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DOCTORAL THESIS SUMMARY

Causes of electrical fires

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The content of the doctoral thesis

Brief introduction

Fire is defined as "the combustion process characterized by heat emission, accompanied by smoke or flames or both simultaneously".

The definition also admits the following wording: "burning that develops in a controlled manner in time and space".

For example, the controlled burning of straw residues is a controlled fire/fire; another example of a controlled fire is the ignition or flame generation of a stove. It is necessary that this application be carried out using the "gas flame" method.

Some of the main causes of fires are generated by electrical installations.

Experience reveals the fact that in most situations, in the technological spaces and their related constructions affected by fires, damage to the electrical installations also took place.

The investigation of the cause of an electrical fire must be based on scientific arguments, thus it is necessary to analyze the phenomena that occurred in the electrical installation and that can be highlighted through a series of traces present in the area of the fire.

The fire risk presented by an electrical installation is based on the thermal effect of the electric current or electric discharges in areas with weak contact and is determined
the quality of the execution, the way the installations are operated, the nature of the materials in their vicinity, etc.

An important cause that is frequently generated is the electric short circuit.

The electric short circuit occurs when the insulation between two conductors of a network or a device degrades and between which there is a potential difference, they can come into contact with each other or when the insulation of a conductor under tension with respect to the ground degrades.

The electric shock accident occurs when the human body is interposed between two points with different electric potentials, located in which an electric current flows through it capable of affecting vital functions (breathing, blood circulation and nervous activity).

The paper presents a series of aspects related to electrical installations, measures imposed with the aim of preventing fires that could be initiated by certain irregularities encountered in their operation, phenomena that occur in functional electrical installations, and last but not least, the existing dangers for humans when they come into contact with electrical voltage in different circumstances.

In accordance with the title of the thesis, of course the first part of the paper is devoted to the description of the heating of conductors and electrical contacts, but also of a phenomenon that can generate catastrophes, loss of human life and destruction of material goods: the fire / explosion.

Special attention was paid to electrical conductors, due to their importance in the production of electrical fires, the complexity of their structure and the strict measures required in their use. Failure to comply with the rules established in this area can lead to events preceding the occurrence of fires.

The last chapters provide details about the causes of fire of an electrical nature, more specifically the phenomena that occur in electrical installations, the methodology that must be applied in order to establish the causes of fire, and last but not least, about short circuit.

In Romania, according to the latest statistics of the General Inspectorate for Emergency Situations (IGSU), around 30,000 firefighting interventions take place every year, of which 26% are electrical fires. Also, at European level, statistics suggest that every year over 5000 people die in fires and around ten times as many are injured. Of the registered fires, a quarter are also of an electrical nature. Although fires of an electrical nature represent an important and hidden threat, with enormous damages and very unpleasant consequences, it is only relatively recently that the causes and methods of extinguishing and prevention have begun to be addressed and studied.

Fire and Explosion Initiation Equation

The phenomenon of initiation of a *fire/ explosion* type event is determined by *the burning triangle* (fig.1) which can be defined by means of equation (1):

fire initiation= (1, (1) 2 , 3, 4) = (1, 2 , 31 , 32, 4),

or

burst start = (1, 2 , 3, 4) = (1, 2 , 31 , 32, 4) (2)

Fig. 1 ÿ The burning triangle.

The variables involved in relations (1 and 2) are:

- 1 - the means or component elements of its structure (it may or may not represent the seat of the phenomenon, i.e. it may or may not contain the ignition/ignition source characterized by the ignition/ignition temperature);

- 2- the source (which can be electrical or non-electric); it is necessary and sufficient that between the source and the first material of a liquid nature, vapors of liquids, powders, dusts, LPG mists, fluff/suspensions of an organic/inorganic nature, gases, etc., that ignite/ignite there is a condition of characteristic distance/length (.), which admits a maximum value; by exceeding/ increasing this value, ignition/ignition can no longer be achieved; to generate the ignition/ignition temperatures, as the case may be, it is necessary for the variable to generate sufficient energy to initiate a fire/explosion; 2

- 31- the first material that can ignite/ignite; in the case of combustible materials such as liquids/vapors of liquids, powders, dusts, LPG mists, lint/suspensions of organic/inorganic nature, gases, etc., an important factor in this regard is the concentration of these substances in the air;

- 32 - the atmospheric air which, in order to contribute to the initiation of an explosion, is necessary and sufficient to contain oxygen for pressure and temperature at predefined values within (16÷21)%;

- 4 - the circumstance;

- *t, s* - the moment of time, respectively the space (volume) at / in which it is realized simultaneously the conditions stated above.

From a spatio-temporal point of view, relation (1) which signifies the initiation of a fire, can also be defined by means of the equation:

$$\text{fire initiation min} \; \bigcap_{k=1}^{k=4} k\,ÿxts\,(, \;), \qquad (3)$$

which represents the minimum time value at which the intersection of the variables under discussion is achieved, in relation to certain conditions, determined mainly by time and space:

= and = , for = 1.4. (4)

Conditions necessary for the initiation of a fire/explosion

The means of producing the fire may or may not contain the source of ignition. The source must generate sufficient energy to initiate ignition and be at a certain minimum distance from the first flammable material. For a fire-type event to be generated, the simultaneity in time and space of the *xk* variables is sufficient
(t,s) in relation (1). For a certain space, each of these variables appears in a certain time interval *ÿtk,* the fire being initiated only in the time interval that corresponds to the intersection of the *k* time intervals (fig. 2), the minimum time at which the initiated fire occurs representing the lower limit of this range.

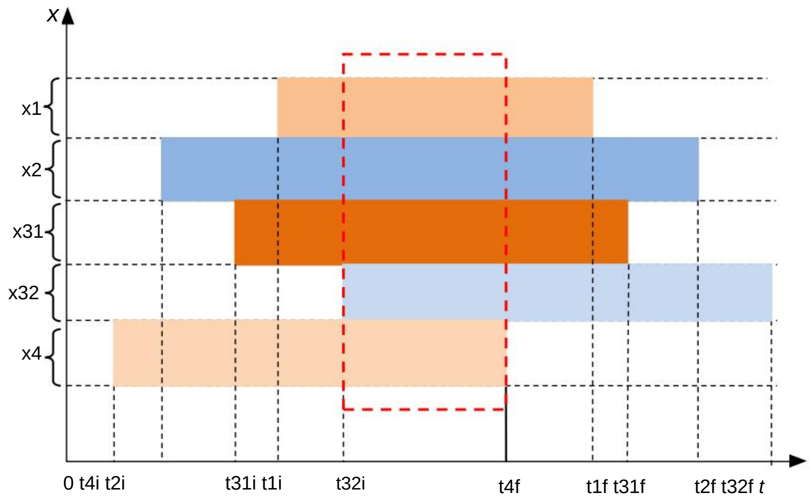


Fig. 2 The time interval in which the fire can occur

The initiation of fires therefore implies the simultaneous existence in time and space of the variables in equation (1):

- the means or the component elements in its structure (devices, devices, tools, etc.), which generate the source of ignition due to the performance of some functional activities (power supply to users, circuit coupling, personnel intervention);

- ignition source (heating of conductors and contacts, piercing insulation, the appearance of an electric arc, etc.) which is necessary to overcome the minimum ignition energy of the nearby flammable material (plastic materials, paper, cardboard, etc.);

- the combustible or flammable material (the first material in the series of combustible materials existing in the space where the fire can occur) that generates the ignition phenomenon (fuel vapors, alcohol, solvents, powders and organic fibers, etc.);

- atmospheric air (for the initiation of combustion it is necessary to contain minimal oxygen between the limits of 16...21%; (as the percentage increases above the value of 21% oxygen, the probability of fire initiation through a combustion reaction increases);

- the circumstances that contribute to the realization of the phenomenon (humidity of the environment, non-compliance with the instructions for use, improvised installations, faulty devices, unauthorized interventions, etc.).

