BRITISH STANDARD

BS EN 60044-6:1999
IEC 60044-6:1992

Instrument transformers —

Part 6: Requirements for protective current transformers for transient performance

The European Standard EN 60044-6:1999 has the status of a British Standard

ICS 17.220.20

National foreword

This British Standard is the English language version of EN 60044-6:1999. It was derived by CENELEC from IEC 60044-6:1992.

The CENELEC common modifications have been implemented at the appropriate places in the text and are indicated by a side line in the margin.

The UK participation in its preparation was entrusted to Technical Committee PEL/38, Instrument transformers, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Cross-references

Attention is drawn to the fact that CEN and CENELEC Standards normally include an annex which lists normative references to international publications with their corresponding European publications. The British Standards which implement these international or European publications may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 32, an inside back cover and a back cover.

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

This British Standard, having been prepared under the direction of the Electrotechnical Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 August 1999

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EUROPEAN STANDARD

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EN 60044-6

March 1999

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English version

Instrument transformers
Part 6: Requirements for protective current transformers for transient performance

(IEC 60044-6:1992, modified)

Transformateurs de mesure
Partie 6: Prescriptions concernant les transformateurs de courant pour protection pour la réponse en régime transitoire
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Meßwandler
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(IEC 60044-6:1992, modifiziert)

This European Standard was approved by CENELEC on 1999-01-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

The text of the International Standard IEC 60044-6:1992, prepared by IEC TC 38, Instrument transformers, together with common modifications prepared by, the Technical Committee CENELEC TC 38X, Instrument transformers was submitted to the formal vote and was approved by CENELEC as EN 60044-6 on 1999-01-01.

The following dates were fixed:

— latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2000-01-01

— latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 2000-01-01

This part 6 of EN 60044 is to be used in conjunction with IEC 60044-1:1996.

Annexes designated "normative" are part of the body of the standard. In this standard, Annex A, Annex B, Annex C, Annex D, Annex E and Annex ZA are normative. Annex ZA has been added by CENELEC.

Contents

Introduction

Performance criteria for class P current transformers included in clause **12** of IEC 60044-1 relate to a steady state a.c. symmetrical primary energizing current which allows the limiting secondary e.m.f. to be as defined in **2.2.4** of IEC 60044-1. In this part of IEC 44, requirements for protective current transformers as classified by **3.5** take account of the additional flux linking the secondary winding due to the d.c. component of energizing current. Strictly, the limiting condition is defined by the integral of the voltage which is induced in the secondary winding of the current transformer in order to drive current in the secondary loop, inclusive of winding and secondary resistance, for the specified energizing conditions. For mathematical convenience, an equivalent sinusoidal e.m.f. is used to define the limiting condition. Refer also to Annex B.

1 Scope

This part of IEC 60044 covers the requirements and tests, in addition to those in IEC 60044-1, that are necessary for inductive current transformers for use with electrical protective schemes in which the prime requirement for the current transformers is the maintenance of a defined performance up to several times the rated current when the current contains an exponentially decaying d.c. component of defined time constant.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of IEC 44. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of IEC 44 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 56:1987, *High-voltage alternating-current circuit-breakers.*

IEC 60044-1:1996, *Instrument transformers — Part 1: Current transformers.*

3 Definitions

For the purpose of this part of IEC 44, the following definitions apply.

3.1
rated primary short-circuit current (I_{psc})

R.M.S. value of primary symmetrical short-circuit current on which the rated accuracy performance of the current transformer is based

3.2
instantaneous error current (i_ε)

difference between the instantaneous values of the secondary current (i_s) multiplied by the rated transformation ratio (K_n) and the primary current (i_p):

$$i_\varepsilon = K_n\, i_s - i_p$$

when both alternating current and direct current components are present, the constituent components are separately identified as follows:

$$i_\varepsilon = i_{\varepsilon ac} + i_{\varepsilon dc} = (K_n\, i_{sac} - i_{pac}) + (K_n\, i_{sdc} - i_{pdc})$$

3.3
peak instantaneous (total) error ($\hat{\varepsilon}$)

maximum instantaneous error current, for the specified duty cycle, expressed as a percentage of the peak instantaneous value of the rated primary short-circuit current:

$$\hat{\varepsilon} = 100\, \hat{i}_\varepsilon / (\sqrt{2}\, I_{psc}) \quad (\%)$$

3.4
peak instantaneous alternating current component error (ε_{ac})

maximum instantaneous error of the alternating current component expressed as a percentage of the peak instantaneous value of the rated primary short-circuit current:

$$\hat{\varepsilon}_{ac} = 100\, \hat{i}_{\varepsilon ac} / (\sqrt{2}\, I_{psc}) \quad (\%)$$

3.5
protective current transformer classes

current transformers for protection are classified according to functional performance as follows:

class P: Accuracy limit defined by composite error ($\hat{\varepsilon}_c$) with steady state symmetrical primary current. No limit for remanent flux.

class TPS: Low leakage flux current transformer for which performance is defined by the secondary excitation characteristics and turns ratio error limits. No limit for remanent flux.

class TPX: Accuracy limit defined by peak instantaneous error ($\hat{\varepsilon}$) during specified transient duty cycle. No limit for remanent flux.

class TPY: Accuracy limit defined by peak instantaneous error ($\hat{\varepsilon}$) during specified transient duty cycle. Remanent flux not to exceed 10 % of the saturation flux.

class TPZ: Accuracy limit defined by peak instantaneous alternating current component error ($\hat{\varepsilon}_{ac}$) during single energization with maximum d.c. offset at specified secondary loop time constant. No requirements for d.c. component error limit. Remanent flux to be practically negligible.

3.6
specified primary time constant (T_p)

that specified value of the time constant of the d.c. component of the primary current on which the performance of the current transformer is based. This value may also be a rated value for class TPX, TPY and TPZ current transformers and then will be marked on the rating plate

3.7
permissible time to accuracy limit (t_{al})

time during which the specified accuracy is maintained during any specified energization period of a given duty cycle

NOTE This time will usually be defined by the critical measuring time of the associated protection scheme. When stable operation of the protection scheme is a limiting requirement, it may also be necessary to consider the time taken by the circuit breaker to interrupt the current.

3.8
time to maximum flux (t_{max})

elapsed time during a prescribed energization period at which the transient flux in a current transformer core achieves maximum value, it being assumed that saturation of the core does not occur

3.9
dead time (during auto-reclosing) (t_{fr})

time interval between interruption and re-application of the primary short-circuit current during a circuit breaker auto-reclosing duty cycle (refer also to IEC 56)

3.10
specified duty cycle (C-0 and/or C-0-C-0)

duty cycle in which, during each specified energization, the primary energizing current is assumed to be "fully offset" (see note below), with the specified decay time constant (T_p) and be of rated amplitude (I_{psc}) duty cycles are as follows:

Single energization: $C - t' - 0$

Double energization: $C - t' - 0 - t_{fr} - C - t'' - 0$

(both energizations in the same polarity of flux)

where:

t' is the duration of first current flow: specified accuracy being maintained during time t'_{al}

t'' is the duration of second current flow: specified accuracy being maintained during time t''_{al}

NOTE Specification of partial offset would reduce the required transient factor by an amount approximately proportional to the reduction. For this reason specification of full offset parameters is recommended.

3.11
rated resistive burden (R_b)

rated value of the secondary connected resistive burden in ohms

3.12
secondary winding resistance (R_{ct})

secondary winding d.c. resistance in ohms, corrected to 75 °C or such other temperature as may be specified

3.13
secondary loop resistance (R_s)

total resistance of the secondary circuit, inclusive of the secondary winding resistance corrected to 75 °C, unless otherwise specified, and inclusive of all external burden connected

3.14
rated secondary loop time constant (T_s)

value of the time constant of the secondary loop of the current transformer obtained from the sum of the magnetizing and the leakage inductances (L_s) and the secondary loop resistance (R_s):

$T_s = L_s/R_s$

3.15
rated symmetrical short-circuit current factor (K_{ssc})

the ratio:

$K_{ssc} = I_{psc}/I_{pn}$

3.16
transient factor (K_{tf})

ratio of the theoretical total secondary linked flux to the peak instantaneous value of the a.c. component of that flux, when a current transformer is subjected to a specified single energization and the secondary loop time constant (T_s) is assumed to have retained a constant value throughout the energization period

3.17
rated transient dimensioning factor (K_{td})

that theoretical value representative of the transient dimensioning necessary to satisfy the specified duty cycle

mathematical relationships between T_p, T_s, K_{tf} and K_{td} are given in Annex A

3.18
low leakage flux current transformer

current transformer for which a knowledge of the secondary excitation characteristic and secondary winding resistance is sufficient for an assessment of its transient performance for any combination of burden and duty cycle at rated or lower value of primary symmetrical short-circuit current up to the theoretical limit of the current transformer capability determined from the secondary excitation characteristic

3.19
high leakage flux current transformer

current transformer which does not satisfy the requirements of **3.18** and for which an additional allowance is made by the manufacturer to take account of influencing effects which result in additional leakage flux. Such a current transformer is expected to satisfy a specified duty cycle

NOTE In general, if the theoretical transient dimensioning factor (K_{td}) is satisfied for a C-0-C-0 duty cycle, then the accuracy is maintained during a C-0 duty cycle at least up to the time at which the rated equivalent limiting secondary e.m.f. (E_{al}), defined in **3.20**, is reached.

3.20
rated equivalent limiting secondary e.m.f. (E_{al})

that r.m.s. value of the equivalent secondary circuit e.m.f. of rated frequency necessary to satisfy the specified duty cycle and derived from the following:

$E_{al} = K_{ssc}\, K_{td}\, (R_{ct} + R_b)\, I_{sn}$ (V, r.m.s.)

3.21
rated equivalent excitation limiting secondary voltage (U_{al})

that r.m.s. value of sinusoidal voltage of rated frequency necessary to ensure that the rated equivalent limiting secondary e.m.f. will be attained after due account is taken of the current transformer construction and which, when applied to the transformer secondary winding, would result in a magnetizing current not exceeding the maximum permissible error current appropriate to the current transformer class

$U_{al} = E_{al}\, F_c$ (V, r.m.s.)

where F_c is the factor of construction defined in **3.29**.

3.22
equivalent secondary accuracy limiting e.m.f. (E_{alc})

that equivalent r.m.s. e.m.f. of rated frequency determined during a direct test when the observed error current corresponds to the appropriate limit for the class

NOTE The error current is an absolute value based on the specified primary current value and is thus not affected by any parametric changes which may have been necessary to attain the secondary error limiting condition.

3.23
equivalent secondary accuracy limiting voltage (U_{alc})

that r.m.s. value of sinusoidal voltage of rated frequency which, if applied to the secondary winding of a current transformer, would result in an exciting current corresponding to the maximum permissible error current appropriate to the current transformer class

3.24
saturation flux (Ψ_s)

that peak value of the flux which would exist in a core in the transition from the non-saturated to the fully saturated condition and deemed to be that point on the B-H characteristic for the core concerned at which a 10 % increase in B causes H to be increased by 50 %

3.25
remanent flux (Ψ_r)

that value of flux which would remain in the core three minutes after the interruption of an exciting current of sufficient magnitude as to induce the saturation flux (Ψ_s) defined in **3.24** above

3.26
remanence factor (K_r)

the ratio $K_r = \Psi_r/\Psi_s$

3.27
accuracy limit flux (Φ_{al})

that peak value of the secondary linked flux corresponding to E_{al}:

$\Phi_{al} = \sqrt{2}\, E_{al}/(2\pi f)$

When E_{al} is given in volts, r.m.s., Φ_{al} is expressed in weber.

