuation of a telecommunication line transformer used in a phantom circuit.

Procedure: A suitable test circuit is shown in Figure 10.

The attenuator shall be adjusted until $U_1 = U_2$.

The cross-talk attenuation a_c in decibels shall then be calculated in terms of the attenuator setting a_r from the following expression:

$$a_c = a_r + 10 \lg 2 - 10 \lg (Z_p / Z_s)$$



T is a precision screened and balanced transformer.

L is a precision screened and balanced centre-tapped inductor, whose symmetry is at least 20 dB better than that expected for the transformer under test.

G is a generator of low-output impedance.

A is a precision variable attenuator of characteristic impedance R_1 .

V is a voltmeter suitable for the operating frequency of the test set and having an impedance greater than 10 kΩ.

S is a switch enabling the transformer's primary centre tap to be earthed, if required.

Z_p is the specified primary impedance.

Z_s is the specified secondary impedance.

R_1 is a resistor of value equal to the characteristic impedance of the attenuator.

R_2 is a resistor of value equal to the phantom circuit impedance.

R_3 is a resistor of value equal to the specified secondary impedance.

Figure 10 – Circuit for determining cross-talk attenuation

Information to be stated:

- transformer primary and secondary impedances;
- phantom circuit impedance;
- test frequency if other than 800 Hz;
- transformer's primary winding centre tap to be earthed or not earthed.

4.4.5.5 Voltage unbalance

Purpose: To determine the voltage unbalance between two windings intended to be equal.

Procedure: The transformer shall be connected to a source of specified voltage and frequency. A resistive load simulating the operating conditions shall be connected to the appropriate windings; the voltages across the windings under test shall be measured and the voltage unbalance determined from the measured values U_1 and U_2 as a percentage, using the formula:

$$\frac{U_1 - U_2}{U_1} \cdot 100$$

or expressed in decibels by the parameter a_{uv} given by the expression:

$$a_{uv} = 20 \lg [U_1 / (U_1 - U_2)]$$

where U_1 is the larger of the measured values.

Information to be stated:

- a) test frequency;
- b) voltage to be applied;
- c) component connections;
- d) load resistance.

4.4.5.6 Resistance unbalance

Purpose: To determine the DC resistance unbalance between two windings intended to be equal.

Procedure: The DC resistance of each specified winding shall be measured using an instrument having a resolution of 0,1 times the ohmic value of the specified DC resistance unbalance, or better. The measuring current shall be chosen so as not to cause heating or significant magnetization of the component under test.

The resistance unbalance shall be calculated as a percentage using the formula:

$$\frac{R_1 - R_2}{R_1} \cdot 100$$

or expressed in decibels by the parameter a_{ur} given by the expression:

$$a_{ur} = 20 \lg [R_1 / (R_1 - R_2)]$$

where R_1 is the larger of the measured values and R_2 is the smaller.

Information to be stated:

- winding connections.

4.4.5.7 Phase unbalance

Purpose: To determine the phase balancing between two windings intended to have equal phases.

Procedure: A pertinent test circuit is shown in Figure 11.

Phase unbalance shall be measured between two output ports. While measuring, the other outputs shall be connected by matched loads which meet the test requirements. Repeat the measurement at the other outputs in the same fashion.

Information to be stated:

- a) test instrument: four-channel vector network analyzer or equivalent;
- b) test channel;
- c) determine by sweep the frequency range required.

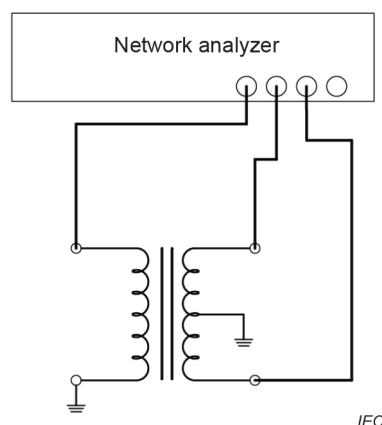


Figure 11 – Schematic diagram of phase unbalance and amplitude unbalance

4.4.5.8 Amplitude unbalance (radio frequency)

Purpose: To determine the amplitude balancing between two windings intended to have equal output levels.

Procedure: A pertinent test circuit is shown in Figure 11.

Amplitude unbalance shall be measured between two output ports. While measuring, the other outputs shall be connected to matched loads which meet the test requirements. Repeat the measurement at the other outputs in the same fashion.

Information to be stated:

- a) test instrument: four-channel vector network analyzer or equivalent;
- b) test channel;
- c) determine by sweep the frequency range required.

4.4.6 Capacitance

4.4.6.1 Self-capacitance (distributed capacitance)

Purpose: To determine the effective self-capacitance (distributed capacitance) of specified windings.

Procedure 1: Measurement shall be made with short leads connecting the terminations to a Q -meter. At the specified frequency (at least five times the self-resonant frequency of the winding) the winding shall be resonated with a specified inductor. Then the winding shall be removed from the Q -meter and, by adding capacitance in place of the winding, the inductor shall be resonated again at the same frequency. The added capacitance shall be taken as the effective self-capacitance of the winding.

