
**Resistance welding equipment —
Transformers — General specifications
applicable to all transformers**

*Matériel de soudage par résistance — Transformateurs — Spécifications
générales applicables à tous les transformateurs*

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International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 5826 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 6, *Resistance welding*.

This second edition cancels and replaces the first edition (ISO 5826:1983), which has been technically revised.

Annexes B, C and D form a normative part of this International Standard. Annex A is for information only.

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Resistance welding equipment — Transformers — General specifications applicable to all transformers

1 Scope

This International Standard give specifications applicable to transformers for resistance welding equipment without connected rectifier.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 669, *Resistance welding equipment — Mechanical and electrical requirements.*

IEC 60051-2, *Direct acting indicating analogue electrical measuring instruments and their accessories — Part 2: Special requirements for ammeters and voltmeters.*

IEC 60085, *Thermal evaluation and classification of electrical insulation.*

IEC 60204-1, *Electrical equipment of industrial machines — Part 1: General requirements.*

IEC 60529, *Degrees of protection provided by enclosures (IP code).*

IEC 60536-2, *Classification of electrical and electronic equipment with regard to protection against electric shock — Part 2: Guidelines to requirements for protection against electric shock.*

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems — Part 1: Principles, requirements and tests.*

IEC 60905, *Loading guide for dry-type power transformers.*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 669 apply.

4 Symbols

The symbols used in this International Standard are listed in Table 1.

Table 1 — List of symbols

Symbol	Description	Reference
I_{1p}	rated permanent input current	10, 12
I_{1X}	input current at a given duty factor	annex C
I_2	output current	annex C
I_{2p}	permanent output current at 100 % duty factor	13.2, annex C
I_{2X}	output current at a given duty factor	annex C
$I_{2/50}$	output current at 50 % duty factor	13.2
m	mass	13.2
P	power	annex C
P_p	permanent input power (at 100 % duty factor)	10, 11, 13.2, annex C
P_X	input power at a given duty factor	annex C
P_{50}	input power at 50 % duty factor	13.2
Q	required total rate of cooling liquid flow	11, 13.2
R_1	initial resistance of a winding	8.2.1, 8.3.2
R_2	resistance of a winding at the end of the heating test	8.3.2
t	time	annex C
t_1	on-load time	annex C
T	cycle time	annex C
U_{cc}	rated short-circuit voltage	10
U_{1cc}	input short-circuit voltage	10
U_{1N}	rated supply voltage	9, 10, 13.2
U_{20}	rated output no-load voltage	9, 13.2
X	duty factor	annex C
X_m	duty factor of the magnetic circuit	annex C
Z_2	total impedance referred to the output	10
Δp	pressure drop of the cooling liquid circuit	11, 13.2
$\Delta\theta_{1,2}$	temperature differences	annex C
θ	temperature	annex C
θ_a	cooling medium temperature	annex C
θ_m	equilibrium temperature	annex C
θ_n	temperature when the transformer starts to cool	annex C
$\theta_{0,1,2}$	temperatures for calculation of the thermal time constant or the winding temperatures during the heating test	8.2.1, 8.3.2, annex C
τ	thermal time constant	annex C
τ_2	thermal time constant at given on-load time	annex C
τ_{2p}	thermal time constant at permanent output current	annex C

5 Physical environment and operating conditions

5.1 General

Transformers shall be suitable for use in the physical environment and operating conditions as specified below.

When the physical environment and/or operating conditions are outside those specified below, an agreement may be needed between the supplier and the user, (see e.g. annex B of IEC 60204-1:1997).

5.2 Ambient air temperature

Transformers shall be capable of operating correctly in an ambient air temperature between + 5 °C and + 40 °C.

In case of other maximum temperatures of the cooling medium, see annex B.

5.3 Humidity

Transformers shall be capable of operating correctly within a relative humidity range of 30 % to 95 %.

Harmful effects of occasional condensation shall be avoided by proper design of the equipment or, where necessary, by proper additional measures (e.g. air conditioners, drain holes).