3.28
accuracy limiting secondary exciting current (I_{al})

peak value of the exciting (error) current appropriate to the current transformer class

3.29
factor of construction (F_c)

factor declared by the manufacturer for the design. The factor of construction is determined from the ratio:

$F_c = U_{alc}/E_{alc}$

4 Ratings and performance requirements

4.1 Standard values for rated symmetrical short-circuit current factor (K_{ssc})

Standard values of K_{ssc} for protective current transformers for transient performance are:

3 – 5 – 7,5 – <u>10</u> – 12,5 – <u>15</u> – 17,5 – <u>20</u> – 25 – 30 – 40 – 50

The preferred values are underlined.

4.2 Standard values for symmetrical short-circuit current

4.2.1 *Rated short-time thermal current* (I_{th})

Standard r.m.s. values, expressed in kiloamperes, are:

6,3 – 8 – 10 – 12,5 – 16 – 20 – 25 – 31,5 – 40 – 50 – 63 – 80 – 100

4.2.2 *Rated primary short-circuit current* (I_{psc})

Preferred values are derived from the product of I_{pn} and K_{ssc} selected from the values given in **4.1.1** of IEC 60044-1 and **4.1** of this part of IEC 44 respectively. The product need not be exactly equal to I_{th}.

4.3 Standard values for rated primary time constant (T_p)

Standard values, expressed in milliseconds, are:

40 – 60 – 80 – 100 – 120

NOTE For some applications, higher values of rated primary time constant may be required. Example: large turbo-generator circuits.

4.4 Standard values for rated transient dimensioning factor (K_{td})

At present there are no standard values for the rated transient dimensioning factor because the values of this factor depend upon the application.

4.5 Standard values of rated resistive burden (R_b)

Standard values of rated resistive burden in ohms for class TP current transformers, based on a rated secondary current of 1 A are:

2,5 – 5 – 7,5 – <u>10</u> – 15

The preferred values are underlined. For current transformers having a rated secondary current other than 1 A, the above values should be adjusted in inverse ratio to the square of the current.

4.6 Error limits for TPS current transformers

The turns ratio of a TPS current transformer shall be numerically equal to $1/K_n$. The error in this turns ratio shall not exceed ± 0,25 %.

The accuracy limiting conditions are defined by the magnetization characteristic and the excitation limiting secondary voltage U_{al} shall not be less than the specified value. The value shall be such that an increase of 10 % in magnitude does not result in an increase in the corresponding peak instantaneous exciting current exceeding 100 %.

When specified by the purchaser, the measured value of the peak exciting current at the excitation limiting secondary voltage shall not exceed the specified value. If no limit is set, the exciting current shall, in any case, not exceed that value corresponding to 10 % of I_{th} referred to the secondary side (see TPX CTs, Table 1).

The excitation limiting secondary voltage defined by the purchaser is generally expressed as follows:

$$U_{al} \geq K\, K_{ssc}\, (R_{ct} + R_b)\, I_{sn}$$

in which K is a dimensioning parameter assigned by the purchaser. R_{ct} is defined by the manufacturer's design except that for some applications limits may need to be set by the purchaser to enable co-ordination with other equipment.

4.7 Error limits for TPX, TPY and TPZ current transformers

With the secondary loop resistance adjusted to the value $R_s = R_{ct} + R_b$, the errors shall not exceed the values given in Table 1.

Table 1 — Limits of error

Class	At rated primary current			At accuracy limit condition
	Ratio error	Phase displacement		Maximum peak instantaneous error
	%	Min	Centirad	%
TPX	± 0,5	± 30	± 0,9	$\hat{\varepsilon} = 10$
TPY	± 1,0	± 60	± 1,8	$\ddot{\varepsilon} = 10$
TPZ	± 1,0	180 ± 18	5,3 ± 0,6	$\hat{\varepsilon}_{ac} = 10$

NOTE For some applications, deviation from the above values may be necessary (refer also to annex **D.3**). Similarly, the absolute value of the phase displacement may in some cases be of less importance than achieving minimal deviation from the average value of a given production series.

5 Methods of specification

The methods of specification for the different CT classes are illustrated in Table 2.

Table 2 — Methods of specification

CT class	TPS	TPX	TPY	TPZ
Rated primary current	×	×	×	×
Rated secondary current	×	×	×	×
Rated frequency	×	×	×	×
Highest voltage for equipment and rated insulation level	×	×	×	×
I_{th}	×	×	×	×
I_{dyn}	×	×	×	×
Ratio to which specification applies	×	×	×	×
K_{ssc}	×	×	×	×
T_p	—	×	×	×
T_s	—	—	— see note	—
Duty cycle Single: t', t'_{al} double: t', t'_{al}, t_{fr}, t'', t''_{al}	—	×	×	—
R_b	×	×	×	×
K	×	—	—	—
Maximum I_{al} at U_{al}	×	—	—	—
R_{ct}	×	—	—	—

× applicable — not applicable

NOTE When the purchaser wishes to obtain compatibility between existing equipment and new units, an alignment specification may define limiting values for certain parameters, for example T_s or R_{ct}. It will be necessary, however, to recognize possible differences between designs. Issue of the principal objectives for the intended application and best available (name-plate) data for the existing current transformers will usually achieve acceptable results.

6 Marking of rating plate

The rating plate shall carry the appropriate information given in accordance with subclause **10.2** of IEC 60044-1. Table 3 identifies additional information to be included.

Table 3 — Information to be included in the rating plate

CT class	TPS	TPX	TPY	TPZ	References		
					To IEC 60044-1	To IEC 60044-6	Notes
I_{pn}	×	×	×	×	**2.1.6**	—	1
I_{sn}	×	×	×	×	**2.1.7**	—	1
I_{th}	×	×	×	×	**2.1.27**	—	3
I_{dyn}	×	×	×	×	**2.1.28**	—	3
K_{ssc}	×	×	×	×	— — —	**3.1** **3.15** **4.2**	
R_b	×	×	×	×	—	**3.11**	
R_{ct} (at ... °C)	×	×	×	×	—	**3.12**	
K_{td}	—	×	×	×	—	**3.17**	
K	×	—	—	—	—	**4.6**	
U_{al}	×	—	—	—	—	**3.21**	
I_{al}	×	—	—	—	—	**3.28**	
F_c	—	×	×	×	—	**3.29**	2
T_p	—	×	×	×	—	**3.6**	5
T_s	—	—	×	—	—	**3.14**	4, 5
Duty cycle single: t', t'_{al} double: t', t'_{al}, t_{fr}, t'', t''_{al}	—	×	×	—	— —	**3.9** **3.10**	 5
× applicable — not applicable							

NOTE 1 For multiratio protective current transformers, I_{pn} and K_n will usually be the highest values applicable to the range of ratios.
NOTE 2 Data to be given if $F_c > 1,1$.
NOTE 3 Values for I_{dyn} may exceed 2,5 I_{th} depending on the values of T_p and I_{psc}.
NOTE 4 When T_s is greater than 10 s, it will usually be adequate to mark on the rating plate $T_s > 10$ s.
NOTE 5 T_p, T_s and the duty cycles are interrelated and their indication on the rating plate could be omitted for low leakage flux CTs.

7 Tests

7.1 To prove compliance of the current transformer with the requirements of this standard the following tests shall be performed as required by the test schedule — Table 4.

Table 4 — Test schedule

Test	CT class				References	
	TPS	TPX	TPY	TPZ	Clause or subclause	Note
Turns ratio error	×	—	—	—	**7.2.1**	1
Steady state ratio error and phase displacement	—	×	×	×	**7.2.2**	1
R_{ct}	×	×	×	×	**7.2.3**	1
Excitation characteristic	×	×	×	×	**7.2.4**	1
K_r	—	—	×	—	**7.2.5**	1
T_s	—	—	×	×	**7.2.6**	1
Errors at limiting conditions	—	×	×	×	**7.3**	2
F_c	—	×	×	×	**7.3.1**	2
Verification of low leakage flux design (F_c < 1,1)	×	—	—	—	**7.4**	3
× applicable — not applicable						
NOTE 1 Type and routine tests. NOTE 2 Type tests. NOTE 3 Special tests performed only on agreement between manufacturer and purchaser.						

7.2 Type and routine tests

7.2.1 *Turns ratio error*

The turns ratio error shall be determined by an appropriate method. Refer to Annex E.

7.2.2 *Steady state ratio error and phase displacement*

With the secondary loop resistance adjusted to rated value ($R_s = R_{ct} + R_b$) ratio error and phase displacement shall be measured at rated current (I_{pn}).

7.2.3 *Determination of secondary winding resistance (R_{ct})*

The secondary winding resistance shall be measured and an appropriate correction applied if the measurement is made at a temperature which differs from 75 °C or such other temperature as may have been specified. The value so adjusted is the rated value for R_{ct}.

7.2.4 *Determination of secondary excitation characteristic*

For type tests, an excitation curve is required up to not less than 1,1 times saturation flux. The manufacturer may choose the test method. Some test methods are given in Annex B.

For routine tests on TPX and TPY current transformers, the peak value of the exciting current at U_{al} is to be measured.

For routine tests on TPZ current transformers, the peak value of the exciting secondary current $\hat{I}_{al}$ shall not exceed the value obtained from the expression given below:

$$\hat{I}_{al} \leq \sqrt{2}\, I_{sn} K_{ssc} \left\{ [(K_{td} - 1) / \omega T_s] + 0,1 \right\}$$

NOTE For TPZ current transformers the accuracy is specified only for the a.c. component while, in the determination of the permissible value of $\hat{I}_{al}$ during indirect tests, it is necessary to take into account also the d.c. component of the exciting current. In the above equation, the d.c. component is represented by ($K_{td} - 1$) and the permissible error in the a.c. component by 0,1.

7.2.5 *Determination of remanence factor (K_r)*

The remanence factor (K_r) shall be determined to prove compliance with the appropriate class limits. Refer to Annex B.

7.2.6 *Calculation of secondary loop time constant (T_s)*

The secondary loop time constant (T_s) shall be determined and shall not differ from the declared or the rated value by more than ± 30 % for class TPY and ± 10 % for class TPZ current transformers. Refer to Annex B.

7.3 Type tests

7.3.1 *General*

Direct tests intended to be made at the specified limiting parameters and duty cycle are type tests. Their purpose is:

— to measure the peak instantaneous error current of the CT, when subjected to the specified duty cycle, according to **3.3** (classes TPX and TPY) and **3.4** (class TPZ);

— to determine the factor of construction (F_c) (see **3.29**).

The tests can be performed on a full scale model of the active part of the current transformer assembly inclusive of all metal housings but with reduced insulation.

Direct tests may be replaced by the secondary exciting test, if either of the following is satisfied:

a) the current transformer is of the low leakage flux type.

To satisfy this requirement, it shall be shown by a drawing that the current transformer has substantially continuous ring core with air gaps uniformly distributed, uniformly distributed secondary winding, a primary conductor symmetrical with respect to rotation and the influences of conductors of the adjacent phase outside of the CT housing and of the neighbouring phases are negligible.

b) a type test report of a current transformer having substantially the same construction and rated primary short-circuit current is available.

NOTE If, despite the information given above, direct tests are required by the purchaser, it will be stated in the order.

7.3.2 *Measurement of peak instantaneous error current*

Methods for direct measurement of the peak instantaneous error current at accuracy limiting conditions are given in Annex C.