Procedure 2: Capacitors of known values shall be connected in parallel with the winding, and the resonant frequencies of the parallel circuits so formed shall be measured on a suitable parallel impedance or admittance bridge. The capacitance values shall be plotted against $1/f^2$. If this yields a straight line, the intercept on the capacitance axis shall be taken as numerically equal to the required capacitance. A typical plot is shown in Figure 12.

A non-linear plot indicates eddy current shielding, in which case the capacitance values shall then be plotted against:

$$\frac{1}{f^2(L_1/L)}$$

where

L is the inductance of the winding at low frequency;

L_1 is the inductance at the frequency of measurement, the change in value occurring because of eddy current shielding;

f is the measuring frequencies.

For both Procedures 1 and 2 the earthing conditions shall be as specified.

NOTE In practice, Procedure 2 is of doubtful accuracy since the intercept is very sensitive to the slope of the "straight line", and the points tend to exhibit scatter and lie too far from the origin.

Information to be stated:

- a) winding connections;
- b) Procedure 1 or 2;
- c) for Procedure 1, the measuring frequencies;
- d) for Procedure 1 only, a description of the specified inductor;
- e) earthing conditions.

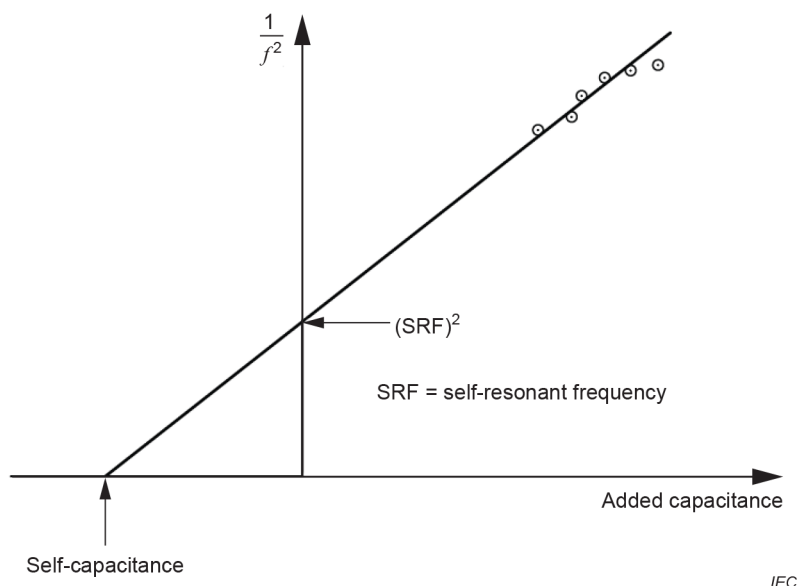


Figure 12 – Typical graph for determining self-capacitance

Procedure 3: The self-capacitance (distributed capacitance) of the winding is calculated according to the resonant frequency and the effective inductance (the inductance value of the linear segment in the range of test frequency).

The winding's own capacitance (distributed capacitance) should be calculated as follows:

$$f = \frac{1}{2\pi\sqrt{L \cdot C}}$$

where

L is the inductance of the winding at low frequency;

f is the L - C parallel resonant frequency.

Information to be stated:

- a) winding connections;
- b) AC voltage;
- c) test frequency range.

For all three Procedures 1, 2 and 3 the earthing conditions shall be as specified.

4.4.6.2 Inter-winding capacitance

Purpose: To determine the static or structural capacitance between specified windings.

Procedure 1: Windings to be included in the measurement shall be short-circuited, unless otherwise specified in the detail specification. The specified points of connection, between which the effective capacitance is required, shall be connected to a suitable capacitance bridge.

NOTE 1 This method is suitable for use at relatively low frequencies.

Procedure 2: The specified points of connection of the windings to be tested, each short-circuited unless otherwise required, shall be connected as shown in a test circuit such as that of Figure 13, where X_C represents the reactance of the capacitance to be measured.

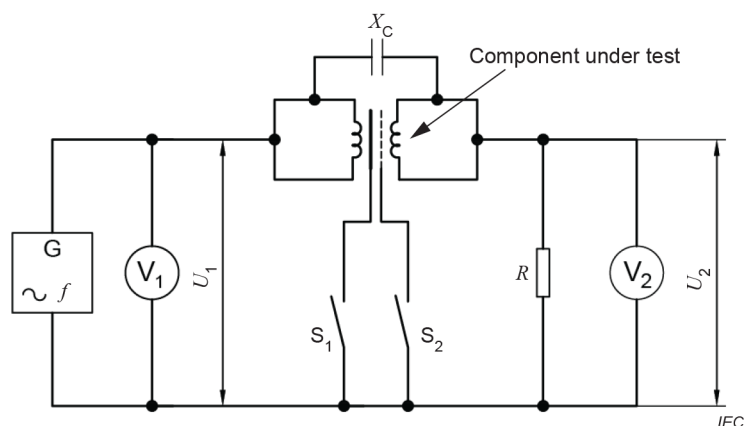


Figure 13 – Circuit for determining inter-winding capacitance

The resistance of R should be 100 to 1 000 times smaller than the value of X_C . The values of U_1 and U_2 are read from the voltmeters V_1 and V_2 respectively, and the inter-winding capacitance is calculated from the formula:

$$C = \frac{1}{2\pi \cdot f \cdot R} \cdot \frac{U_2}{U_1}$$

where

f is the frequency of the generator G .

