

# INTERNATIONAL STANDARD

**Compression and mechanical connectors for power cables –  
Part 1-1: Test methods and requirements for compression and mechanical  
connectors for power cables for rated voltages up to 1 kV ( $U_m = 1,2$  kV) tested on  
non-insulated conductors**

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INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**COMPRESSION AND MECHANICAL  
CONNECTORS FOR POWER CABLES –****Part 1-1: Test methods and requirements for compression and  
mechanical connectors for power cables for rated voltages up to 1 kV  
( $U_m = 1,2$  kV) tested on non-insulated conductors**

## FOREWORD

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International Standard IEC 61238-1-1 has been prepared by IEC technical committee 20: Electric cables.

This first edition, together with IEC 61238-1-2 and IEC 61238-1-3, cancels and replaces IEC 61238-1:2003.

This edition includes the following significant technical changes with respect to IEC 61238-1:2003:

- a) The scope has been widened to cover connectors for copper conductors from 10 mm<sup>2</sup> down to 2,5 mm<sup>2</sup> and has been limited to 1 200 mm<sup>2</sup> for connectors for copper and aluminium conductors because test experience and applications are rare for conductors of larger cross-sectional areas.

- b) Two new mechanical classes have been introduced to satisfy the demand for connectors subjected to no mechanical force and for connectors subjected to higher mechanical forces than those specified in Class 1 for conductors of larger cross-sectional areas.
- c) For the electrical test, a maximum elevated heating current has been set in order to avoid unrealistic current densities during testing which may change properties of tested connectors.
- d) For the short-circuit test, the method of calculation and requirements have been updated.
- e) For the mechanical test, the methods and requirements have been updated.

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

| FDIS         | Report on voting |
|--------------|------------------|
| 20/1788/FDIS | 20/1803/RVD      |

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

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

A list of all parts in the IEC 61238 series, published under the general title *Compression and mechanical connectors for power cables*, can be found on the IEC website.

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

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

A bilingual version of this publication may be issued at a later date.

## INTRODUCTION

The IEC 61238 series has been divided into the following parts:

- Part 1-1: Test methods and requirements for compression and mechanical connectors for power cables for rated voltages up to 1 kV ( $U_m = 1,2$  kV) tested on non-insulated conductors
- Part 1-2: Test methods and requirements for insulation piercing connectors for power cables for rated voltages up to 1 kV ( $U_m = 1,2$  kV) tested on insulated conductors
- Part 1-3: Test methods and requirements for compression and mechanical connectors for power cables for rated voltages above 1 kV ( $U_m = 1,2$  kV) up to 30 kV ( $U_m = 36$  kV) tested on non-insulated conductors

This Part 1-1 of IEC 61238 deals with type tests for compression and mechanical connectors for use on copper or aluminium conductors of power cables for rated voltages up to 1 kV ( $U_m = 1,2$  kV).

When a design of connector meets the requirements of this document, then it is expected that in service:

- a) the resistance of the connection will remain stable within specified limits;
- b) the temperature of the connector will be of the same order or less than that of the conductor during current heating;
- c) if the intended use demands it, application of short-circuit currents will not affect a) and b);
- d) independently from the electrical performance, conforming axial tensile strength will ensure an acceptable mechanical performance for the connections to the cable conductors, when applicable.

It should be stressed that, although the object of the electrical and mechanical tests specified in this document is to prove the suitability of connectors for most operating conditions, they do not necessarily apply to situations where a connector may be raised to a high temperature by virtue of connection to a highly rated plant, to corrosive conditions, or where the connector is subjected to external mechanical stresses such as excessive vibration, shock and large displacement after installation. In these instances, the tests in this document may need to be supplemented by special tests agreed between supplier and purchaser.

This document 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 document.

Once successfully completed, these tests are not repeated unless changes are made in material, manufacturing process and design which might adversely change the connector performance characteristics.

## COMPRESSION AND MECHANICAL CONNECTORS FOR POWER CABLES –

### Part 1-1: Test methods and requirements for compression and mechanical connectors for power cables for rated voltages up to 1 kV ( $U_m = 1,2$ kV) tested on non-insulated conductors

## 1 Scope

This part of IEC 61238 applies to compression and mechanical connectors for power cables for rated voltages up to 1 kV ( $U_m = 1,2$  kV), for example buried cables or cables installed in buildings, having

- a) conductors complying with IEC 60228 having nominal cross-sectional areas between  $2,5 \text{ mm}^2$  and  $1\,200 \text{ mm}^2$  for copper and between  $16 \text{ mm}^2$  and  $1\,200 \text{ mm}^2$  for aluminium;
- b) a maximum continuous conductor temperature not exceeding  $90^\circ\text{C}$ .

This document is not applicable to connectors for overhead line conductors nor to connectors with a sliding contact.

The object of this document is to define the type test methods and requirements which apply to compression and mechanical connectors for power cables with copper or aluminium conductors. The reference method is to perform the tests on unused conductors.

## 2 Normative references

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

IEC 60050-461, *International Electrotechnical Vocabulary – Part 461: Electric cables* (available at <http://www.electropedia.org>)

IEC 60228, *Conductors of insulated cables*

IEC 60493-1, *Guide for the statistical analysis of ageing test data – Part 1: Methods based on mean values of normally distributed test results*

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

IEC 60949:1988/AMD1:2008

## 3 Terms and definitions

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

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

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

### 3.1

#### **connector**

<of cables> device for connecting a conductor to an equipment terminal or for connecting two or more conductors to each other

[SOURCE: IEC 60050-461:2008, 461-17-03, modified – the definition has been revised.]

### 3.2

#### **through connector**

device for connecting two consecutive lengths of conductor together

[SOURCE: IEC 60050-461:2008, 461-17-04, modified – the term "joint ferrule" has been deleted and the definition revised.]

### 3.3

#### **branch connector**

device for connecting a branch conductor to a main conductor at an intermediate point on the latter

[SOURCE: IEC 60050-461:2008, 461-17-05, modified – the term "branch ferrule" has been deleted and in the definition "metallic" has been deleted.]

### 3.4

#### **termination**

device fitted to the end of a cable conductor to ensure electrical connection with other parts of the system

[SOURCE: IEC 60050-461:2008, 461-10-01, modified – "conductor" has been added and "and to maintain the insulation up to the point of connection" has been deleted.]

### 3.5

#### **terminal lug**

device to connect a cable conductor to other electrical equipment

[SOURCE: IEC 60050-461:2008, 461-17-01, modified – "metallic" has been deleted.]

### 3.6

#### **palm**

<of terminal lug> part of a terminal lug used to make the connection to electrical equipment

[SOURCE: IEC 60050-461:2008, 461-17-07]

### 3.7

#### **barrel**

<of terminal lug, of connector, etc.> part of a device into which the conductor to be connected is introduced

[SOURCE: IEC 60050-461:2008, 461-17-06]

### 3.8

#### **reference conductor**

length of unjointed bare conductor or conductor with the insulation removed, which is included in the test loop and which enables the reference temperature and reference resistance to be determined

**3.9****equalizer**

arrangement used in the test loop to ensure a point of equipotential and uniform current distribution in a stranded conductor

**3.10****compression jointing**

method of securing a connector to a conductor by using a special tool to produce permanent deformation of the connector and the conductor

**3.11****mechanical jointing**

method of securing a connector to a conductor, for example by means of a bolt or screw acting on the latter or by alternative methods

**3.12****median connector**

connector which during the first heat cycle records the third highest temperature of the six connectors in the test loop

**3.13****conductor**

<of a cable> part of a cable which has the specific function of carrying current

[SOURCE: IEC 60050-461:2008, 461-01-01]

**3.14****family of connectors**

group of connectors of a manufacturer to be considered of the same design criteria, the same material characteristic and the same installation procedure