Records shall be taken of the instantaneous values of primary, secondary and error currents in addition to the integral with time of the voltage across the secondary terminals from which record the equivalent secondary e.m.f. can be derived at limiting conditions (E_{al} and E_{alc}).

The following data shall be included in the type test report:

a) type designation;

b) year of manufacture/serial number;

c) rating plate markings;

d) results of secondary exciting test (see Annex B);

e) results of direct tests including test parameters, test circuit diagram, photo(s) of test arrangement, records and evolution of results;

f) declaration of the manufacturer concerning the validity to the ordered CT of the type test made on CT having other technical data.

Correlation between direct and indirect (secondary excitation characteristic measurement) tests may be selected from either of the following but may not be necessary if certificates are available for a previously type-tested unit of substantially the same construction and performance requirements.

7.3.3 *Determination of factor of construction (F_c)*

The method for the determination of the factor of construction is given in Annex D.

The factor of construction, obtained from the ratio U_{alc}/E_{alc}, is valid for the current transformer performance at rated conditions and at the highest theoretical value of the transient dimensioning factor (K_{td}). That is, if both C-0 and C-0-C-0 duty cycles are specified, K_{td} will be determined from whichever duty cycle yields the higher value.

When the factor of construction does not exceed 1,1, the design may or may not satisfy the criteria for a low leakage flux design.

Strictly, the factor of construction relates the secondary excitation characteristics to the current transformer performance under specified conditions only.

7.4 Special tests to verify a low leakage flux design

Direct tests to verify that a current transformer will satisfy the basic requirements of a low leakage flux design (see **3.18**) shall be made at a sufficiently large number of energizing current, duty cycle and burden combinations as can reasonably establish that the deviation between the theoretical equivalent secondary e.m.f. and the measured value does not exceed 10 %.

NOTE 1 Available test experience does not permit precise specification of parametric relationships and limits for all classes at this time.

NOTE 2 Indirect tests to verify that the design is of the low leakage flux type may be made in addition to direct tests at specified limits.

The value U_{al} is determined from the secondary excitation characteristics at a value such that a 10 % increase in r.m.s. value results in an increase in the peak value of the secondary excitation current of not less than 50 % and not more than 100 %.

Annex A Basic theoretical equations for transient dimensioning

A.1 Short-circuit current

The general expression for the instantaneous value of a short-circuit current having a symmetrical component (I_{psc}) may be written:

$$i(t) = \sqrt{2}\, I_{psc} \left[e^{-t/T_p} \cos\theta - \cos(\omega t + \theta) \right] \qquad \text{(A1)}$$

The current is fully offset when θ = 0 and

$$i(t) = \sqrt{2}\, I_{psc} \left(e^{-t/T_p} - \cos \omega t \right) \qquad \text{(A2)}$$

A.2 Transient dimensioning factor

The transient factor for a fully offset short-circuit current after t seconds [equation (A2)] is given by:

$$K_{tf} = [\omega T_p T_s / (T_p - T_s)] \left(e^{-t/T_p} - e^{-t/T_s} \right) - \sin \omega t \qquad \text{(A3)}$$

When calculating the transient factor necessary for dimensioning purposes, equation (A3) is simplified by writing sin $\omega t = -1$. K_{tf} will then have a maximum value at a time $t = t_{max}$. The value of t_{max} is given by:

$$t_{max} = [T_p\, T_s / (T_p - T_s)] \ln (T_p / T_s) \qquad \text{(A4)}$$

and the corresponding value of K_{tf} is:

$$K_{tfmax} = \omega T_p (T_p / T_s)^{T_p / (T_s - T_p)} + 1 \qquad \text{(A5)}$$

For the C-0 duty cycle (see **3.10**), the necessary transient dimensioning factor is given by:

$$K_{td} = [\omega T_p T_s / (T_p - T_s)] \left(e^{-t'_{al}/T_p} - e^{-t'_{al}/T_s} \right) + 1 \qquad \text{(A6)}$$

For the C-0-C-0 duty cycle (see **3.10**), the necessary transient dimensioning factor is given by:

$$K_{td} = \left\{ [\omega T_p T_s / (T_p - T_s)] \left[e^{-t'/T_p} - e^{-t'_{al}/T_s} \right] - \sin \omega t' \right\} \cdot e^{-(t_{fr} + t'_{al})/T_s} + \\ + [\omega T_p T_s / (T_p - T_s)] \left[e^{-t''_{al}/T_p} - e^{-t''_{al}/T_s} \right] + 1 \qquad \text{(A7)}$$

Annex B Determination of core magnetization characteristic

B.1 General

When a current transformer is energized by a fully offset asymmetrical short-circuit current, a large flux wave of relatively long duration is caused in the core by the unidirectional component. Indirect tests which subject the transformer core to a unidirectional flux will accordingly be deemed to be the more realistic.

For TPS and TPX current transformers it is necessary to demagnetize the core before each test, because of the high remanence factor. For TPY current transformers the remanent flux is often so low that it can be neglected.

Demagnetization requires additional means by which the core can be subjected to slowly decreasing hysteresis loops starting from saturation. A direct current manually or automatically regulated source will normally be provided when the d.c. test method has to be used.

Measuring the core magnetization characteristic implies establishing the relationship between the core secondary linking flux and magnetizing current.

If an arbitrary voltage $U(t)$ is applied to the secondary terminals (see Figure B.1) the core flux $\Phi(t)$ linked through the secondary winding at time t is related to this voltage through the equation:

$$\Phi(t) = \int_0^t (U - R_{ct}\, i_m)\, dt \quad \text{(Wb)} \qquad \text{(B1)}$$

The methods described in the following clauses take advantage of this relationship.

The effect of the voltage drop across the secondary winding resistance shall be estimated. If it exceeds 2 %, this drop shall be deducted from the voltage value measured.

B.2 A.C. method

A substantially sinusoidal a.c. voltage is applied to the secondary terminals and the corresponding value of magnetizing current is measured. The test may be performed at reduced frequency to avoid unacceptable voltage stressing of the winding and secondary terminals. Effects of undue eddy current losses in the core and capacitive currents between the winding layers will be less likely to cause false readings at lower frequencies.

The exciting current shall be measured with a peak reading instrument in order that the result will align with the peak flux value.

The exciting voltage is measured with an instrument whose response is proportional to the average value, but calibrated r.m.s.

The secondary linked flux value Φ may be derived from the measured r.m.s. value of the applied voltage U' at the frequency f' as follows:

$$\Phi = \frac{\sqrt{2}}{2\pi f'} \cdot U' \quad \text{(Wb)} \qquad \text{(B2)}$$

and the r.m.s. equivalent voltage U at rated frequency f is given by:

$$U = \frac{2\pi f}{\sqrt{2}} \cdot \Phi \quad (V, \text{r.m.s.}) \qquad \text{(B3)}$$

The result is shown as a curve giving the required relationship between the peak value of the magnetizing current i_m and the peak value of the flux Φ through its equivalent r.m.s. voltage U at rated frequency.

The magnetizing inductance is given by the mean slope of the above curve estimated in the range between 20 % and 90 % of the saturation flux Φ_s:

$$L_m = \frac{\Phi_s}{i_m} = \frac{\sqrt{2}\, U}{2\pi f\, i_m} \quad \text{(H)} \qquad \text{(B4)}$$

When the leakage inductance of the secondary is negligible, the secondary circuit time constant T_s for the resistive total burden ($R_{ct} + R_b$) may be calculated as follows:

$$T_s = \frac{L_s}{R_s} \approx \frac{L_m}{R_{ct} + R_b} \quad \text{(s)} \qquad \text{(B5)}$$

In determining the remanence factor K_r by the a.c. test method, it is necessary to integrate the exciting voltage as shown in Figure B.2. The integrated voltage with the corresponding current will display a hysteresis loop on an X-Y oscilloscope. If the exciting current has been such that the saturation flux Φ_s is reached, the flux value at zero crossing of current is deemed to represent the remanent flux Φ_r. The remanence factor K_r is then calculated as the ratio $\Phi_r/\Phi_s = \Psi_r/\Psi_s$ according to definition.

B.3 D.C. method

The d.c. saturation method uses a d.c. voltage of such duration that the same value of flux is reached. The slow increase of magnetizing current implies accounting for the voltage drop across the winding resistance. The flux measurement is derived from the integral of the voltage across the terminals of the energized winding plus an additional voltage corresponding to $R_{ct}i_m$. A typical test circuit is shown in Figure B.3.

If an additional independent winding is available on the same core, or if the secondary winding is provided with taps on which the test might be made, the induced voltage on free winding may be used directly to derive the flux value by integration, provided that the respective turns ratio is known and that both energized and free winding portions are uniformly distributed along the mean path of the core. In addition to assessment of flux value, respective turns ratio may be used in assessing measured magnetizing current values when transient performance requirements are for other than the energized tap. Figure B.5 illustrates a typical test circuit.

In order that the limiting values of exciting current required will be reached in reasonable time, the maximum energizing current value (I_m) shall be higher than required. For example, I_m may be two times the transient error current limiting value for all classes except TPS. For class TPS, I_m may be five times the exciting current at E_{al}. Even higher values of I_m may be necessary to reach core saturation in determining the remanence factor (K_r).

The voltage of the chosen battery shall be slightly higher than the product $R_{ct}I_m$ to provide current adjustment through the limiting resistor R_1 as shown.

The discharge resistor R_d shall be connected, as otherwise the core inductance may cause very high overvoltages when switch S is opened and the inductive current interrupted.

If the resistance value of R_d is so chosen that the sum of $R_d + R_{sh}$ is equal to R_b, the discharging circuit loop time constant will be about the same as the rated secondary circuit time constant (T_s), and the secondary circuit discharge behaviour could be recorded at the opening of S. However, this value may give in practice too high currents, and R_d may then need to be chosen with a higher resistance value.

Some time after the switch S has been closed, the exciting current i_m will be deemed to have reached its maximum value (I_m) at which the core flux would remain constant. If the circuit of Figure B.3 is not used, the uncompensated voltage drop $R_{ct}i_m$ would give an undue increment to the integrator, and the result would be a false continuous rise of flux during time. Compensation is made by adjusting the gain of the amplifier connected to the shunt, and balancing is obtained when the flux value indicated is stationary when $i_m = I_m$ and remains constant.

All electronic components of the integrating circuits shall be assembled into a specific apparatus for resistance compensated flux measurements, capable of being calibrated to an appropriate accuracy.

NOTE The indicated voltage integral of a known voltage U during a period of 15 s should not differ from 15 U voltseconds, by more than ± 3 %.

In determining the excitation characteristic, the switch S shall be closed immediately after the resetting of integrator has been made. The rising values of the magnetizing current and of the flux shall be recorded up to the time at which the values become constant, then the switch S will be opened.

Typical test records of the flux value $\Phi(t)$ and of the magnetizing current $i_m(t)$ as a function of time t are shown in Figure B.4, where the flux values may be given in weber or through the equivalent r.m.s. voltage $U(t)$ at rated frequency f, in accordance with equation (B3).

The magnetizing inductance (L_m) may be deduced from suitable points on the magnetizing curves dividing $\Phi(t)$ by the corresponding $i_m(t)$, or using equation (B4) when the flux values are given through the equivalent r.m.s. voltage $U(t)$.

As TPS and TPX current transformers require the estimation of the mean slope of the combined Φ (i_m) characteristic, the use of an X-Y recorder is recommended.

The secondary circuit time constant (T_s) is then calculated using equation (B5).

At the opening of switch S, a decreasing magnetization current flows through the secondary winding and the discharging resistor R_d. The corresponding flux value decreases, but may not fall to zero at zero current. When a suitable exciting current I_m has been chosen to achieve the saturation flux Φ_s, the remaining flux value at the zero current shall be deemed to be the remanent flux Φ_r.

