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Test requirements for low voltage aerial bundled cable accessories - Part 5: Electrical ageing test

Prescriptions relatives aux essais des accessoires pour réseaux aériens basse tension torsadés - Partie 5: Essai de vieillissement électrique

Prüfanforderungen für Bauteile für isolierte Niederspannungsfreileitungen - Teil 5: Elektrische Alterungsprüfungen

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: avenue Marnix 17, B - 1000 Brussels

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Foreword

This European Standard was prepared by a sub-group of WG 11 of the Technical Committee CENELEC TC 20, Electric cables.

The text of the draft was submitted to the formal vote and was approved by CENELEC as EN 50483-5 on 2008-12-01.

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)	2009-12-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2011-12-01

This is Part 5 of CENELEC standard EN 50483 “*Test requirements for low voltage aerial bundled cable accessories*”, which has six parts:

– Part 1: Generalities;

– Part 2: Tension and suspension clamps for self supporting system;

– Part 3: Tension and suspension clamps for neutral messenger system;

– Part 4: Connectors;

– Part 5: Electrical ageing test;

– Part 6: Environmental testing.

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1 Scope

EN 50483 series applies to overhead line fittings for tensioning, supporting and connecting aerial bundled cables (ABC) of rated voltage U_0/U (U_m): 0,6/1 (1,2) kV.

This Part 5 applies to the connections described in EN 50483-4, including branch connectors, Insulation Piercing Connectors (IPC), pre-insulated lugs (terminals) and through pre-insulated connectors (sleeves).

The objective is to provide a method of testing the suitability of connectors when used under normal operating conditions with low voltage aerial bundled cables complying with HD 626**.**

Two classes of connectors are covered by this standard:

Class A: These are connectors intended for electricity distribution or industrial networks in which they can be subjected to short-circuits of relatively high intensity and duration. As a consequence, Class A connectors will be suitable for the majority of applications.

Class B: These are connectors for networks in which overloads or short-circuits are rapidly cleared by the operation of protection devices.

Depending on their application, the connectors are subjected to heat cycles and short-circuit current tests.

Class A: the connectors are subjected to heat cycles and short-circuit current tests.

Class B: the connectors are subjected to heat cycles only.

The object of this Part 5 is to define the heating cycles test methods and requirements which apply to compression through connectors, insulation piercing connectors and all other type of connections for low voltage aerial bundled cables.

NOTE This European Standard does not invalidate existing approvals of products achieved on the basis of national standards and specifications and/or the demonstration of satisfactory service performance. However, products approved according to such national standards or specifications cannot directly claim approval to this European Standard. It may be possible, subject to agreement between supplier and purchaser, and/or the relevant conformity assessment body, to demonstrate that conformity to the earlier standard can be used to claim conformity to this standard, provided an assessment is made of any additional type testing that may need to be carried out. Any such additional testing that is part of a sequence of testing cannot be done separately.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50483 series, *Test requirements for low voltage aerial bundled cable accessories*

EN 61238-1:2003, *Compression and mechanical connectors for power cables for rated voltages up to 36 kV (U_m = 42 kV) – Part 1: Test methods and requirements* (IEC 61238-1:2003, mod.)

IEC 60050-461, *International Electrotechnical Vocabulary (IEV) – Part 461: Electric cables*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-461 and the following apply.

3.1
adiabatic
occurring with no addition or loss of heat from the system under consideration

3.2
aerial bundled cable (ABC)
aerial cable consisting of a group of insulated conductors which are twisted together including, or not, a non insulated conductor
[IEV 461-08-02, modified]

NOTE The terms bundled conductors, bundled cables, bundled cores, conductor bundles and bundle could be used as equivalent to the term aerial bundled cable (ABC).

3.3
aerial-insulated-cable
insulated cable designed to be suspended overhead and outdoors
[IEV 461-08-01]

3.4
branch connector
metallic device for connecting a branch conductor to a main conductor at an intermediate point on the latter
[IEV 461-17-05]

3.5
branch conductor
conductor connected to the main conductor by a connector

3.6
conductor insulation
insulation applied on a conductor
[IEV 461-02-02, modified]

3.7
conductor (of a cable)
part of a cable which has the specific function of carrying current
[IEV 461-01-01]

3.8
connector
metallic device to connect cable conductors together
[IEV 461-17-03]

3.9
core
assembly comprising conductor and its own insulation
[IEV 461-04-04, modified]

3.10
equalizer
arrangement used in the test loop to ensure a point of equipotential in a stranded conductor
[EN 61238-1:2003, 3.8]

3.11
insulation (of a cable)
insulating materials incorporated in a cable with the specific function of withstanding voltage
[IEV 461-02-01]

3.12
insulation piercing connector (IPC)
connector in which electrical contact with the conductor is made by metallic protrusions which pierce the insulation of the ABC core
[IEV 461-11-08, modified]

3.13
median connector
connector which during the first heat cycle records the third highest temperature of the six connectors in the test loop
[EN 61238-1:2003, 3.11]

3.14
pre-insulated (terminal) lug
insulated metallic device for connecting an insulated cable conductor to other electrical equipment

3.15
pre-insulated through connector (sleeve)
insulated metallic device for connecting two consecutive lengths of insulated conductors

3.16
reference conductor
length of conductor(s) without any joints, which is included in the test loop and which enables the reference temperature and reference resistance(s) to be determined

3.17
reusable connector
connector for connecting ABC to stripped cable or bare conductor where only the branch connection can be reused

3.18
sheath
uniform and continuous tubular covering of metallic or non metallic material, generally extruded
[IEV 461-05-03]

3.19
shear head
head of a bolt, or a device fitted over the head of a bolt or a nut, which is designed to break at a specified torque

3.20
type test
test required to be made before supplying a type of material covered by this standard on a general commercial basis, in order to demonstrate satisfactory performance characteristics to meet the intended application

NOTE These tests are of such a nature that, after they have been made, they need not be repeated unless changes are made to the accessory materials, design or type of manufacturing process which might change the performance characteristics.

4 Symbols

A, A_1, A_2	electrical cross-sectional area of the conductors
D	conductor diameter
D_{Eq}	equalizer diameter
d	conductor length between connectors
I	direct current flowing through a connection during resistance measurement
I_{rms}	equivalent r.m.s. short-circuit current
I_N	alternating current necessary to maintain the reference conductor at its equilibrium temperature
ℓ_a, ℓ_b, ℓ_j	lengths of the conductor assembly associated with the measurement points after jointing
ℓ_e	length of equalizer
ℓ_r, ℓ_{ra}, ℓ_{rb}	length of the reference conductor between measurement points
R_1, R_2	linear resistance of conductors of respectively cross-section A_1 and A_2
R_{20}, R_{ra}, R_{rb}	the calculated resistance between two equalizers and corrected to 20 °C
TC	thermocouple
t_1	heating period within heat cycle
t_2	cooling period within heat cycle
$t_{1\text{-}a}$	time period to reach the required temperature on the reference cable
$t_{1\text{-}b}$	time period of stable temperature on the median connector
U_{AB}	potential difference between measurement points of reference conductor of cross-section A_1
U_{CD}	potential difference between measurement points of the connector
U_{EF}	potential difference between measurement points of reference conductor of cross-section A_2
α	temperature coefficient of resistance at 20 °C
β	mean scatter of the connector resistance factors
$\Delta\theta_j$	temperature difference between reference cable and connector
δ	initial scatter of the connector resistance factors

λ resistance factor ratio; change in the resistance of the connector relative to its initial resistance

θ temperature of a connector while measuring resistances

θ_{max} maximum temperature recorded on a connector over the total period of test

θ_N highest rated temperature of insulating compound in normal operation

θ_R temperature of the reference conductor determined in the first heat cycle

θ_r temperature of the reference conductor while measuring resistances

θ_{ref} temperature of the reference conductor at the moment of measuring θ_{max}

5 Type test

5.1 Principle

Connectors shall be subjected to 1 000 cycles of heating and cooling. The cold resistance of the connectors shall be measured at specific steps to determine their suitability when used with conductors carrying a load.