NOTE 2 Where many components are measured, it can be convenient to use fixed values of f , R and U_1 such that U_2 can be read directly in capacitance units.

Switches S_1 and S_2 allow the core, shield or both to be connected to earth.

Information to be stated:

- a) winding connections;
- b) for Procedure 1, test frequency.

4.4.6.3 Inter-element capacitance

Purpose: To determine the static capacitance between two elements of a transformer (e.g. winding to shield and/or core).

Procedure: As in 4.4.6.2.

Information to be stated: As in 4.4.6.2.

4.4.7 Transformation ratios

4.4.7.1 Transformation ratio by impedance

The transformation ratio of a practical transformer with a first winding having N_1 turns to a second winding magnetically coupled to it and having N_2 turns, can be determined as the ratio of the impedances of the two windings, including the mutual impedances:

$$a_{12} = \frac{Z_{10} + K\sqrt{Z_{10} \cdot Z_{20}}}{Z_{20} + K\sqrt{Z_{10} \cdot Z_{20}}}$$

where

a_{12} is the transformation ratio;

Z_{10} is the open-circuit impedance of the primary winding, $= R_{10} + j\omega L_{10}$;

Z_{20} is the open-circuit impedance of the secondary winding, $= R_{20} + j\omega L_{20}$;

K is the coefficient of the coupling, with the term $K\sqrt{Z_{10} \cdot Z_{20}}$ representing the mutual impedance between the two windings.

In the special case when the phase angles of Z_{10} and Z_{20} are equal, the transformation ratio is equal to the ratio of the mutual inductances of the two windings, including the inductances:

$$a_{12} = \frac{L_{10} + K\sqrt{L_{10} \cdot L_{20}}}{L_{20} + K\sqrt{L_{10} \cdot L_{20}}}$$

where

a_{12} is the ratio of the transformation;

L_{10} is the inductance of the primary winding with the secondary in open-circuit;

L_{20} is the inductance of the secondary winding with the primary open-circuit;

K is the coefficient of the coupling, with the term $K\sqrt{L_{10} \cdot L_{20}}$ representing the mutual inductance between the two windings.

This condition is established in the most conventional ratio-of-transformation bridges.

4.4.7.2 Coefficient of coupling

The coupling coefficient is the tightness of the coupling between the windings:

$$K = \frac{M}{\sqrt{L_{10} \cdot L_{20}}}$$

where

M is the mutual inductance.

In coupling inductors, the coupling coefficient expression is:

$$K = \frac{L_{sa} - L_{so}}{4\sqrt{L_{10} \cdot L_{20}}}$$

where

L_{sa} is the inductance of the two windings connected in aiding series;

L_{so} is the inductance of the two windings connected in opposing series;

L_{10} is the inductance of the primary winding with the secondary open-circuit;

L_{20} is the inductance of the secondary winding with the primary open-circuit.

In a transformer, the coupling coefficient expression is:

$$K = \sqrt{1 - \frac{L_s}{L_{10}}}$$

L_{10} is the inductance of the primary winding with the secondary open-circuit;

L_s is the inductance of the primary winding with the secondary short-circuit.

4.4.7.3 Voltage transformation ratio

Purpose: To verify that the voltage transformation ratio of two windings of a transformer is within specified limits.

Procedure 1: A supply of specified voltage and frequency shall be connected to the specified winding, all other windings being in open-circuit. The output voltage of the appropriate winding shall be measured and the required ratio determined.

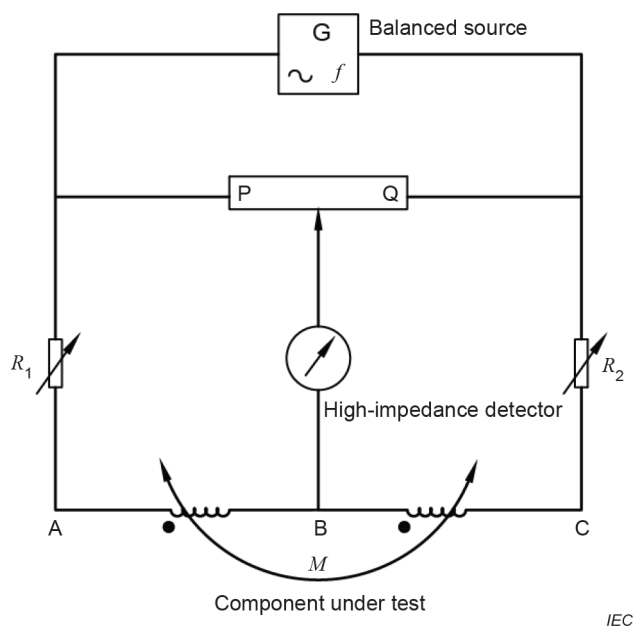
The measuring instrument should be of sufficiently high impedance for the effect on the measured voltage to be negligible.