For TPS and TPX current transformers whose core has been mandatorily demagnetized before, and for demagnetized TPY current transformers the remanence factor K_r is determined from the ratio Φ_r/Φ_s.

For a TPY current transformer whose core has not been demagnetized before, the remanence factor (K_r) may be determined by an additional test in which the secondary terminals have been interchanged. In this case, the remanence factor K_r may be calculated as above, but assuming for Φ_r the halved value of the remanent flux measured in the second test.

B.4 Alternative d.c. method

For TPY current transformers, the following simplification of the basic d.c. method described in **B.3** may be used, provided that the magnetizing inductance (L_m) is known to have a constant value up to the saturation current, and that the battery used has been shown to have a constant e.m.f. up to that current value. The test circuit is shown in Figure B.6.

To determine the excitation characteristic, the switch S is closed and the rising value of the magnetizing current recorded up to a time at which the value i_m is deemed to have become constant and equal to I_m (see Figure B.7).

If the battery e.m.f. has been constant, the current rises up to saturation exponentially at a rate governed by the time constant T and by the asymptotical value I_m.

From the record, the time constant T is evaluated taking into account that the time to reach a current value of 0,393 · I_m is equal to $T/2$. The total equivalent resistance (R_{eq}) of the circuit is derived from the battery e.m.f. (E) divided by I_m.

The magnetizing inductance is then calculated as:

$$L_m = T \cdot R_{eq} = T \cdot \frac{E}{I_m} \quad \text{(H)} \qquad \text{(B6)}$$

The flux linked through the secondary winding at given i_m in the non-saturated zone is then:

$$\Phi = L_m\, i_m \ \text{(Wb)} \qquad \text{(B7)}$$

The equivalent limiting r.m.s. voltage at rated frequency when $i_m \leq i_{al}$ may be obtained using equation (B3).

B.5 Capacitor discharge method

The capacitor discharge method uses the charge of a capacitor for energizing the current transformer core from the secondary. The capacitor is charged with a voltage sufficiently high so as to produce a voltage with a voltage-time integral, at the current transformer terminals equal to or greater than that corresponding to the required rated equivalent excitation secondary limiting voltage (U_{al}) (see **3.21**).

The peak value of the secondary exciting current i_m shall be measured and shall not exceed the secondary accuracy limiting exciting current (I_{al}) (see **3.28**). The test-circuit is shown in Figure B.8.

The value of the capacitor shall be chosen in such a way that the voltage drop on the secondary winding resistance need not be taken into account. This will be fulfilled if the voltage integral of $R_{ct} \cdot i_m$ during time interval t_D does not exceed 2 % of the total and thus with no saturation:

$$t_D \leq 0{,}02\ \pi\ \frac{L_s}{R_{ct}} \approx 0{,}06\ T_s\ \frac{R_{ct} + R_b}{R_{ct}} \quad \text{(s)} \qquad \text{(B8)}$$

Typical records are shown in Figure B.9.

The secondary time constant (T_s) shall be determined by applying a voltage with a voltage-time integral of 90 % of the rated excitation limiting secondary voltage to the secondary terminals of the CT. The corresponding excitation current i'_m is measured and the secondary time constant calculated as follows:

$$T_s = \frac{\sqrt{2} \times 0{,}9\ U_{al}}{2\,\pi f\,(R_{ct} + R_b)\ i'_m} \quad \text{(s)} \qquad \text{(B9)}$$

In determining the remanence factor (K_r) the integrated voltage with the corresponding current will determine a hysteresis loop on an X-Y oscilloscope.

If the exciting current has been such that the saturation flux is reached, the flux value at zero crossing of the current is deemed to represent the remanent flux Φ_r. The remanence factor K_r is thus obtained from the ratio Φ_r/Φ_s.