5.4 Altitude

Transformers shall be capable of operating correctly at altitudes up to 1 000 m above mean sea level.

In case of other altitudes, see annex B.

5.5 Transportation and storage

Transformers shall be designed to withstand, or suitable precautions shall be taken to protect against, transportation and storage temperatures between – 25 °C and + 55 °C and for short periods not exceeding 24 h up to + 70 °C. Suitable means shall be provided to prevent damage from humidity, vibration and shock.

5.6 Provisions for handling

Transformers shall be provided with suitable means for handling by cranes or similar equipment.

5.7 Temperature of the cooling liquid

The temperature of the cooling liquid may be up to + 30 °C at the inlet of the transformer.

NOTE Condensation caused by high cooling liquid flow or low cooling liquid temperature in relation to the relative humidity should be prevented.

6 Test conditions

6.1 General

The tests shall be carried out on new, dry and completely assembled transformers at an ambient air temperature between + 10 °C and + 40 °C. The ventilation shall be identical with that prevailing under normal service conditions. When placing the measuring devices, the only access permitted shall be through openings with cover plates, inspection doors or easily removable panels provided by the manufacturer. The measuring devices used shall not interfere with the normal ventilation of the transformer or cause transfer of heat to or from it.

Liquid cooled transformers shall be tested with liquid conditions as specified by the manufacturer.

The accuracy of measuring instruments shall be:

- a) electrical measuring instruments: Class 0,5 (0,5 % full scale, see IEC 60051-2);
- b) thermometer: ± 2 K.

Unless otherwise specified, the tests required in this International Standard are type tests.

The sequence for some of the type tests is specified in 6.2.

The routine tests are specified in 6.3.

Compliance with other standards referred to shall be checked according to these standards.

6.2 Type tests

All type tests shall be carried out on the same transformer except otherwise specified.

Those type tests given below shall be carried out in the following sequence without delay between f), g), h) and i).

- a) General visual inspection;
- b) Insulation resistance (see 7.1) preliminary check;
- c) Thermal rating (see clause 8);
- d) Rated short-circuit voltage (see clause 10);
- e) Protection provided by the enclosure (see 7.3.1);
- f) Insulation resistance (see 7.1);
- g) Dielectric strength (see 7.2);
- h) Dynamic characteristic (see clause 12);
- i) General visual inspection.

The other tests of this International Standard not mentioned above may be carried out in any convenient sequence.

NOTE The preliminary check on insulation resistance is required to determine whether the transformer is safe to connect to the supply.

6.3 Routine tests

Each transformer shall be submitted successively to the following routine tests.

- a) General visual inspection;
- b) Dielectric strength (see 7.2);
- c) Rated no-load output voltage (see clause 9);
- d) Cooling liquid circuit (see clause 11);
- e) General visual inspection.

7 Protection against electric shock

7.1 Insulation resistance

The insulation resistance shall not be less than 50 M Ω .

Compliance is checked by measuring the insulation resistance using a d.c. voltage of 500 V between

- a) the input and output windings and
- b) the windings and the frame.

7.2 Dielectric strength (routine test)

The insulation shall withstand the following test voltages without any flashover or breakdown and no damage shall occur which might impair the function of the insulation.

Compliance is checked according to IEC 60664-1 and the following test.

An a.c. voltage, having the frequency of the mains supply, of:

- a) 4 000 V r.m.s. for integrated gun transformers and
- b) 2 500 V r.m.s. for all other transformers

is applied between the inlet and one winding of the outlet circuit, of class I or class II transformers. However, if the design of class I is so that one point of the secondary is connected to earth, the test voltage can be decreased to 2 500 V r.m.s.

An a.c. voltage of 1 000 V r.m.s. having the same shape is applied between one winding of the outlet circuit and earth.

The 1 000 V test voltage shall be applied instantaneously.

The 2 500 V and 4 000 V test voltages shall be applied progressively so that the prescribed value is reached in about 20 s.