Heat cycle and, short-circuit tests shall be made with alternating current.

NOTE Direct current may be used for heat cycle only when agreed between customer and manufacturer.

5.2 Test arrangement

5.2.1 Installation

The test circuit shall be as shown in Figure 5, 6, 7 or 8.

Figures 5, 6, 7 and 8 represent the test circuits respectively for main and branch connectors having equal cross-sections and linear resistance(s); for main and branch connectors having unequal cross-sections and linear resistance(s); for through connectors having equal or unequal cross-sections and linear resistance(s); for terminal lugs.

5.2.1.1 Optional immersion test

EN 50483-6, 8.4.3.1 provides an optional immersion test for samples which are intended for use in saline polluted areas. When the inclusion of this test has been agreed between the manufacturer and the customer this heat cycle test shall be modified to accommodate immersion of the test samples during each cycle.

5.2.2 Disconnection devices

The test circuit may include sectioning joints so that it can be dismantled and short-circuit tests can be made easily.

In Figure 6, the disconnection devices (X) are

- closed when the circuit is carrying heating current, and
- opened when resistance measurements and short-circuit applications are being made.

The sectioning joints shall be arranged and constructed so that they do not significantly affect the measurements.

5.2.3 Conductors

Phase and neutral conductors including reference conductors used in the test circuit shall remain insulated (except bare conductors).

5.2.4 Method of measuring ambient temperature

It is important that ambient temperature is measured accurately and is not affected by the heating produced by the test. The following provides a proven method for achieving this measurement though alternative methods can be used.

Ambient temperature shall be measured at the middle of the test loop with a thermocouple whose junction is placed in a polished metallic tube manufactured from metal foil formed into a cylinder. Its height shall be 100 mm and its diameter shall be between 35 mm and 45 mm. The thermocouple shall be located approximately at one third of the tube height from its upper end and fitted to it (e.g. with a cross-support).

5.2.5 Ambient conditions

The test loop shall be installed in a location where the air is not disturbed. The ambient temperature of the test location shall be between 15 °C and 30 °C.

During the connector installation and resistance measurements, ambient temperature shall remain within the limits of (23 ± 3) °C and recorded.

5.2.6 Equalizers

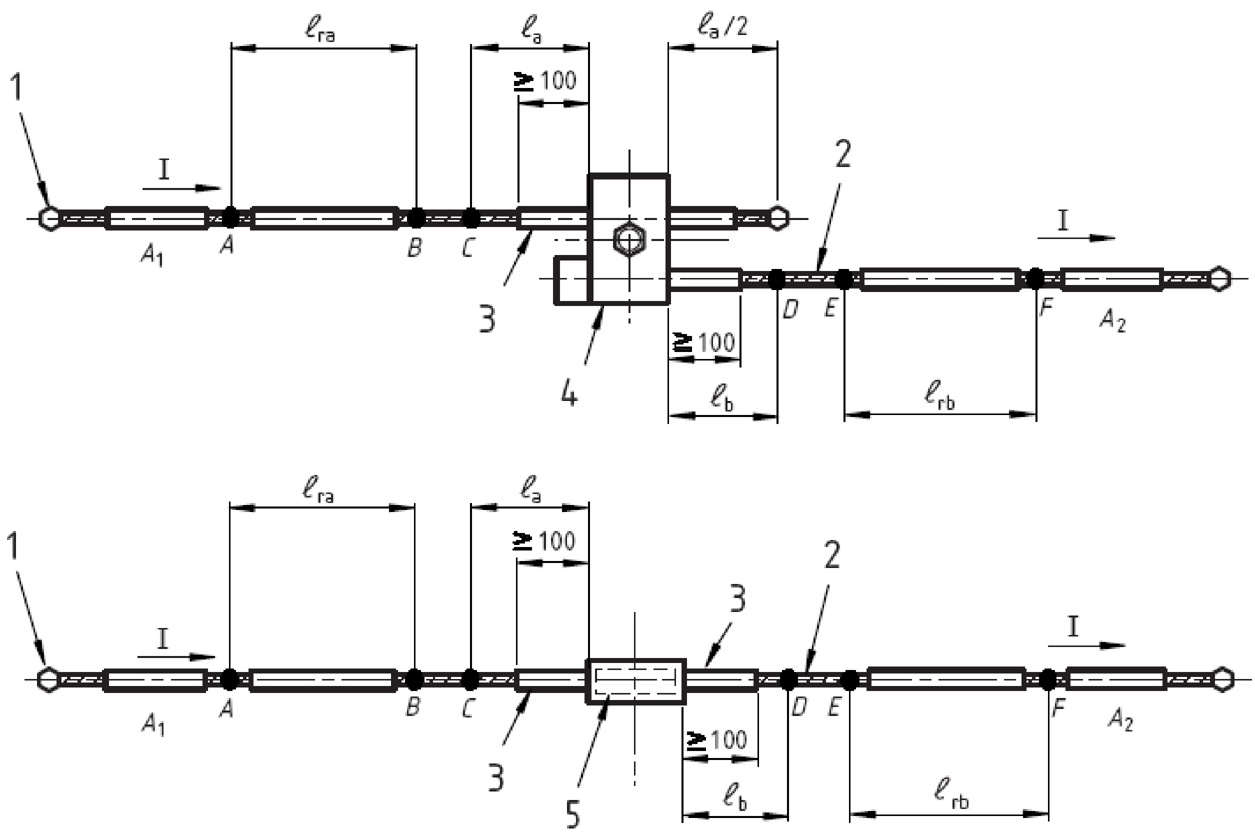
For stranded conductors, potential between the strands at measuring points can cause errors in measuring electrical resistance.

Welded or soldered equalizers, as shown in Annex A, shall be used to overcome this problem, and to ensure uniform current distribution in the reference conductor. Welded or soldered equalizers shall be the recommended methods to ensure reliable measurements.

NOTE Other methods may be used provided that they give comparable results and do not affect the temperature of the connectors or the reference conductor.

Annex A provides details on the construction of welded equalizers.

5.2.7 Lengths and configurations of conducting paths



Key

A, B, C, D, E, F	equalizers (see Annex A).	1	conductor 1
A_1 and A_2	cross-sections relative to conductivity of the conductors 1 and 2 in mm²	2	conductor 2
A, B	potential points for measuring the potential difference between the extremities of the reference conductor corresponding to conductor of cross-section A_1	3	insulation
E, F	potential points for measuring the potential difference between the extremities of the reference conductor corresponding to conductor of cross-section A_2	4	branch connector
ℓ_{ra}	distance between potential points A and B	5	sleeve connector
ℓ_{rb}	distance between potential points E and F		
C, D	potential points for measuring the potential difference between the extremities of the related connector		
ℓ_a	distance between C and the nearest surface of the connector body		
ℓ_b	distance between D and the nearest surface of the connector body		
ℓ_a and ℓ_b	are dependent on the cross-section *A* of the related conductor according to the Table 1 below		

Figure 1 – Lengths and configurations of conducting paths

The conducting path lengths (see Figure 1, 5, 6, 7 or 8) shall comply with Table 1.

Table 1 – Conducting path lengths

Conductor cross-section *A* mm²	**Distances ℓ_a or ℓ_b** mm
$A \leq 50$	150
$50 < A \leq 120$	200
$120 < A \leq 240$	250

If $A_1 \neq A_2$, the cross-section of the reference conductor related to conductor A_1 shall be A_1 and the cross-section of the reference conductor related to A_2 shall be A_2. Both reference conductors shall have the same length $\ell_r = \ell_a + \ell_b$.

Potential points shall be placed at a distance ℓ_a and ℓ_b from the nearest surface of the connector body.

Conductor length between connectors shall be a distance d, expressed in millimetres, at least equal to $80 \sqrt{A}$, subject to a minimum of 500 mm. In the case of branch connectors, *A* shall be the cross-section of main conductor.