It is generally advisable to apply the test voltage to the highest impedance winding and measure the output of the low impedance winding at a frequency where the winding exhibits its highest Q -value but avoids self-resonance.

Information to be stated:

- a) AC voltage;
- b) measuring frequency;
- c) windings to be connected and measured;
- d) the voltage transformation ratio limits.

Procedure 2 (for single-phase components only): The two windings under test shall be incorporated in the bridge circuit as shown in Figure 14. The two windings under test shall be connected so that the total inductance between terminals A and C is augmented by the effect of mutual inductance, M , between the windings. Resistors R_1 and R_2 are set to the values given in the detail specification and an initial balance is obtained by varying P/Q. A final bridge balance, as indicated by a minimum detector reading, shall then be obtained by adjustment of both R_1 (or R_2) and P/Q, and the voltage transformation ratio calculated as $AB/BC = P/Q$.



P and Q are non-reactive decade resistance units.

R_1 and R_2 are non-reactive variable resistors.

NOTE Terminal letters are for reference only.

Figure 14 – Circuit for measurement of voltage transformation ratio

Information to be stated in the detail specification:

- alternating voltage level;
- measuring frequency;
- initial values of R_1 and R_2 ;
- terminations between which measurements are to be made;
- voltage transformation ratio limits.

Procedure 3 (applies to secondary windings and multiple windings): Input the specified frequency and voltage on the turn ratio meter, and set the number of turns for windings connected to the instrument at the output. Connect the output terminal of the instrument to the specified winding, and the input terminal to the other winding to measure the output value of the corresponding winding and to determine the required voltage transformation ratio from the fact that the number of turns equals the voltage ratio ($N_1 / N_2 = U_1 / U_2$).

Information to be stated:

- measuring voltage;
- measuring frequency;
- the number of turns for windings connected to the instrument at the output terminal;
- windings to be connected and measured;
- allowable deviation of the voltage transformation ratio.

4.4.7.4 Current transformation ratio

Purpose: To determine the current transformation ratio between two windings of the current transformer.

Procedure 1: Connect the current transformer CT to the measuring circuit in Figure 15, adjust the tapped point on R_2 and M , and set the indicator to zero to let the following formula hold:

$$k = \frac{i_1}{i_2} = \frac{R_2''}{R_1 \cdot \cos \beta}$$

$$\beta = \arctan \frac{\omega \cdot M}{R_2''}$$

where

k is the current transformation ratio;

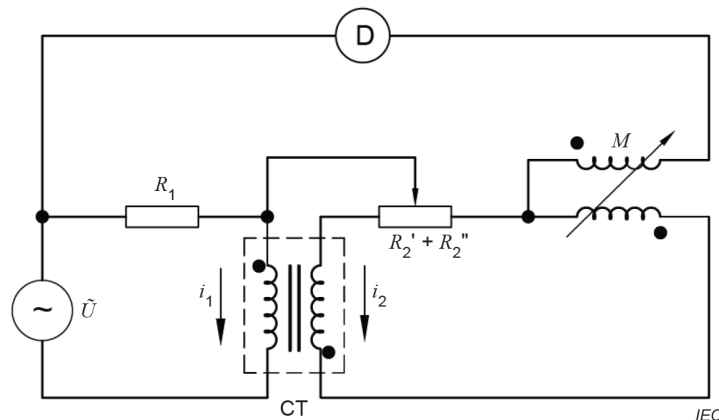
β is the phase displacement of current between two windings ;

R_2'' is one part of R_2 in the indicator loop ($R_2' + R_2''$);

$\omega = 2\pi f$, where, f is the measuring frequency.

The polarity of the current transformer winding shall indicate that the voltage phase between terminals R_1 and R_2 is series-opposing with respect to the indicator. The polarity of winding M shall achieve a balance.

NOTE A value for R_2 is chosen to load the secondary winding of the CT under its rated load. For the first approximate loading, the value of R_1 is brought out by that chosen for R_2 , which, combined with the rated load, determines the approximate value of i_2 . Assuming that the specified value of K is correct, the value of i_1 can be calculated. The voltage of the test signal generator is known, and the value of R_1 can be given.



CT is the current transformer under test

M is a variable mutual inductor

R_1 and R_2 are non-inductive resistors

D is a null detector

$R_2 = R_2' + R_2''$

Figure 15 – Circuit for measuring current transformation ratio and phase displacement

Information to be stated:

- rated primary current;
- rated load;
- measuring frequency;
- current transformation ratio and allowable deviation;
- current phase displacement and allowable deviation.

Procedure 2: Measure the current transformation ratio and current phase displacement digitally.

