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TECHNICAL REPORT

RAPPORT TECHNIQUE

Guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals

Guide concernant l'échauffement admissible des parties des matériels électriques, en particulier les bornes de raccordement

IEC/TR 60943:1998+A1:2008

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INTERNATIONAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

GUIDANCE CONCERNING THE PERMISSIBLE TEMPERATURE RISE FOR PARTS OF ELECTRICAL EQUIPMENT, IN PARTICULAR FOR TERMINALS

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
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- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 60943, which is a technical report of type 3, has been prepared by IEC technical committee 32: Fuses.

This consolidated version of IEC 60943 consists of the second edition (1998) [documents 32/142/CDV and 32/148/RVC] and its amendment 1 (2008) [documents 32/187/DTR and 32/188/RVC].

The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience.

It bears the edition number 2.1.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

Annexes are for information only.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

INTRODUCTION

a) The temperature rise encountered in electrical assemblies as a result of the various losses in the conductors, contacts, magnetic circuits, etc. is of growing importance as a result of the development of new techniques of construction and operation of equipment.

This development has been particularly significant in the field of assemblies, where numerous components dissipating energy (contactors, fuses, resistors, etc.), in particular modular devices are found within enclosures of synthetic materials which are somewhat impermeable to heat.

This temperature rise results in a relatively high temperature of the basic elements constituting the electric contacts: a high temperature favours oxidation at the contact interface, increases its resistance and thereby leads to further heating, and thus to an even higher temperature. If the component material of the contact is unsuitable or insufficiently protected, the contact may be irreparably damaged before the calculated useful life of the equipment has expired.

Such temperature rises also affect connection terminals and the connected conductors, and their effects should be limited in order to ensure that the insulation of the conductors remains satisfactory throughout the life of the installation.

b) In view of these problems, this report has been prepared with the following objectives:

– to analyze the various heating and oxidation phenomena to which the contacts, the connection terminals and the conductors leading to them are subjected, depending on their environment and their arrangement;

– to provide elementary rules to product committees to enable them to specify permissible temperatures and temperature rises.

c) Attention is drawn to the precautions to be taken for sets of components when parts are grouped together in the same enclosure.

The attention of users should be drawn particularly to the fact that the temperature rise of terminals permitted by particular switchgear standards results from conventional situations during type tests; these can differ appreciably from the situations met with in practice, which have to be taken into account, particularly because of the temperatures permitted by the insulation of the conductors which may be connected to the terminals under normal conditions.

d) Attention is drawn to the fact that in the relevant product standards, the permissible temperature and temperature rise for the external terminals are measured during conventional type tests and therefore they may not reflect the actual situation likely to occur in normal use.

Suitable precautions should then be adopted to avoid exposure to temperatures that may affect the life of materials adjacent to the terminals of components.

In this case, it is essential to distinguish the concept of "external ambient temperature" which prevails outside the enclosure from that of "the temperature of the fluid surrounding a part" which comprises the external ambient temperature plus the internal temperature rise due to the parts. These concepts, as well as other complementary concepts such as the thermal resistance of an enclosure, are dealt with in clause 5 and explained by means of numerical examples.

In order to facilitate complete calculation, this report links up the temperature of the fluid surrounding a component to the external ambient temperature by the introduction of the concept of "coefficient of filling" and gives a numerical example (5.2.3.2) which specifies the values of the coefficient of filling to be used in several practical cases.

The quantities involved in calculating contact constriction resistance are subject to wide variations due to the physical conditions and degree of contamination of the surface in contact. By calculation alone, therefore, the contact resistance can be estimated to an accuracy of no better than an order of magnitude.

More precise and more accurate values should be obtained by direct measurement on given items of electrical equipment, because in practice it is often the case that other incalculable degradation mechanisms predominate.

This report is not meant to give guidance on the derating of components.

It is strongly advised that the reference literature quoted at the end of this report be studied before attempting to apply the data to a practical problem.

GUIDANCE CONCERNING THE PERMISSIBLE TEMPERATURE RISE FOR PARTS OF ELECTRICAL EQUIPMENT, IN PARTICULAR FOR TERMINALS

Section 1: General

1 General

1.1 Scope and object

This report is intended for guidance in estimating the permissible values for temperature and temperature rise of component parts of electrical equipment carrying current under steady state conditions.