Where a test loop comprises of only one cross-section of conductor, a single reference conductor shall be used.

Where a test loop comprises of more than one cross-section of conductor, one reference conductor shall be required for each cross-section.

One (two) insulated length(s) of conductor(s) that constitute the heating loop shall be called the reference conductor(s); there shall be a potential point at each of its (their) extremities.

The reference conductor shall not have its insulation removed if insulated. In order to control the test a thermocouple shall be placed at the mid point of the reference conductor.

The reference conductor shall be of sufficient length to prevent thermal interference from its end terminations.

In the case of unequal cross-sections, both references conductors of lengths ℓ_{ra} and ℓ_{rb} shall reach the defined reference temperatures.

5.3 Test specimen

5.3.1 Setting up of the test loop

The conductors shall be identified by their cross-section A_1 and A_2 so that the resistance R_1 of the conductor with cross-section A_1 is less than the resistance R_2 of the conductor with cross-section A_2.

Where $R_1 = R_2$ then the conductor will be referred to by its cross-section A_1.

Conductor resistances R_1 and R_2 are measured in the same periodicity as connector resistance.

Various types of test loops are defined in Figures 5 to 8.

Where $A_1 = A_2$, the test loop shall consist of

- six identical connectors,
- one conductor of cross-section A_1 with linear resistance R_1,
- one reference conductor of length ℓ_{ra} on cross-section A_1.

Figure 5 shows the diagrammatic layout of the loop, where $\ell = \ell_a = \ell_b$.

Where $A_1 \neq A_2$, the test loop shall consist of

- six identical connectors,
- one conductor of cross-section A_1 with linear resistance R_1,
- one conductor of cross-section A_2 with linear resistance R_2,
- one reference conductor of length ℓ_{ra} on cross-section A_1,
- one reference conductor of length ℓ_{rb} on cross-section A_2.

Figure 6 shows the diagrammatic layout of the loop.

The configuration and dimensions of the test loops shall be recorded.

Two test loops shall be used for each type of connector as given in Table 2.

Table 2 – Testing cross-sections of main and branch conductors

Loop	Main conductor cross-section	Branch conductor cross-section
1st loop	max.	max.
2nd loop	max. or min. [a]	min.
[a] The choice of max. or min. cross-section should be agreed between the customer and the manufacturer.		

5.3.2 Preparation of cables and cores before tests

New insulated cores or cables shall be used.

The same core of a cable cross-section (e.g. Phase 1), shall be used for the whole test.

Insulated cores shall be conditioned beforehand. The purpose of this treatment is to ensure the dimensional stabilisation of the insulating sheath. The core sections shall be kept, in an enclosure at (30 ± 2) K above the conductor normal operating temperature indicated in Annex C of EN 50483-1 for approximately 1 h and letting them cool down naturally to ambient temperature.

5.3.3 Installation of the connectors

Connectors shall be installed according to the manufacturer's installation instructions.

5.3.3.1 For bolted connectors

A torque meter shall be used for all tightening operations. The accuracy and resolution of the torque meter is given in EN 50483-1.

The connectors shall be held in position during tightening.

Connectors shall be tightened to the minimum manufacturer's declared torque (connectors with shear head) or 90 % of the nominal manufacturer's declared torque (connectors without shear head).

Tightening shall be realised in accordance with EN 50483-1, 9.1.8.

The rate of tightening shall be in accordance with EN 50483-1, 9.1.10.

When a connector provides independent tightening facility for main pierced and branch stripped connections, the branch stripped connection shall be mounted 4 times and fully removed 3 times. The branch conductor shall be prepared before the first installation and this prepared end shall be used for the whole of the test. The orientation of the branch cable, with respect to the connector, shall be maintained.

5.4 Measurement

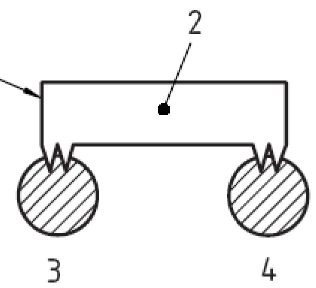
5.4.1 Method of temperature measurement

The temperature of a reference conductor or of a connector shall be measured with a thermocouple located at the point shown in Figure 2.

Accuracy of temperature measurement shall be ± 2 K or better.

Connectors shall have a small hole drilled in the outer housing, to allow a thermocouple to be applied directly at the midpoint of the metallic current path between the connector and the connected conductors.

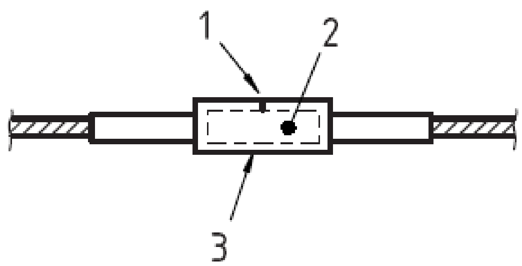
The hole shall be drilled so that the connector's mechanical performance is not affected.



Key

1	metallic current path	3	main conductor
2	thermocouple position	4	branch conductor

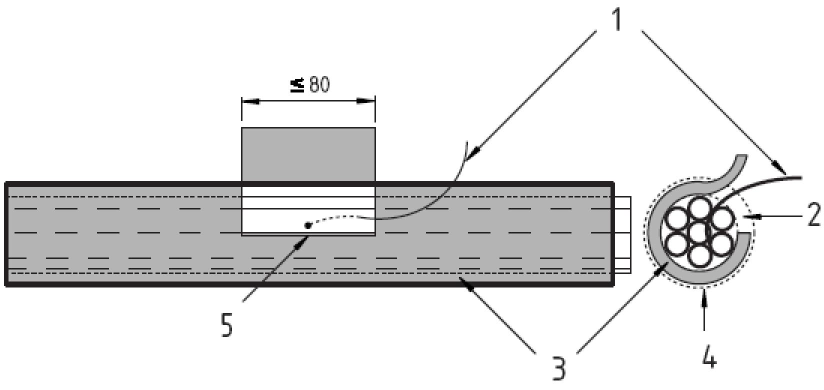
a) Location of thermocouple in an IPC



Key

1	thermocouple position	3	connector
2	metallic part		

b) Location of thermocouple in a through connector



Key

1	thermocouple	4	adhesive tape: thermocouple and insulation are covered with 2 half-lap layers adhesive tape
2	open position to place the thermocouple	5	small windows in the insulation of the reference conductor
3	conductor insulation		

c) Location of thermocouple on the reference cable

Figure 2 – Location of thermocouples

In the case of the reference conductor, the thermocouple shall be positioned as close as possible by the midpoint of the conductor and securely located, by sliding it under the strands of the outer layer of a stranded conductor and under the cable insulation.

An equivalent method can be used.

5.4.2 Electrical resistance measurement

The resistance of the connectors and the reference conductor(s) shall be measured between two adjacent measurement points. These measurements shall be carried out using a direct current not exceeding 10 % of I_N, the heat cycling current required to maintain the stable conductor temperature and measuring the voltage drop between measurement points. The resistance value is the ratio of the voltage drop to the direct current.

While measuring the resistance, the reference conductor(s), connectors, direct current and ambient temperatures shall be noted in the test report. Reference conductors and connectors temperatures shall not exceed ambient temperature +2 K.

Indirect resistance measurements:

- voltage measurements shall have an accuracy within ± 0,5 % or ± 10 µV, whichever is the greater;
- current measurements shall have an accuracy within ± 0,5 % or ± 0,1 A, whichever is the greater.

Direct resistance measurements:

- resistance measurements shall have an accuracy within ± 1 % or ± 0,5 µΩ, whichever is the greater when the instrument is calibrated against a certified standard resistance.

NOTE Annex C provides recommendations to improve accuracy of measurement.

5.5 Heat cycle

Figure 3 diagrammatically represents the heat cycle curve.

5.5.1 First cycle

The object of the first heat cycle is to determine the reference conductor temperature to be used for subsequent cycles and also to identify the median connector.