Connect the current transformer CT to the measuring circuit in Figure 16, adjust the output current of the broadband constant-current source i_1 , and let the following formula hold:

$$K = \frac{|\dot{I}_1|}{|\dot{I}_2|} = \frac{|U_1 \cdot R_2|}{|U_2 \cdot R_1|}$$

$$\beta = \angle(\dot{U}_1 - \dot{U}_2)$$

where

K is the current transformation ratio;

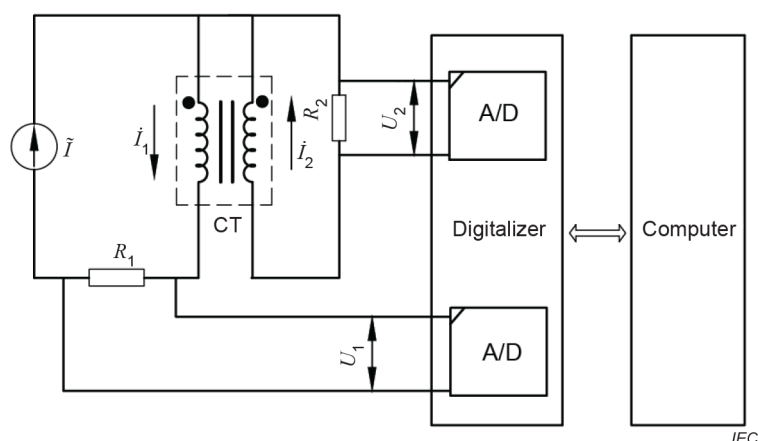
β is the current phase displacement between two windings;

$\dot{I}_1$ is the current in primary circuit;

$\dot{I}_2$ is the current in secondary circuit;

R_1 is the sampling resistor in primary circuit;

R_2 is the sampling resistor in secondary circuit.



CT is the current transformer under test

NOTE R_1 and R_2 are non-inductive resistors

Figure 16 – Measuring circuit of current transformation ratio and phase displacement

Information to be stated:

- rated primary current;
- rated load;
- measuring frequency;
- current transformation ratio and allowable deviation;
- current phase displacement and allowable deviation.

4.4.8 Resonant frequency

4.4.8.1 General

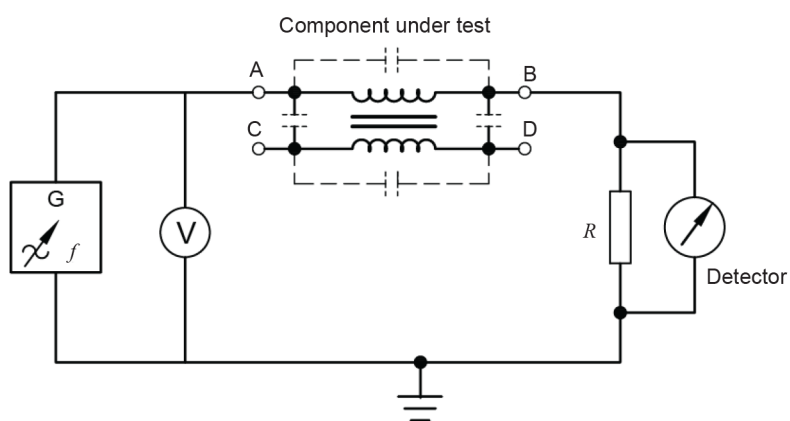
In the following two tests, care should be taken to avoid inaccuracies caused by the capacitance between test terminals or between the components and earth, especially if it is necessary to perform the test with the core connected to one of the test terminals.

4.4.8.2 Inherent self-resonance

Purpose: To determine the frequency of the parallel self-resonance of an inductive component.

Procedure 1: The component under test is connected into the test circuit of Figure 17, whose elements satisfy the following requirements:

- the signal source shall have a sufficiently low output impedance to supply the reactive current on each side of the resonant frequency;
- the detector shall have a high impedance and a preferred minimum indication of 0,01 V;
- the resistor R shall be non-reactive and shall have a value as low as practicable consistent with obtaining a suitable voltage level.



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NOTE Terminal letters are for reference only.

Figure 17 – Circuit for determining parallel self-resonant frequency

Starting at the lowest frequency within the specified frequency range, the frequency shall be increased and the voltmeter observed for a minimum reading. The frequency at which this minimum occurs is the self-resonant frequency.

Information to be stated:

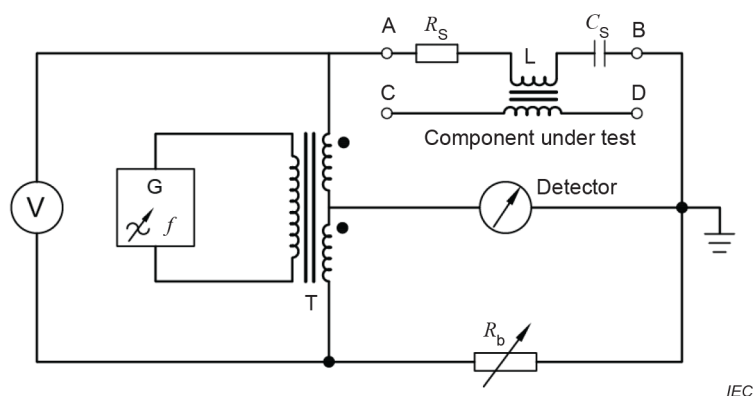
- AC voltage;
- value of resistor R ;
- connections, including earthing of parts of the component and test circuit;
- frequency range to be examined.

NOTE Procedures 2 and 3 found in 4.4.6.1 can be used as alternate procedures in 4.4.8.2.

4.4.8.3 Resonant assemblies

Purpose: To determine the resonant frequency and, if required, the effective resistance of a component which normally includes the effects of added discrete components, for example a resonating capacitor.