This report applies to electrical power connections and materials adjacent to them.

This report is concerned with the thermal effects of currents passing through connections, therefore there are no voltage limits to its application.

This report is only applicable when referred to in the appropriate product standard.

The extent and manner to which the contents of this report are used in standards is the responsibility of individual Technical Committees.

Whenever "permissible" values are stated in this report, they mean values permitted by the relevant product standard.

The present report is intended to supply:

– general data on the structure of electric contacts and the calculation of their ohmic resistance;
– the basic ageing mechanisms of contacts;
– the calculation of the temperature rise of contacts and connection terminals;
– the maximum “permissible” temperature and temperature rise for various components, in particular the contacts, the connection terminals and the conductors connected to them;
– the general procedure to be followed by product committees for specifying the permissible temperature and temperature rise.

1.2 Reference documents

IEC 60050(441):1984, *International Electrotechnical Vocabulary (IEV) – Chapter 441: Switchgear and controlgear and fuses*

IEC 60085:1984, *Thermal evaluation and classification of electrical insulation*

IEC 60216-1:1990, *Guide for the determination of thermal endurance properties of electrical insulating materials – Part 1: general guidelines for ageing procedures and evaluation of the test results*

IEC 60364-4-42:1980, *Electrical installations of buildings – Part 4: Protection for safety - Chapter 42: Protection against thermal effects*

IEC 60694:1996, *Common specifications for high-voltage switchgear and controlgear standards*

IEC 60721-2-1:1982, *Classification of environmental conditions – Part 2: environmental conditions appearing in nature. Temperature and humidity*

IEC 60890:1987, *A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low voltage switchgear and controlgear*

IEC 60947-1:1988, *Low-voltage switchgear and controlgear – Part 1: General rules*

1.3 Definitions

Definitions of terms used in this report may be found in the International Electrotechnical Vocabulary. For the purposes of this technical report, the following terms also apply:

1.3.1
ambient air temperature Θ_a
the temperature, determined under prescribed conditions, of the air surrounding the complete device [IEV 441-11-13]

NOTE For devices installed inside an enclosure, it is the temperature of the air outside the enclosure.

1.3.2
contact (of a mechanical switching device)
conductive parts designed to establish circuit continuity when they touch and which, due to their relative motion during an operation, open or close a circuit or, in the case of hinged or sliding contacts, maintain circuit continuity [IEV 441-15-05]

NOTE Do not confuse with "IEV 441-15-06 Contact (piece): one of the conductive parts forming a contact."

1.3.3
connection (bolted or the equivalent)
two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts, or the equivalent [3.5.10 of IEC 60694]

1.4 Symbols

A list of symbols used in this report is given in annex F.

Section 2: Theory

NOTE This theory applies to both "contacts" and "connections" as defined in 1.3.2 and 1.3.3. For convenience, only the word "contact" only is used in this section to cover both applications.

2 General considerations concerning the nature of electric contact and the calculation and measurement of the ohmic resistance of contacts

2.1 Electric contacts and connection terminals

Electric contact, in its simplest and most general configuration, results from contact established between two pieces of (usually metallic) conducting material. In the case of connection terminals, these are the terminal itself and the conductor which is connected to it.

The active zone is the contact "interface" which is the region where the current passes from one piece to the other. It is in this area that the contact resistance occurs, causing heating by Joule effect, and it is also where ageing occurs through chemical reaction with the surrounding atmosphere.

2.2 Nature of electric contact

When one piece of metal is applied to another, contact is not made over the whole apparent contact area, but only at a certain number of points called "elementary contacts".

The effective total cross-sectional area of these contacts is equal to the effective contact area S_a [1] if the possible presence of impurities is ignored (dust, etc.) at the contact interface.

There is also a fine layer of air or of oxide normally present, the effect of which upon the contact resistance will be examined later (see 2.3).

In the following, for ease of calculation and for a better understanding of the contact mechanisms, the simplifying assumption is made that there are n elementary contacts on the apparent contact area, uniformly distributed, of average constant radius a (see figure 1). The average distance between these elementary contacts is l.