An important variable or parameter that belongs to the multitude of circumstances is the humidity of the environment (surrounding, ambient or technological), in which the various specific activities (industrial, domestic, etc.) are carried out; for numerical values of the humidity of the environment that exceed the value of 75% in the air or in the atmospheric environment, no phenomena of electrostatic charge are generated, thus not being possible to initiate fires or explosions, through this phenomenon.

Some causes of fire initiation in electrical installations

Electrical distribution boards are components of electrical installations with the role of ensuring the distribution of electricity, either to other boards or to various receivers. They contain cables as well as connection, protection, control or maneuvering elements, and in the case of important panels, also measurement, control, signaling, regulation and eventually automation equipment.

In abnormal conditions, when the insulation of the conductors is damaged or destroyed, local heating or electric arcs may occur in these switchboards, which can lead to fires followed by putting the electrical installation out of service by destroying the switchboard, or they can spread outwards, starting fires in the premises neighboring. The most common causes of fires in electrical panels are abnormal regimes caused by electric overcurrent, overvoltage, voltage drop below certain limits or distorted regimes. Aging and penetration of insulations, wear of connecting and switching elements, electric springs, electric leakage currents, reduction of contact pressure but also other causes, such as improper handling or maintenance, can also cause fires. All these causes determine the initiation of the fire through the appearance of single or multiple ignition centers, due to the increase of the local temperature above the limit of melting or ignition of the insulations or the materials with which there is contact.

If a cable is damaged or a poor contact occurs, fire can start took place starting from two phenomena:

ÿ local carbonization;

ÿ the appearance of an electric arc.

The local accumulation of carbon at the site of charring allows the electric current to continue to pass through the charred material. Due to its non-uniformity, electric currents cause different voltage drops and therefore the possibility of electric arcs that cause the amplification of carbonization until the amount of carbon is sufficient for a spontaneous inflammation of the area.

If the fault occurs in the space between two conductors or in the space between a live conductor and a body at zero potential, an electric arc appears through the determined conductor channel that leads to local carbonization and fire initiation by igniting the carbon produced.

Electrical overcurrent can be short-lived (under 10-15 seconds) or long-lived (overload). In the case of short-term electrical overcurrent (electrical fault current), the intensity of the electrical current may exceed the nominal values, but these phenomena are generally less dangerous because there is not enough time for the temperature to rise to the melting point of the conductor and fire starter. In the case of long-term ones, more moderate exceeding of the nominal values can cause the temperature to rise over time to the ignition limit of the insulation or the materials with which the conductor is in contact.

Overvoltage is the exceeding of the rated voltage, which, over time, has the effect of aging the insulating material, reducing its life span and increasing the probability of electrical fault or short-circuit currents that can cause fire (fig. 2.4).

The decrease in supply voltage leads, over time, to undesirable effects because, in the case of certain categories of receivers, such as electric motors, it causes the increase in the intensity of the electric current and the heating of the supply conductors, with all the consequences that follow from here.

Distorted regimes are due to the increasing use of non-linear circuits in AC networks, which generates high-intensity current harmonics in the network. In the case of unbalanced three-phase circuits, the generated harmonics can cause the neutral conductor to be charged with a third-order harmonic electric current, which could reach the intensity of the phase electric current. Under these operating conditions, significant overheating of the neutral conductor can occur, developing the risk of insulation damage and ultimately fire conditions.

The aging of the insulations, as a normal phenomenon in operation or due to the aggressive action of the environment (subjection to extreme temperatures and humidity or the action of corrosive substances), causes the loss of the quality of the insulation or the appearance of cracks in the material, thus favoring the appearance of electrical leakage currents due to the defect or breaking the insulation, causing a short circuit to neighboring conductors or to ground.

Wear of contact or switching elements is one of the frequent causes of electrical fires. Loosening of fixed contacts (connection points) or repeated actuation of mobile contacts (switches, disconnectors, coupling bars, etc.) causes sparks and electric arcs that heat, oxidize and melt the contacts, causing a strong increase in contact resistance and local temperature.

Fig. 3. Fires at electrical panels

These phenomena determine the melting and ignition of the insulation, as well as the support materials in the immediate vicinity, which can generate strong fires, the melting of the metal of the conductors and the production of short circuits.

Mishandling by maintenance personnel or improper maintenance can also promote and generate fire conditions.

Non-checking and improper fixing of connection points, installation of uncalibrated fuses, non-periodic control of socket contacts, switches and coupling elements, connecting receivers through improvised installations, connecting receivers with rated powers higher than the load allowed in the general table or in the network, non-compliance with the rules of fire prevention and extinguishing, are just some of the frequent causes that lead to dangerous overheating that can generate fires.

The concept of extinguishing a fire

Starting from the post-initiation equation of a fire:

$$\text{post-initiation fire} = ÿ = ÿ(ÿ_2, ÿ_{31}, ÿ_{32}), \qquad (5)$$

(in which, ÿ marked the burning triangle), a situation that practically constitutes the essence of the theory of burning/use of extinguishing substances, it is observed that the intervention/operation of extinguishing a fire is carried out by the action of extinguishing substances only on the variables that determine/ form the combustion triangle.

The extinguishing operation/action can be carried out, as the case may be, by intervening only on variables:

- $ÿ_2$: represents the source, which is of the type: open flame or states/phenomena determined by smoldering combustion, incandescent combustion;
- $ÿ_{31}$: represents the material subject to combustion/burning; this may be the second, al third, etc., material subject to combustion;
- $ÿ_{32}$: represents the oxygen existing in the volume of air/space where it takes place develops combustion;
- two variables or three variables, simultaneously.

When a fire is intervened, in the sense of achieving its extinguishment/liquidation, the extinguishing substance is applied as appropriate.

Thermal conduction

The concept of conduction is related to the activity of microscopic particles: molecules, atoms, free electrons. Thermal conduction can be seen as the transfer of energy from higher energy particles belonging to the body or region of higher temperature to lower energy particles belonging to the body or region of lower temperature. The actual transfer is achieved through the interaction between the particles.

Elastic collisions, which inherently occur between neighboring molecules, transfer kinetic energy from neighbor to neighbor, from molecules with higher energy to molecules with lower energy. In this way, macroscopically, the net energy transfer occurs in the direction of decreasing temperature. Due to its association with the disordered motion of particles, conduction can be viewed as a *diffusion* of energy.

The situation is similar in the case of liquids, where the molecules are closer in space and stronger and more frequent molecular interactions. Similarly, in solids, conduction is attributed to molecular activity in the form of thermal vibration of the crystalline network. This mode of energy transfer is sometimes viewed as a superposition of elastic acoustic waves induced by the motion of atoms in the lattice. Phonons (quanta of acoustic energy) thus become analogous to photons in the theory of electromagnetic radiation. In non-conducting solids, thermal energy transfer is exclusively due to these lattice waves or phonons. In solid conducting bodies, energy transfer via free electrons also occurs.

Thermal convection

The transfer of thermal energy by convection is achieved by the combined action of two mechanisms. To the thermal energy transferred by the disordered movement of the microscopic particles (conduction or diffusion) is added the thermal energy transferred by the overall movement (ordered, macroscopic) of the fluid. The combination of the two mechanisms is due to the superposition of the overall movement over the thermal (disordered microscopic) movement for each molecule in the fluid. Convection is the most important way of heat transfer between a moving fluid and a surface that borders it, when they are at different temperatures.