**4 Symbols**

|                                            |                                                                                                                                                                          |
|--------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $A$                                        | nominal cross-sectional area of the conductor                                                                                                                            |
| $D$                                        | change in the resistance factor of the connector                                                                                                                         |
| $I$                                        | direct current flowing through a connection during resistance measurement                                                                                                |
| $I_{\text{RMS}}$                           | equivalent RMS short-circuit current                                                                                                                                     |
| $I_{\text{N}}$                             | alternating current necessary to maintain the reference conductor at its equilibrium temperature                                                                         |
| $I_{\text{r}}$                             | direct current flowing through the reference conductor/conductors during resistance measurement                                                                          |
| $k$                                        | connector resistance factor: ratio of the resistance of a connector to that of the resistance of the equivalent length of the reference conductor                        |
| $k_0$                                      | initial connector resistance factor: ratio of the resistance of a connector to that of the resistance of the equivalent length of the reference conductor at cycle no. 0 |
| $l_{\text{a}}, l_{\text{b}}, l_{\text{j}}$ | lengths of each connector assembly associated with the measurement positions in the test setup after installation                                                        |
| $l_{\text{r}}$                             | length of the reference conductor between measurement positions                                                                                                          |
| $R$                                        | measured resistance value of connector/conductor installation under an electrical test corrected to 20 °C                                                                |
| $R_{\text{r}}$                             | measured resistance value of the reference conductor corrected to 20 °C                                                                                                  |
| $R_{\text{j}}$                             | length related calculated resistance value of a connector under an electrical test corrected to 20 °C                                                                    |

|                       |                                                                                                                                           |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| $t_1$                 | heating time                                                                                                                              |
| $t_2$                 | time necessary for the connectors and the reference conductor to cool to a value equal to or less than 35 °C                              |
| $U$                   | potential difference between measurement positions while current $I$ is applied                                                           |
| $U_r$                 | potential difference between measurement positions on a reference conductor while current $I_r$ is applied                                |
| $\alpha$              | temperature coefficient of resistance at 20 °C                                                                                            |
| $\beta$               | mean scatter of the connector resistance factors                                                                                          |
| $\delta$              | initial scatter of the connector resistance factors                                                                                       |
| $\lambda$             | resistance factor ratio: the actual resistance factor of the connector at each measurement stage divided by its initial resistance factor |
| $\theta$              | temperature of a connector                                                                                                                |
| $\theta_{\max}$       | maximum temperature recorded on a connector over the total period of test during heat cycling                                             |
| $\theta_R$            | temperature of the reference conductor determined in the first heat cycle                                                                 |
| $\theta_{\text{ref}}$ | temperature of the related reference conductor at the moment of measuring $\theta_{\max}$                                                 |

## 5 General

### 5.1 Definition of classes

Although it is not possible to define precisely the service conditions for all applications, the following requirements have been identified:

#### a) Electrical requirements:

##### *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 are suitable for the majority of applications.

##### *Class B*

These are connectors for networks in which overloads or short-circuits are rapidly cleared by the installed protective devices, for example fast-acting fuses.

#### b) Mechanical requirements:

##### *Class 0*

Connectors subjected to practically no mechanical pull-out force. These are for example, connectors inside switchgear where the cable or conductors are secured or anchored.

##### *Class 1*

Connectors subjected to a mechanical pull-out force related to the conductor nominal cross-sectional area and material (according to Table 4) but limited to a 20 kN pull-out force. These are for example connectors for underground cable joints.

##### *Class 2*

Connectors subjected to a mechanical pull-out force above 20 kN and related to the conductor nominal cross-sectional area and material (according to Table 4). This Class 2 is only applicable to conductor nominal cross-sectional areas  $\geq 400 \text{ mm}^2$  for copper and  $\geq 630 \text{ mm}^2$  for aluminium. These are for example connectors in cable installations where thermomechanical forces are estimated to exceed 20 kN.

Hence, the five classes correspond to the following tests:

*Class A:* heat cycling and short-circuit tests;

*Class B:* heat cycling test only;

*Class 0:* no mechanical test;

*Class 1:* mechanical test with limited maximum tensile force;

*Class 2:* mechanical test with no maximum tensile force.

## 5.2 Conductor

The following information shall be recorded in the test report:

- conductor material;
- nominal cross-sectional area, dimensions and shape;
- detail of conductor construction shall be given when known, or can be determined by inspection, for example:
  - class according to IEC 60228 (solid, stranded and flexible);
  - compacted or non-compacted for stranded conductor;
  - number and arrangement of strands;
  - type of plating, if applicable;
  - type of impregnation, water blocking, etc., if applicable.

## 5.3 Connectors and installation procedure

The following information shall be recorded in the test report:

- the assembly method or the installation instruction that is to be used;
- tooling, dies and any necessary setting;
- if not part of the delivered product, for example at cable conductor termination: bolts, nuts, washers, lubricant, torque, etc.;
- preparation of contact surfaces, if applicable, for example cleaning, brushing and/or greasing of inner and/or outer conductor and/or connector surfaces;
- identification of the connector, for example name of the supplier, drawing, reference number, type.

## 5.4 Range of approval

In general, tests made on one type of connector/conductor combination apply to that arrangement only. However, to limit the number of tests, when using the same conductor material, the following is permitted:

- a connector which can be used on stranded round conductors or on stranded sector-shaped conductors which have been rounded, is approved for both types if satisfactory results are obtained on a compacted round conductor;
- a connector which covers a range of consecutive cross-sectional areas shall be approved, if satisfactory results are obtained on the smallest and the largest cross-sectional areas;
- if a connector is a through connector for two conductors of different cross-sectional areas, shapes, or materials, and if the jointing method and the connector barrels used have already been tested separately for each cross-sectional area, no additional test is necessary. If not, and if it is required for bimetallic through connectors, additional tests shall be made using the conductor having the highest temperature of the two conductors, as reference conductor;
- if a type test for a range taking mechanical connector is passed on the biggest possible conductor cross-sectional area, this result is also valid for similar connector designs with the same material of the connector body but bigger outer diameter provided that the design of the conductor clamping channel (inner diameter, shape, etc.), quantity and

design of clamping screws (torque, material, size, shear-off characteristic, etc.) are identical;

- if a manufacturer can clearly demonstrate that common and relevant connector design criteria were used for a family of connectors, conformity to this document is achieved by successfully testing the largest, the smallest and two intermediate connector sizes;
  - exception no.1: for a family of connectors consisting of five sizes, only the largest connector, the smallest connector, and one connector of a representative intermediate size need to be tested;
  - exception no.2: for a family of connectors consisting of four sizes or less, only the largest connector and the smallest connector need to be tested;
- if conformity to this document is achieved by successfully testing a connector on a dry conductor then approval is achieved for the same conductor used in an impregnated paper insulated cable;
- for connectors where one or both sides are designed for a range of cross-sectional areas, and a common clamping or crimping arrangement serves for the connection of the different cross-sectional areas, then mechanical tests on conductors with the largest and smallest cross-sectional areas shall be carried out according to Clause 7 for connectors according to Class 1 or Class 2;
- if conformity to this document is achieved by successfully testing a mechanical connector on round stranded aluminium conductors, this type test approval can be applied to solid aluminium conductors of the same cross-sectional area(s);
- if conformity to this document is achieved by successful testing of a through connector, this type test approval can apply to the barrel of a termination which uses the same design criteria. Approval of the complete termination can be achieved if the termination connection does not influence the barrel performance, proven through design parameters, drawings or through thermal verification tests;
- if conformity to this document is achieved by successfully testing a connector on a conductor with water blocking, approval is achieved for the same conductor without any water blocking but not for the same conductor with different types of water blocking;
- if conformity to IEC 61238-1-3 is achieved by successfully testing a connector, approval is achieved for the same classes and conductors in this document.

## 6 Electrical tests

### 6.1 Installation

#### 6.1.1 General

All conductors of the same nominal cross-sectional area in the test loop shall be taken from the same conductor length.

For each series of tests, six connectors shall be installed in accordance with the manufacturer's instructions, on a bare conductor or on a conductor that has had the insulation removed before assembly, to form a test loop together with the corresponding reference conductor.

For stranded conductors, potential differences between the strands at potential measuring positions can cause errors in measuring electrical resistance. Equalizers according to Annex A shall be used to overcome this problem and to ensure uniform current distribution in the reference conductor and between connectors at the equalizer positions. The recommended method is to prepare equalizers on the test loop before installing connectors.

The test loop shall be installed in a location where the air is calm.

The ambient temperature of the test location shall be between 15 °C and 30 °C.

For conductor cross-sectional areas above 1 000 mm<sup>2</sup>, it is allowed to increase the ambient temperature range of the test location between 15 °C and 40 °C. At the end of the cooling phase the ambient temperature shall be between 15 °C and 30 °C.

In the case of solid conductors, the potential measuring positions shall be as close as possible to the connector in order to reduce  $I_a$  and  $I_b$  close to zero.

The test loop may be of any shape according to Figure 2 or Figure 3 provided that it is arranged in such a way that there is no adverse effect from the floor, walls and ceiling, other test loops and adjacent test branches.

To facilitate the short-circuit test for connectors according to Class A, the loop may be disassembled as shown in Figure 2 b). In this case, the sectioning connections shall not influence the temperatures of the test objects during heating.

Retightening of bolts or screws of the connectors under test is not permitted.

### 6.1.2 Through connectors and terminations

The test loop shown in Figure 2 indicates the dimensions that shall be used.

Where terminal lugs or mechanical connectors for terminal bars are to be tested, they shall be bolted to linking bars in accordance with the manufacturer's instructions or other relevant standards/specifications defining methods and instructions for fastening terminations. These linking bars shall, at the point of connection, be of the same dimensions and thickness as the palm, and also of the same material.

It may be necessary to adjust the thermal characteristics of the linking bar outside the point of connection, to achieve the temperatures specified in 6.3.