The effective contact area is then:

$$S_a = n \pi a^2$$

[1] For an explanation of the symbols used in this report, see annex F.

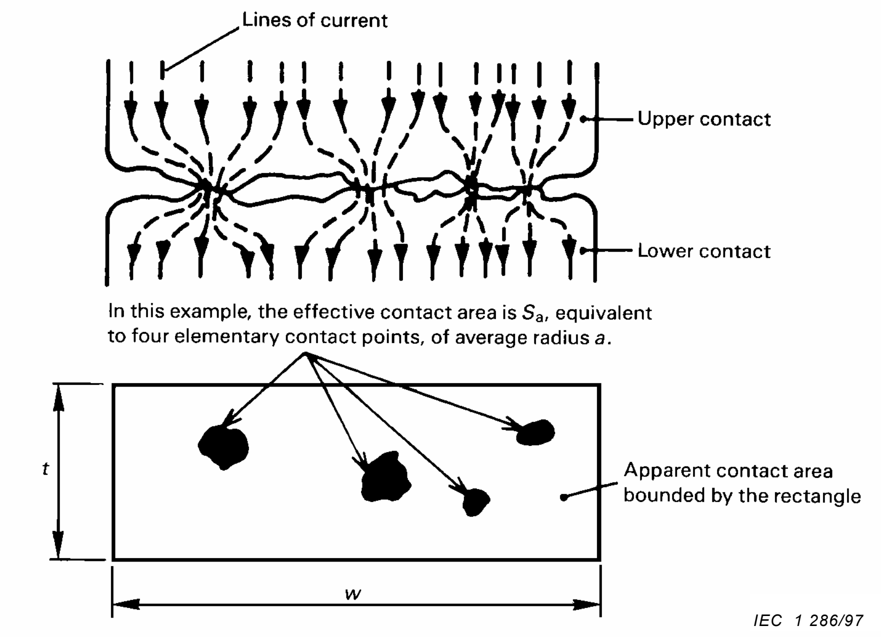

Figure 1 – Illustration of apparent contact and effective contact areas

The contact area S_a depends upon how hard the contacts are pressed against each other, i.e. upon the force applied, the surface state of the contacts, and the hardness of the material used.

For the forces normally found in electrical technology, the contact area is, in practice, the area over which the force applied reaches the ultimate strength of the contact material characterised by the "hardness" of that material.

In fact, the asperities on each of the two surfaces before they are brought into contact and which are due to previous preparation of the surface are of small dimension (of the order of 1/100 mm) and are crushed even by small forces of the order of 0,1 N.

Assuming that the pressure exerted upon the contact area is equal to the contact hardness of the metal (H), then the following equation is obtained:

$$\frac{F}{S_a} = \xi \ H$$

However, this equation applies only for a contact force of $F \geq 50$ N, in fact:

$$S_a = n\pi \ a^2 = \frac{F}{\xi \ H}$$

where ξ is a dimensionless "coefficient of flatness" dependent upon the state of the surfaces in contact, usually having a value of between 0,3 and 0,6 for normal forces, but which can be much smaller after extensive polishing of the contact surfaces against each other.

As a result, the elementary contact radius a is given by the equation:

$$a = \sqrt{\frac{F}{n\pi\xi H}} \qquad (1)$$

The number *n* of elementary contacts can be worked out approximately by the formula:

$$n = n_k H^{0,625} F^{0,2} \quad (2)$$

where $n_k \approx 2,5 \times 10^{-5}$ (SI units)

The above expression gives only the order of magnitude of the number of elementary contacts. Values of n_k can differ significantly from the value estimated, for example between $0,5 \times 10^{-5}$ and 30×10^{-5} (SI units).

2.3 Calculation of contact resistance

Contact resistance is made up of two components:

a) constriction resistance, due to the drawing together of the lines of current as they pass through the elementary contacts;

b) film resistance, corresponding to the film of oxide or of adsorbed molecules at the interface.

2.3.1 Calculation of the constriction resistance

Consider (see figure 2) an idealised elementary contact of radius *a*. If the electrical conductors are large in relation to the elementary contact, the lines of current are hyperbolae with foci located at the ends of the elementary contact diameter and the equipotential surfaces are flattened ellipsoids of the same foci.