Procedure: With the component under test connected as shown in the basic circuit diagram given in Figure 18, the frequency of the generator and the value of R_b shall be set approximately to the values specified in the detail specification. With the output of the generator maintained at the level specified in the detail specification, the generator frequency and the value of R_b shall be varied, each in turn, until minimum deflection is obtained on the detector. These values of f and R_b correspond to the required resonant frequency and the effective series resistance of the component under test.



Key

G is a power oscillator, covering the required resonant frequency range, with an output adequate to energize the component to a level comparable with its normal application;

R_b is a non-reactive variable resistor of at least twice the value of the component's effective series resistance;

T is a screened transformer with an accurately balanced output winding suitable for use over the frequency range specified in the detail specification.

NOTE 1 The detector is a high-impedance meter of suitable sensitivity, suitable for the specified frequency range. This circuit element can incorporate a screened transformer.

NOTE 2 Terminal letters are for reference only.

NOTE 3 This circuit is also suitable for parallel combinations of L and C.

Figure 18 – Circuit for determining resonant frequency of resonant assemblies

Information to be stated in the detail specification:

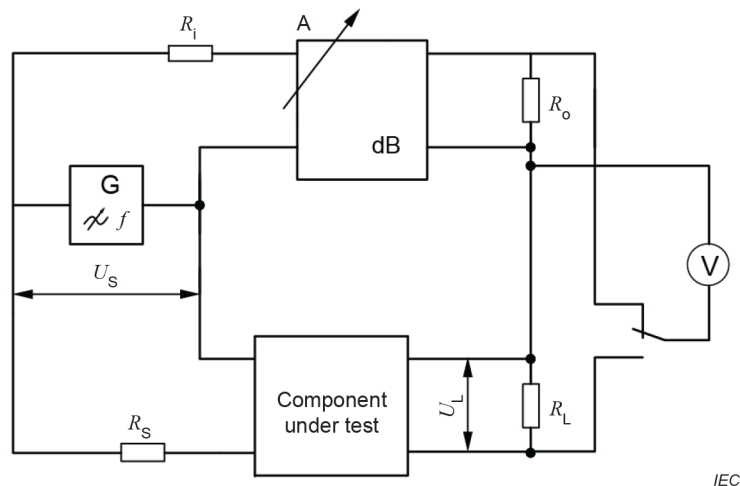
- the AC voltage level;
- the required resonant frequency limits (minimum and maximum);
- the value of effective series resistance (maximum and/or minimum) if required;
- the loading details and connections with particular reference to the earthing of parts of the component(s).

4.4.9 Signal transfer characteristics

4.4.9.1 Insertion loss

Purpose: To determine the insertion loss of a transformer at a specified voltage and throughout a specified frequency range when the transformer is inserted between specified source and load impedances.

Procedure: The transformer shall be connected in the basic circuit of Figure 19.



G is a variable frequency generator covering the specified frequency range of the test;

A is a precision variable attenuator having an input impedance R_i and output impedance R_o ;

V is a frequency selective, high-impedance voltmeter;

R_i is a resistor of a value equal to the input impedance of the attenuator;

R_o is a resistor of a value equal to the output impedance of the attenuator;

R_L is a resistor of a value equal to the specified load impedance of the transformer;

R_s is a resistor of a value equal to the specified source impedance of the transformer;

U_L is the voltage across the load;

U_s is the voltage across the source;

U_o is the voltage across R_o .

NOTE This arrangement applies only if $U_L \leq U_s / 2$ and $R_L \leq R_s$.

Figure 19 – Circuit for determination of insertion loss

At each specified frequency U_L shall be measured and the attenuator adjusted to make U_o equal to U_L .

For a transformer ratio of 1:1 the insertion loss is equal to the attenuator reading.

If the ratio is not 1:1 the attenuator reading a_r shall be noted, and the insertion loss a_i in decibels calculated from the expression:

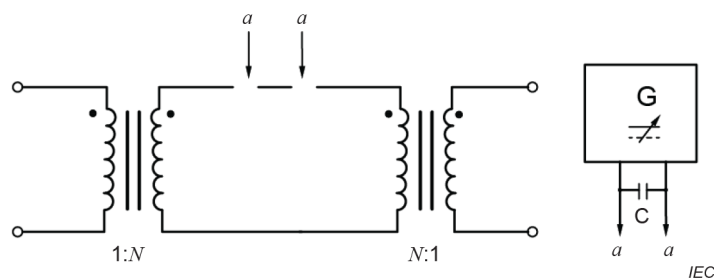
$$a_i = a_r - 10 \lg(R_s/R_L)$$

This gives the correct insertion loss when any reactive part of the source and load impedances is defined as part of the transformer. If this is not so then the insertion loss between impedances Z_s (source impedance) and Z_L (load impedance) is given by:

$$a_i = 20 \lg \left(\frac{U_s}{U_L} \left| \frac{Z_L}{Z_s + Z_L} \right| \right)$$

NOTE In general, Z_s and Z_L are complex quantities.