The intensity of heat transfer by convection depends to a large extent on the mixing motion of the fluid particles. As a result, convection can be classified according to the nature of the flow. Thus, convection is called *forced* when the flow of the fluid is the result of external causes, such as a fan, a pump or atmospheric winds. On the contrary, convection is called *natural or free* when the overall movement of the fluid is induced by the upward forces resulting from the density differences due to the temperature gradients in the fluid.

It should be noted that, due to natural convection, the transfer of thermal energy exclusively by conduction rarely exists in a fluid.

Convection was, therefore, defined as the mode of heat transfer in a fluid, achieved by the combined action of conduction and overall movement of the fluid. In general, the energy that is transferred is the internal sensible or thermal energy (kinetic energy of the microparticles) of the fluid. There are, however, convection processes in which *latent energy* (potential energy of microparticles) is also transferred. It is the case of phase change processes between the liquid and vapor states of a fluid.

Thermal radiation

Thermal radiation is the energy emitted by bodies (solid, liquid or gaseous) having a finite temperature. The emission is attributed to changes in the configuration of the constituent electrons of the atoms or molecules in the emitting body. The energy of the radiation field is transported in the form of electromagnetic waves (or energy quanta called photons) and comes from the internal energy of the emitting matter. Thermal radiation has a wavelength between approximately 0.1 and 100 ÿm. They obey the same laws as light radiation: they propagate in a straight line, reflect, refract and absorb.

Both conduction and convection require the presence of an intermediate transport medium, while radiative transfer does not. In fact, radiative transfer is most efficient in a vacuum. Energy transfer through radiation is carried out from a distance, without direct contact between bodies. The phenomenon has a double meaning: a body radiates energy, but also it absorbs the energy emitted or reflected by the surrounding bodies. In solid and liquid bodies, the transformation of electromagnetic energy into thermal energy takes place in the superficial layers, and in gaseous bodies in the volume.

Thermal conductivity

The thermophysical properties of matter are particularly important in the analysis of heat transfer processes. These properties are divided into transport properties (thermal conductivity *ÿ,* kinematic viscosity ÿ, diffusion coefficient D) and thermodynamic properties (density ÿ, specific heat c).

The use of Fourier's law requires knowledge of thermal conductivity, *c* transport property that indicates the efficiency of energy transfer through the conduction process (thermal diffusion). Thermal conductivity depends on the physical structure of the matter, which in turn depends on the state of aggregation of the matter.

It can be intuited that the thermal conductivity property is generally higher for a solid than for a liquid, and higher for a liquid than for a gas. This aspect is largely due to the differences in the intermolecular space from one state of aggregation to another, being illustrated in value in figure 4.

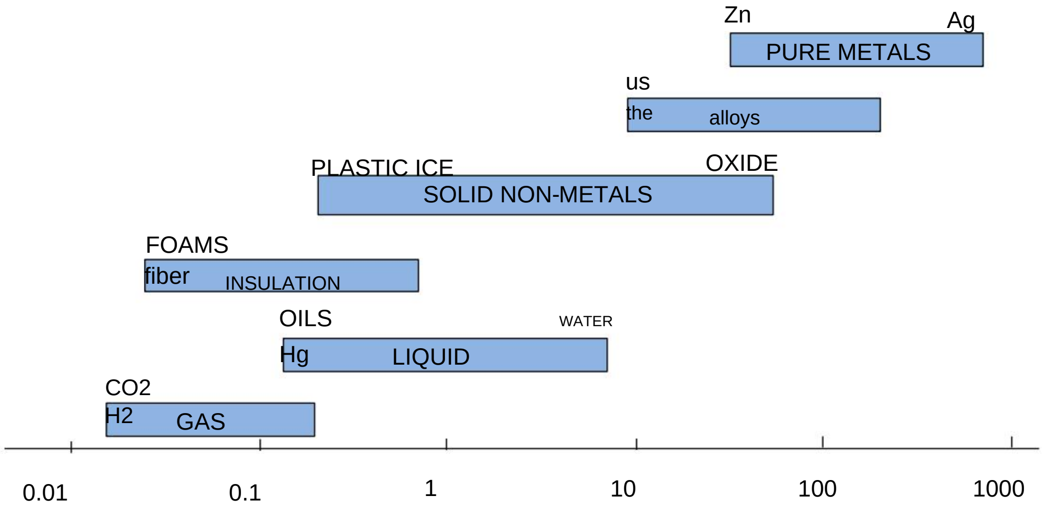


Fig. 4 The spectrum of values for the thermal conductivity [W/(mÿK)] of various categories of substances at atmospheric temperature and pressure.

Heating of electrical conductors

The heating of electrical conductors above the permitted limit and the occurrence of fires are due to several phenomena that occur as a result of non-compliance with the rules of design, execution and operation of electrical energy distribution facilities.

When heating the conductors due to the passage of the electric current, part of the dissipated heat *dQ* determines the heating of the provided conductor dQ1, and part of the heat *dQ2* is transmitted outside through its side surface. So the energy balance equation has the form:

$$= {}_1 + {}_2. \qquad (6)$$

The final temperature of the conductor is established when the variation of conductor temperature becomes zero.

The Joule-Lenz effect consists in the dissipation of energy in the conductor and the appearance of a thermal effect, resulting in an increase in temperature. In a conductor that has the electrical resistance R, through which an effective electric current I passes, in the time interval *dt* the heat flow *dQ is generated:*

$$\frac{}{ÿ} = ÿ = ÿ \quad ^2 \ [W], \tag{7}$$

which ensures the heating of the conductor but a part is transmitted to the outside through the insulation, whose temperature is a dependent function of the intensity of heat transfer to the surrounding air with *your* temperature :

$$= + \frac{1}{ÿ ÿ \quad ' \quad ÿ a} ÿ ÿ = + \frac{\quad ' \quad 2}{ÿ ÿ \quad ' \quad ÿ a} \ [K]. \tag{8}$$

The influence of the distorted regime on the heating of conductors

Exceeding a limit value obviously leads to heating of the conductor, deterioration of the insulation and the possible occurrence of a short circuit, ultimately leading to the development of a fire. In figure 5, the different local conditions of the conductor covered by the electric current determine its different temperatures.

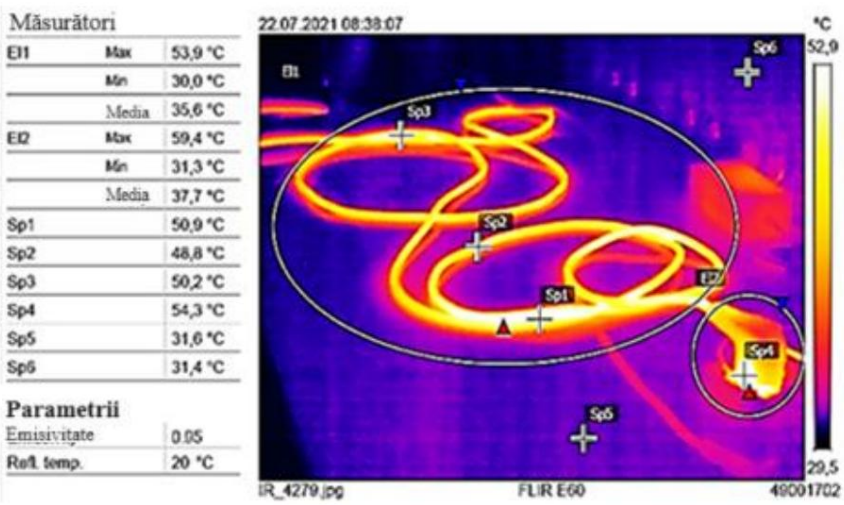


Fig. 5 Conductor heated due to overload

Figure 6 shows the temperature variation of the insulation surface of a three-phase ACYAby 3ÿ150SE+70RE ROMCAB type cable (low-voltage cable with PVC insulation and outer sheath diameter of 46 mm) depending on the effective intensity of the phase electric current , for the undisturbed sinusoidal regime (= 0; ÿ = 0) and for the harmonic regimes with different values of the distortion factor.