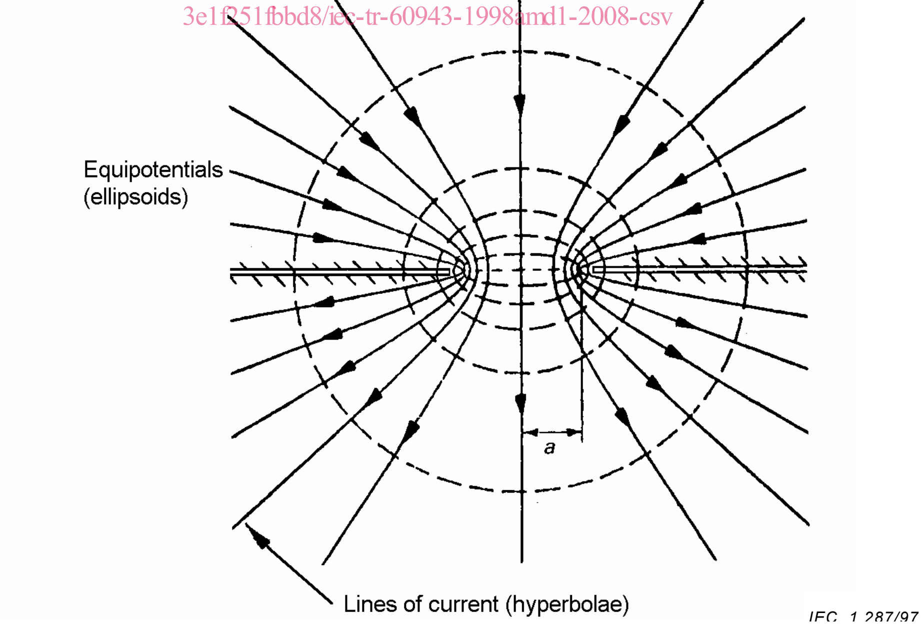

Figure 2 – Equipotentials and lines of current at an elementary contact point

The resistance $R_{(a,l)}$ between the point of contact (heavy broken line in figure 2) and the semi-ellipsoid of major semi-axis l (l being the average distance between neighbouring elementary contacts and ρ the resistivity of the metal) is equal to half the contact resistance, and is written:

$$R_{(a,l)} = \frac{\rho}{2\pi . a} \arctan \frac{\sqrt{l^2 - a^2}}{a}$$

If l is large compared with a, which is the more common case:

$$R_{(a,l)(l/a \to \infty)} = \frac{\rho}{4a}$$

since the constriction resistance is the sum of both halves

$$R_{(e)} = \frac{\rho}{2a} \qquad (3)$$

For an actual contact comprising n relatively widely spread elementary contact points, the constriction resistance is thus:

$$R_e = \frac{\rho}{2na} \qquad (4)$$

2.3.2 Calculation of the film resistance

The elementary contact points generally do not have a corrosion-free interface. Indeed, any initially pure metal surface becomes covered with a molecular layer of oxygen, leading in a few minutes to the formation of a homogeneous layer of oxide a few nanometres thick. If this layer is sufficiently compact and uniform, it protects the metal to some extent, the oxidation can then stop and the metal is "passivated"; this is particularly the case with aluminium and stainless steel at ordinary temperatures.

For other metals (copper, nickel and tin in the presence of oxygen; silver in the presence of sulphurous gases), the formation of this first layer of reaction product produced by oxidation or corrosion slows up the subsequent reaction which nevertheless continues, but more and more slowly.

For certain other metals (iron), the "oxidation" speed is more or less constant because the surface is not protected by the layer formed.

The main formulae for surface chemical reactions giving the thickness s formed as a function of time t and thermodynamic temperature T are contained in annex D for different metals.

They are derived from the general formula:

$$s = X \cdot \exp\left(-\frac{w}{2kT}\right) \cdot \sqrt{t} \qquad (5)$$

If the activation energy w is expressed in electronvolts, it is necessary to multiply w by $1{,}6021 \times 10^{-19}$ J/eV. X is a constant and k is the Boltzmann constant.