In both cases, the test voltage shall be continuously maintained at the required value for 60 s, then stopped as quickly as the equipment allows, without creating overvoltage during stopping.

NOTE Dielectric tests shall not normally be repeated on a same transformer. If, for any reason, they should be, they should be tested again with a test voltage of only 75 % of the above-mentioned values.

7.3 Protection against electric shock in normal service (direct contact)

The minimum degree of protection for transformers provided by the enclosure shall be IP 54 as specified in IEC 60529.

If the transformer is intended to be in-built, the degree of protection may be IP 00.

Compliance is checked according to IEC 60529.

7.4 Protection against electric shock in case of a fault condition (indirect contact)

Transformers shall be built to protection class I or II according to IEC 60536-2.

Compliance is checked by visual inspection.

7.5 Isolation of input and output circuits

The welding circuit shall be electrically isolated from the input circuit and from all other circuits having a voltage higher than the no-load voltage by reinforced or double insulation. If another circuit is connected to the output circuit, the power of the other circuit shall be supplied by an isolating transformer or equivalent means.

Compliance is checked by visual inspection of the design.

8 Thermal requirements

8.1 Limits of temperature rise

The thermal requirements for transformers are given as follows:

- a) for windings: in accordance with 8.1.1;
- b) for accessible surfaces: in accordance with 8.1.2.

8.1.1 Windings

The temperature rise of windings shall not exceed the values given in Table 2.

No part shall be allowed to reach any temperature that will damage another part even though that part might be in compliance with Table 2.

Table 2 — Temperature limits for windings

Class of insulation in accordance with IEC 60085 °C	Peak temperature in accordance with IEC 60905 °C	Limits of temperature rise K			
		Air cooled windings		Liquid cooled windings	
		Embedded temperature sensor	Resistance	Embedded temperature sensor	Resistance
105 (A)	140	60	60	70	70
120 (E)	155	75	75	85	85
130 (B)	165	85	85	95	95
155 (F)	190	110	105	120	115
180 (H)	220	135	130	145	140
200	235	155	145	165	155
220	250	175	160	185	170

NOTE 1 The highest temperature occurring in a winding (hot spot) can be measured by embedded temperature sensors. The temperature measured by the resistance method gives the average between all temperatures occurring in the windings.

NOTE 2 Other classes of insulation having higher temperature limits than those given in Table 2 are available, see IEC 60085.

Compliance is checked by measurement in accordance with 8.2.

8.1.2 Accessible surfaces

The temperature rise with reference to the ambient air temperature (see 5.2) and the cooling liquid (see 5.7) for accessible surfaces shall not exceed the limits given in Table 3.

Table 3 — Limits of temperature rise for accessible surfaces

Accessible surface	Limits of temperature rise K	
	Air cooled transformers	Liquid cooled transformers
Bare metal enclosures	25	35
Painted metal enclosures	35	45
Non-metallic enclosures	45	55
Metal handles	10	20
Non-metallic handles	30	40

Compliance is checked by measurement in accordance with 8.2 using a surface temperature sensor (see 8.3.3).

8.2 Heating test

The test shall be carried out for all settings.

For liquid cooled transformers the flow rate shall be specified for a 100 % duty factor.

The actual values during the heating test shall meet the rated values within the following tolerances:

- a) output current: $\pm 2\%$ of the permanent output current;
- b) cooling liquid flow (if applicable): $\pm 5\%$ of the rated value.

The test is carried out at reduced voltage on a new transformer being short-circuited. In case of two output windings, they are short-circuited in parallel.

8.2.1 Start of the heating test

- a) In the case of embedded or surface temperature sensors (see 8.3.1 or 8.3.3) the test may be started before a temperature balance between the transformer and the cooling liquid is reached.
- b) In the case of resistance measurement (see 8.3.2) the test shall be started only when the temperature difference between cooling liquid inlet and outlet is within 1 K.

The temperature θ_1 of the cooling liquid shall be taken as the initial temperature of the winding during which the initial resistance R_1 is measured.