When the transformer has a ratio significantly different from 1:1, more reliable measurements can be made by using two identical specimens in the manner shown in Figure 20 to form the "component under test" of Figure 19. This arrangement also facilitates making measurements when polarizing currents are required.



C shall be a negligible reactance at the test frequency

Figure 20 – Use of two identical transformers when the transformation ratio is not unity and/or a DC bias is required

In this case, the value of the insertion loss for each transformer shall be taken to be half the attenuator reading.

Information to be stated:

- a) winding connections;
- b) source impedance;
- c) load impedance;
- d) source voltage;
- e) measuring frequency range;
- f) polarizing current (if any).

Unwanted couplings between input and output should be kept to a minimum by appropriate shielding and earthing.

4.4.9.2 Return loss

Purpose: To determine the degree of impedance mismatch, in terms of return loss, presented by a particular transformer winding when all other windings are terminated with their appropriate load impedances.

Return loss a_{rl} as a measure of mismatch between a source and a load is given in decibels by the expression:

$$a_{rl} = 10 \lg(W_a/W_r)$$

where

W_a is the maximum available power in the load;

W_r is the reflected power.

Thus, as illustrated in Figure 21, for a generator of output impedance R_G and open-circuit voltage U_o connected to a load R_L , the maximum available power condition occurs when $R_L = R_G$ and so under these circumstances

$$W_a = \frac{U_o^2}{4R_G}$$

When R_L has some other value, the difference between the actual power developed and the maximum possible in the load, that is the reflected power, is given by:

$$W_r = \frac{U_o^2}{4R_G} \left(\frac{R_L - R_G}{R_L + R_G} \right)^2$$

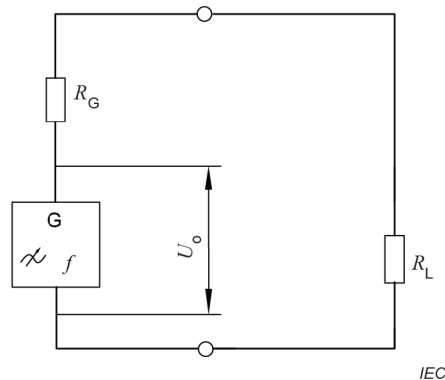


Figure 21 – Illustration of return loss

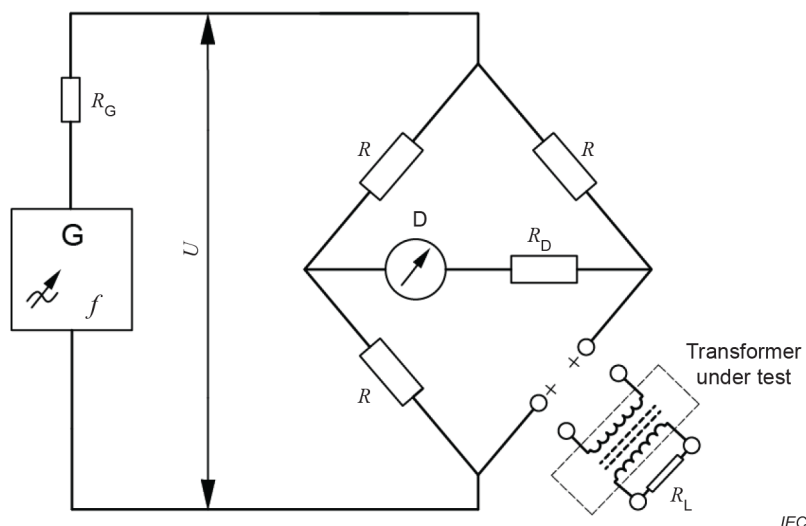
Hence the value of the return loss a_{rl} in decibels is given by:

$$a_{rl} = 20 \lg \frac{R_L + R_G}{|R_L - R_G|}$$

Procedure: The basic bridge measurement circuit shown in Figure 22 is set up with its elements equal to R_G , and the source voltage U and source frequency f are set to the specified values. The initial bridge circuit loss registered on the calibrated decibel-meter D when the terminals X are either short-circuited or open-circuited is recorded. Let this loss be a_1 . The terminated transformer under test is then connected to the terminals X and the loss indicated by D again recorded. Let this loss be a_2 .

The return loss of the transformer a_{rl} in decibels is then given by the expression:

$$a_{rl} = a_2 - a_1$$



Resistors R are frequency independent and matched, relative to each other, to within $\pm 0,1 \%$.

$R = R_G = R_D$ (= typically 600 Ω)

D is a decibel-meter, readily available for standard reference impedances such as 600 Ω .

Figure 22 – Basic return loss test circuit

The initial bridge circuit loss a_1 should be close to 12 dB; the measured value is subject to the accuracy of the bridge circuit elements, particularly the source and calibrated decibel-meter impedances.

NOTE Suitable commonly available commercial measuring instruments incorporating the necessary network to provide a direct measurement of return loss can be used.