For terminal lugs, the use of linking bars is the recommended test method although it is alternatively possible to test terminal lugs with palms connected directly to palms.

If it is requested that the terminal lug test includes an evaluation of the performance of the bolted palm when connected to a specified plant terminal, then the linking bar method shall be used and the linking bar ends, or an intermediate piece, shall be defined and described in material, size and surface coating.

### 6.1.3 Branch connectors

When the branch connector is intended for a branch nominal cross-sectional area equal to the main, or a nominal cross-sectional area immediately above or below the main, it is treated as a through connector between the main and the branch, and the test method for through connectors as shown in Figure 2 is applicable. In other cases, the test loop shall be as shown in Figure 3. Where a type of connector makes it necessary for the main conductor to be cut, that part of the connector which acts as a through connector, shall also be tested as for through connectors.

## 6.2 Measurements

### 6.2.1 General

Measurements shall be made at stages throughout the test according to Table 2.

NOTE Recommendations to decrease uncertainties of measurements are given in Annex C.

### 6.2.2 Electrical resistance measurements

The resistance measurements shall be made under steady temperature conditions of both the test loop and test location. The ambient temperature shall be between 15 °C and 30 °C.

The recommended method is to pass a direct current of up to 10 % of the estimated heat cycling current, through the connectors and the reference conductor, without significantly increasing the temperature and to measure the potential difference between two specific potential measuring positions. The ratio of potential difference and direct current is the electrical resistance between those two positions.

To decrease the uncertainty of the resistance measurement, it is recommended that the direct current is adjusted to the same value throughout the electrical test.

For branch conductors assembled in accordance with Figure 4, the whole of the measuring current shall flow through that part of the connector whose potential difference is being measured. Switches or disconnecting terminals may be provided for this purpose.

Thermoelectric voltages may affect the uncertainty of low resistance measurements (of the order of 10  $\mu\Omega$ ). If this is suspected, the recommended method is to take two resistance measurements with the direct measuring current reversed between readings. The mean of the two readings is then the actual resistance of the sample.

The potential measuring positions shall be as indicated in Figure 4 and Annex B. The various lengths shall be measured individually to enable the actual connector resistances to be determined. The temperature of connector and reference conductor shall be recorded when resistance measurements are made. For direct comparison, the resistance values shall be corrected to 20 °C. Information on the recommended method is also given in Annex B. Temperature measurements at these positions shall be made during the heat cycling test.

Indirect resistance readings:

- voltage measurements shall have a device uncertainty within  $\pm 0,5 \%$  or  $\pm 10 \mu\text{V}$ , by taking the greater value;
- current measurements shall have a device uncertainty within  $\pm 0,5 \%$  or  $\pm 0,1 \text{ A}$ , by taking the greater value.

Direct resistance readings:

Resistance measurements shall have a device uncertainty within  $\pm 1 \%$  or  $\pm 0,5 \mu\Omega$ , by taking the greater value when the instrument is calibrated against a certified standard resistance.

### 6.2.3 Temperature measurements

Temperatures of both connectors and reference conductors shall be measured at the positions indicated in Figure 4. The recommended method of temperature measurement is to use thermocouples. The temperature measurements shall have a device uncertainty within  $\pm 2 \text{ K}$ .

## 6.3 Heat cycling test

### 6.3.1 General

The heat cycling test shall be made with alternating current.

NOTE In the case of DC applications, direct current might be used.

### 6.3.2 First heat 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 (see 3.12) at equilibrium.

Equilibrium is reached when the reference conductor and the connectors do not vary in temperature by more than  $\pm 2$  K during application of the heating current. Minimum periods to maintain temperature stability are defined in Table 1.

#### a) Through connectors and terminations

Current is circulated in the test loop, bringing the reference conductor to 120 °C at equilibrium.

If the temperature of the median connector is equal to or greater than 100 °C, the reference conductor temperature for subsequent heat cycles shall be deemed to be 120 °C. If not, then the current shall be increased until the median connector temperature reaches 100 °C at equilibrium, subject to the reference conductor temperature not exceeding 140 °C. If the temperature of the median connector does not reach 100 °C, even with a reference conductor temperature of 140 °C, the test shall be continued at that temperature. The measured reference conductor temperature  $\theta_R$  shall then be used for subsequent heat cycles ( $120\text{ °C} \leq \theta_R \leq 140\text{ °C}$ ).

Where linking bars are used for terminal lugs, the temperature at the midpoint of the bar linking the palms should also be measured. This temperature should be equal to the temperature of the reference conductor  $\theta_R$ , with a tolerance of  $\pm 5$  K.

#### b) Branch connectors

Where it is necessary to use the circuit shown in Figure 3, current shall be circulated in the test loop, bringing the main reference conductor and the three branch reference conductors to 120 °C at equilibrium. To achieve this, the currents in the three branches shall be adjusted by current injection or impedance control. If the temperature of the median connector according to definition 3.12 is then equal to or greater than 100 °C, the reference conductor temperature for subsequent heat cycles shall be deemed to be 120 °C. If not, then the current shall be increased in the loop until the median connector temperature reaches 100 °C at equilibrium, provided the reference conductors do not exceed 140 °C. It may be necessary at this stage, and also at intervals throughout the test, to adjust the current in an individual branch so as to ensure that each branch reference temperature is the same as the main reference temperature with a tolerance of  $\pm 2$  K. The measured reference conductor temperature  $\theta_R$  on the main and branch conductors, shall then be used for subsequent heat cycles ( $120\text{ °C} \leq \theta_R \leq 140\text{ °C}$ ).

**Table 1 – Minimum period of temperature stability**

| Nominal conductor cross-sectional area $A$ (mm <sup>2</sup> ) | for aluminium: | $A \leq 300$ | $300 < A \leq 630$ | $630 < A \leq 1\,000$ | $A > 1\,000$ |
|---------------------------------------------------------------|----------------|--------------|--------------------|-----------------------|--------------|
|                                                               | for copper:    | $A \leq 240$ | $240 < A \leq 400$ | $400 < A \leq 800$    | $A > 800$    |
| Minimum period (min)                                          |                | 15           | 20                 | 30                    | 60           |

### 6.3.3 Second heat cycle

The object of this second heat cycle is to determine the heat cycle duration and temperature profile which will be used on the test loop for all subsequent heat cycles. Current is circulated in the loop until the main reference conductor temperature reaches the value  $\theta_R$  determined in

6.3.2, with a tolerance of  ${}^{+6}_0$  K and the median connector temperature is stable within a band of 2 K over a 10 min period and does not differ by more than 3 K compared to the temperature measured during the first heat cycle.

For branch connectors that need to use the circuit shown in Figure 3, current is circulated in the loop until the branch reference conductor temperature reaches the value  $\theta_R$  determined in 6.3.2, with a tolerance of  ${}^{+6}_0$  K and the main reference conductor temperature reaches the value  $\theta_R$  determined in 6.3.2, with a tolerance of  ${}^{+6}_{-4}$  K. The median connector temperature is stable within a band of 2 K over a 10 min period and does not differ by more than 3 K compared to the temperature measured during the first heat cycle.

At the beginning of the heat cycle, an elevated current up to 150 % of  $I_N$  may be used as the preferred method, to reduce the heating period. The current shall thereafter be decreased or regulated to a mean value of the current close to  $I_N$  to ensure stable conditions during the median-connector control period. It may be necessary to use more than one cycle to determine the second heat cycle.

The reference conductor temperature shall be the control parameter, in order to keep the temperature profile during the heat cycling test. In this way, the fluctuation of the ambient temperature will not affect the temperature profile of the reference conductor within the tolerances given in this document.