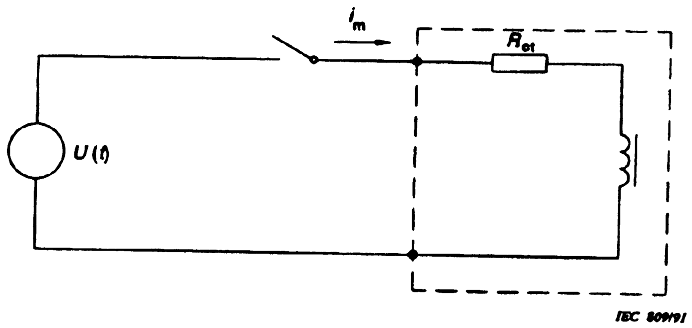


Figure B.1 — Basic circuit

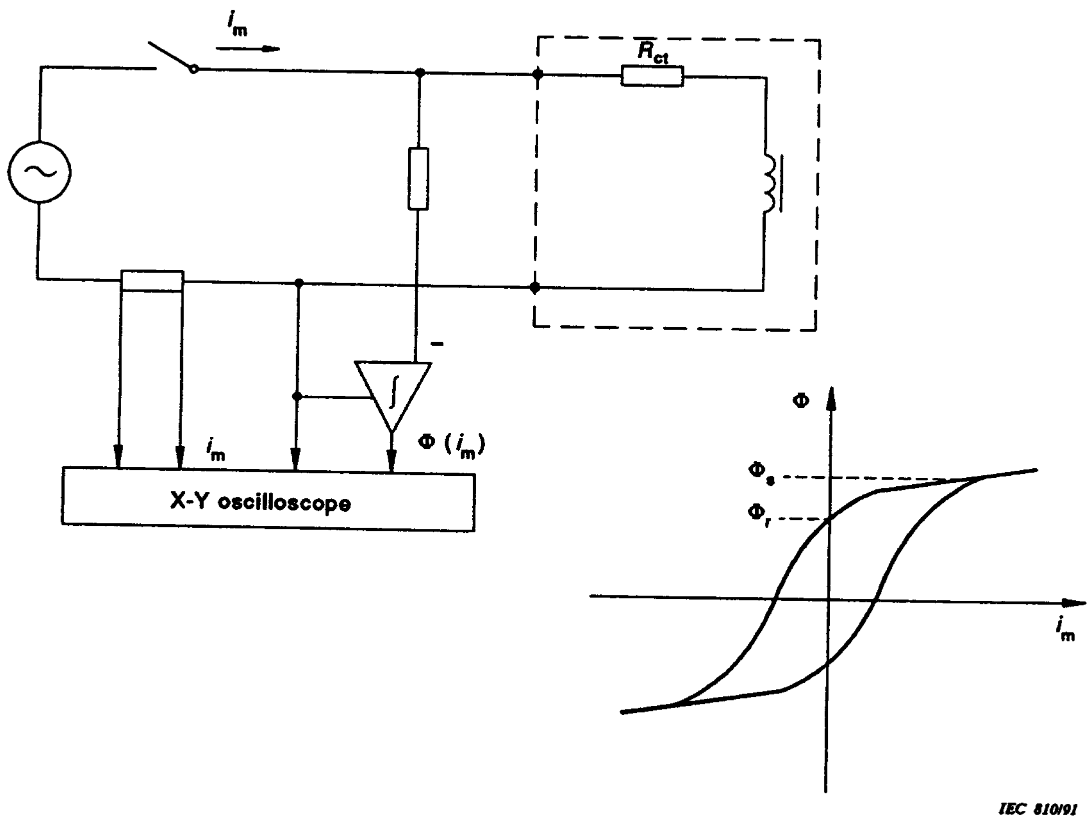


Figure B.2 — Determination of remanence factor K_r by hysteresis loop

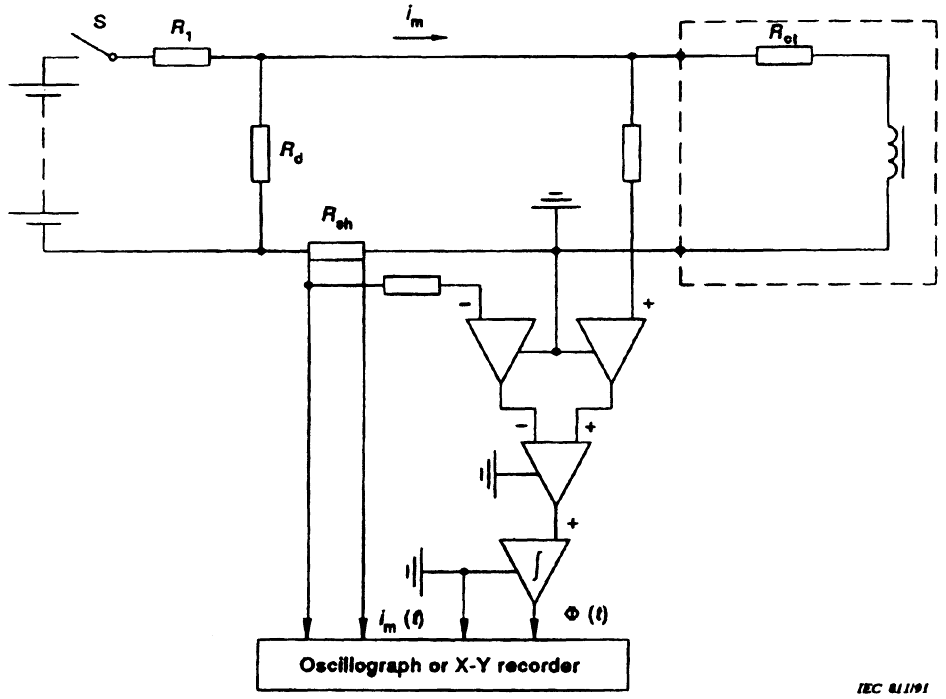


Figure B.3 — Basic circuit for d.c. method

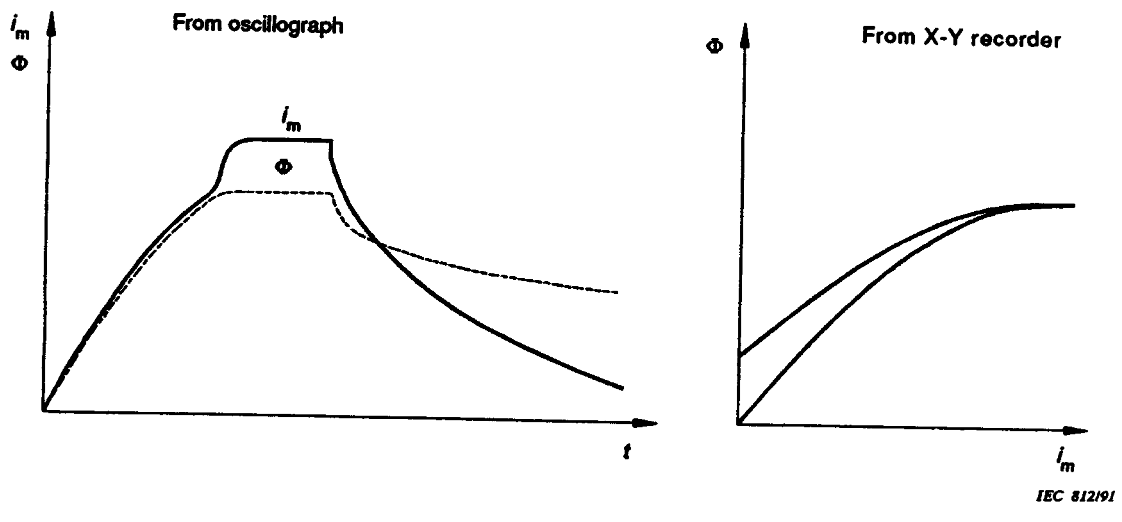


Figure B.4 — Typical records

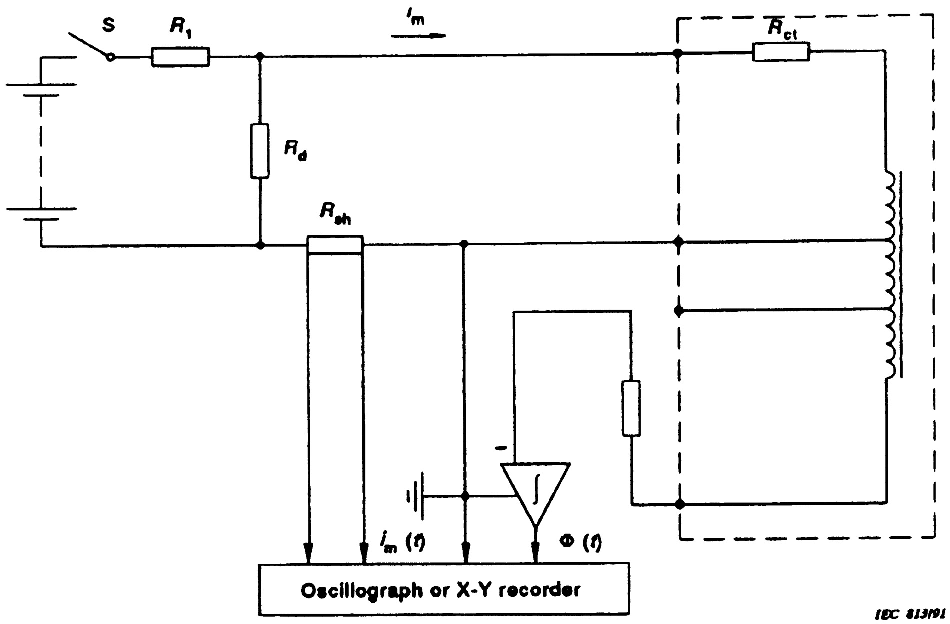


Figure B.5 — Flux measurement by additional winding

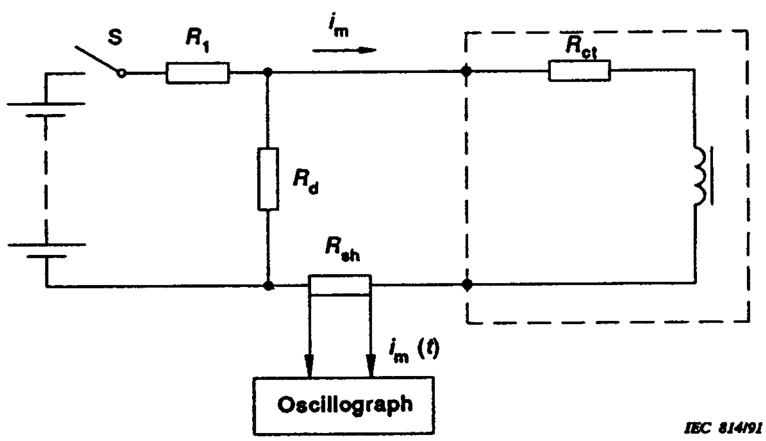


Figure B.6 — Circuit for alternative d.c. method

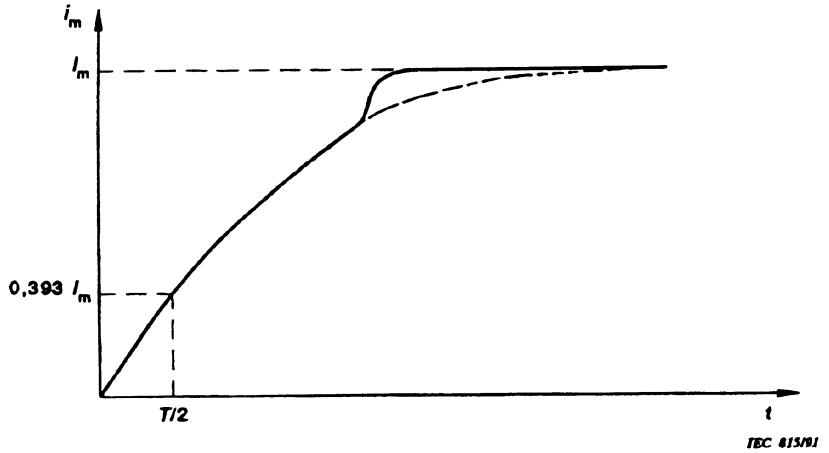


Figure B.7 — Typical record by alternative d.c. method

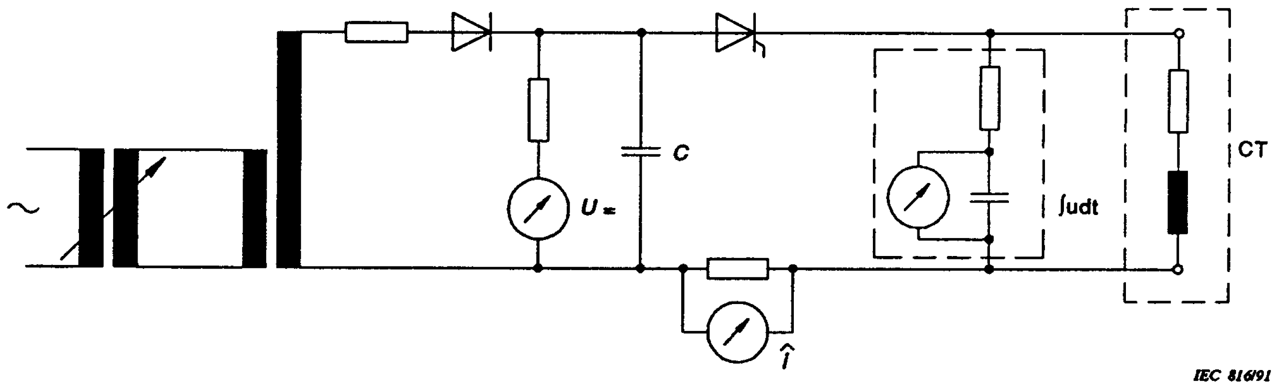


Figure B.8 — Circuit for capacitor discharge method

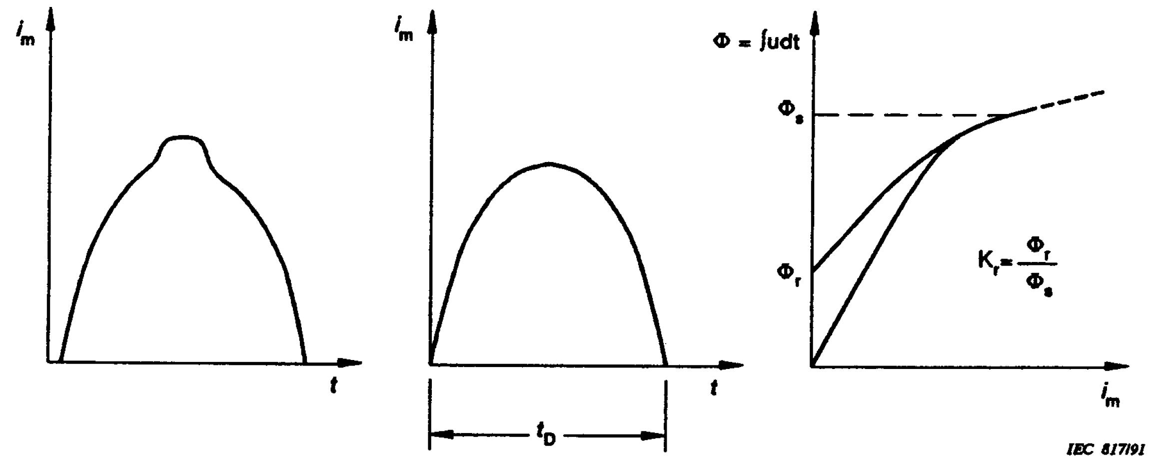


Figure B.9 — Typical records for capacitor discharge method

Annex C Direct tests

C.1 Measurement of error currents

The instantaneous error current can be measured in many different ways. In all cases, the errors of the measuring system shall not exceed 10 % of the error limit corresponding to the class of the tested CT during the whole of the duty cycle.

a) In test circuits of Figure C.1 and Figure C.2a, a reference current transformer is used. The reference current transformer shall be of the low leakage flux type and so mounted that the influencing effects of loop conductors are negligible. When the reference current transformer has a high remanence factor, core demagnetization before the test energization may be necessary. The error of the reference CT can be ignored if its secondary time constant, inclusive of shunts, is greater than that of the tested CT by a factor of at least 10 during the whole of the duty cycle. See examples of oscillograms in Figure C.3a and Figure C.3b.

b) In using the voltage differential methods of Figure C.2a and Figure C.2b, care is necessary to ensure that the measuring shunts have the same time constant, and that electrical noise in the measuring circuit is reduced to a minimum. For the circuit of Figure C.2b the shunts are so matched that they have an effective overall ratio identical to that of the tested current transformer.

c) Digital techniques can also be used to measure the primary and secondary currents separately and compute the instantaneous error currents according to their definitions (see **3.3** and **3.4**). The sampling process of primary and secondary currents shall be synchronized and the sampling interval shall be sufficiently short to obtain the required accuracy.

C.2 Measurement of secondary voltage integral

The integral during time of the voltage across the secondary terminals can also be measured by using analogue techniques (e.g. by using operational amplifiers) or digital techniques (e.g. by using data acquisition and processing techniques).

In both cases, the following equation is valid:

$$\Phi(t) = \frac{R_{ct} + R_b}{R_b} \int_0^t R_b i_s \, dt \qquad \text{(C1)}$$

where:

$\Phi(t)$ is the secondary linked flux, in weber

R_{ct} is the secondary winding resistance

R_b is the secondary connected resistance

The equivalent r.m.s. voltage $U(t)$ at rated frequency f is then given by:

$$U(t) = \frac{2\pi f}{\sqrt{2}} \quad \frac{R_{ct} + R_b}{R_b} \int_0^t R_b i_s \, dt \qquad \text{(C2)}$$

Error in flux measurement by direct test shall not exceed ± 5 %.

C.3 Direct tests in accuracy limiting conditions

Class TPS and class TPX current transformers should be demagnetized before the direct test because of the high remanence factor. It may be necessary to demagnetize class TPY current transformers if the remanence factor K_r is not negligible.

Two direct tests are performed at rated frequency and with rated secondary burden:

a) The rated primary short-circuit current at rated frequency is applied without any offset. The a.c. component of the instantaneous error current is measured and shall be in accordance with the theoretical value corresponding to the secondary time constant ($1/\omega T_s$).

b) The rated primary short-circuit current at rated frequency is applied with maximum offset. For specified values of primary time constant up to 80 ms, the test is performed in the specified accuracy limiting condition (specified duty cycle). The primary time constant shall not deviate by more than 10 % from the specified value. For specified values of primary time constant above 80 ms, the tests can be performed in equivalent accuracy limiting conditions, subjected to agreement between user and manufacturer.

During each energization period, the first peak instantaneous primary current shall be not less than the value corresponding to the specified conditions. The duration of the energization(s) and/or secondary burden are adjusted so that the measured secondary voltage integral [equation (C1)] reaches the accuracy limit flux (Φ_{al}) (see **3.27**) during the test.