Current shall be circulated in the test loop, bringing the reference conductor to the temperature value (θ_R). At equilibrium the temperature θ_R shall be regulated between the normal operating temperatures θ_N^{+5K} as a minimum and the normal operating temperature θ_N^{+10K} as a maximum. The normal operating temperature can be found in Annex C of EN 50483-1.

The median connector temperature shall be stable within 2 K for a minimum of 10 min (period $t_{1\text{-b}}$ on Figure 3).

For through connectors with unequal cross-sections, the reference conductor is that associated with the smallest electrical cross-section.

Main reference conductor and branch reference conductor shall be maintained within the temperature limit θ_N^{+5K} and θ_N^{+15K} for main and θ_N^{+5K} and θ_N^{+10K} for branch.

The temperature (θ_R) - time (t_1) heating profile determined in this way shall be recorded and used for all subsequent cycles. The equilibrium current(s) I_N shall be recorded in the test report.

A higher current can be used for an initial period in the heating cycle ($t_{1\text{-a}}$), to reduce the heating time. The minimum duration of this higher current shall be as given in Table 3.

Table 3 – Minimum elevated current heating time

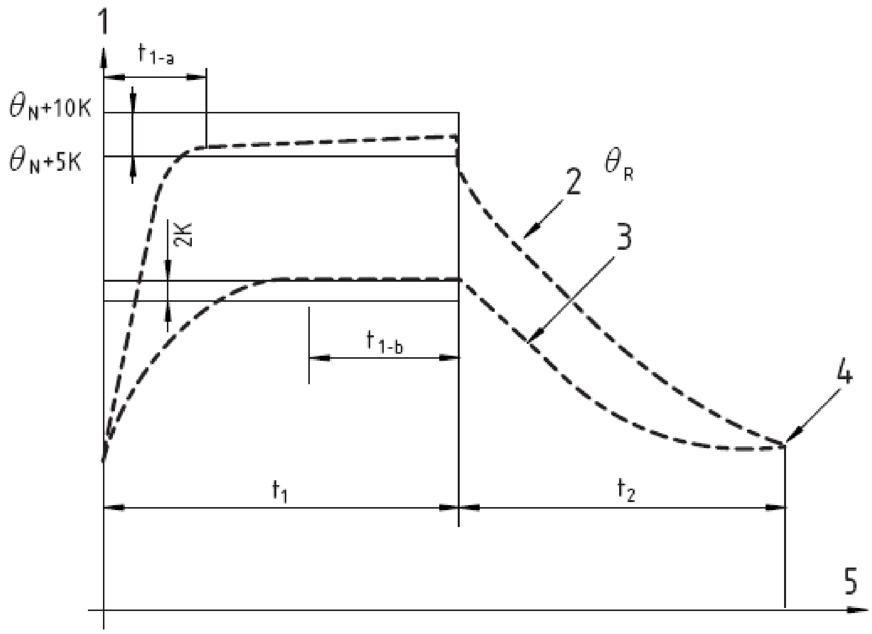
Nominal conductor cross-section area mm^2	**Time** **($t_{1\text{-a}}$)** min
≤ 50	5
> 50 up to 240 inclusive	10

After period t_1, there shall follow a period of cooling t_2.

The rate of cooling shall be adjusted so that the connector and reference conductor can be cooled to ambient temperature +5 K in 10 min or more. This rate of cooling shall be applied throughout the test.

When the connector and reference conductor reaches a temperature of 35 °C or less then heating can be restarted as long as the minimum cooling time would be achieved if the cooling were to continue.

If accelerated cooling is used, it shall act on the whole of the loop, and use air within ambient temperature limits.



Key

1 temperature axis

2 reference conductor temperature θ_R

3 median connector temperature

4 temperatures ≤ 35 °C for connectors and reference conductor

5 time axis

Figure 3 – First heat cycle

The total period t_1 + t_2 constitutes a heat cycle.

5.5.2 Subsequent heat cycles

A total of 1 000 heat cycles shall be made. After the cooling period of the cycles indicated below the resistance and temperature of each connector and each reference conductor shall be recorded. The maximum temperature of each connector during the cycle just prior to or following the resistance measurements shall also be recorded.

Measurements shall be made at the following cycles:

Class A	Class B
0 (before the first heat cycle only for resistance measurements)	0 (before the first heat cycle only for resistance measurements)
200, before short circuit	250
200, after short circuit	Then every 75 cycles
250	(12 measurements in total)
Then every 75 cycles (14 measurements in total)	

A tolerance of ± 10 cycles shall be allowed.

5.5.3 Short-circuit tests (for Class A connectors only)

Six short-circuits shall be applied after the 200th cycle.

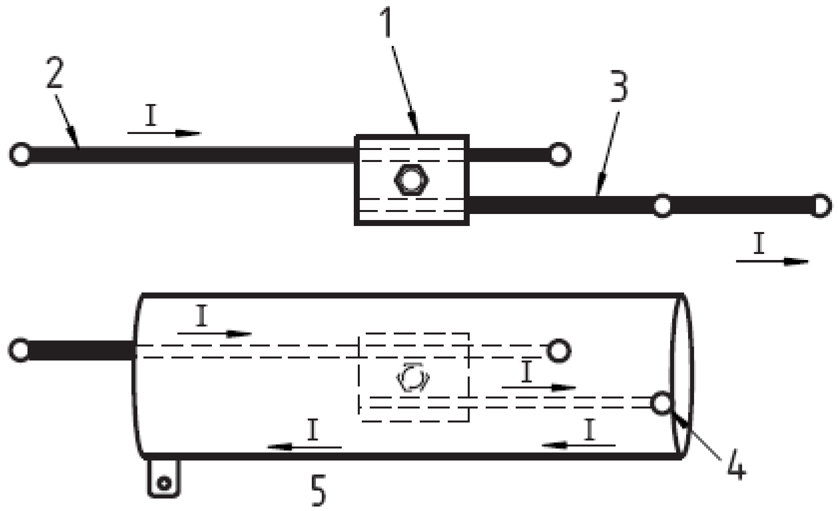
The short-circuit current level shall be such that it raises the temperature of the reference conductor from ambient temperature to not less than the short circuit temperature given in Annex C of EN 50483-1. The short circuit duration shall be short enough to be considered as adiabatic.

For unequal cross-sections, the lowest current shall be used. The duration of the short-circuit current shall be (1,00 ± 0,15) s. If the required short-circuit current exceeds 25 kA, a longer duration ≤ 5 s can be used. The duration of this current shall be stated.

After each short circuit, the test loop shall be cooled to a temperature ≤ 35 °C.

NOTE 1 The test loop may be dismantled for these tests. Since the short-circuit test is intended to produce the thermal effects of high current only, the recommended method is to use a concentric return conductor in order to reduce the electrodynamic forces, see Figure 4.

The test arrangements shall be noted in the test report.



Key

1	connector under test	4	conductor connected to the metallic tube
2	main conductor	5	current flow through metallic tube
3	branch conductor		

Figure 4 – Use of a concentric return conductor

NOTE 2 The short circuit current may be calculated according to IEC 60949:1988, Clause 3, and may be determined in accordance with Annex B as a method for selecting the current needed for a certain temperature rise, providing the actual conductor cross-sectional area has been verified.

NOTE 3 It should be observed that bending or vibrations during assembly, transport and handling may give rise to mechanical forces that affect the contact resistance of the test objects and should be avoided.

NOTE 4 The temperature given in Annex C of EN 50483-1 is difficult to measure, in practice. It is permissible for the short circuit current and duration of current to be calculated and, if these values are used, it may be assumed that the short circuit temperature is achieved. As the critical value is a quantity of energy delivered to the system the value of current and the duration of current may be adjusted in the required interval as long as this quantity of energy is achieved.