Information to be stated:

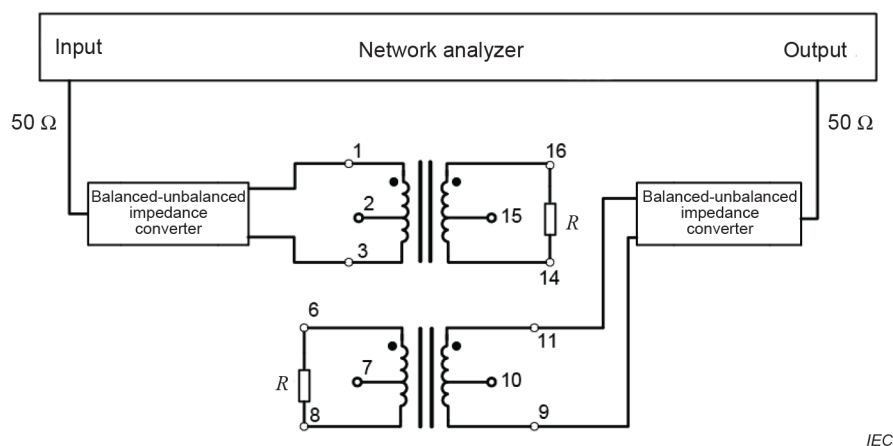
- a) impedance against which the return loss is to be measured, R ;
- b) winding connections;
- c) load resistance R_L or impedance Z_L ;
- d) source voltage(s);
- e) measurement frequencies;
- f) DC current in output winding, if required.

4.4.10 Cross-talk

Purpose: To determine the coupling of corresponding spatial induction or parasitic parameters of a specific transformer winding on all other windings. The coupling is expressed by the crossover loss.

Procedure: The basic measuring circuit as shown in Figure 23 consists of a network analyzer and a balanced-unbalanced impedance converter. The network analyzer test program is called out and the frequency adjusted to a specified value. When the start of a set of windings is connected to the output terminal of the network analyzer, the finish end is connected to the load (according to the detail specification); the start of the other set of windings is connected to the load (according to the detail specification), and the finish end is connected to the input terminal of the network analyzer. The decibels at each frequency point in the network analyzer correspond to the crossover interference.

The measuring circuit diagram of crossover interference for transformers (dB) is as shown in Figure 23:



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The load resistor R is a typical value, such as $50\ \Omega$ and $100\ \Omega$.

Figure 23 – Circuit diagram for measuring the crossover interference between two transformer coils

Information to be stated:

- a) winding connections;
- b) source impedance and load impedance;
- c) test frequency range.

4.4.11 Frequency response

Purpose: To determine the frequency response of the voltage output of a component when it is connected between the specified source and load impedances.

Procedure: The component, together with its specified source and load impedances, shall be connected into a transmission measuring set, the basic circuit of which is the same as that used for the insertion loss measurement of 4.4.9.1 (see Figure 19). If specified, other windings shall be loaded and the polarizing direct current applied. At the specified reference frequency, f_0 , the attenuator shall be adjusted until U_o is equal to U_L as indicated by the frequency selective voltmeter. The attenuator reading shall be noted. The change in attenuator reading required to make U_o equal to U_L at any other frequency gives the relative gain or loss of the component at that frequency compared to the reference frequency. A plot of this gain (loss) against the frequency constitutes a frequency response curve.

NOTE Precautions such as screening, earthing and suppression of feedback by the use of co-axial chokes can be required, and corrections can be necessary to ensure that the response calculated from the reading of the calibrated attenuator gives the same result as determined from the following formula:

$$20 \lg (U_f / U_{f0})$$

where

U_f is the output voltage at frequency f ;

U_{f0} is the output voltage at the reference frequency f_0 .

Information to be stated:

- a) component connections;
- b) source impedance(s);
- c) load impedance(s);
- d) source voltage;

- e) reference frequency f_0 ;
- f) frequency band or test frequencies;
- g) polarizing current, if any.

4.4.12 Pulse characteristics

Purpose: To verify that, with a specified pulse applied to the input winding of a transformer, the correct output waveform is obtained when the transformer is connected to the circuit for which it was designed.

Procedure: The specified input pulse shall be applied to the input winding with the output windings connected to the specified loads. The pulse obtained in the specified load shall be displayed on an oscilloscope having a calibrated time base and voltage deflection. The characteristics of the oscilloscope and its associated circuits shall be such that the pulse being displayed is not degraded because of problems such as excessive capacitance, insufficient bandwidth or excessive load inductance.

The following measurements shall be made as required by the relevant specification:

- a) peak pulse amplitude, U_m ;
- b) pulse duration, t_d ;
- c) pulse rise time, t_r ;
- d) pulse fall time, t_f ;
- e) pulse droop;
- f) overshoot;
- g) backswing;
- h) return backswing;
- i) recovery time.

Information to be stated:

- a) input peak pulse amplitude, duration, rise time, fall time, droop and repetition frequency;
- b) load impedance(s);
- c) output characteristics to be measured;
- d) ambient temperature.

Test specifications:

- a) the test instruments are pulse signal generator and digital oscilloscope;
- b) measure the specified windings and open all other windings;
- c) the voltage impulse applied shall drop less than 2 %;
- d) the amplitude of the applied impulse voltage shall not exceed the value of the dielectric withstanding voltage test;
- e) connect according to Figure 24, adjust the pulse signal and observe the oscilloscope.