The corresponding recorded value of the peak instantaneous error current is measured and shall not exceed the error current limiting value for the accuracy class concerned (Table 1). For class TPX and TPY current transformers, the total error current is measured. For class TPZ current transformer, the a.c. component of the error current is measured as one half of the peak-to-peak value (see Figure C.4).

NOTE 1 If for TPZ current transformers the rated value of I_{psc} cannot be achieved and the secondary burden is adjusted in order to reach the required flux level (Φ_{al}) during the test, the measured value of the a.c. component of the error current shall be multiplied by the following correction factor:

$(R_{ct} + R_b)/(R_{ct} + R'_b)$

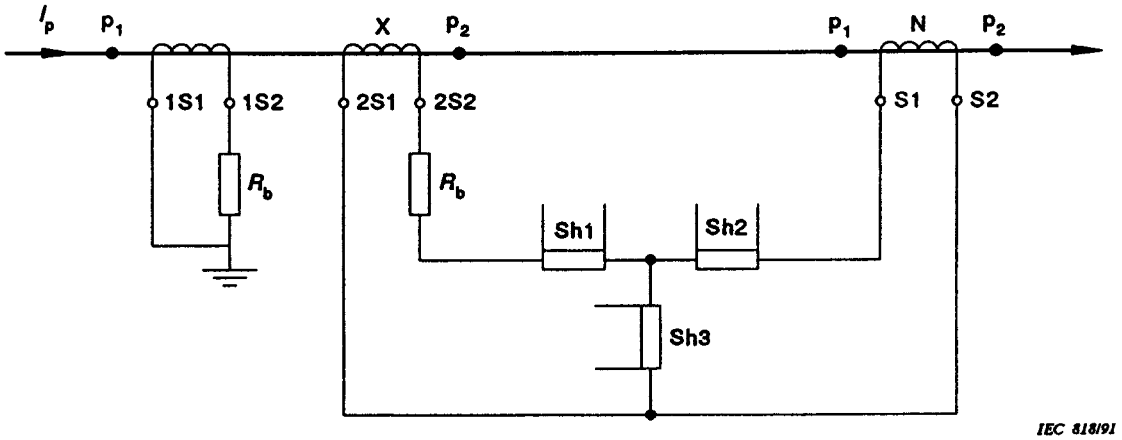
where R_b is the rated burden and R'_b is the burden during the test.

NOTE 2 If the secondary burden is adjusted in order to reach the required flux level during the test, it should be observed that the length of the necessary energization period(s) is changed. This should in particular be recognized for the C-0-C-0 duty cycle, class TPX and TPY current transformers where the flux level at the beginning of the second energization remains unchanged. The result of changing parameters is seen in the equations of Annex A.

C.4 Determination of the factor of construction (F_c) (see 3.29)

Referring to test b) in clause **C.3** above, the duration of the energization(s) and/or secondary burden are increased so that the measured instantaneous error current reaches the limiting value for the accuracy class concerned (Table 1). The corresponding voltage time integral is determined. For class TPZ, linear interpolation is used to determine the instant at which the limiting value of the a.c. component of the error current is reached.

From the secondary exciting test, the voltage time integral up to the same value of the exciting current is determined and the primary winding influence construction factor is calculated.



Symbols

X = CT under test

N = reference CT low leakage flux type

Sh = non-inductive shunt

1 = I_s

2 = I_p/K_n

3 = I_ε

R_b = rated secondary burden adjusted if necessary to meet test parameters

Figure C.1 — Current difference test arrangement

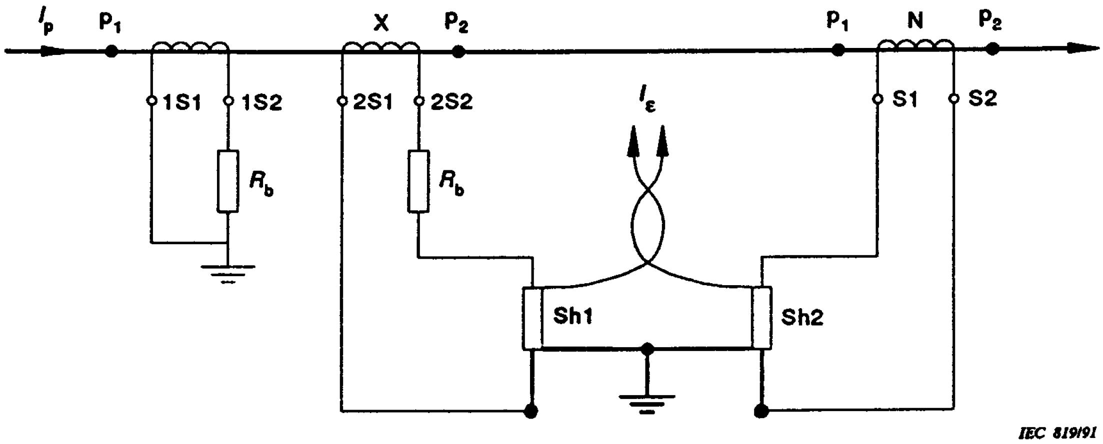


Figure C.2a — With secondary connected shunts

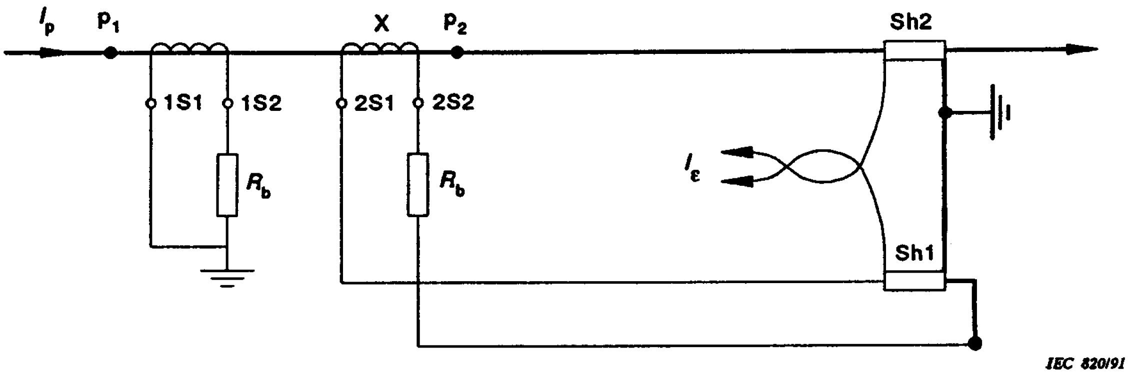


Figure C.2b — With primary shunt-adjusted ratio

Symbols

X = CT under test

N = reference CT low leakage flux type

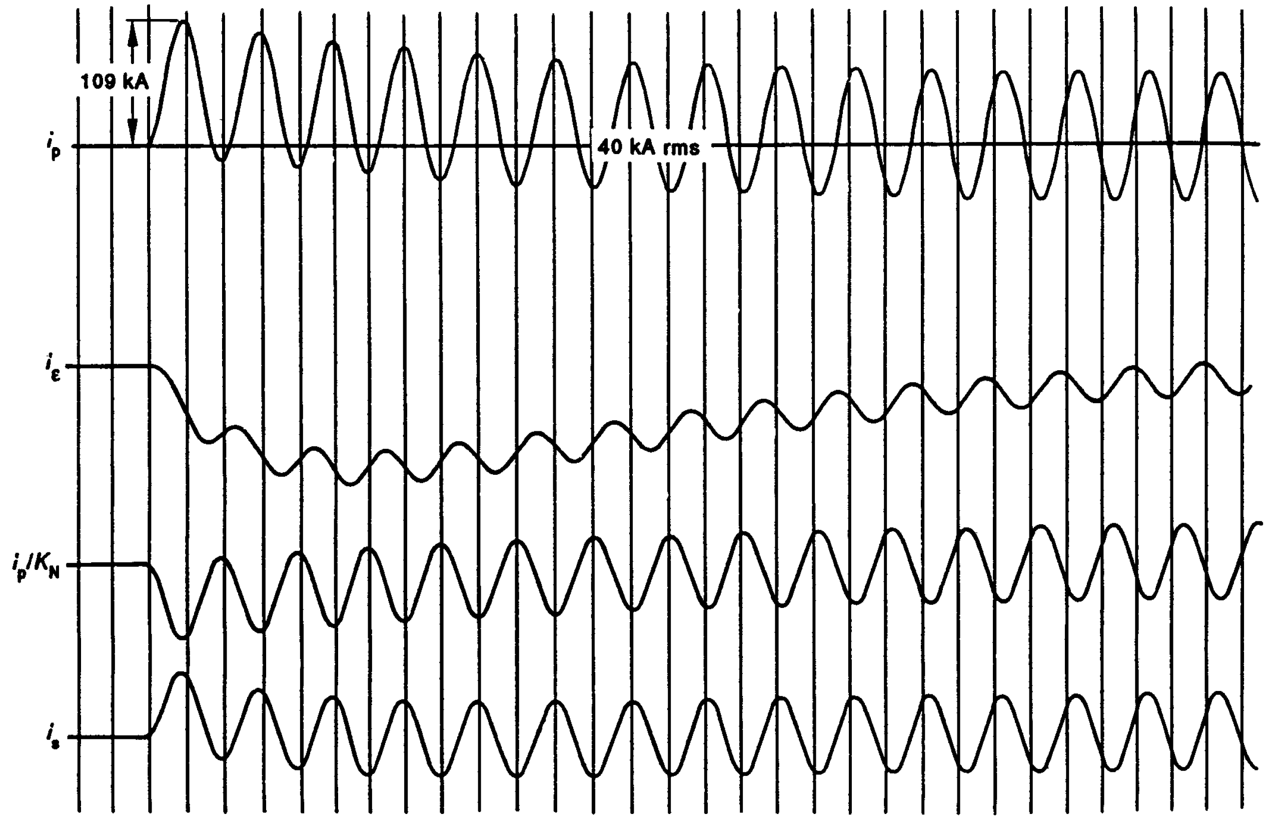
Sh = non-inductive shunt

1 = I_s

2 = I_p/K_n

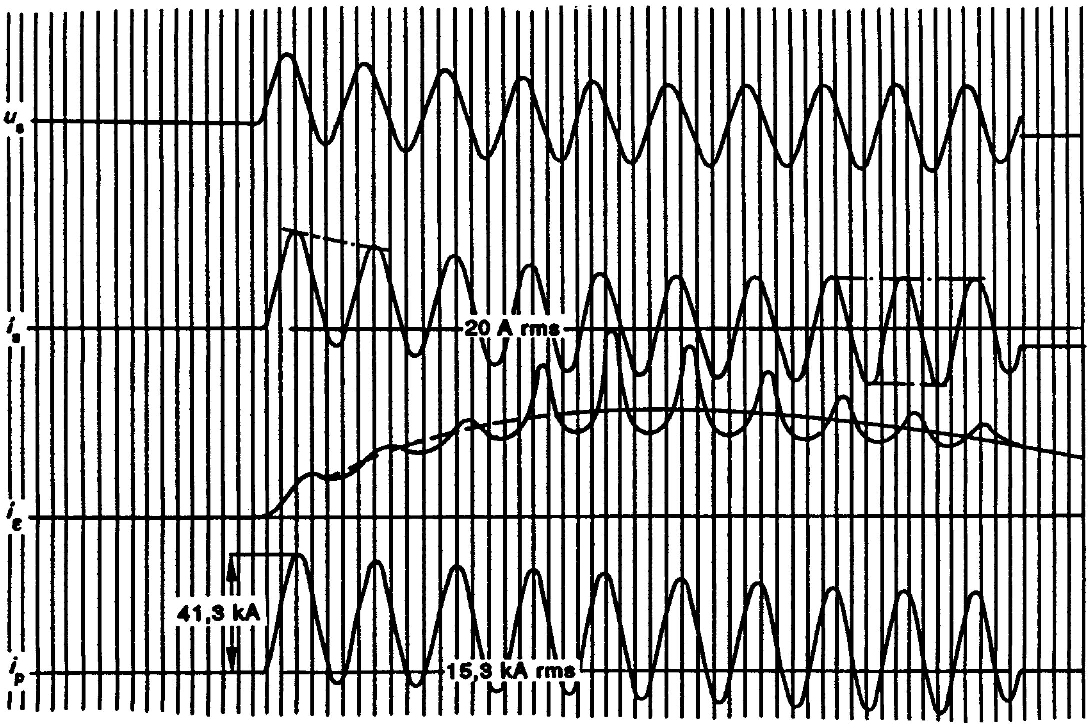
R_b = rated secondary burden adjusted if necessary to meet test parameters