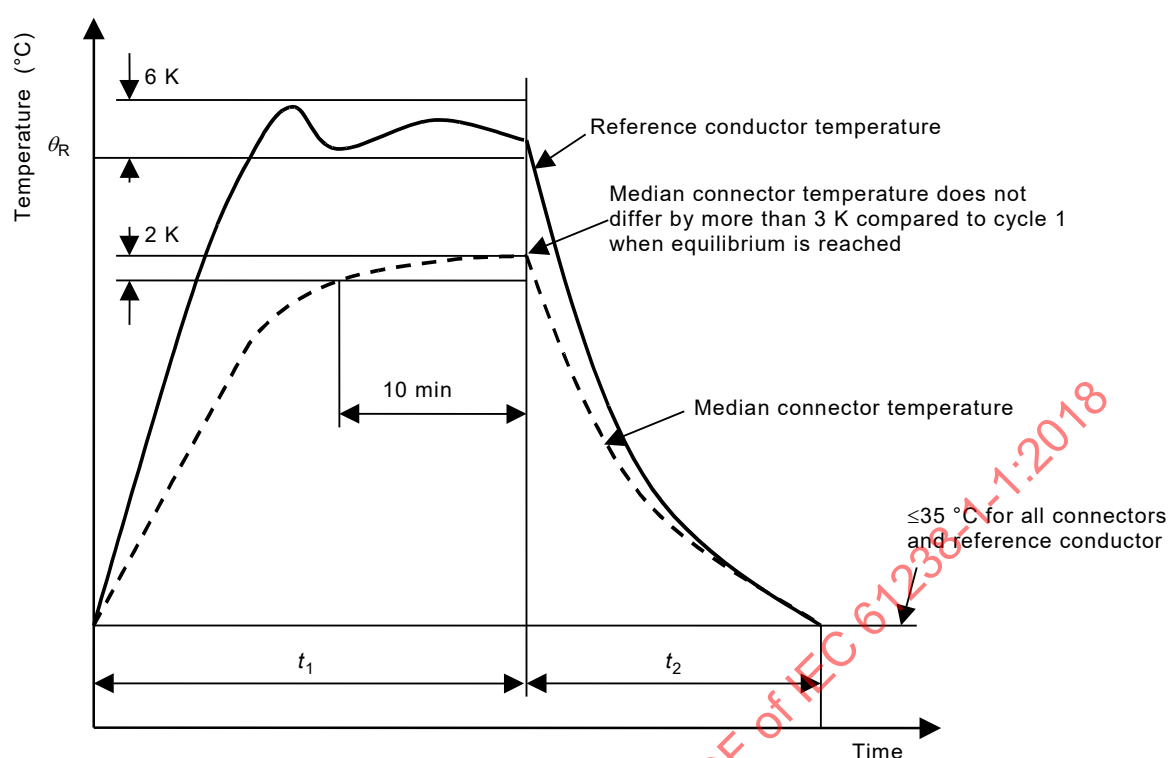
The determined heating profile of the reference conductor containing the characteristics of temperatures during time, as shown in Figure 1, shall be recorded and reproduced for all subsequent heat cycles.

The heating period  $t_1$  is followed by a cooling period  $t_2$  to bring the temperatures of all connectors and the reference conductor to values  $\leq 35$  °C.

It may be necessary in subsequent heat cycles to adjust  $t_2$  to ensure that the temperature conditions are reached, in particular during the measurement of resistances in order to respect the conditions of 6.2.2.

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

The total period  $t_1 + t_2$  constitutes a heat cycle (see Figure 1).



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Figure 1 – Example of second heat cycle profile

#### 6.3.4 Subsequent heat cycles

A total of 1 000 heat cycles shall be made according to 6.3.3. After the cooling period of the cycles indicated in Table 2, the resistance and temperature of each connector and each reference conductor shall be recorded as described in 6.2. The maximum temperature of each connector during the cycle just prior to or following the resistance measurements shall also be recorded.

Table 2 – Electrical resistance measurements during the electrical test

| Class A                                                                         | Class B                                             |
|---------------------------------------------------------------------------------|-----------------------------------------------------|
| cycle no. 0, before the first heat cycle, see 6.3.2                             | cycle no. 0, before the first heat cycle, see 6.3.2 |
| after cycle no. 200 before short-circuit test                                   |                                                     |
| after cycle no. 200 and after short-circuit test                                |                                                     |
| after cycle no. 250 <sup>a</sup>                                                | after cycle no. 250 <sup>a</sup>                    |
| then after 75 cycle intervals <sup>a</sup>                                      | then after 75 cycle intervals <sup>a</sup>          |
| (in total 14 measurements)                                                      | (in total 12 measurements)                          |
| <sup>a</sup> A tolerance of ±10 cycles may be used for collecting measurements. |                                                     |

## 6.4 Short-circuit test for connectors according to Class A

### 6.4.1 General

The short-circuit test shall be made with alternating current.

After finishing 200 heat cycles, six short-circuit currents shall be applied on each connector.

After each short-circuit current application, the test loop shall be cooled to a temperature  $\leq 35\text{ }^{\circ}\text{C}$ .

The measured initial reference conductor temperature, the current and the duration, as well as the Joule integral of each short-circuit current application shall be recorded in the test report.

When through connectors are used to connect different conductors in the same test, the conductor with the highest nominal electrical resistance per unit length shall be used as reference conductor.

When branch connectors are used, the short-circuit current shall be applied from the main conductor to the branch conductor for each connector under test.

As stated in 6.1.1 the test loop may be disassembled for this test. Since the short-circuit test is intended to reproduce the thermal effects of high currents only, the recommended method is to use a concentric return conductor in order to reduce the electro-dynamic forces. The test arrangements shall be described in the test report.

For aluminium conductor nominal cross-sections  $> 400\text{ mm}^2$  and for copper  $> 300\text{ mm}^2$ , pre-heating up to  $90\text{ }^{\circ}\text{C}$  may be used. However, for nominal cross-sectional areas exceeding  $630\text{ mm}^2$  for copper or  $1\,000\text{ mm}^2$  for aluminium, the defined parameters (45 kA and 5 s) are insufficient to reach  $250\text{ }^{\circ}\text{C}$ .

When determining the short-circuit current RMS value, a device taking into account the DC component should be used. Alternatively, the determination of  $I^2t$  can be obtained using the method described in Annex E, noting this method does not take into account the DC component of the current.

NOTE The measured final reference conductor temperature can be recorded in the test report for information.

#### **6.4.2 Aluminium conductors with cross-sectional areas below $1\,000\text{ mm}^2$ and copper conductors with cross-sectional areas below $630\text{ mm}^2$**

The short-circuit test current level shall be such, that it raises the reference conductor from a temperature  $\leq 35\text{ }^{\circ}\text{C}$  to a temperature between  $250\text{ }^{\circ}\text{C}$  and  $270\text{ }^{\circ}\text{C}$ .

The duration of the short-circuit test current shall be  $(1^{+0,5}_{-0,1})\text{ s}$  with a maximum current of 25 kA.

If the required short-circuit test current exceeds this value, a longer duration  $\leq 5\text{ s}$  with a current between 25 kA and 45 kA shall be used.

The minimal applicable adiabatic Joule integral  $I^2_{AD}t$ , which raises the temperature of the reference conductor to  $250\text{ }^{\circ}\text{C}$ , shall be calculated according to the formula in Annex D, as well as the maximum applicable adiabatic Joule integral  $I^2_{AD}t$  necessary to reach a final temperature of  $270\text{ }^{\circ}\text{C}$ .

The adiabatic Joule integral  $I^2_{AD}t$  used for each short-circuit current application during the short-circuit test shall be between both previous calculated values of Joule integrals  $I^2_{AD}t$ .

NOTE To allow adjustment of the current for the short-circuit test, the first short-circuit test current can be extended to achieve a final temperature between  $250\text{ }^{\circ}\text{C}$  and  $280\text{ }^{\circ}\text{C}$ .

#### **6.4.3 Aluminium conductors with cross-sectional areas $\geq 1\,000\text{ mm}^2$ and copper conductors with cross-sectional areas $\geq 630\text{ mm}^2$**

A short-circuit test current of 45 kA for 5 s shall be applied.

## 6.5 Assessment of results

An individual connector resistance factor  $k$  enables a common method of connector assessment to be made over the range of conductor cross-sectional areas applicable to this document. The parameters listed below shall be calculated according to Annex F:

- The connector resistance factor  $k$  shall be calculated according to Clause F.3, for each of the six connectors at all the measurement intervals listed in Table 2.
- The initial scatter  $\delta$ , between the six initial values of  $k_0$ , measured before heat cycling, shall be calculated according to Clause F.4.
- The mean scatter  $\beta$ , between the six values of  $k$ , averaged over the last 11 measurement intervals, shall be calculated according to Clause F.5.
- The change in resistance factor  $D$  for each of the six connectors shall be calculated according to Clause F.6.  $D$  is the change in the value of  $k$  taken over the last 11 measurement intervals, calculated as a fraction of the mean value of  $k$  in this interval;
- The resistance factor ratio  $\lambda$  shall be calculated according to Clause F.7.
- The maximum temperature  $\theta_{\max}$  on each connector shall be recorded according to Clause F.8.

NOTE An explanation for assessing the results of the electrical test on connectors can be found in Annex G.

## 6.6 Requirements

The six connectors shall satisfy the requirements shown in Table 3. If one connector out of the six does not satisfy one or more of the requirements, a re-test may be carried out. In this event, all six new connectors shall satisfy the requirements.