8.2.2 Duration of the heating test

The heating test shall be carried out until the rate of the temperature rise does not exceed 2 K/h on any component of the transformer.

8.3 Methods of temperature measurements

One method to determine the temperature of any particular part is sufficient.

8.3.1 Embedded temperature sensor

The temperature is measured by one or more embedded thermocouples or other suitable temperature measuring instruments of comparable size applied during the manufacturing of the transformer to the predicted hottest points of the windings.

A thermocouple applied to the hottest point of a single layer winding shall be considered as embedded.

Recording of measurement results shall be carried out under load, which means immediately before cutting off the current.

8.3.2 Resistance

This method only applies to input windings. The temperature rise of windings is determined by increase of resistance and is obtained for copper by the following formula:

$$\theta_2 - \theta_a = \frac{(235 + \theta_1)(R_2 - R_1)}{R_1} + (\theta_1 - \theta_a)$$

where:

θ_2 is the the temperature of the winding at the end of the test (calculated value) in degrees Celsius;

θ_a is the the temperature of the cooling liquid at the end of the test in degrees Celsius;

θ_1 is the the temperature of the winding at the moment of the initial resistance measurement in degrees Celsius;

R_2 is the the resistance of the winding at the end of the test in ohms;

R_1 is the the initial resistance of the winding in ohms.

For aluminium, the number 235 in the above formula shall be replaced by the number 225.

Recording of measurement results shall be carried out in the following steps, without delay between them:

- a) stop of the cooling liquid flow;
- b) cut off of the current;
- c) record of the resistance R_2

8.3.3 Surface temperature sensor

The temperature at accessible external surfaces is determined by a temperature sensor (e.g. thermocouple, resistance thermometer) under the following conditions:

- a) temperature sensors shall be placed at accessible spots where the maximum temperature is likely to occur. It is advisable to locate the predictable hot spots by means of a preliminary check;
- b) efficient heat transmission between the point of measurement and the temperature sensor shall be ensured, and protection shall be provided for the temperature sensor against the effect of air currents and radiation.

Recording of measurement results shall be carried out as follows:

- 1) cut off of the current;
- 2) record the highest temperature obtained.

8.3.4 Determination of the ambient air temperature

Thermometers shall be protected against heat radiation and draughts. For balancing the temperature variations, the thermometer bulbs may be placed in small holders filled with oil.

8.3.5 Determination of cooling liquid temperature

The thermometers shall be placed at the cooling liquid inlet of the transformer.

For recording the measurement results the average temperature obtained during the last quarter of the test shall be taken.

9 Rated no-load output voltage (U_{20})

The rated no-load output voltage (U_{20}) for all settings shall be determined with transformers operating with open output terminals and shall be indicated with a tolerance of $\pm 2\%$.

Compliance is checked by measurement at a rated supply (primary) voltage for all settings.

10 Rated short-circuit voltage (U_{CC})

The short-circuit voltage U_{CC} shall be as given by the manufacturer.

For transformers with two separate output windings, the values measured for each winding may differ up to $\pm 5\%$ from the maximum value.

Compliance is checked by the following measurements at the end of the heating test:

- a) short-circuit the output winding(s);

If the transformer has two output windings, the measurements are performed under the following conditions:

- 1) both output windings are short-circuited in parallel,
- 2) both output windings are short-circuited in series,
- 3) one output winding is short-circuited the other is open;

- b) adjust the input voltage (U_{1CC}) to the value for which the admissible permanent input current (I_{1p}) is reached;

NOTE
$$I_{1p} = \frac{S_p}{U_{1N}}$$

where I_{1p} is expressed in amperes.

- c) calculate the short-circuit voltage, in percent, by the formula:

$$U_{CC} = \frac{U_{1CC}}{U_{1N}} \times 100$$

- d) calculate the total impedance referred to the output (Z_2), in ohms, by the formula:

$$Z_2 = \frac{U_{1CC} \times U_{20}^2}{100 \times I_{1p} \times U_{1N}}$$

11 Cooling liquid circuit

The flow rate at permanent power shall not exceed the values given in Table 4.