According to the manufacturer's specification, the operating limit is 70 [oC], a limit that is reached in the case of a perfect sinusoidal regime for a phase current intensity of 200 [A], and the short circuit limit at over 300 [A].

In the case of distorted electric current, a strong heating can be observed the cable. For strongly distorted harmonic regimes (= 1; ÿ = 3), the maximum working temperature is reached at half the value of this electric current (ÿ100 A), but for the maximum electric current of the undisturbed regime, the short circuit is not reached.

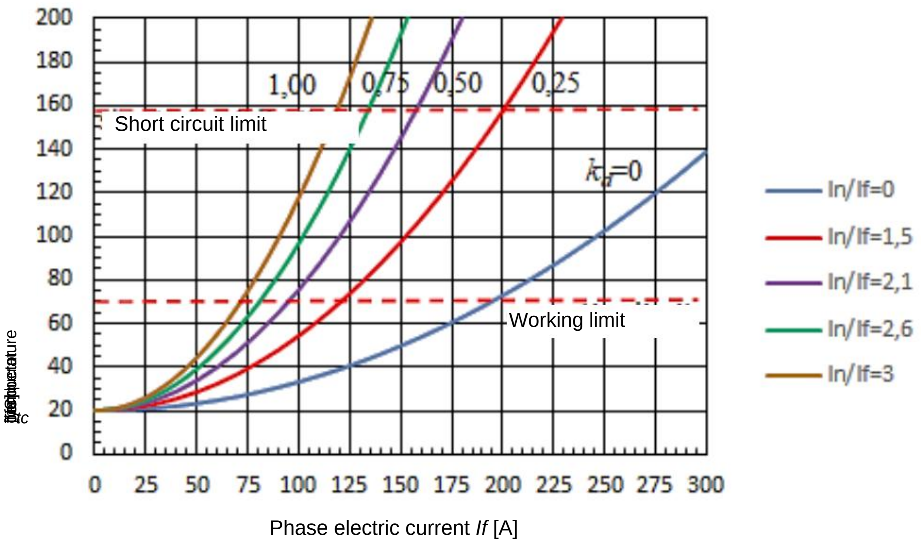


Fig. 6 Heating of three-phase cable ACYAby 3ÿ150SE+70RE due to operation in distorted mode *(In* ÿ electric current in the neutral conductor; *If* ÿ phase electric current).[8]

If it is considered that the initial temperature t0 is 40[ÿC], the melting temperature of copper is 1083[ÿC] for a unit length of the analyzed conductor {cross-sectional area 2.5 [mm2]}, it follows that the range of time ÿ in which the melting temperature is reached, for a short-circuit electric current of 300 [A] is:

$$ÿ = \frac{0}{2} \quad ÿ = 15.8 \text{ [s]}.$$

Figure 7 shows the duration until the studied conductor melts depending on the intensity of the electric current in the circuit {ÿCu=8960 [kg/m3]}.

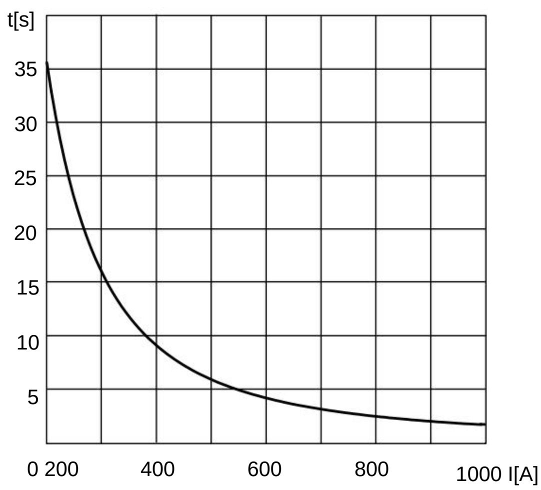


Fig. 7 Variation of the duration until the copper conductor melts of 2.5 mm2 depending on the intensity of the electric current in the conductor.

In general, the protection system ensures the disconnection of the installation before the conductor melts, but in affected areas of the conductor, the local electrical resistance may be lower and melting may occur. At the melting point, both components appear at temperatures above 1000[ÿC], but an electric arc can also form in the ionized space of the melted zone.

Loading the conductors with high power and non-linear loads can lead to the strong increase in heat generation through the Joule-Lenz effect and the rapid increase in temperature to the short-circuit limit, ultimately triggering the occurrence of fire.

Physical phenomena in electrical contacts

In the usual technical language, the expression *"electrical contact"* has a double meaning, denoting, in turn:

- either *the situation of mechanical contact* between two bodies, good conductors of electricity;

- either *specially constructed parts,* between which the continuity of a circuit is achieved when these parts (contacts) touch. In this context, any electrical equipment is considered essentially as an assembly of electrically interconnected functional elements and conductors. The point in the circuit where the electric current passes from a path of current in another is called *an "electrical contact point".* In practice, an *electrical contact* means an assembly composed of two metal parts, by touching which conduct is established in an electrical circuit. The two parts are called *contact elements* or , simply, *contacts.* Constructively, in an electrical contact, the contact is made by pressing (with the help of a force) the *contact* surface of the contact parts.

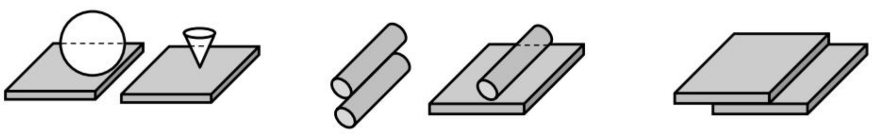
Electrical contacts can be *classified* according to different criteria:

1. According to *the geometric shape of the contact surface,* electrical contacts are conventionally divided into three groups:

a) *Point contacts,* where, macroscopically, the touch occurs only in a single point, and microscopically, on a circular surface of very small radius. This group includes, for example, sphere-sphere, sphere-plane, cone-plane contacts [fig. 8 a)].

b) Linear contacts, where the contact takes place along a line, that is, practically, on an extremely narrow surface. This group includes, for example, contacts between the side surface of a cylinder and a plane or contacts between two cylinders with axes parallel [(fig. 8 b)].

c) Planar contacts, where the contact of the two parts is made on a contact surface. This group includes, for example, the contacts made between two flat surfaces, with a rectangular section [fig. 8c)].



a) b) c)

Fig. 8 Different geometries of surfaces in contact:
a) - punctate; b) – linear; c) - surface.

2. Depending on *the kinematics of the elements,* electrical contacts can be classified into:

a) Fixed contacts, made, in general, by the mechanical joining of the two contact elements through screws, rivets, bolts [shown schematically in figure 9 a)].

b) Removable contacts, where one of the two contact elements is fixed and the other is removable (no load and no voltage). A typical example is the contact made between the leg of a plug and the contact plate of the socket [fig. 9 b)].

c) Movable contacts for switching electrical circuits, where at least one of the elements is movable (during normal operation of the equipment), thus determining the closing or opening of the circuit [fig. 9c)].