5.5.4 Assessment of results

An individual connection resistance (R_j) enables a common method of connector assessment to be made over the six connections. The parameters listed below are calculated according to 5.6.1 and 5.6.2.

a) The connection resistance (R_j) shall be calculated for each of the six connectors at all the measurement intervals listed before.

b) The initial scatter δ, between the six initial values of (R_j) measured prior to heat cycling, shall be calculated.

c) The mean scatter β, between the six values of (R_j) averaged over the last 11 measurement intervals, shall be calculated.

d) The assessment of resistance stability, the larger relative change of each connector resistance, shall be calculated over the last 11 measurements.

e) The resistance factor ratio λ shall be calculated.

f) The stability of the connector's temperature shall be calculated.

g) The maximum temperature θ_{max} on each connector shall be recorded.

5.6 Requirements

5.6.1 General requirements

The six connectors shall satisfy the requirements shown in Table 4. If one connector out of the six does not satisfy one or more of the requirements, a new loop can be tested. In this case, all six connectors shall satisfy the requirements.

If more than one connector out of the six does not satisfy one or more of the requirements, no re-test shall be permitted and the type of connector does not conform to this standard.

5.6.2 Resistances

The resistance, referred to 20 °C, between measuring points spanning a connector, is:

$$R_{20} = \frac{U_{CD}}{I} \times \frac{1}{1+\alpha(\theta-20)}$$

The resistance, referred to 20 °C, of the reference conductor of cross-section A_1 is:

$$R_{ra} = \frac{U_{AB}}{I} \times \frac{1}{1+\alpha(\theta_{ra}-20)}$$

The resistance, referred to 20 °C, of the reference conductor of cross-section A_2 is:

$$R_{rb} = \frac{U_{EF}}{I} \times \frac{1}{1+\alpha(\theta_{rb}-20)}$$

Actual connector resistance is calculated as follows:

$$R_j = R_{20} - \left[\left(\frac{R_{ra}}{\ell_a + \ell_b} \times \ell_a \right) + \left(\frac{R_{rb}}{\ell_a + \ell_b} \times \ell_b \right) \right]$$

Connector resistance:

$$R_j = R_{20} - \left(\frac{R_{ra} \times \ell_a + R_{rb} \times \ell_b}{\ell_a + \ell_b} \right)$$

where

U_{CD}	is the voltage drop between measurement points of the connector;
U_{AB}	is the voltage drop between measurement points of reference conductor of cross-section A_1;
U_{EF}	is the voltage drop between measurement points of reference conductor of cross-section $A_{2;}$
θ	is the connector temperature while measuring resistances;
θ_r	is the reference conductor temperature while measuring resistances;
R_{20}	is the calculated resistance between two equalizers and corrected to 20 °C;
ℓ_a	is the distance from connector to equalizer on cross-section A_1 conductor;
ℓ_b	is the distance from connector to equalizer on cross-section A_2 conductor;
R_{ra}	is the resistance of cross-section A_1 reference conductor and corrected to 20 °C;
R_{rb}	is the resistance of cross-section A_2 reference conductor and corrected to 20 °C;
α	is the coefficient of variation in resistivity with temperature for Al and Cu = 4,0 x 10^{-3} K^{-1}, Al alloy = 3,6 x 10^{-3} K^{-1}.

5.6.2.1 Initial scatter

The scatter between the six values of R_j (one value for each connector) at cycle zero shall be calculated as follows:

Calculate the mean value:

$$\overline{R_0} = \frac{1}{6} \sum_{j=1}^{6} R_j$$

then the standard deviation:

$$s_0 = \sqrt{\frac{1}{5} \sum_{j=1}^{6} \left(R_j - \overline{R_0} \right)^2}$$

and finally the initial scatter:

$$\delta = \frac{1}{\sqrt{6}} \times \frac{s_0}{\overline{\overline{R_0}}} \times t_s$$

where

t_s is the Student coefficient;

t_s = 4,032 for 99 % two-sided confidence level and five degrees of freedom.

Hence, the initial scatter is:

$$\delta = 1{,}65 \frac{s_0}{\overline{\overline{R_0}}}$$

5.6.2.2 Mean scatter β

For each connector, its mean value over the interval x = -5 to +5 shall be calculated:

$$\overline{R_j} = \frac{1}{11} \sum_{-5}^{+5} R_j$$

Hence six values are obtained. The mean of these six values shall be calculated:

$$\overline{\overline{R}} = \frac{1}{6} \sum_{1}^{6} \overline{R_j}$$

The standard deviation:

$$s = \sqrt{\frac{1}{5} \sum_{1}^{6} \left(\overline{R_j} - \overline{\overline{R}} \right)^2}$$

and the scatter:

$$\beta = \frac{1}{\sqrt{6}} \times \frac{s}{\overline{\overline{R}}} \times t_s$$

where

t_s = 4,032 as before.

Hence, the mean scatter is:

$$\beta = 1{,}65 \times \frac{s}{\overline{\overline{R}}}$$

5.6.2.3 Assessment of resistance stability for each connector

For each connector, its mean value over the interval x = -5 to +5 shall be calculated.

$$\overline{R_j} = \frac{1}{11}\sum_{-5}^{+5} R_j$$

and

$$\Delta R_j = R_j \max - R_j \min$$

the resistance stability is given by the ratio

$$\frac{\Delta R_j}{\overline{R_j}}$$

5.6.2.4 Resistance factor ratio

$$\lambda = \frac{R_j}{R_{j0}}$$

where

R_j is the connector resistance for each connector found at any stage of the measurement series;

R_{j0} is the connector resistance of the same connector measured at cycle zero.

5.6.3 Temperatures

5.6.3.1 Temperature stability

For each connector, the temperature stability shall be estimated over the last 11 measurements.

$$\overline{\Delta\theta_j} = \frac{\sum_{j=1}^{11} \Delta\theta_j}{11}$$

where

$\Delta\theta_j$ = temperature difference between reference cable and connector.

5.6.3.2 Maximum temperature of each connector

Each connector temperature, θ_j shall be lower than or equal to the warmest reference conductor:

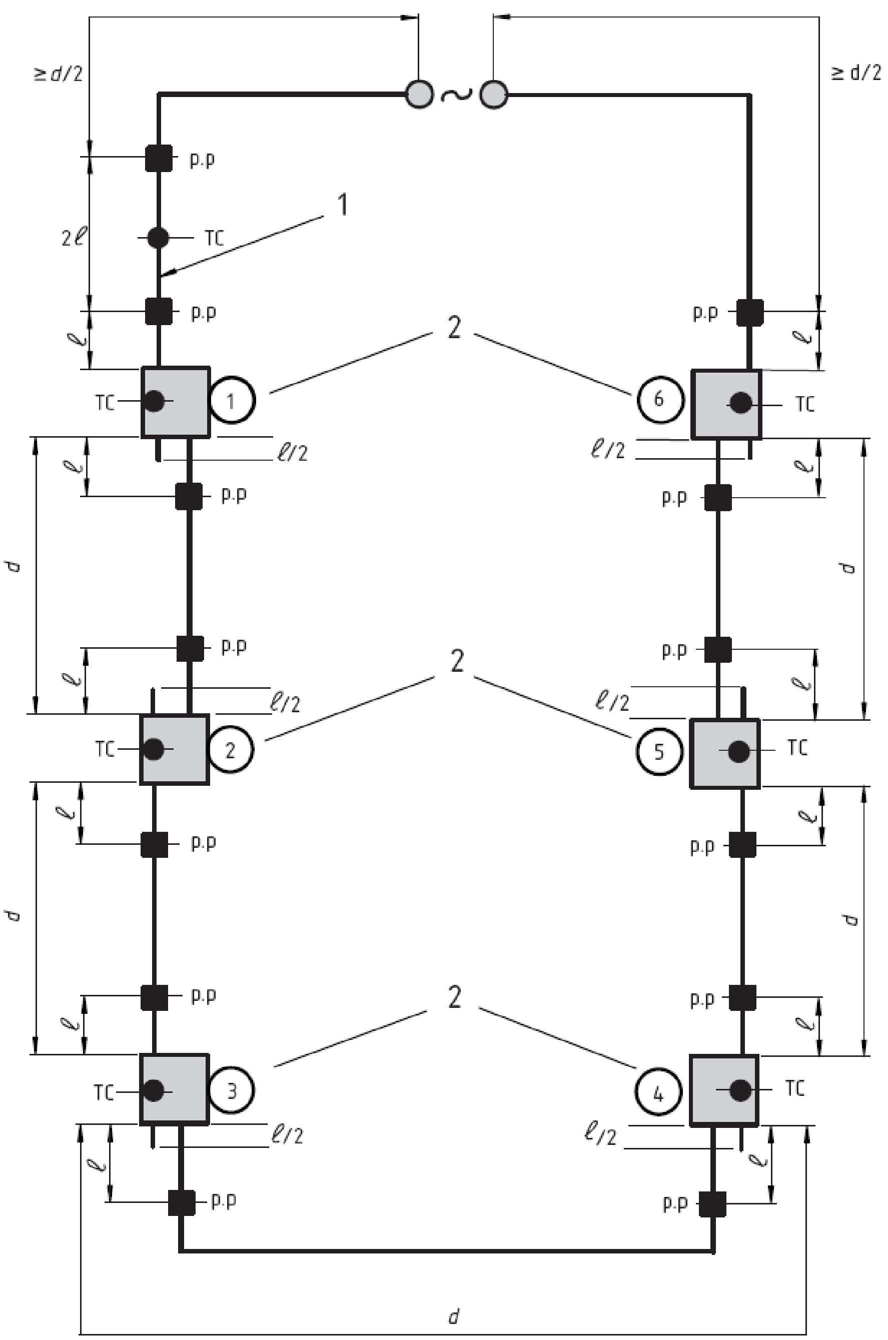
$$\theta_j \leq \theta_R$$

5.6.4 Test requirements

Table 4 – Test requirements

Parameter	**Maximum value**
Initial scatter δ	0,3
Mean scatter β	0,3
Assessment of resistance stability	15 %
Resistance factor ratio λ	2,0
Temperature stability $\Delta\theta_j$	$\overline{\Delta\theta_j} - 10 \leq \Delta\theta_j \leq \overline{\Delta\theta_j} + 10$
Maximum temperature θ_j of each connector	θ_R

NOTE An explanation of the terms used in the preceding statistical analysis and background papers may be founded in EN 61238-1:2003.



Key

$\ell_a = \ell_b = \ell$ and $= \ell_r = 2\ell$

1 reference conductor insulated between equalisers

2 connectors

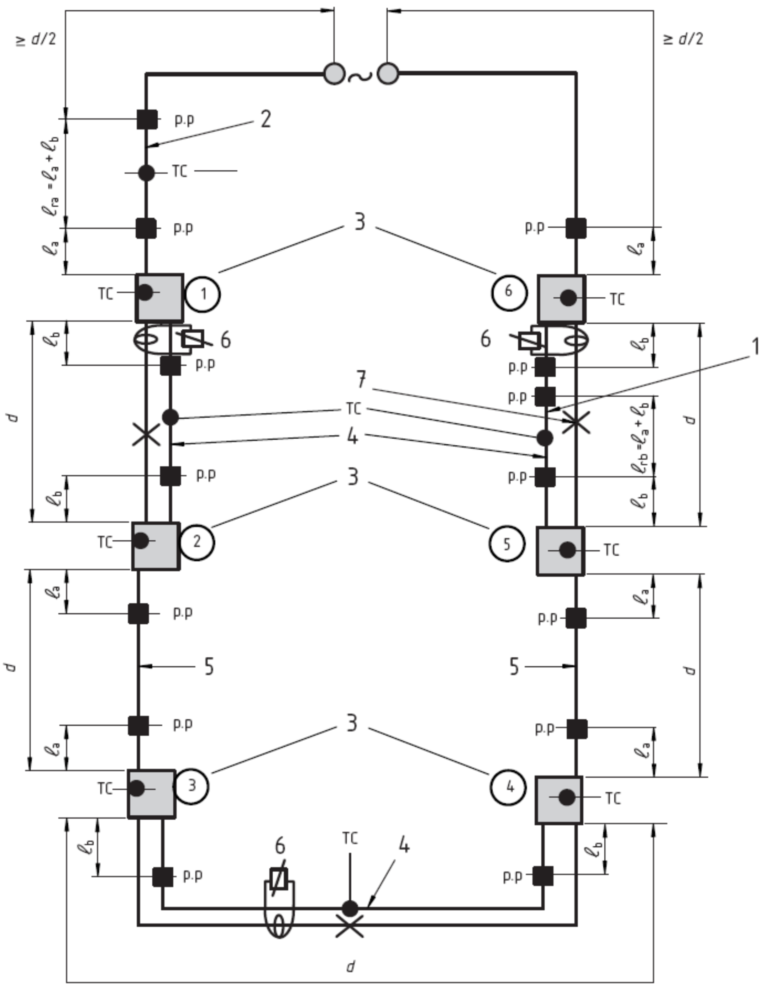
d conductor length between two connectors
$d \geq 80 \sqrt{A}$ or 500 mm minimum

A conductor cross-section (mm^2)

p.p potential point

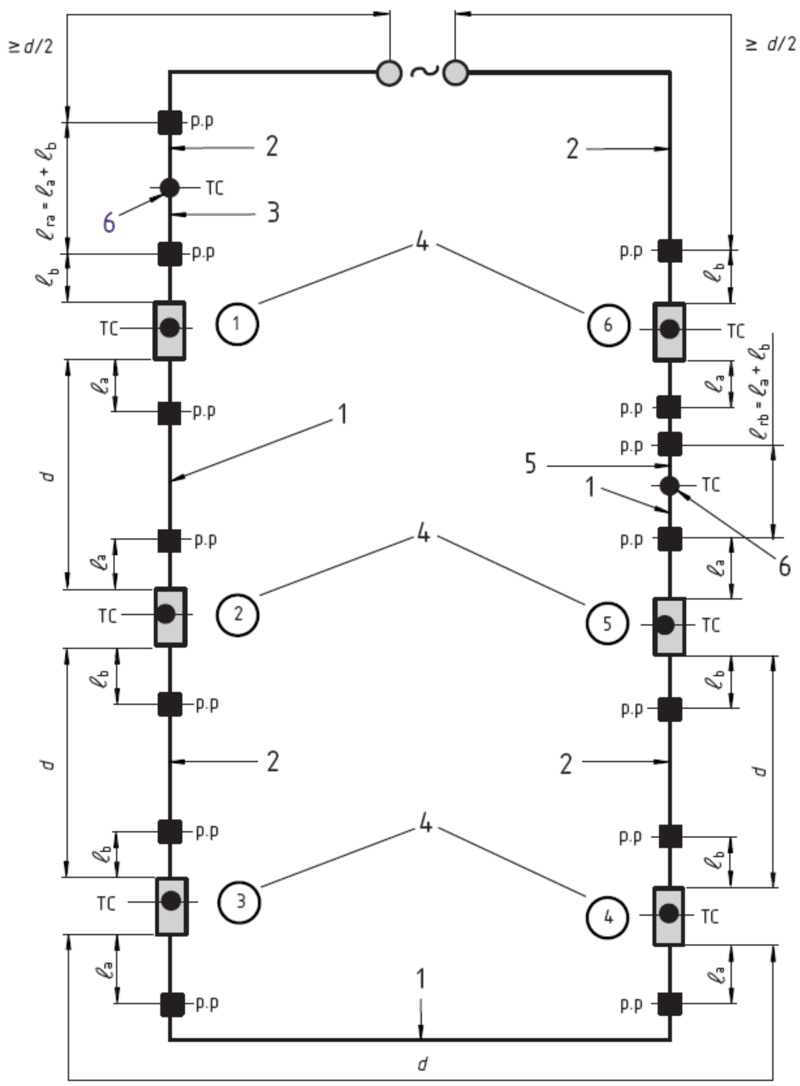
TC thermocouple

Figure 5 – Test loop for branch connectors with main and branch conductors having equal cross-sections and linear resistances