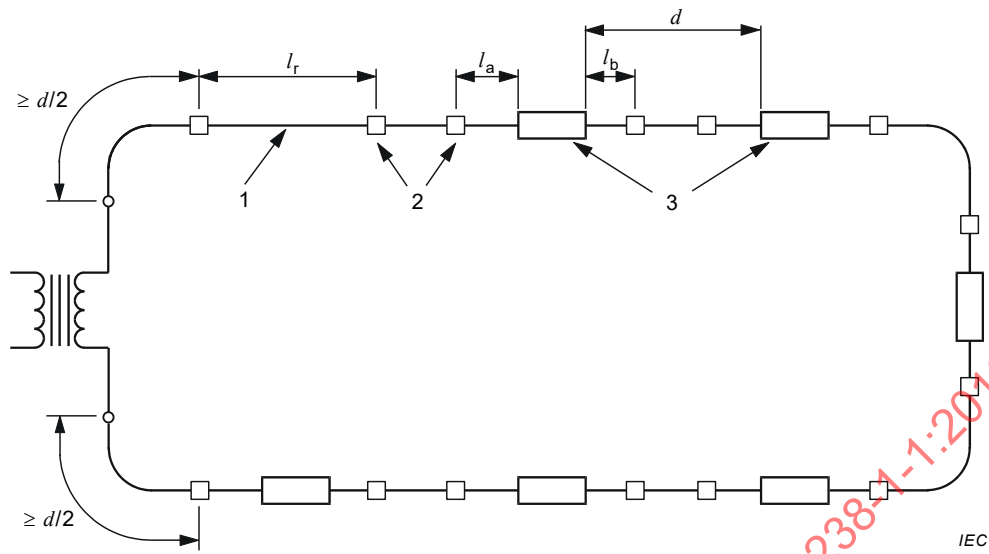
If more than one connector out of the six do not satisfy one or more of the requirements, no re-test is permitted and the type of connector shall be deemed as not conforming to this document.

**Table 3 – Electrical test requirements**

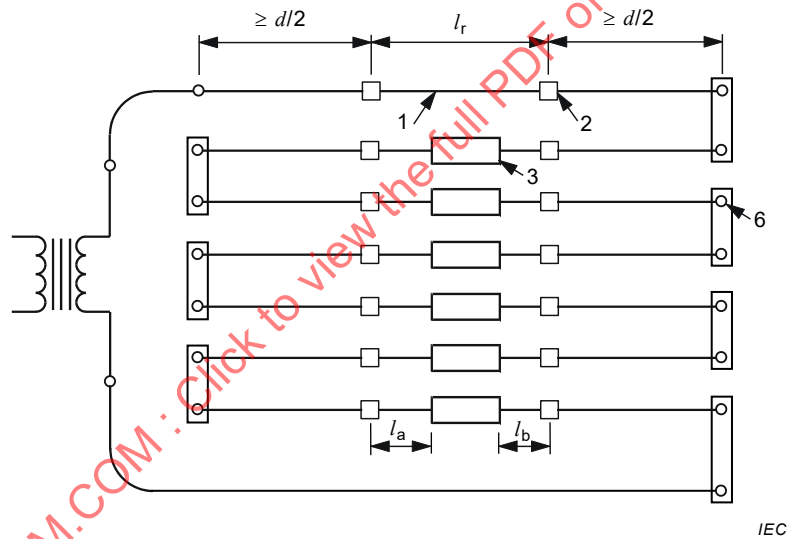
| Parameter                                      | Designation     | Text reference | Maximum value         |
|------------------------------------------------|-----------------|----------------|-----------------------|
| Initial scatter                                | $\delta$        | Clause F.4     | 0,30                  |
| Mean scatter                                   | $\beta$         | Clause F.5     | 0,30                  |
| Change in resistance factor                    | $D$             | Clause F.6     | 0,15                  |
| Resistance factor ratio                        | $\lambda$       | Clause F.7     | 2,0                   |
| Maximum temperature                            | $\theta_{\max}$ | Clause F.8     | $\theta_{\text{ref}}$ |
| NOTE Specified values are based on experience. |                 |                |                       |

## 6.7 Examples of electrical test loop configurations and associated parameters

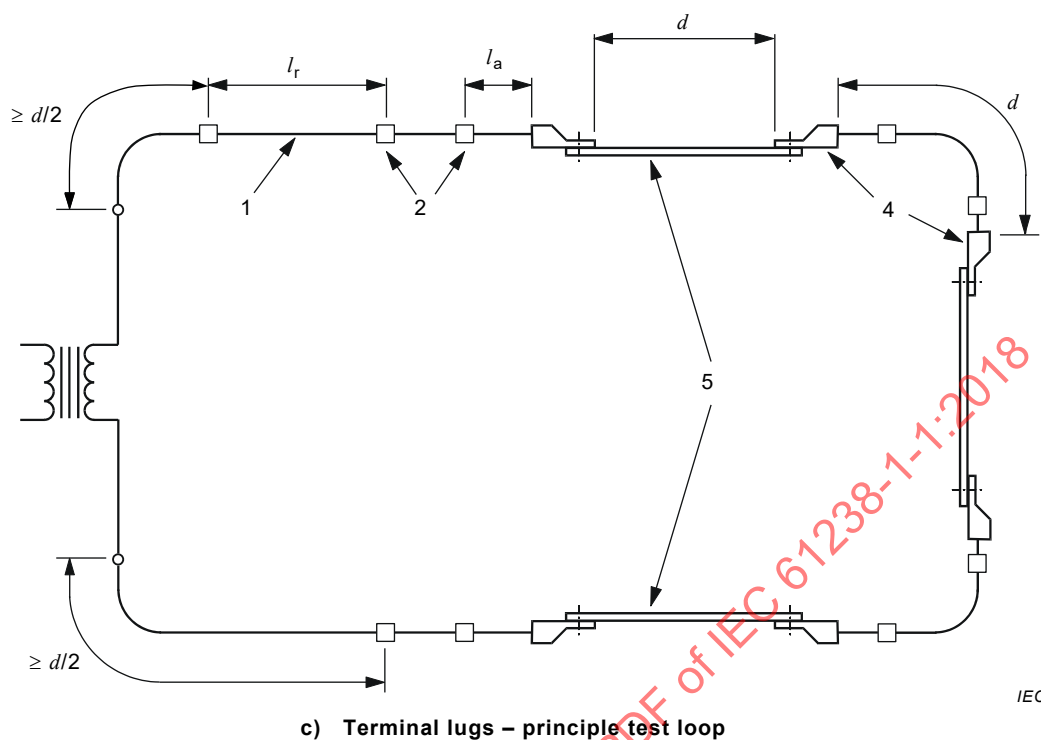
See Figures 2, 3 and 4.



a) Through connectors – principle test loop



b) Through connectors with separable sections according to 6.1.1



where:

$d \geq 80 \sqrt{A}$  or 500 mm, whichever is the greater

$A$  is the corresponding conductor nominal cross-sectional area, in mm<sup>2</sup>

$l_r \geq l_a + l_b + l_j$  (for  $l_j$ , see Figure 4)

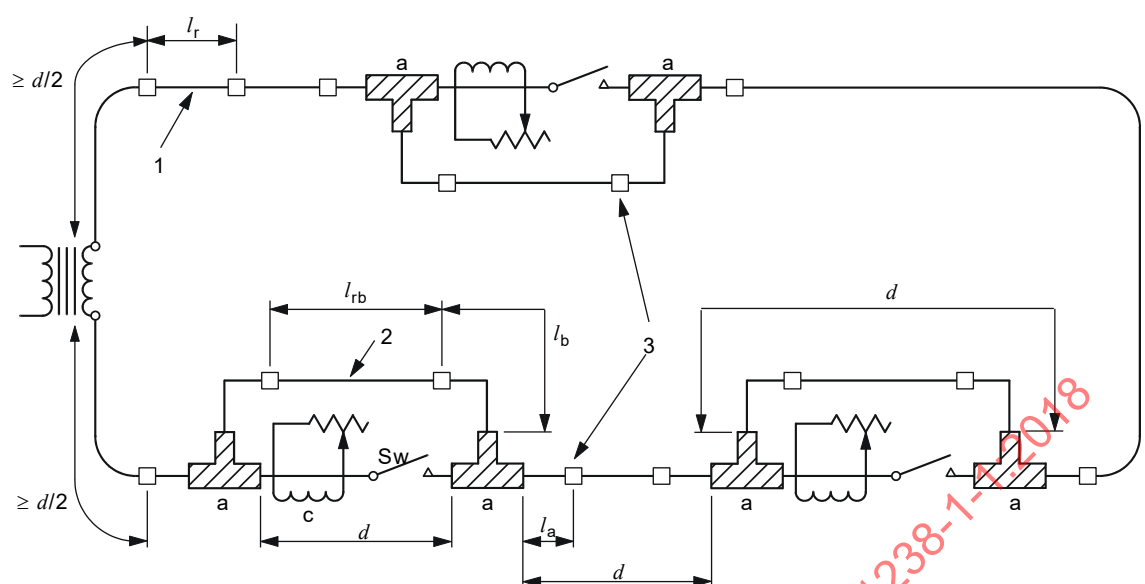
For stranded conductors:

$l_a, l_b \approx 15 \sqrt{A}$  or 150 mm, whichever is the greater

#### Key

- |   |                                      |
|---|--------------------------------------|
| 1 | reference conductor                  |
| 2 | equalizers (for stranded conductors) |
| 3 | through connectors                   |
| 4 | terminal lugs                        |
| 5 | linking bars                         |
| 6 | disconnecting terminals              |