Table 4 — Limits for cooling liquid flow

Permanent power P_p kVA	Flow rate Q l/min
$100 \geq P_p$	$4 \geq Q$
$101 \geq P_p \geq 350$	$8 \geq Q$

The cooling liquid circuit:

- a) shall be tight at a pressure of 10 bar for 10 min and

b) shall not have a maximum pressure drop (Δp) higher than 0,6 bar at the flow rates (Q) according to Table 4.

Compliance is checked by leak-tightness and flow check.

12 Dynamic behaviour

The transformer shall withstand the dynamic test without any damage. Compliance is checked by the following test:

- a) the transformer is connected with short-circuiting conductors which will simulate the mechanical loading of the output terminals when in use;
- b) the transformer is operated at the rated supply voltage. The current shall be as high as possible but not more than nine times the permanent output current (I_{2p}) for 4 h at 1,23 % duty factor and a cycle time of 10 s.

13 Rating plate

13.1 General

A clearly and indelibly marked rating plate shall be fixed securely to or printed on each transformer.

If the transformer is designed for several rated supply voltages, the electrical characteristics for each supply voltage shall be indicated. This may be made by several rating plates or by an appropriate table.

Compliance is checked by visual inspection and by rubbing the marking by hand for 15 s with a piece of cloth soaked in water and again for 15 s with a piece of cloth soaked in petroleum spirit.

After the test the marking shall be easily legible; it shall not be easy to remove the rating plates and they shall show no curling.

13.2 Description

The rating plate shall be divided into sections containing information and data for the:

- a) identification;
- b) electrical characteristics;
- c) other characteristics.

The arrangement and sequence of the data shall comply with the principle shown in Figure 1 (for examples see annex A).

NOTE 1 The dimensions of the rating plate are not specified and may be chosen freely.

NOTE 2 Other useful information may be given in technical literature supplied by the manufacturer.

13.3 Contents

The following explanations refer to the numbered boxes shown in Figure 1.

a) Identification	
1)	
2)	
3)	
4)	
b) Electrical characteristics	
5)	
6)	
7)	
8)	
c) Other characteristics	
9)	10)
11)	12)
13)	14)

Figure 1 — Principle of the rating plate

a) Identification:

- Box 1 Name and address of the manufacturer or distributor and optionally a trade mark and the country of origin if required.
- Box 2 Type (identification) as given by the manufacturer.
- Box 3 Traceability of design and manufacturing data (e.g. serial number) and year of production.
- Box 4 Reference to this International Standard confirming that the transformer complies with its requirements.

b) Electrical characteristics

- Box 5 $U_{1N} = \dots V / \dots \sim \dots \text{ Hz}$ Rated supply voltage; number of phases, e.g. 1 or 3; symbol for alternating current (\sim) and the rated frequency, e.g. (50 or 60) Hz.

- Box 6 $P_p = \dots \text{ kVA}$ Permanent power (power at 100 % duty factor).
 $(P_{50} = \dots \text{ kVA})$ Power at 50 % duty factor.

NOTE $P_{50} = P_p \times \sqrt{2}$ will only be given for a transition period.

- Box 7 $U_{20} = \dots V \text{ to } \dots V$ Range of rated a.c. no-load voltage and number of adjustable steps.
in ... steps

- Box 8 $I_{2p} = \dots \text{ kA}$ Permanent output current.
 $(I_{2/50} = \dots \text{ kA})$ Output current at 50 % duty factor.

NOTE $I_{2/50} = I_{2p} \times \sqrt{2}$ will only be given for a transition period.

c) Other characteristics

Box 9	$Q = \dots$ l/min	Rated cooling liquid flow.
Box 10	$\Delta p = \dots$ bar	Rated cooling liquid pressure drop.
Box 11		Insulation class.
Box 12		Protection class.
Box 13	Mass = ... kg	Mass of the transformer.
Box 14		Additional information, if applicable (e.g. type code as given in annex D).