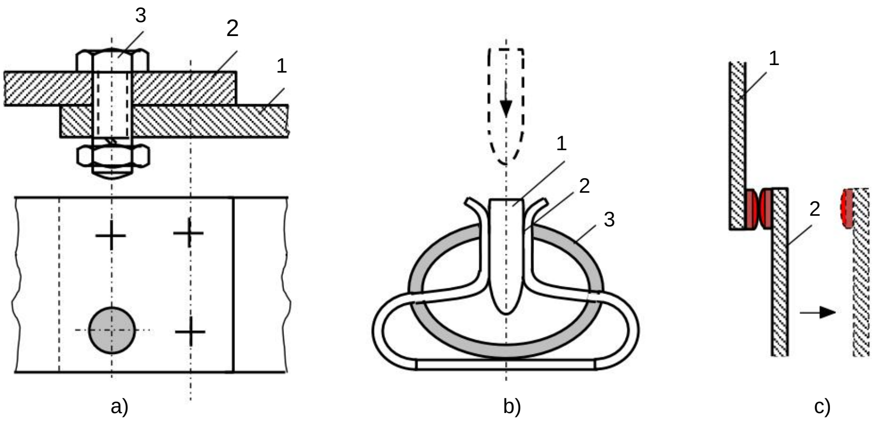


Fig. 9 Contacts according to kinematics:
a) – fixed contacts; b) – removable contacts; c) – mobile contacts.

During their operation, contacts are subjected to various demands. Thus, fixed contacts and removable contacts are subject *to heating* both in normal mode and in overload mode and sometimes in short circuit mode. In all these situations, the heating must not exceed the overtemperature values prescribed by the standards for each of the above-mentioned regimes. The contacts of switching equipment (in particular, mobile contacts) or fixed and removable contacts with play, are also subject to the action of *the electric arc,* which occurs between the contact elements when they are separated. Although the duration of the electric arc is limited (5-30 ms), the high temperature of the arc causes intense heating of the contact elements. In addition, in equipment that executes a large number of switchings under load, there is also an *electrical wear* of the contacts, that is, a migration of material from the contact elements, under the action of the temperature of the electric arc. Also, *mechanical wear may occur at the moving contacts,* as a result of crushing and deformation of the contact parts after a large number of maneuvers. Therefore, electrical contacts require proper operation and maintenance.

Failure to remove contact wear, even insignificant at first glance, can cause serious defects (overheating of contacts and even their melting), leading to the equipment being put out of service or generating fires.

In the case of imperfect fixed or removable contacts of an electrical device or when the contact breaks, the following phenomena occur in a very short time (fig. 10):

a) *closed contact:* the electric current passes through several contact points;

b) *breaking contact:* there is only one point of contact that concentrates all power lines;

c) *contact at the first moment of breaking:* the electric current continues to pass through a bridge of liquid metal;

d) *open contact:* an electric arc was formed from the liquid metal bridge.

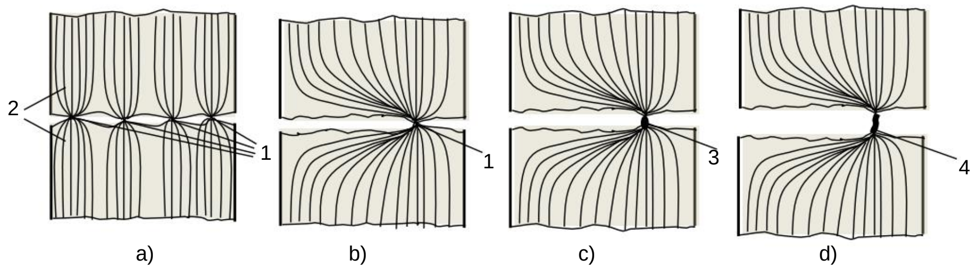


Fig. 10 Stages of electric arc formation in case of imperfect contacts:
1- contact points; 2 - contact parts; 3 - liquid metal bridge; 4 - electric arc
a) closed contact: the electric current passes through several contact points;
b) contact in the process of breaking: there is only one contact point that concentrates all the electric current lines;
c) contact at the first moment of breaking: the electric current continues to pass through a bridge of liquid metal; d) open contact: an electric arc was formed from the liquid metal bridge.

As the parts in contact move further apart, the actual contact area decreases greatly, so that the entire electrical current in the circuit passes through a single contact point; At this point of contact, the electric current density is so high that the metal is heated until it melts.

As the parts in contact move further apart, the liquid metal bridge thins and eventually, due to the ever-increasing heating caused by the passage of the electric current, vaporizes; the existence, in a very small space, of a large amount of metal vapors and highly heated electrolytes creates the conditions for the appearance of an electric arc between the contacts, through which the electric current in the circuit continues to flow.

In this situation, air - normally considered an insulator, becomes electrically conductive because a hot, highly ionized zone (plasma) is formed between the two parts.

Disturbing movie

In the case of a clean metal contact, i.e. when there are no disturbing films (oxides, sulfides, etc.) on the contact surface, the through resistance *Rt* is constituted only by the clamping resistances. However, in reality, the metal surfaces of the contact elements react with the surrounding atmosphere, and the transformations that occur cause the appearance of oxide films and depend on both the nature of the contact metal and the properties of the surrounding environment. Therefore, the through resistance *Rt* consists of both the clamping resistance (of two contact elements) and the disturbing film resistance (oxides, sulphides). In addition, the disturbing films formed on the metal contact surfaces (of the electrical contacts) do not greatly prevent the passage of electric current through the contacts, because they eventually break down.

If the pressing force of the contacts is not high enough to produce the plastic deformation of the contact surfaces (and, therefore, cracks in the film), then the conduction of the electric current is achieved by the phenomenon of *frying* (calcination of the film). Thus, if a progressively increasing electrical voltage is applied to a disturbing film, it is found that the resistance of the film begins to decrease, since the film behaves like a semiconductor. If the frying voltage *Uf* is exceeded (which at film thicknesses of 1000 Å can be about 10-100 V), the voltage across the film suddenly drops to 0.5-1 V, and the electrical resistance of the disturbing film will also drop suddenly.

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Case studies

1. The voltage on a silver contact is determined, so that it does not melt at the ambient temperature *tma*= 40 [ÿ] and the temperature of the current path in which the contact is inserted tmax=960.5 [°C]. Relationship:

$$ÿ (\, ^2 \quad _0^2) = \frac{^2}{4}, \tag{9}$$

takes the form:

$$= 2ÿ ÿ (\, ^{2\,t} \quad _0^2), \tag{10}$$

where:

$$= 273 + 960.5 = 1233.5 \text{ K},$$

and:

$$_0 = 273 + 40 = 313 \text{ K}.$$

It is obtained:

$$= 2 ÿ ÿ2.4 ÿ 10ÿ8(1233.5\ 2 ÿ 3132) = 0.37V.$$

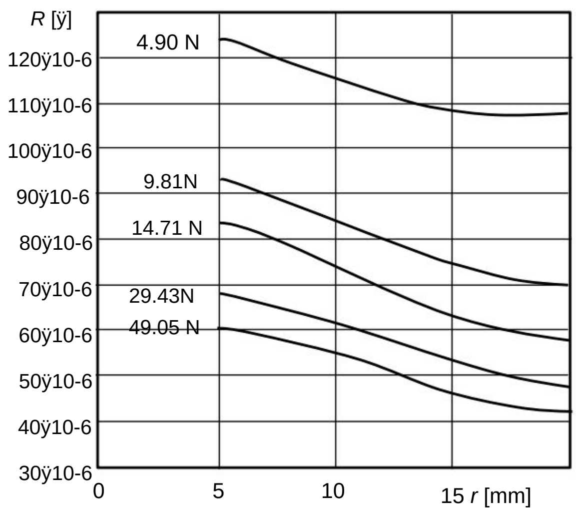


Fig. 11 Dependence between contact resistance and radius of curvature for silver-plated copper contacts.