**Figure 2 – Typical electrical test loops for through connectors and terminal lugs**



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where:

$d \geq 80 \sqrt{A}$  or 500 mm, whichever is the greater

$A$  is the main conductor cross-sectional area, in mm<sup>2</sup>

$l_r, l_{rb} \geq l_a + l_b + l_j$  (for  $l_j$ , see Figure 4)

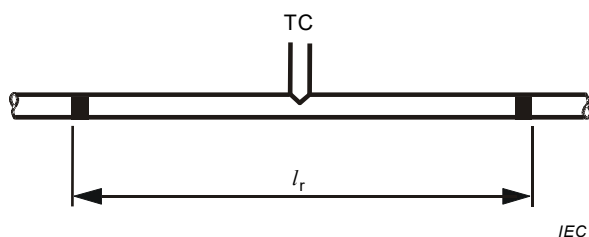
For stranded conductors:

$l_a, l_b \approx 15 \sqrt{A}$  or 150 mm, whichever is the greater

#### Key

- |    |                                                                                                             |
|----|-------------------------------------------------------------------------------------------------------------|
| 1  | main reference conductor                                                                                    |
| 2  | branch reference conductor                                                                                  |
| 3  | equalizer (for stranded conductors)                                                                         |
| a  | branch connector                                                                                            |
| c  | current control                                                                                             |
| Sw | switch (for branch resistance measurement) a distance of $d/2$ between switch and connectors should be used |

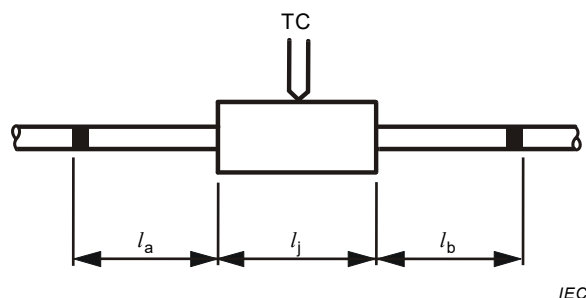
Figure 3 – Typical electrical test loop for branch connectors



a) Reference conductor

Formula:

$$R_r = \frac{U_r}{I_r} \times \frac{1}{1 + \alpha(\theta_r - 20)}$$



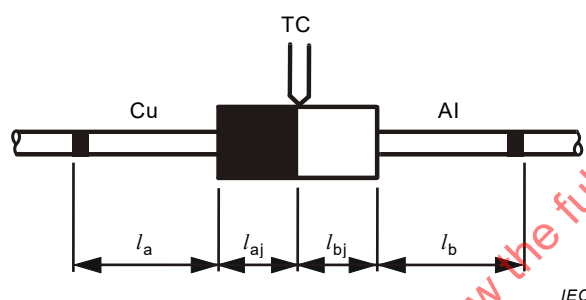
b) Through connector

Formulas:

$$R_j = R - R_r \times \frac{(l_a + l_b)}{l_r}$$

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j}$$

Reference: same conductor on both sides



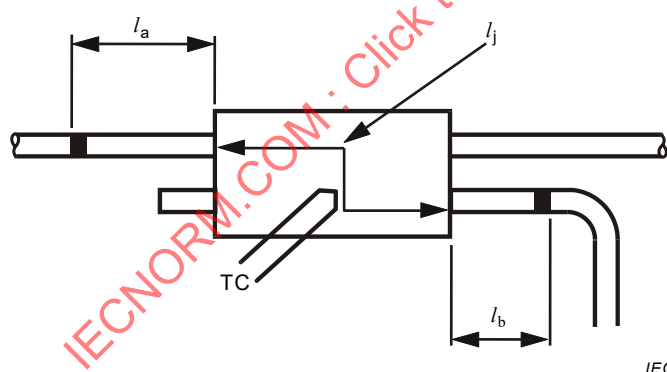
c) Bimetallic through connector

Formulas:

$$R_j = R - \left( \frac{R_r \text{Cu}}{l_r \text{Cu}} \times l_a + \frac{R_r \text{Al}}{l_r \text{Al}} \times l_b \right)$$

$$k = \frac{R_j}{\frac{R_r \text{Cu}}{l_r \text{Cu}} \times l_{aj} + \frac{R_r \text{Al}}{l_r \text{Al}} \times l_{bj}}$$

References: copper and aluminium conductors



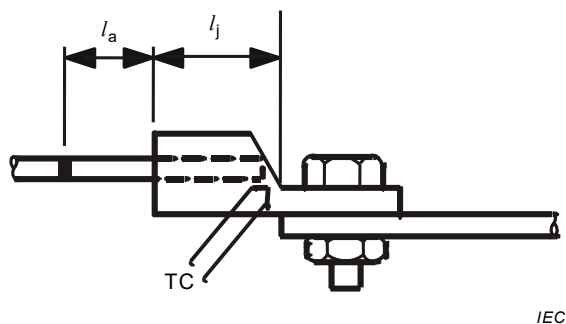
d) Branch connector

Formulas:

$$R_j = R - \left( \frac{R_r \text{main}}{l_r \text{main}} \times l_a + \frac{R_r \text{branch}}{l_r \text{branch}} \times l_b \right)$$

$$k = \frac{R_j}{R_r \text{branch}} \times \frac{l_r \text{branch}}{l_j}$$

References: main and branch conductors



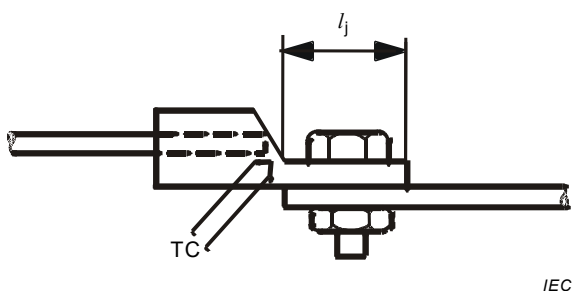
Formulas:

$$R_j = R - R_r \times \frac{l_a}{l_r}$$

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j}$$

Reference: conductor

e) Barrel of terminal lug



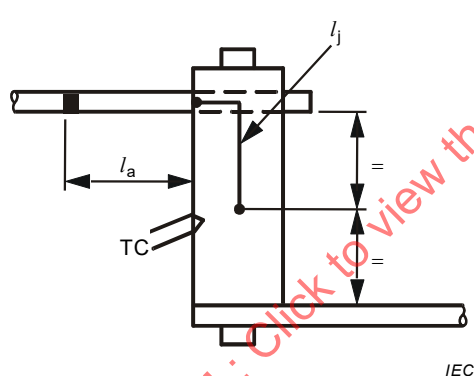
Formulas:

$$R_j = R$$

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j}$$

Reference: conductor

f) Palm of terminal lug



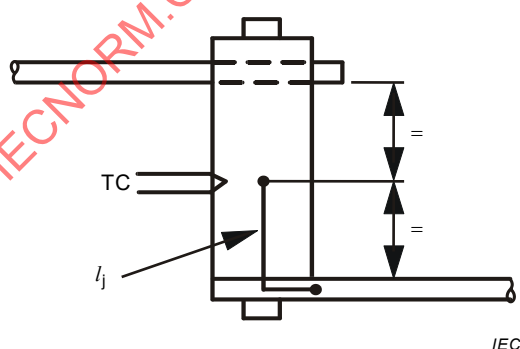
Formulas:

$$R_j = R - R_r \times \frac{l_a}{l_r}$$

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j}$$

Reference: conductor

g) Connection to the conductor for a mechanical connector



Formulas:

$$R_j = R$$

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j}$$

Reference: conductor

h) Connection to a terminal bar for a mechanical connector

Key

TC = Temperature measurement positions

Figure 4 – Typical cases of resistance measurements

## 7 Mechanical test

### 7.1 General

The purpose of this test is to ensure an acceptable mechanical strength for the connections to the conductors of power cables.

NOTE The mechanical test does not give any indication that the connector will be able to fulfill the electrical test requirements.

### 7.2 Method

The test shall be made on three additional connectors having the same combination of conductors and installation procedure as used for the electrical test. The recommended conductor length between connectors or between connector and tensile test machine jaws is  $\geq 500$  mm. The rate of application of the load shall not exceed 10 N per square millimeter of nominal cross-sectional area and per second up to 25 % of the value in Table 4 in order to mark the conductor relatively to the connector, then up to the value in Table 4, which is then maintained for 1 min.

The applicable tolerance for applying the mechanical load shall be within  $\pm 5$  %.

When the axes of two conductors are not aligned, the connector shall be fixed and the force applied in the axis of the clamping channel on each conductor core. One sample of connector shall be used per tensile test.

For example for a branch connector as shown in Figure 4 d), six connectors are needed, three samples are required for testing the main conductor and three samples for the branch conductor.