Figure C.2 — Voltage difference method



IEC 821/91

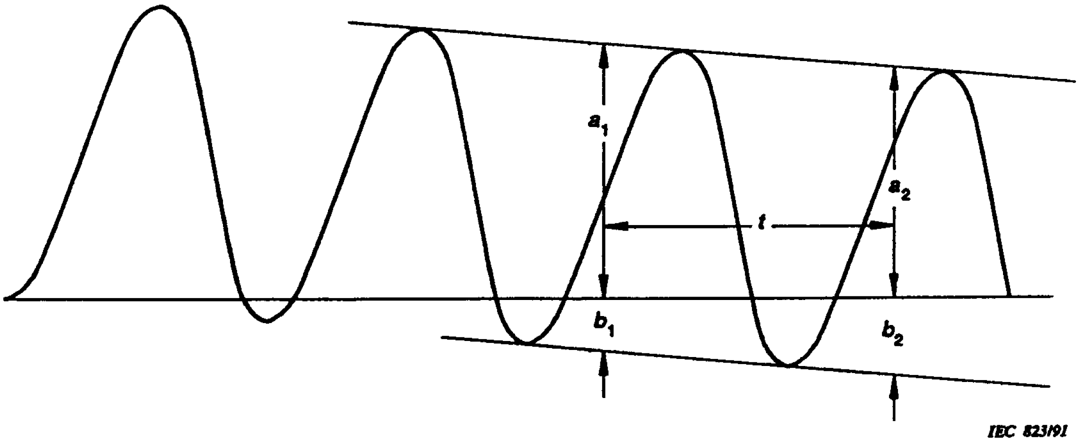
Figure C.3a — Typical oscillogram for a current transformer type TPZ



IEC 822/91

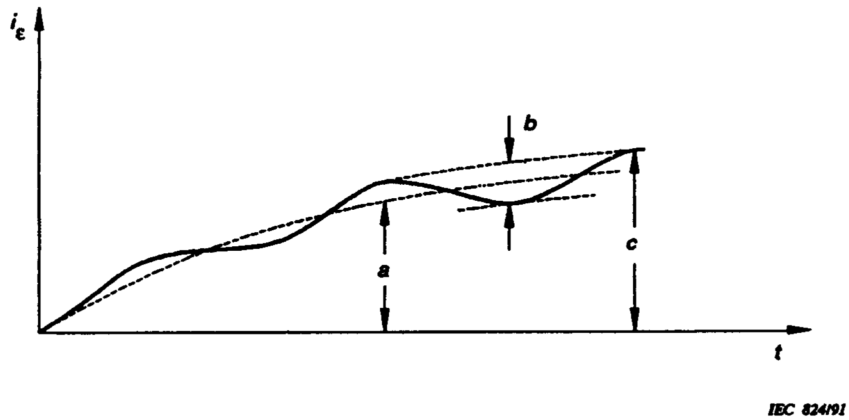
Figure C.3b — Typical oscillogram for a current transformer type TPY

Figure C.3 — Oscillograms



$$T_p = t / \ln \frac{a_1 - (a_1 + b_1)/2}{a_2 - (a_2 + b_2)/2} = \frac{t}{\ln\left(\frac{a_1 - b_1}{a_2 - b_2}\right)}$$

Figure C.4a — Measurement of primary time constant for a current transformer type TPZ



a = $\hat{i}_{\varepsilon dc}$ b = 2 $\hat{i}_{\varepsilon ac}$ c = $\hat{i}_{\varepsilon ac} + \hat{i}_{\varepsilon dc}$

For TPY: $\hat{i}_\varepsilon = c$ For TPZ: $\hat{i}_\varepsilon = \hat{i}_{\varepsilon ac} = b/2$

Figure C.4b — Measurement of error currents for current transformers type TPY and TPZ

Figure C.4 — Oscillograms

Annex D Guide to performance criteria for current transformer for protection relaying

D.1 Introduction

This guide is intended to identify some of the principal factors which may affect the choice of current transformer class with particular reference to primary system fault currents containing d.c. transients.

Class P current transformers (see clause **12** of IEC 60044-1) performance requirements are defined relative to a symmetrical sinusoidal primary energizing current. This does not exclude class P current transformers from being assigned a transient performance capability provided that appropriate data are available. For example, a current transformer which satisfies the requirements of the item b) of subclause **12.5** of IEC 60044-1 is essentially of low leakage flux construction and can be treated in the same way as a class TPS current transformer so far as application is concerned.

Extensive experience both in service and by laboratory testing supports the usage of class P current transformers including designs for which an additional transient dimension has been included by specifying a larger nominal output. The main practical problem arises from the need to take account of the internal burden (winding resistance) in considering the total performance.

For example, a current transformer rated for 60 VA 5P20 and intended for use with a secondary connected burden of 2 W, may be thought to be over-dimensioned by a factor of 30. In practice, however, such a current transformer could well have an internal burden approaching 20 W, leading to a practical over-dimensioning factor of the order of 3.

The current transformer capabilities can be defined in terms of the power to be dissipated in the secondary circuit or by the equivalent maximum exciting voltage necessary to drive current in the secondary circuit. Herein, voltage relationships will be used with the following equivalents:

$$E_{al} \approx K_{ssc} \cdot K_{td} \, (R_{ct} + R_b) \, I_{sn} \approx \frac{P_i + P_e}{I_{sn}} \cdot K_{ssc} \cdot K_{td} \qquad \text{(D1)}$$

In the foregoing equation P_i and P_e represent equivalent power dissipated in the current transformer secondary winding and in the externally connected burden respectively. All parameters can be either specified or estimated by the purchaser with reasonable accuracy with the possible exception of the current transformer secondary winding resistance.

D.2 Primary time constant (T_p)

The specified primary time constant (see **3.6**) is intended to ensure that the current transformer is adequately dimensioned for the intended application inclusive of the duty cycle. If there are a number of infeeds to the busbar of interest on the primary network, each infeed can be assumed to contribute a discrete sinusoidal current with a corresponding d.c. offset and time constant of decay.

Relative to a given duty cycle, the flux in the current transformer attributable to that discrete component of current can be represented by a corresponding value for E_{al}. The sum of the values so derived is representative of the total flux requirements for the current transformer. A simplifying assumption is that all sinusoidal currents are in phase.

D.3 Choice of current transformer class

Choice between classes TPS, TPX, TPY or TPZ will, in many cases, be determined by the purchaser's preferred practice taking account of relay equipment commonly in service on the network for which the current transformers are destined for use. Some of the main characteristics of the individual classes are discussed below.

In addition to being of the low leakage flux type, class TPS current transformers are required to have close control of the turns ratio. Both requirements are essential to both phase fault and earth fault protection schemes based on the simple circulating current principle and using high impedance relays. Since the remanent flux has no specified limit, application limits for measuring protection relays are usually based on empirical formulae derived from test and field experience. Interruption of the primary energizing current when the current transformer is severely saturated will result in a very rapid decay of the current in the secondary circuit as the flux falls from the saturated to the remanent level. Resetting times for protection relays are not usually significantly affected by the decay characteristics of class TPS current transformers.

The basic characteristics for class TPX current transformers are generally similar to those of class TPS current transformers except for the different error limits prescribed and possible influencing effects which may necessitate a factor of construction greater than 1,1.

Class TPY current transformers control the remanent flux to not more than 0,1 per unit of the saturation flux. During the transition from the saturated to the remanent flux conditions, current in the secondary circuit will be maintained at a much higher level and for longer than would be the case for a class TPS or TPX current transformers of similar dimensions and with similar secondary connected burden.
For a C-0-C-0 duty cycle, the transient dimensioning factor necessary for class TPY current transformers will be critically affected by the relationship between the secondary circuit time constant (T_s) and the dead time (t_{fr}).

Since the total permissible error limit is 10 %, the transient dimensioning factor shall be considered conjunctively with the secondary circuit time constant:

$$\frac{100\, K_{td}}{2\,\pi\, f\, T_s} = \varepsilon \le 10\,\% \qquad \text{(D2)}$$

For class TPZ current transformers, the remanent flux is negligible and the secondary loop time constant parametric limits are specified. The decaying secondary current following severe saturation will be maintained at a higher value than would be the case for class TPY during the initial period of interest (relay reset time). Many relay systems have input current/voltage transductors to convert the measurands for processing. Thus, only the a.c. component of secondary current is of interest and relay reset characteristics are largely independent of current transformer decrement.

Calculation of the transient dimensioning factor necessary for each of the above current transformer classes can be made by substitution of data into the appropriate equations given in Annex A.

D.4 Typical example of steps in preparation of specification

The C-0 duty cycle for class TPZ current transformers is based on maximum flux conditions being achieved. Since the secondary loop time constant tolerance limits are specified, K_{td} can be calculated directly.

For class TPS and TPX current transformers for which $t' < t_{max}$ and $T_p << T_s$, a simplified equation for the transient factor for a single energization is:

$$K_{tf} \approx 2 \cdot \pi \cdot f \cdot T_p \cdot (1 - e^{-t'_{al}/T_p}) + 1 \qquad \text{(D3)}$$

Requirements for class TPY current transformers are less easily defined and are considered below.

Suppose data for a high voltage power transmission network and basic requirements are as follows:

Switchgear rating:	50 Hz, rated current: 2 000 A Rated short-circuit breaking current: 40 kA (see **4.101** of IEC 56)		
Fault infeeds at busbar:	I'_p: 15 kA at T'_p = 240 ms (local generation, X/R = 76) I''_p: 20 kA at T'_p = 60 ms (network infeed)		
Current transformer:	Class TPY ratio 2000/1 Secondary Connected burden $R_b = (3 + 4) = 7\ \Omega$		
Duty cycles:	C-0	t'_{al}	= 240 ms
	C-0-C-0	t'	= 120 ms
		t''	= 60 ms
		t_{fr}	= 450 ms

Transient factors (K_{td}, K_{tf} and $K_{tf\,max}$) are determined by substitution of derived data into the appropriate equations given in Annex A, except that in all cases – 1 is substituted for sin ωt.

Optimization of current transformer design is the responsibility of the manufacturer.

However, in order to verify that the specification to be issued does not result in an unrealistically large design, any or all of the following steps may be taken.

Step 1

The current transformer specification may be based on I_{psc} = 40 kA. For a first approximation, the equivalent primary time constant may be taken as:

$$T_p \text{ equivalent} = \frac{15\,000}{40\,000} \cdot 240 + \frac{20\,000}{40\,000} \cdot 60 = 120 \text{ ms} \qquad \text{(D4)}$$

Step 2

Determine T_s. The practical range will usually be between 1 s and 3 s. Using T_s = 3 s and T_p = 120 ms, determine the corresponding value for K_{td}. For C-0 duty cycle, K_{td} = 34. For C-0-C-0 duty cycle, K_{td} = 36.