14 Instruction manual

Each transformer shall be delivered with an instruction manual which shall include the following:

- a) a general description including all information given on the rating plate;
- b) correct methods of handling e.g. by fork lift or crane and precautions to be taken;
- c) correct operational use of the transformer (e.g. location and cooling requirements to prevent overheating or condensation);
- d) duty factor limitations;
- e) basic guidelines regarding protection against personal hazards for operators and persons in the work area (e.g. danger of metal objects shorting output terminals or being propelled by the magnetic field);
- f) maintenance;
- g) adequate circuit diagram together with a list of essential parts;
- h) installation and mounting.

Other usefull information may be given (e.g. control device, indicators, max. time per pulse, power factor, impedance, type code, meaning of indications, markings and graphical symbols, etc.).

Compliance is checked by reading the instruction manual.

Annex A (informative)

Example of a rating plate

a) Identification	
1) Manufacturer, Country	Trade mark
2) Resistance welding transformer	
3) Serial number	Year of production
4) ISO 5826	
b) Electrical characteristics	
5) $U_1 = 400 \text{ V}/1 \sim 50 \text{ Hz}$	
6) $P_p = 71 \text{ kVA}$ ($P_{50} = 100 \text{ kVA}$)	
7) $U_{20} = 7,1 \text{ to } 10 \text{ V}$ in 4 steps	
8) $I_{2p} = 7,1 \text{ kA}$ ($I_{2/50} = 10 \text{ kA}$)	
c) Other characteristics	
9) $Q = 4 \text{ l/min}$	10) $\Delta p = 0,3 \text{ bar}$
11) Insulation class F	12) Protection class II
13) Mass = 35 kg	14)

Figure A.1 — Transformer with one rated input voltage

Annex B (normative)

Corrections for higher altitudes and cooling medium temperatures

B.1 Altitude above 1 000 m

For air-cooled transformers designed for operation at an altitude above 1 000 m, the temperature rise, if measured at an altitude lower than 1 000 m, shall not exceed the values given in Table B.1 less 0,5 % per 100 m if the place of installation is above 1 000 m.

B.2 Cooling medium temperatures above standardized values

If the temperature of the cooling medium is higher than the standardized values, the admissible temperature rise limits are modified as follows

Table B.1 — Reduction of the temperature rise limits

Cooling medium	Cooling medium temperature θ_a °C	Reduction of the temperature rise limit K
Liquid	$\theta_a \leq 30$	0
	$31 \leq \theta_a \leq 35$	5
	$36 \leq \theta_a \leq 40$	10
Air	$\theta_a \leq 40$	0
	$41 \leq \theta_a \leq 45$	5
	$46 \leq \theta_a \leq 50$	10

Annex C (normative)

Notes on physical concepts and comments on some definitions

C.1 Temperature rise and cooling of a transformer

During operation, the temperature of a transformer generally rises to a maximum equilibrium temperature θ_m .

The equilibrium temperature is a quadratic function of the current flowing through the windings and depends on:

- manufacture and assembly conditions and
- the heat transfer to the cooling medium.

When the transformer stops operation, its various parts are cooling down to the temperature of the cooling medium.

After the transformer has been cooled down and is in thermal equilibrium with the cooling medium, it is loaded with a current $I_2 = 1,26 \times I_{2p}$. The time to reach the same temperature as before with I_{2p} and 100 % duty factor is equal to the measured time constant τ .

The temperature variation of the transformer (see Figure C.1) follows a time-related exponential law according to the following formulae:

$$\text{for the temperature rise: } \theta = \theta_m - (\theta_m - \theta_a) e^{-\frac{t}{\tau}}$$

$$\text{for the cooling: } \theta = \theta_a - (\theta_n - \theta_a) e^{-\frac{t}{\tau}}$$

where

θ_m is the equilibrium temperature in degrees Celsius;

θ_a is the cooling medium temperature in degrees Celsius;

θ_n is the temperature when the transformer starts to cool in degrees Celsius.