2. For a contact with T0 = 373 [K], determine the overtemperature, knowing the contact voltage *U* = 10 [mV].

Relationship:

$$ÿ = ÿ = \frac{^2}{8 ÿ ÿÿÿÿÿ}$$

takes the form:

$$= ÿ\, 2 \frac{}{4\, ÿ} + \, _0^2 = ÿ\, 10ÿ4 \frac{}{4\, ÿ\, 2.4\, ÿ\, 10ÿ8} + 3732 = 374.39 \text{ [K]}.$$

Overtemperature is:

ÿ = ÿ = 373.39 ÿ 373 = 1.39 [K].

3. Determine the pressing force at a point contact made of silvered Cu, through which an electric current of *I* = 1000 [A] passes, so that the overtemperature of the contact is 5ÿ. The ambient temperature is *tma* = 40 ÿ, and the overtemperature of the conductor is 30 ÿ.

We consider the hardness of silver *H* = 5ÿ108 Pa and the thermal conductivity of copper ÿ=393 W/(mÿgrd.

$_0$ = 273 + + ÿ = 273 + 40 + 30 = 343 [K];

= 343 + 5 = 348 [K] ; arc cos(343ÿ348) = 0.1691 [rad].

By applying the relation:

$$= \frac{2 \; ÿ ÿ ÿ}{16 ÿ ÿ 2} \cdot \frac{1}{(\text{bow basket } \overline{0})^2}, \quad (11)$$

it is obtained:

$$= \frac{106 ÿ 2.4 ÿ 10ÿ8 ÿ ÿ ÿ 5 ÿ 108}{16 ÿ 3932 ÿ 0.16912} = 533.5 \text{ [N]}.$$

Data resulting from experiments

In order to validate some theoretical data, an experiment was carried out that aimed to determine the maximum intensity of an electric current and the time period in which, due to some electric consumers, the electric conductor traversed by this electric current increases its temperature to the level critical when the insulation loses its properties (fig. 12), thus causing an electrical short circuit.

Fig. 12 Conductor temperature after 15 min. from the passage of the electric current.

After approx. 15 min., the first time (t1) of data measurement. When charging with approx. 1 kW, it is observed that the temperature has increased by almost 0.5oC compared to the initial temperature (t0) – the ambient temperature (approx. 31.5oC).

Fig. 13 Various receivers used in the experiment.

Purely resistive receivers were analyzed in order not to induce deforming regimes (fig. 13).

Consumers with non-linear characteristics can influence the temperature regime of the conductors (in the sense that they heat up more). The contacts at one end and the other of the extension cord are kept at the initial temperature.

In figure 14, the shape of the voltage, respectively the shape of the electric current is purely sinusoidal (fig. 14).

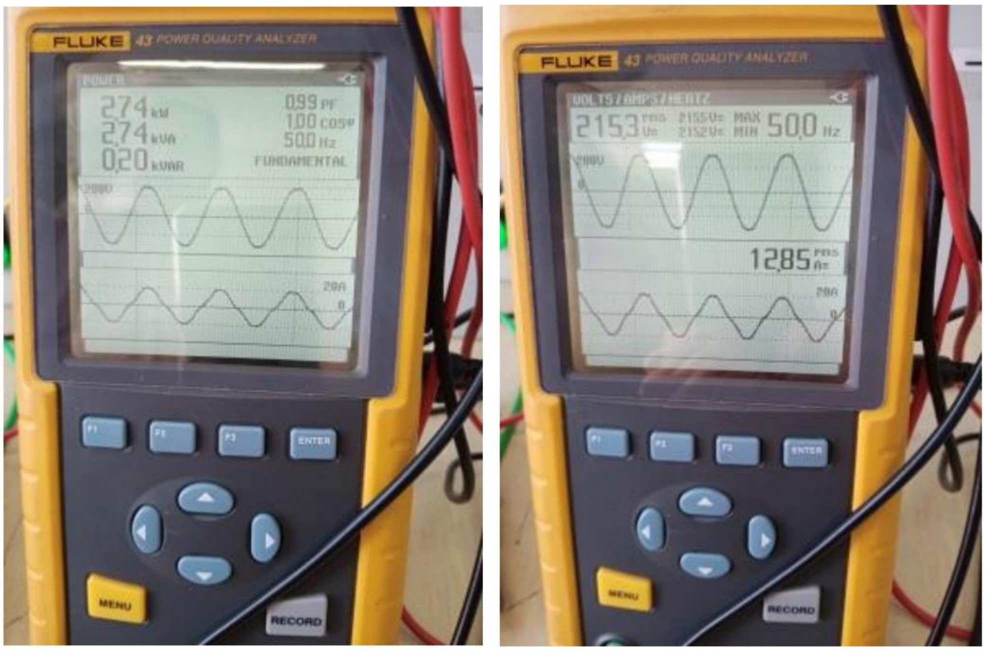


Fig. 14 The purely sinusoidal form of the electric current in the experiment.

At a current of 150 mA, the contacts do not heat up, maintaining their properties.

After another 15 minutes, (t2), the load rose to 12.84 A (fig. 15). At an interval of 5 minutes, the temperature rose to over 50 oC.

Fig. 15 Temperature difference along the length and at the contact points of the electrical conductor after increasing the load to 12.84 A.

The increase in temperature at the ends of the conductor is observed (the temperature at which a object can be touched without causing negative effects on the skin is 50 oC).

After another 11 minutes, approximately (t3), the temperature rose to 60.1 oC at one end (at the plug) and 64.9 oC at the other end (at the outlet).

The condition is met: **current 12.8** A, below the extension limit of 16A (imposed by the manufacturer through the catalog and the characteristics of the extension cord).

After another 3 minutes, approximately (t4), the temperature is approx. 62.5 oC (plug) and 64.9 oC (socket) – at the contact points, in conditions where there is a slight air current (open window) (fig. 16).

Fig. 16 Temperature at the contact points after approx. 30 minutes from the beginning of the experiment.

Figure 17 shows the temperature at which the cable loses its insulating and mechanical characteristics.

ConCluSIonS

It is noted that depending on the specific conditions and how the cable is laid, some areas heat up more or less than others. So, in conclusion, the cable does not heats evenly along the entire length.

Table 3.9 shows how, at an electric current of 18.39 A and a power of 3.84 kW, but at different times, the temperature along the entire length of the conductor varies during the connection of 2 or 3 resistors to the receiver.

Table 1 Temperature at different contact points and along the length of the cable at different times.

Time / time	Temperature Plug	temperature [oC] outlet [oC]	Cable Temperature	Observations
t5	80.9 60.5 91 65	100 73.8 104	[oC]	2 resistors
t6 *	76 134 102 79	88 65.3 78	62.4	2 resistors
t7				2 resistors
t8				2 resistors
t9 **			68.9	3 resistors
t10 ***			76	0 resistors
t11			80	0 resistors
* 106 74 53 - Contactors also worked. Only 2 resistors are mounted.				
** - Another resistor is connected, the temperature exceeding 100 oC in approx. 1 min. There is a specific smell on both ends.				
*** - After removing all resistors.				

Fig. 17 The critical temperature at which the cable loses its properties.

It is observed, therefore, that the insulation property of the electric conductor is not maintained throughout the period of use, the characteristics given by the manufacturer being strictly commercial (the maximum intensity of the electric current that can pass through the conductor has not been reached), thus great attention must be paid to the number , as well as the power, the consumers served by the conductor in question, existing with certainty the imminence of an electric short circuit (due to the thermal effect of the electric current) followed, most likely, by a fire.