From equation (D2) above, the permissible value for T_s to satisfy the class error limit is:

$$T_s = \frac{100}{10} \cdot \frac{36}{2\pi f} = 1{,}15 \text{ s}$$

Allowing for manufacturing tolerances and a base current I_{psc} = 40 kA, a new value T_s = 1,35 s would be reasonable for further assessment.

Step 3

Estimate secondary winding resistance (R_{ct}). In principle, the value for R_{ct} should not exceed about 50 % of the external connected burden R_b. In this case $R_{ct} \leq 7/2 = 3{,}5\ \Omega$.

The actual value will be determined by interrelated parameters including core cross-section, space available for secondary winding, number of turns and cross-section of secondary winding conductors. Whilst there are no absolute limits, a core cross-sectional area of 10^4 mm^2 may be taken as representative of the upper limiting value for an economic design with a corresponding secondary winding resistance of approximately $7/A_w \cdot$ mΩ/turn (where A_w is the cross-sectional area of the (copper) winding in mm^2). A practical range will usually be between 1 and 3,5 Ω/1 000 turns.

Hence R_{ct} = 3,5 Ω is reasonable and the secondary loop resistance R_s = 10,5 Ω may be used in subsequent calculations.

Step 4

Determine equivalent secondary limiting e.m.f. (E_{al}) using revised data:

I_{psc} = 40 kA, T_p = 120 ms, T_s = 1,35 s, R_s = 10,5 Ω

For C-0 duty cycle: t'_{al} = 240 ms, whence:

$K_{td} = 30$

For C-0-C-0 duty cycle: t' = 120 ms, t_{fr} = 450 ms, t'' = 60 ms, whence:

$K'_{tf} = 23{,}6$ and $K''_{tf} = 15{,}5$

$K_{td} = 23{,}6 \cdot 0{,}685 + 15{,}5 = 31{,}7$

with $e^{-}(t_{fr} + t''_{al})/T_s = 0{,}685$

$$E_{al} = 31{,}7 \cdot \frac{40\,000}{2\,000} \cdot 10{,}5 = 6{,}7 \text{ kV (r.m.s.) or } 3{,}35 \text{ V/turn}$$

For a grain oriented silicon steel core of 10^4 mm^2 cross sectional area, approximately 4 V/turn is within theoretical capability. A specification based on the above-defined parametric limits would therefore be acceptable.

Step 5

Determination of E_{al} for actual service condition energizing current(s). Simplifying assumptions are: a) the effects of phase displacement between components are ignored and b) the maximum transient value attained to satisfy a current component is used for each energizing case considered as follows:

C-0 duty cycle:

when T_p = 240 ms, $K_{td} = K_{tf}$ = 44

when T_p = 60 ms, $K_{td} = K_{tf\,max}$ = 17,3

$$E_{al} = \left[44 \cdot \frac{15\,000}{2\,000} + 17{,}3 \cdot \frac{20\,000}{2\,000} \right] \cdot 10{,}5 = 5\,282 \text{ V}$$

C-0-C-0 duty cycle:

when T_p = 240 ms, K_{td} = 29,3 · 0,685 + 17,3 = 37,4

when T_p = 60 s, K_{td} = 16,4 · 0,685 + 12,6 = 23,8

$$E_{al} = \left[37{,}4 \cdot \frac{15\,000}{2\,000} + 23{,}8 \cdot \frac{20\,000}{2\,000} \right] \cdot 10{,}5 = 5\,444 \text{ V}$$

From the above combinations of parameters, some further refinement of the specification from step 4 could be considered. For example, a reduction of T_p to 80 ms would result in a reduction of the theoretical value for E_{al} to about 6,1 kV whence the recommended specification becomes:

2 000/1 A; TPY; K_{ssc} = 20; T_p = 80 ms

R_b = 7 Ω; K_r ≤ 0,1; T_s ≥ 1,35 s

Duty cycles: C – 240 ms – 0

C – 120 ms – 0 – 450 ms – C – 60 ms – 0

NOTE The foregoing procedures may be adapted for partial offset but equivalence immediately after energization is problematic because of the need to take account of the amplitude of the first peak of primary energizing current.

D.5 Influencing effects of return conductor

A ring-type current transformer with a uniformly distributed secondary winding and having a single bar type primary conductor passing through the geometric centre of the assembly will be of the low leakage flux type unless influenced by a nearby conductor.

During a direct test, the recorded error will be composed of a d.c. component plus a superimposed a.c. component of rated frequency. The a.c. component should be strictly proportional to the corresponding magnetization current. In a practical test installation, however, the a.c. component of error current may also contain a component of magnitude determined by ratio differences between the measurement derived from the tested current transformer and the measurement representing the primary energizing current.

For this reason, it is sometimes advantageous to base assessment of the test record on the estimated d.c. component over the unsaturated range of operation.

When, however, there is another current carrying conductor outside but adjacent to the current transformer ring, as in the case of a hairpin or ring-type primary winding, flux due to the second conductor also impinges upon the core. The principal effect of this is to cause premature local saturation over part of the core with a consequential change in the operating characteristic.

During a direct test, the effects will be shown quite clearly in the record of the error current in which the a.c. component will show a series of gradually increasing peaks of short duration superimposed on the basic sinusoidal shape.

Prior to the onset of saturation, the measured d.c. error may well be somewhat less than would be anticipated from an estimate of the secondary induced voltage compared with the corresponding magnetizing current from the secondary excitation (indirect) test.

The application of "stacked" windings so arranged as to achieve a secondary turns distribution which theoretically corresponds to the net ampere turn distribution when account is taken of the return conductor effects and the application of flux equalizing windings are both methods by which the current transformer performance can be improved, and hence the factor of construction (F_c) correspondingly reduced compared with a design having a simple uniformly distributed secondary winding.

For designs in which a non-uniformly distributed secondary winding is deliberately used, it is important to ensure that the current transformers are correctly located relative to the primary energizing conductors on all production units. Measurement of secondary excitation characteristics does not usually assist in this respect and rigid controls during the construction period may be needed.

Annex E Determination of turns ratio error

There is no simple direct method of precisely determining the turns ratio error on a completed current transformer. The actual transformation ratio is affected by errors from three sources:

a) the difference between the turns ratio and the rated transformation ratio;

b) the core excitation current (I_e);

c) the currents which flow in the stray capacitances associated with the windings.

Figure E.1 illustrates a simplified basic circuit for a current transformer resistive and reactive components whilst Figure E.2 is expanded to represent the stray capacitances which may be of significance for current transformers having a large number of turns (more than 1 000).

If the transformation ratio error is small (e.g. 1 %) it is reasonable to assume that for a given secondary winding induced e.m.f. (E_s), the error currents due to stray capacitances and core magnetization will maintain a constant value irrespective of the value of the primary energizing current (I_p).

E_s can theoretically be maintained at a constant value for a range of energizing currents provided that the secondary loop impedance can be appropriately adjusted. For current transformers designed to be of the low leakage flux type (e.g. class TPS) the secondary leakage reactance can be ignored and only the secondary winding resistance considered. Thus, for any two currents I'_s and I''_s the basic equation defining the test requirement is given by:

$$I'_s\,(R_{ct} + R'_b) = E_s = I''_s\,(R_{ct} + R''_b)$$

Assuming that the measured ratio errors are ε'_c and ε''_c the turns ratio error is denoted as ε_t and the combined magnetization and stray currents are given by I_x, the respective error currents will be approximately given by:

$$(\varepsilon'_c - \varepsilon_t)\ \frac{K_n I'_s}{100} = I_x = (\varepsilon''_c - \varepsilon_t) \cdot K_n\ \frac{I''_s}{100}$$

whence:

$$\varepsilon_t = \frac{\varepsilon'_c I'_s - \varepsilon''_c I''_s}{(I'_s - I''_s)}$$

If $I'_s = 2\,I''_s$ the turns ratio error is given approximately by $2\,\varepsilon'_c - \varepsilon''_c$.

A test at rated current with minimum secondary connected burden followed by a test at half rated current and suitable increase in secondary loop resistance will usually give satisfactory results.

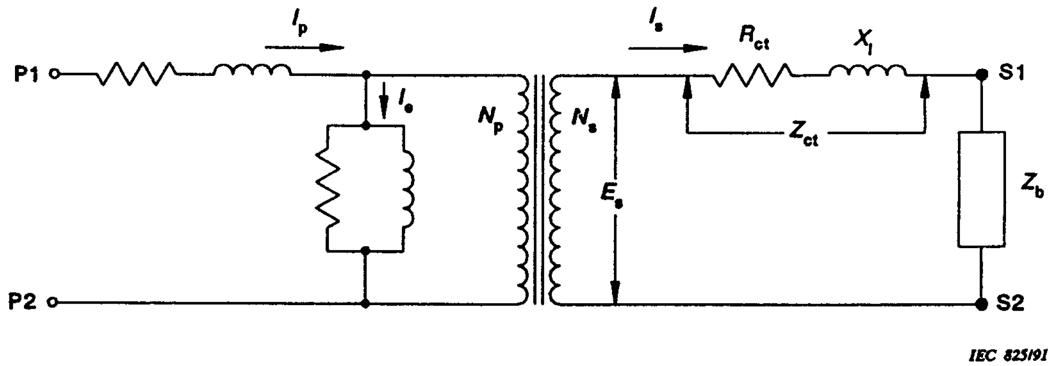


Figure E.1 — Simplified equivalent circuit for a current transformer

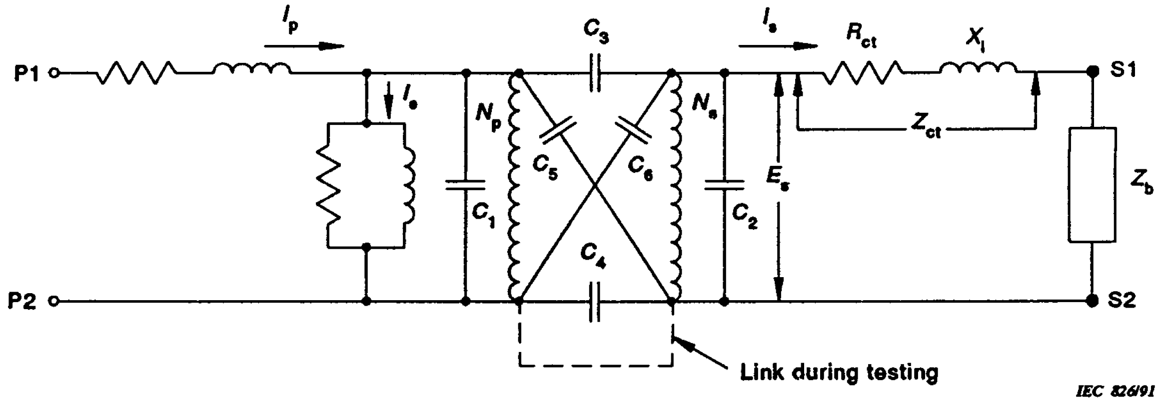


Figure E.2 — Simplified equivalent circuit for a current transformer with stray capacitances

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Annex ZA (normative)
Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60044-1	1996	*Instrument transformers* Part 1: *Current transformers*	—	—
IEC 60056 (mod)	1987	*High-voltage alternating-current circuit-breakers*	HD 348 S7[a]	1998

[a] HD 348 S7 includes A3:1996 to IEC 60056.

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