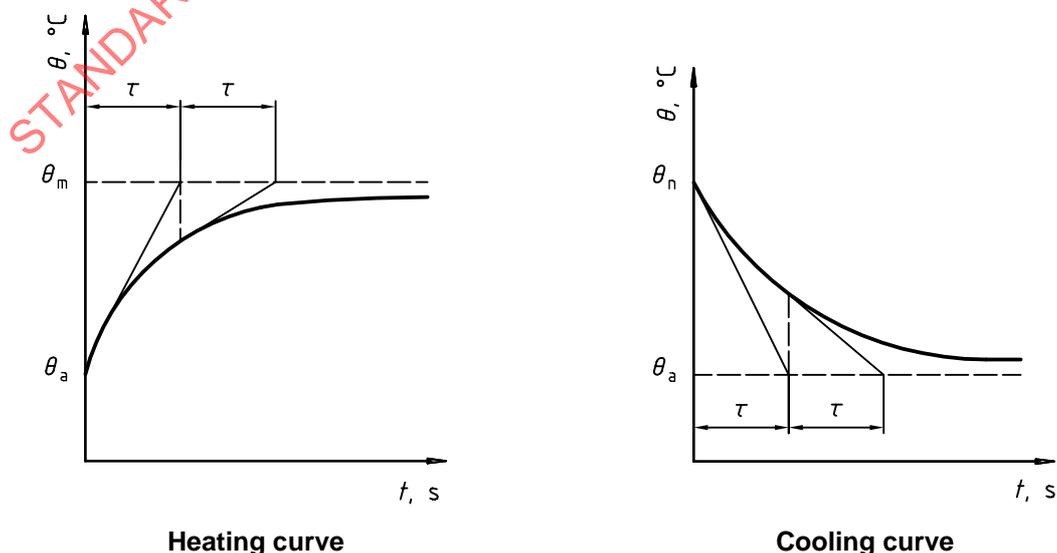


Figure C.1 — Temperature variation of a transformer

The coefficient $1/\tau$, appearing as an exponent is a physical quantity that depends on:

- a) design and assembly of the transformer and
- b) the heat transfer to the cooling medium.

The thermal time constant (τ):

- 1) is a measurable physical quantity;
- 2) is a characteristic of a transformer part;
- 3) determines the speed of temperature rise and cooling;
- 4) corresponds to the time after which the temperature has reached its maximum value if it maintains its initial variation speed;
- 5) corresponds to the time after which the temperature variation has reached 63 % of the difference between the equilibrium temperature and the temperature at a time t .

C.2 Determination of the thermal time constant (τ) of the input winding

The thermal time constant may be determined by one of the following methods.

a) Method 1

- 1) Load the transformer
 - i) under conditions indicated in 8.2 at 100 % duty factor;
 - ii) until it is in thermal equilibrium with the cooling medium, whatever the method of temperature measurement.
- 2) Measurement of the following temperatures:
 - i) θ_0 at the beginning
 - ii) θ_1 at the end of the time $t = t_1$
 - iii) θ_2 at the end of the time $t = 2 \times t_1$
- 3) Calculation by the formulae:

$$\Delta\theta_1 = \theta_1 - \theta_0$$

$$\Delta\theta_2 = \theta_2 - \theta_1$$

$$\tau = \frac{t_1}{\ln \frac{\Delta\theta_1}{\Delta\theta_2}}$$

where temperature is expressed in kelvin and the thermal time constant, τ , in seconds.

b) Method 2

- 1) Cut off current after the heating test.

For liquid-cooled transformers the cooling liquid flow is maintained.
- 2) Plot the cooling curve by using thermocouples fixed on the windings by:
 - i) permanent plotter or

- ii) readings at the beginning of the cooling and the end of the times t_1 , $2 \times t_1$, $3 \times t_1$, etc., calculated from the time the current is cut off. It is necessary to take readings for a maximum number of points, particularly when cooling starts.