Extinguishing fires at electrical installations

The most used substances for extinguishing fires in electrical panels are water, foam, powders and inert gases (carbon dioxide, nitrogen, inergen, etc.). The means used to extinguish fires cause the interruption of the combustion process due to the effects that these media have on the fire:

- cooling the combustion area (water, foam);
- isolation of the burned area from atmospheric air (water, foam);
- dilution of gases in the combustion zone that can maintain and develop the fire (water, inert gases);
- combustion inhibition (powders);
- the chemical effect on combustion reactions (powders).

Water is the oldest and most used extinguishing agent, being the cheapest, easy to procure and with a considerable cooling capacity. In case of fire, water is used in the form of compact jet, spray jet, water curtain, water mist or steam.
The sizes of the water droplets are of great practical importance, because it is necessary that as much water as possible reaches the focus of the fire and remains there until complete evaporation.

Foam is the main extinguishing agent of combustible liquids lighter than water, stored in tanks or leaked and accumulated in the layer, in case of damage to warehouses and technological installations.

Dry ***powders*** are a particularly effective extinguishing agent. The extinguishing effect of the powders is due either to the components resulting from the thermal decomposition of the powder (water vapor, carbon dioxide and sometimes nitrogen), or thermal decomposition as an endothermic reaction (cooling effect), or the inhibition of the combustion reaction (anti-catalytic effect).

Inert gases are a good extinguishing agent because, having a high density, they quickly infiltrate the entire space, displacing the air and depriving the fire source of oxygen. They are used **exclusively for extinguishing fires that develop in closed spaces** (inside buildings or constructions).

Carbon dioxide is an extinguishing agent used in many applications. It does not conduct electricity and therefore can be used for extinguishing fires and in electrical installations.

Nitrogen can be used for the inertization of spaces or technological installations by partially replacing the air in those spaces, for diluting fuel-air mixtures, for extinguishing fires in technological installations or closed spaces, for transporting extinguishing powders or for activating the automatic opening of fixed extinguishing installations of fires with the help of powders.

Inergen is a mixture of inert gases (52% N, 40% Ar, 8% CO_2) that has the property of reducing the oxygen level in the room so that combustion can no longer be maintained.

The agent FM 200® is an HFC freon (R 227ea - heptafluoropropane).
Its main extinguishing mechanism is heat absorption, with a secondary chemical contribution through thermal decomposition in the flame.

NOVEC® 1230 is a clean fire extinguishing agent developed as an alternative to replace halons and hydrofluorocarbons (HFCs), being chemically a fluoroketone.

The use of new synthetic materials in constructions and the improvement of insulation in buildings significantly influence the behavior of fires. Their propagation it can be very fast. Thus, depending on the quality of the air flow that supplies them, the following phenomena are distinguished:

1. *The thermal flashover phenomenon* corresponds to the normal development of a fire and occurs when combustion is fed with the optimum amount of oxidant. When flashover is imminent, the combustibles present in the room (surfaces, objects) they are heated until they reach the auto-ignition point.

At approximately 600°C there is a sudden transition from a localized fire to a widespread fire. This is the "flashover" phenomenon . The fire, located in a only part of the volume, turns the room **into a considerable commotion.** In average, a flashover occurs at a temperature of 6000C and develops a caloric load of about 7 MW.

2. *The backdraft thermal phenomenon* is defined as a **thermal accident** that is difficult to predict, which appears under the following conditions:

- volume closed under pressure;
- incomplete combustion;
- considerable heat;
- cracking of partitioning elements.

A crack in the partitioning elements is enough for the mixture fuel, fed again with oxidizer, to re-enter the flammability zone. Upon contact with the initial source, a violent explosion occurs. The entire room ignites instantly and a "tongue of flames" due to the overpressure will appear in the opening created. This is the *backdraft phenomenon.*

Visible only from the outside of the affected volume, the signs that induce the appearance imminent of a backdraft are:

- no clear flame or light, except embers, is visible through the windows a few small blue flames of CO combustion;
- the windows, covered with soot, become black and opaque, and may vibrate slightly the effect of heat and internal pressure;
- the thick and dark smoke, of an unusual color, comes out in the form of puffs through the interstices, through the area of the door frames, where the air usually enters fresh, giving the impression that the fire is breathing;
- the sounds are muffled, no noise of a fire can be heard in the interior of the room;
- the doors, locks and their handles are very hot to the touch.

The ignition of the smoke can be equivalent to an explosion if the "combustion-fuel" mixture is in optimal proportions, thus favoring a rapid reaction of combustion.

Interventions for extinguishing fires at electrical switchboards can be done with fixed means, which are component parts of the respective equipment, or with mobile means, handled by the intervention personnel.

Firefighting means/installations

The fixed water mist extinguishing system is the simplest and cheapest system of extinguishing, using a small amount of water.

The fields of use are multiple: storages of flammable liquids, electrical transformer stations; gas tanks; cable galleries etc. The extinguishing installation with fog is currently associated with a fire detection system that actuates the opening of solenoid valves, as well as a control panel that triggers the fire alarm (fig. 18). The discharge nozzles are fed with water from the distribution network through a filter that removes particles larger than 500 microns in size. They generate a fine, conical and directional mist of water spray where the droplet size is on the order of 20 to 200 microns.

The special geometry of these nozzles allows their use at low pressure without requiring a pressurizing agent, which leads to a simplification of the installation compared to high pressure systems and a lower price. The installation can work automatically or manually.

Fig. 18. Fixed extinguishing system with water mist in action and spray nozzle.

The fixed extinguishing system with inert gases. These installations represent the most widespread option in Romania as a fire extinguishing system in closed spaces, due to the ability to minimize damage to goods and people in the protected space. Compared to water, which is an excellent extinguishing agent due to its ability to stop the burning process and absorb the heat released, inert gas installations also ensure asset protection, as the extinguishing agent leaves no residue and does not react with the materials inside the protected space . Areas of use: warehouses or premises with valuable products, premises for storage or use of electrical appliances and equipment, halls or factories and car garages.

Mobile fire extinguishers come in a wide variety of sizes and capacities, can operate with water, powder, foam, or inert gases, and can be hand-carried, carted, or self-propelled. Among them, the most important are the following:

- High-capacity fire extinguishers, transported on wheels;
- Self-propelled means for extinguishing fires;
- Impulse fire extinguishing system (IFEX).

The extinguishing agent is sent at very high speed, in a fraction of a second, directly to the source of the fire. Propulsion of the extinguishing agent is carried out with compressed air, having a pressure of about 2.5 MPa. The extinguishing agent is primarily water, but the system can use most extinguishing agents, even special agents used to extinguish metal fires. The impulse created by the high exhaust velocity, over 100 m/s, and the large cooling surface allow effective extinguishing of fires from a safe distance. Fires in medium voltage electrical appliances can be extinguished with water. In this case, the minimum distance to be kept is only 1 meter.

As the first recently released prototype, the IFEX® Impulse Fire Extinguisher (fig. 19) *is the centerpiece of Impulse Fire Extinguishing Technology.* The flame is practically blown out, being extinguished instantly, both by impact and by cutting off the oxygen supply. The device can be carried on the operator's back or mounted on a self-propelled vehicle.

Fig. 19 The IFEX® Impulse Fire Extinguisher

Means of protection against electric arc in low voltage networks

Statistics on fires highlight the fact that 95% of them occur in buildings. Of these, in 25% of cases the initiation is of an electrical nature.

One of the main causes that provide the source of fire is the electric arc that forms when the conductors are interrupted due to excessive heating or in the case of poor contacts. The formed electric arc ensures the continued passage of the electric current through the circuit, but the form of the voltage at the use terminals is deformed, and the electric current presents interruptions, having non-zero values only during the burning of the electric arc.