		Key	
If the difference between the main and branch electrical cross-sections is greater than half a step as defined below, this test loop shall be used. Where the change is lower than or equal to half a step, Figure 5 shall be used. Cross-sections steps (mm^2): 1,5, 2,5, 4, 6, 10, 25, 35, 50, 70, 95, 120, 150, 185, 240		1	reference conductor A_2R_2 insulated between equalisers
NOTE For branch cable having a cross-section below 16 mm^2, the impedance adapter may not be necessary if agreed between manufacturer and customer. In this case only the branch conductor shall be maintained within the temperature limit.		2	reference conductor A_1R_1 insulated between equalisers
d	conductor length between two connectors $d \geq 80 \sqrt{A}$ or 500 mm minimum	3	connectors
A	conductor cross-section (mm^2)	4	conductor A_2R_2 insulated between equalisers
p.p	potential point	5	conductor A_1R_1 insulated between equalisers
TC	thermocouple	6	impedance adapter
		7	disconnection device

Figure 6 – Test loop for branch connectors with main and branch conductors having unequal cross-sections and linear resistances



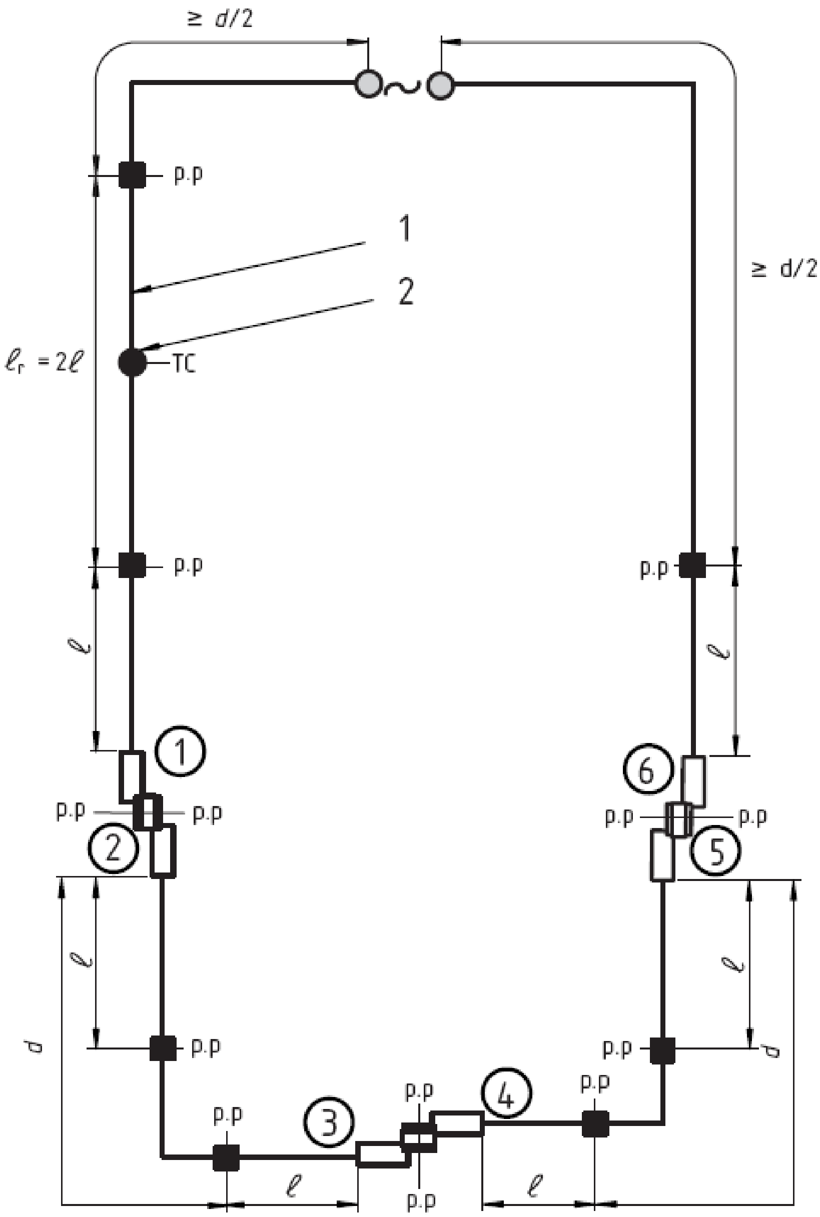
When the connectors have equal cross-section, then $\ell_a = \ell_b$ and $\ell_{ra} = \ell_{rb}$

d	conductor length between two connectors $d \geq 80 \sqrt{A}$ or 500 mm minimum
A	conductor cross-section (mm²) $A = A_1$ or A_2 - The largest conductor cross-section shall be used.
p.p	potential point
TC	thermocouple

Key

1	conductor A_1R_1 insulated between equalisers
2	conductor A_2R_2 insulated between equalisers
3	reference conductor A_2R_2 insulated between equalisers
4	connectors
5	reference conductor A_1R_1 insulated between equalisers
6	thermocouple middle of the conductor

Figure 7 – Test loop for through connectors with conductors having equal or unequal cross-sections and linear resistances



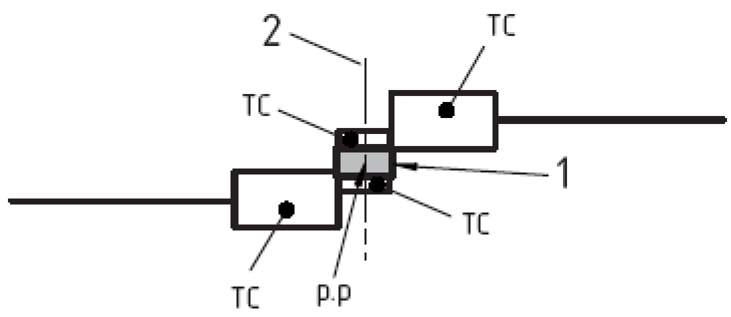
$\ell_a = \ell_b = \ell$ and $= \ell_r = 2\ell$

d	conductor length between two connectors $d \geq 80\sqrt{A}$ or 500 mm minimum
A	conductor cross-section (mm^2)
p.p	potential point
TC	thermocouple

Key

1	reference conductor insulated between equalisers
2	thermocouple middle of the conductor

a) Test loop for pre-insulated lugs



Key

1	intermediate part of material and cross-section identical to those of the connections palms: 14 mm thickness	*TC*	thermocouple
2	nut and bolt	p.p	potential point

b) Test loop for pre-insulated lugs – Lug connection detail

Figure 8 – Test loop for pre-insulated lugs

Annex A
(normative)

Equalizers

For stranded conductors, potential between the strands at measuring points may cause errors in measuring electrical resistance.

Welded or soldered equalizers may be used to overcome this problem, and to ensure uniform current distribution in the reference conductor. Welded or soldered equalizers are the recommended methods to ensure reliable measurements.

Other methods may be used provided they give comparable results and do not affect the temperature of the connectors or the reference conductor.

A.1 Copper conductors

Special equipment:

- silver solder;
- support;
- cooling plates;
- heating equipment.

Cut the conductors square and clean the ends. Place the ends in contact in a support. Solder the ends with a silver solder, ensuring that the conductor remote from the ends is kept sufficiently cool not to be affected.

A.2 Stranded aluminium conductors (Figure A.1)

Special equipment:

- apparatus for TIG (Tungsten Inert Gas) or MIG (Metal Inert Gas) welding;
- welding support;
- welding rod A5 (1 100), welding rod A5 (1 050) or equivalent.