3) Determination of the thermal time constant (τ), in seconds:

- i) by carefully tracing the sub-tangent to the cooling curve (see Figure C.1) or
- ii) by the formula:

$$\tau = \frac{t}{\ln \frac{\theta_2}{\theta}}$$

where

θ_2 is the maximum temperature at the end of the heating test;

θ is the temperature after time t .

c) Method 3

The transformer in thermal equilibrium with the cooling medium is loaded with a current $I = 1,26 \times I_{2p}$ for the time t . After time t the temperature rise is the same as if the transformer were loaded with the current I_{2p} at 100 % duty factor.

The thermal time constant τ is equal to this time t .

C.3 Operation of a transformer

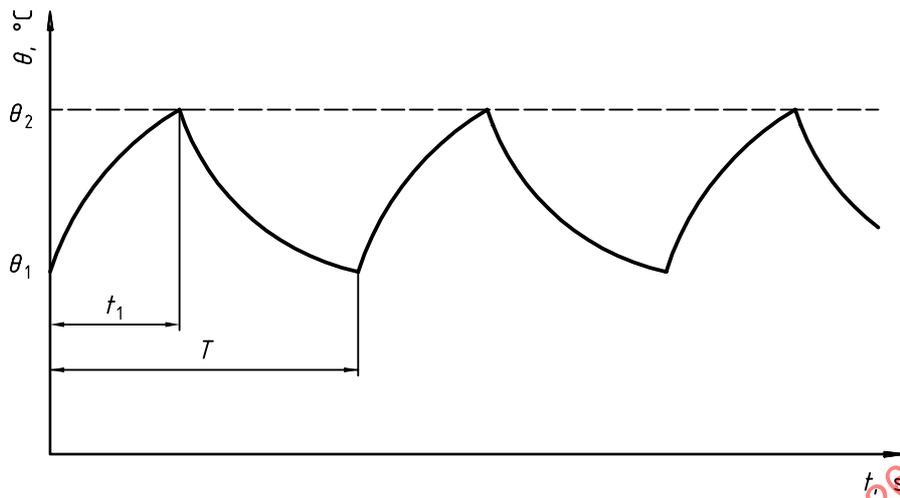
In general, transformers do not operate continuously but periodically with on-load and no-load times by switching them on and off.

The ratio of the on-load time (t_1) and the cycle time (T) is the duty factor (X). Its value is expressed in %:

$$X = \frac{t_1}{T} \times 100$$

The cycle time and the duty factor may vary according to the welding operation and the condition of use of the transformer.

During an operation cycle (see Figure C.2) the temperature of a transformer rises during the on-load time and cools during the no-load time. The temperature varies between θ_1 and θ_2 .



NOTE The curve shows the equilibrium

Figure C.2 — Operating cycle of a transformer

C.3.1 Windings

The maximum temperature of the windings θ_2 depends on the:

- a) current;
- b) cycle time;
- c) duty factor;
- d) thermal time constant.

The temperature rise of the windings shall not exceed the limit specified for their insulation class. Consequently, if e.g. its duty factor is low, it will be possible to have a higher current pass through the transformer than if its duty factor is high.

If the permanent input power P_p or the permanent output current I_{2p} and the thermal time constant τ of the transformer are known, the input power P_X or the output current I_{2X} at a duty factor X and a cycle time T can be determined by the formulae:

$$P_X = P_p \sqrt{\frac{1 - e^{-\frac{T}{\tau}}}{1 - e^{-\frac{XT}{100\tau}}}}$$

$$I_{2X} = I_{2p} \sqrt{\frac{1 - e^{-\frac{T}{\tau}}}{1 - e^{-\frac{XT}{100\tau}}}}$$

where P_X is expressed in kilovolt amps and I_{2X} in kiloamps.

NOTE In general, if the ratio between the thermal time constant and the cycle time is above 5 ($\tau/T > 5$), the following simplified formulae may be used:

$$P_X = P_p \sqrt{\frac{100}{X}}$$

$$I_{2X} = I_{2p} \sqrt{\frac{100}{X}}$$

where P_X is expressed in kilovolt amps and I_{2X} in kiloamps.