If the connector is tested electrically for conductors of different nominal cross-sectional area, three connectors shall be tested individually with the same conductor as used in the electrical test, in accordance with Table 4.

**Table 4 – Selection of tensile force withstand values for the mechanical test**

| Class   | Conductor material | Nominal cross-sectional area $A$ (mm <sup>2</sup> ) | Tensile force (N) |
|---------|--------------------|-----------------------------------------------------|-------------------|
| Class 0 | Aluminium          | –                                                   | No test           |
|         | Copper             | –                                                   | No test           |
| Class 1 | Aluminium          | $\leq 500$                                          | $40 \times A$     |
|         |                    | $\geq 630$                                          | 20 000            |
|         | Copper             | $\leq 300$                                          | $60 \times A$     |
|         |                    | $\geq 400$                                          | 20 000            |
| Class 2 | Aluminium          | $\geq 630$                                          | $40 \times A$     |
|         | Copper             | $\geq 400$                                          | $60 \times A$     |

### 7.3 Requirements

Not more than 3 mm slippage shall occur during the last minute of the test.

## 8 Test reports

### 8.1 General

The type test results according to this document may be presented in separate test reports.

### 8.2 Electrical tests

The test report shall include the following information:

- connector class (see 5.1);
- conductor used (see 5.2);
- connector and installation procedure (see 5.3);
- installation for example in the case of terminations, where bolted connections are not supplied and not described by the manufacturer, for example palms of cable lugs, where additional information shall be given about material, surface and lubrication of used bolts, nuts, washers and applied torques;
- temperature measurement method (see 6.2.3);
- current  $I_N$  at equilibrium temperature (see 6.3.2);
- for Class A the short-circuit test parameters (see 6.4);
- test loop configuration;
- values and graph of the connector resistance factor  $k$  versus the cycle number (see 6.5);
- values and graph of the maximum temperatures versus the cycle number (see 6.3.4);
- results of the electrical test (see Table 3).

It is advisable to show a graph of the temperature profile of the second cycle (see 6.3.3).

### 8.3 Mechanical test

The test report shall include the following information:

- connector class (see 5.1);
- conductor used (see 5.2);
- connector and installation procedure (see 5.3);
- results of the mechanical test.

## **Annex A** (normative)

### **Equalizers and their preparation**

#### **A.1 Requirements for equalizers**

For stranded and flexible conductors, the potential difference between the strands at measuring positions may cause errors in measuring electrical resistance.

Therefore equalizers are needed, the requirements for which are:

- achieve the electrical connection of all the strands to ensure accurate electrical resistance measurements;
- achieve thermomechanical strength throughout the electrical test including the short-circuit test if applicable (e.g. by avoiding excessive annealing or constricting of strands during preparation of equalizers and providing adequate current carrying volume);
- avoid thermal effect on the connector or the reference conductor temperature readings during current heating (e.g. by using bulky equalizers).

Welded, soldered or crimped equalizers may be used to overcome this problem and to ensure uniform current distribution during resistance measurement. Welding equalizers is the recommended method for stranded conductors 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.2 Recommendations for welding equalizers**

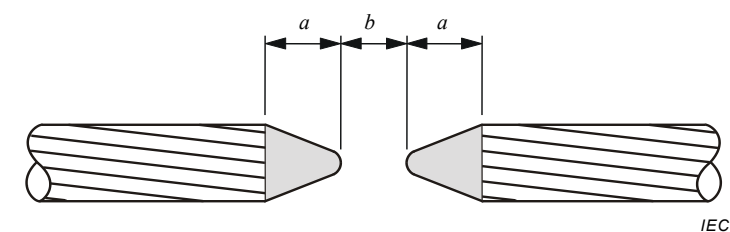
The welding material should be similar to the conductor material.

Cut the conductors square, clean the ends, and melt them with the welding torch ensuring all strands are welded together. Build up the weld until the chamfer dimensions are achieved. The length of the chamfer is referenced as  $a$ , and the separation between the conductors for final welding is referenced as  $b$ .

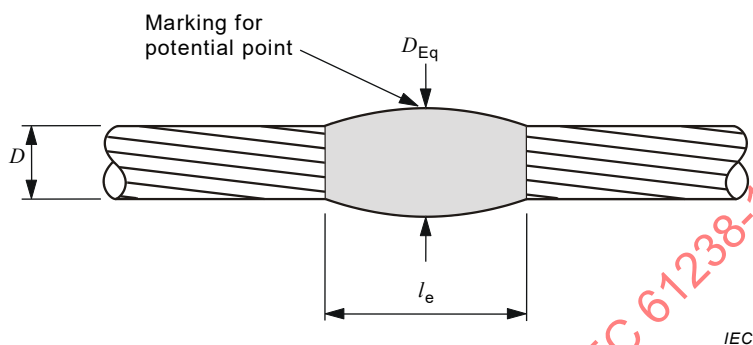
With the conductors supported and spaced by dimensions  $b$ , build weld metal up at the centre and turn the conductors so as to obtain a uniform circular weld profile.

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.

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



a) Ends prepared



b) Welded/soldered equalizer

where:

For circular shape

$$D \leq D_{Eq} \leq 1,4 \times D$$

$$l_e \leq 1,5 \times D + 10 \text{ mm}$$

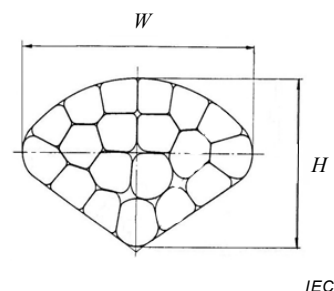
For sectoral shape

$$H \leq H_{Eq} \leq 1,4 \times H \text{ and } W \leq W_{Eq} \leq 1,4 \times W$$

$$l_e \leq 1,5 \times H + 10 \text{ mm}$$

**Key**

|            |                      |
|------------|----------------------|
| $a$ :      | chamfer length       |
| $b$ :      | conductor separation |
| $D$ :      | conductor diameter   |
| $D_{Eq}$ : | equalizer diameter   |
| $l_e$ :    | equalizer length     |
| $H$ :      | sector height        |
| $W$ :      | sector width         |



**Figure A.1 – Preparation of equalizers**

## Annex B (normative)

### Measurements

#### B.1 Potential measuring positions for typical connectors

Potential measuring positions for the purpose of resistance measurement are shown in Figure 4. Potential measuring positions on solid conductors shall be adjacent to, but not touching, the connector. For stranded conductors, the potential measuring positions are the mid-point of the equalizers, which shall be  $15\sqrt{A}$  mm or 150 mm, whichever is the longer, away from the connector. The actual lengths of  $l_a$  and  $l_b$  can vary in a real test set-up at each connector. It is therefore necessary to take into account these individual readings for the calculation of the resistance for every individual connector.

#### B.2 Temperature measurement

A good thermal contact between the thermocouple junction and the measuring object shall be established.

In the case of the reference conductor (Figure 4 a)), the thermocouple shall be positioned at the mid-point and secured either in a small hole drilled in a solid conductor, or by sliding it under the strands of the outer layer of a stranded conductor.

In the case of connectors (Figure 4 b) to Figure 4 h)), the thermocouple may either be inserted in a small hole drilled into the main body of the connector, or be secured to the outside surface using a thermally conductive adhesive or self-adhesive thermal tape. In the latter case, the amount of glue or tape used to install the thermocouple should not affect the heat dissipation in the connector.

#### B.3 Equivalent conductor resistance

It is necessary to measure the resistance of a known length of the reference conductor and its temperature (Figure 4 a)), so that the actual connector resistance  $R_j$  may be calculated, by subtracting the resistance due to the conductor lengths  $l_a$  and  $l_b$ . The various lengths, which need to be recorded, are shown in Figure 4.

It should be noted that in the case of branch connectors, resistances of both the main and the branch reference conductors are used when calculating the actual connector resistance (see Figure 4 d)).

It is necessary to measure the resistance of the reference conductor on each occasion that the connector resistance measurement is made. All measured resistance values of the reference conductor (corrected by temperature) shall be stable throughout the complete test to show that the equalizers are stable in principle. For the determination of the parameter  $k$  (see Annex F) it is essential that during resistance measurement the reference conductor and all connectors are in the range of ambient temperature such as defined in 6.2.2.

## **Annex C** (informative)

### **Recommendations to decrease uncertainties 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 potential measuring positions should be used throughout the test, they should be clearly marked since calculation always refers to the initial situation. Verification of measuring positions, especially after the short-circuit test, is advised.

#### **C.2 Measurements, instruments and readings**

For 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.

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

If possible, use the same instrument for voltage ( $\Delta U$  DC), current ( $\Delta U$  DC of a shunt) and temperature ( $\Delta U$  DC 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 throughout the whole test;
- to avoid, whenever possible, the replacement of any instrument, since 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 programme for the calculation to avoid errors by accident.