Cut the conductors square, clean the ends, and melt them with the welding torch. (For cable cross-sectional areas greater than 95 mm^2, melt the periphery first and then add weld metal to the centre to complete the chamfer.) The length of the chamfer "*a*" and the separation between the conductors for final welding "*b*" are:

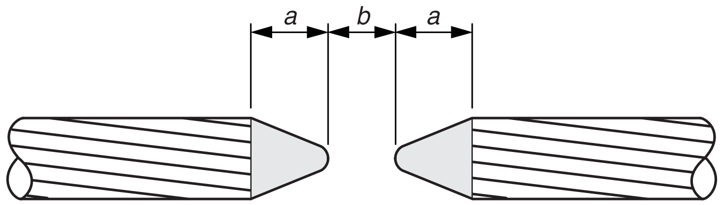
Table A.1 – Dimensions of equalizers

Cross-sectional area *A* mm^2	**$A \leq 95$**	**$95 < A \leq 240$**	**$A > 240$**
a (mm)	3 to 5	5 to 10	7 to 12
b (mm)	1 to 2	2 to 5	4 to 6

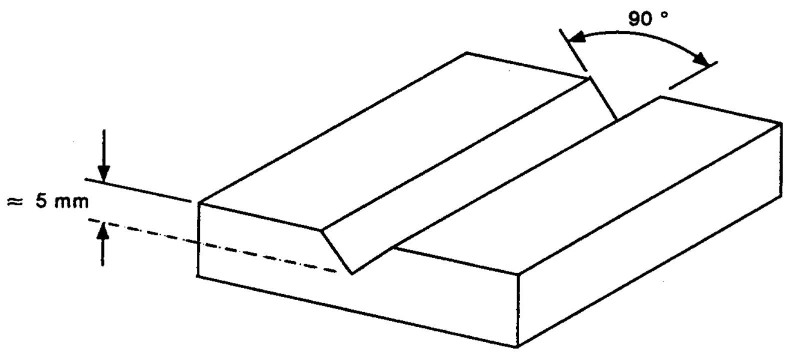
With the conductors supported and spaced by dimensions "*b*", build weld metal up at the centre, and turn the conductors so as to obtain a uniform circular weld profile. Ensure that the conductor remote from the ends is kept sufficiently cool in order not to change the mechanical properties of the conductor in the region where the contact will be made.

A.3 Dimensions

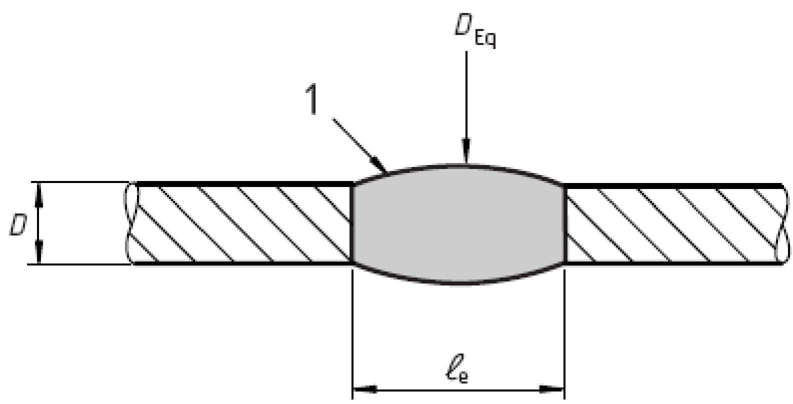
The dimensions of the equalizer shall be as indicated in Table A.1.



a) Ends prepared



b) Welding/soldering support



$D \leq D_{Eq} \leq 1{,}2\ D$

ℓ_e = 10 mm to 15 mm for cross-sectional area $A \leq 95$ mm^2

ℓ_e = 15 mm to 25 mm for cross-sectional area 95 mm^2 $< A \leq 240$ mm^2

ℓ_e = 25 mm to 35 mm for cross-sectional area $A > 240$ mm^2

Key

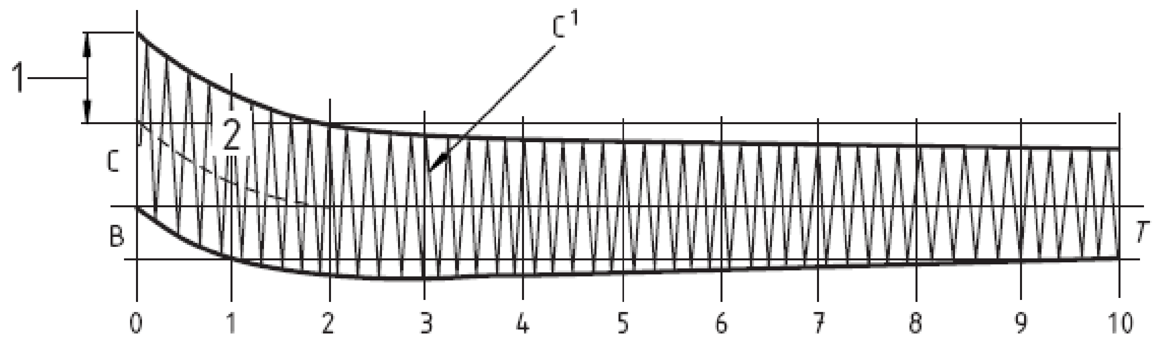
1 marking for potential point

c) Welded/soldered equalizer

Figure A.1 – Equalizers

Annex B
(informative)

Determination of the value of the short-circuit current



Key

1 I_{max0}

2 I_{max1}

Figure B.1 – Diagram of short-circuit current

On the diagram giving the current as a function of time, the total time BT is divided into 10 equal parts and the value of the alternating current component is measured at the verticals at points 0, 1, 2, 10.

These values are designated by I_{max0}, I_{max1}, I_{max2}, I_{max10}.

Then effective values

$$I_i = \frac{I_{max}}{\sqrt{2}}$$

where

I_{max} is the maximum value of the alternating component of the current at each point.

The equivalent r.m.s current during this time BT is given by:

$$I_{rms} = \sqrt{\frac{1}{30}\left[I_0^2 + 4\left(I_1^2 + I_3^2 + I_5^2 + I_7^2 + I_9^2\right) + 2\left(I_2^2 + I_4^2 + I_6^2 + I_8^2\right) + I_{10}^2\right]}$$

NOTE 1 The direct current component (CC') is neglected.

NOTE 2 This annex is consistent with EN 61238-1:2003.

Annex C
(informative)

Recommendations to improve accuracy of measurement

C.1 Handling the test loop

Bending or vibrations during transport and handling may give rise to mechanical forces, which affect the contact resistance of the test objects and should be avoided.

The same measuring points should be used throughout the test, since calculation always refers to the initial situation. Verification of measuring points, especially after short-circuit test is advised.

C.2 Measurements, instruments and readings

In the case of stranded conductors the distances between any equalizer in the test set up where no connectors are installed may be used for verification of resistance measurements.

All recorded values should show that the equalizers have acceptable stability throughout the test.

Check the validity of calibration or make a calibration of each instrument prior to the test.

If possible, calibrate the whole measuring chain.

Temperature readings may easily be checked at a temperature of 100 °C in boiling water and at 0 °C in ice water.

For measuring the current, a calibrated shunt may be introduced into the test loop.

If possible, use the same instrument for voltage (ΔU d.c.), current (ΔU d.c. of a shunt) and temperature (ΔU d.c. of thermocouple-voltage output) measurement.

A calibrated resistance with a value in the same order as the readings may be used for the calibration of the voltage measurement or a direct measurement of the resistance. A check should be made before, during and after the test.

It is recommended

- to use the same instruments during the whole test,
- to avoid whenever possible the replacement of any instrument or the change in the systematic uncertainty may influence the assessment of the measuring results,
- to use automatic storage of the measured values to avoid copy errors,
- to use a validated computer program for the calculation to avoid errors by accident.

Every effort should be made to avoid spurious readings.

Data of instrument performance should be given in the test report.

Bibliography

HD 626, *Overhead distribution cables of rated voltage $U_o/U(U_m)$: 0,6/1 (1,2) kV*

IEC 60949:1988, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*