When calculating the  $k$  value, it is possible to use the measured resistance values of the reference conductor and the connectors without any temperature correction, provided that the resistance of the reference conductor does not change during the test and the temperatures of all parts of the test loop are the same and in stable conditions when resistance measurements are made.

Every effort should be made to avoid spurious readings.

## Annex D (normative)

### Calculation of adiabatic short-circuit current

The general form of the adiabatic temperature rise formula which is applicable to any initial temperature is:

$$I_{AD}^2 t = K^2 S^2 \ln \left( \frac{\theta_f + \beta}{\theta_i + \beta} \right)$$

where:

- $I_{AD}$  is the short-circuit current (RMS over duration) calculated on an adiabatic basis (A)
- $t$  is the duration of short-circuit (s)
- $K$  is the constant depending on the conductor material ( $As^{1/2}/mm^2$ ) see Table D.1 below for normative values of  $K$
- $S$  is the actual cross-sectional area of the conductor ( $mm^2$ ) see below
- $\theta_f$  is the final temperature ( $^{\circ}C$ )
- $\theta_i$  is the initial temperature ( $^{\circ}C$ )
- $\beta$  is the reciprocal of temperature coefficient of resistance of the conductor at  $0^{\circ}C$  (K) see Table D.1 below for normative values of  $\beta$
- $\ln$  is  $\log_e$

**Table D.1 – Material properties**

| Material  | $K$ ( $As^{1/2}/mm^2$ ) | $\beta$ (K) |
|-----------|-------------------------|-------------|
| Copper    | 226                     | 234,5       |
| Aluminium | 148                     | 228         |

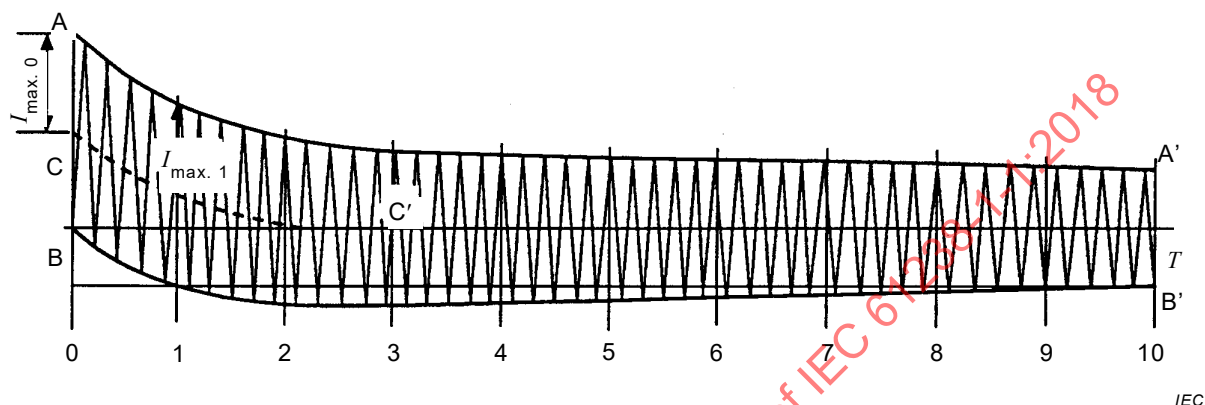
Although it is not required to measure the final temperature of a conductor during the short-circuit test, experience has shown that the actual final temperature for some conductor sizes is significantly higher when applying this calculation by using the nominal cross-sectional area. Therefore it is recommended to determine the actual cross-sectional area ( $S$ ) to prevent overheating. In this case, the preferred method is to weigh a fixed length of conductor and calculate the actual cross-sectional area ( $S$ ) using the material density. The fixed length of conductor should not be lower than the reference length ( $l_r$ ) used in the electrical ageing test or 1 000 mm, whichever is the greater.

Annex D is based on Clause 3 and Table I of IEC 60949:1988 and IEC 60949:1988/AMD1:2008 wherein the complete calculation method can be found. This method shall be used for alloys.

## Annex E (informative)

### Determination of the value of the short-circuit current

In the case where there is no constant symmetrical RMS value during the short-time current, the equivalent RMS value can be determined from an oscillogram, using the method described below (see Figure E.1).



#### Key

|                   |                                                                                                                      |
|-------------------|----------------------------------------------------------------------------------------------------------------------|
| AA' and BB'       | Envelopes of current waves                                                                                           |
| CC'               | Displacement of current-wave zero line from normal zero line at any instant                                          |
| $I_0, \dots, I_i$ | RMS value of the AC component of current at any instant calculated from normal zero: DC component (CC') is neglected |
| $I_{\max 0}$      | Peak value of the AC component of current at the instant of initiating short circuit                                 |
| BT                | Duration of short circuit                                                                                            |

**Figure E.1 – Determination of equivalent RMS value  
of current during the short-circuit test**

The total time BT of the test is divided into 10 equal parts by verticals 0 to 1...10 and the peak value of the AC component of the current is measured at these verticals.

These values are designated:  $I_{\max 0}, I_{\max 1}, I_{\max 2}, \dots, I_{\max 10}$ .

The effective values are then:  $I_i = I_{\max i} / \sqrt{2}$ .

The equivalent RMS current during the time BT is given by:

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

NOTE Annex E is consistent with Annex G of IEC 62475:2010.

## Annex F (normative)

### Calculation method

#### F.1 General

This statistical evaluation shall follow IEC 60493-1.

#### F.2 Measurements made

To the cycles listed in Table 2, the following measurements with the test loop at ambient temperature shall be taken (see 6.2 and Annex B):

$U$  potential difference between measurement positions spanning each connector;

$I$  direct current at the moment of measuring  $U$ ;

$\theta$  temperature of each connector at the moment of measuring  $U$ ;

$U_r$  potential difference between measurement positions on the reference conductor;

$I_r$  direct current at the moment of measuring  $U_r$ ;

$\theta_r$  temperature of the reference conductor at the moment of measuring  $U_r$ .

The above is the recommended method. Direct measurements of resistance  $R$  and  $R_r$  may, alternatively, be used for any of the above  $U/I$  values.

In addition, temperature measurements on each connector and on the reference conductor during heat cycling on the cycle prior to, or following the resistance measurements shall be recorded.

Distances  $l_a$ ,  $l_b$ ,  $l_j$ ,  $l_r$  defined in Figure 4, are measured and are applicable for the whole test. The distances shall be measured with a tolerance of  $\pm 2$  mm for lengths  $\geq 40$  mm, or  $\pm 5$  % for lengths  $< 40$  mm.

#### F.3 Connector resistance factor $k$

The resistance, referred to 20 °C, between measuring positions spanning a connector is as follows:

$$R = \frac{U}{I} \times \frac{1}{1 + \alpha(\theta - 20)}$$

Where the temperature coefficient of resistance  $\alpha$ , for the purposes of this document, is regarded as equal for copper and aluminium:

$$\alpha = 0,004 \text{ K}^{-1}$$

The resistance of the reference conductor, referred to 20 °C, is as follows:

$$R_r = \frac{U_r}{I_r} \times \frac{1}{1 + \alpha(\theta_r - 20)}$$

The connector resistance  $R_j$  is then:

$$R_j = R - R_r \times \frac{(l_a + l_b)}{l_r}$$

and the connector resistance factor  $k$ :

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j} \quad (\text{F.1})$$

#### F.4 Initial scatter $\delta$

The scatter between the six values of  $k_0$  (one value for each connector) at cycle no. zero is calculated as follows:

calculate the mean value:

$$\bar{K}_0 = \frac{1}{6} \sum_1^6 k_0$$

then the standard deviation:

$$s_0 = \sqrt{\frac{1}{5} \sum_1^6 (k_0 - \bar{K}_0)^2}$$

and finally the scatter:

$$\delta = \frac{1}{\sqrt{6}} \frac{s_0}{\bar{K}_0} t_s$$

where:

$t_s$  is the Student coefficient;

$t_s = t_{5;0,995} = 4,032$  for 99 % two-sided confidence level and five degrees of freedom;

hence:

$$\delta = 1,65 \frac{s_0}{\bar{K}_0} \quad (\text{F.2})$$

#### F.5 Mean scatter $\beta$

This scatter shall be determined using the last 11 measurement readings of resistance. These 11 readings start after the 250<sup>th</sup> cycle and then every 75 cycles up to 1 000 cycles. A tolerance of  $\pm 10$  cycles is permitted on the timing of any reading, and in this case, the statistical formulae listed in this document are applicable. Outside this tolerance, a detailed statistical treatment is necessary. For convenience of calculation, the origin is transferred to the mid-point of the 11 readings and the statistical variable  $x$  is introduced (see Figure F.1). The symbol  $x$  has the values 0,  $\pm 1$ ,  $\pm 2$ , ...,  $\pm 5$ .