After the ignition of the arc at the voltage *Uam* (moment t1) the voltage at the use terminals remains practically constant until the moment t2 when the electric current in the circuit passes through the zero value. The re-ignition of the electric arc takes place in the next half-cycle at the time t3 when the voltage reaches the value *Uam.*

The AFDD *(Arc Fault Detection Device)* type equipment , based on microprocessor technology, ensures a continuous monitoring of the shape of the voltage and current curves in the circuit and has the function of limiting the occurrence of fires due to the electric arc in the electrical circuits by interrupting the circuit in which appeared the electric arc, based on the analysis of the shape of the voltage and the electric current in the circuit (fig. 20).

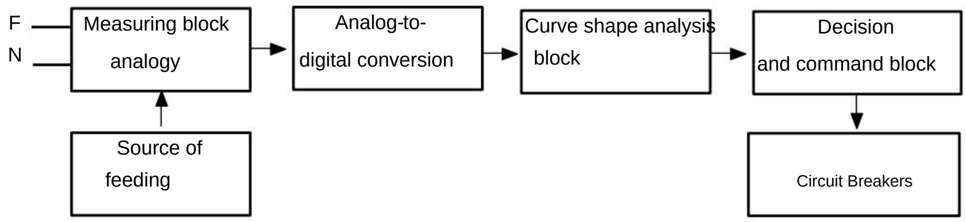


Fig. 20 Principle diagram of an AFDD equipment.

AFDD-type equipment becomes mandatory in low-voltage installations that supply areas with a significant risk of fire spread:

ÿ buildings with forced ventilation;

ÿ buildings with high density of people (theatres, cinemas, concert halls);

ÿ buildings with evacuation difficulties;

ÿ buildings that contain significant quantities of flammable materials (deposits of grain, paper warehouses, etc.).

Protection against the appearance of an electric arc in electrical panels

Most electrical faults in low or medium voltage switchboards are accompanied by the appearance of an electric arc. Disconnecting the circuit that feeds the electric arc within 100 ms at most after its occurrence allows to avoid serious consequences, which can cause major fires in these installations.

The electric arc is accompanied by significant light emissions in the visible spectrum and in the ultraviolet spectrum. The LAD *(Light Arc Detector)* type equipment includes a light sensor in the ultraviolet spectrum specific to the electric arc, an opto-electronic converter, a numerical signal analysis and comparison block with characteristic signals and a decision block (fig. 21). In some models, a noise sensor is also included to process the sound emissions specific to the appearance of the electric arc.

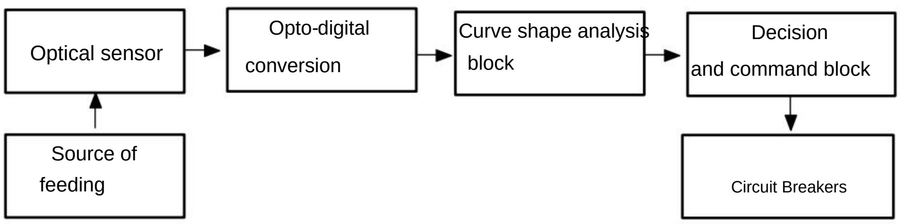


Fig. 21 Principle diagram of a LAD equipment.

Detecting the light emission of the electric arc {10ÿÿÿ30 [kLux]} in a time interval of about 2.5 [ms] and transmitting the power circuit disconnection command 5ÿÿÿ10 [ms] from the moment the appearance of the electric arc, allows limiting the burning duration of the electric arc and thus the formation of the components that ensure the initiation of the fire.

The LAD system is included in the protection systems in the medium and low voltage electrical cabinets, in the enclosures with MV/LV transformers as well as in the electrical connection cabinets, especially in fire hazard areas.

Protection by interrupting the electric leakage current

Defects in the insulation of low-voltage cables can lead to the appearance of electrical leakage currents that, in passing to areas with zero potential (earth), can travel through portions with a fire hazard. Disconnecting the circuit in which electric leakage currents appear has an important role in ensuring the safety of personnel due to direct contact with the live circuit, but it also ensures the limitation of the fire hazard by quickly removing these electric currents. Current differential protection systems (fig. 22) using RCD relays *(Residual Current Device)* ensure disconnection in no more than 40 [ms] when an electrical leakage current over 30 [mA] occurs.

In an intact electrical installation, the leakage current *iS* is zero and the phase current *iF* is equal in value to the current *iN* in the neutral conductor.

The sum of the two electric currents is zero, and coil B of the RCD differential relay is not energized. When an electric leakage current *iS* occurs, the electric current in the neutral conductor is lower and if the difference is over 30 [mA], the RCD relay is activated and the electricity supply is interrupted. The value of 30 [mA] also provides protection in the event of a person touching the live conductor.

RCD relays are also installed in three-phase circuits; RCD differential relays set to an electric current of 300 [mA] are installed in the supply circuits of the local electric tabos, in order to ensure the selectivity of the protections.

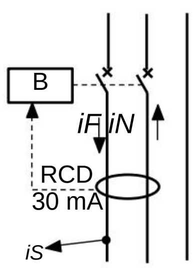


Fig. 22 Principle diagram of a differential protection relay (RCD).
Principle diagram of an LAD equipment.

Finding

Analysis of the data obtained by monitoring the electrical values during the course of a week, as well as of the records at a given time, allows the following general conclusions to be drawn:

- the voltage at the power bars falls within the parameters allowed from in terms of frequency power quality standards, effective voltage value, asymmetry, flicker level;
- the analysis section presents an electricity consumption accompanied by significant distortions, which causes a low power factor; improving the power factor by fitting a capacitor bank it can be inefficient, as for a distorted voltage at the power bars, the capacitor bank amplifies the distortion and can lead to a reduction in power factor;
- the capacitor bank can only become efficient if measures are taken to limiting the distortion of the curves characterizing the consumption in the analyzed area; for the analysis of the behavior of the capacitor bank in the distortion situation is necessary to consider, differently, the two notions of power factor:
- in the case of the analyzed section, the deforming power has an important weight, which requires that the proposed solution be based first on limiting the deforming power, by limiting the distortion of the electric current curves and adopting a reactive power limitation solution.

The propagation process

The propagation of a fire is defined as the extension of combustion to the nearest combustible materials, being an extremely complex dynamic process, which can involves a large number of intervening phenomena involving fuel, oxygen, CO_2, H_2O, CO, N_2.

The most important characteristics of the fire propagation phenomenon are:

ÿ propagation speed;
ÿ acceleration of fire propagation;
ÿ fire front pressure;
ÿ the development zone in front of the fire characterized by temperature and length.

The heat released during the burning of the combustible material contributes to the continuous development of the fire.

Flammability is a measure of the possibility of igniting the vapors of a combustible material. Most of the combustible materials inside are textiles and plastics that ignite at relatively low temperatures {150-250[ºC]}, but laminated materials due to their pressure production ignite at higher temperatures {around 400[ºC]} .

Interactions between a fire and the local environment, which includes fuels, meteorological conditions and topography, can produce very complex patterns of fire spread that are currently not fully understood. Understanding the physical processes underlying these complex ways of fire propagation is essential for the development of mathematical models of fire propagation processes and the development of measures to limit its effects.

It should be noted that during the burning process of the organic fuel material, smoke and toxic gases may appear.

Current models for fire spread analysis are either entirely empirical or semi-empirical. Almost all are based on the phenomenon of radiation to the flammable medium up to the ignition temperature with subsequent propagation. The speed of propagation of a fire is very sensitive to local air currents. Also, the characteristics of the fuel medium and its moisture content must be taken into account. The speed of propagation of a fire can be considered a measure of the risk determined by the fire with the occurrence of significant damages.

Fire propagation involves the transfer of heat from the heat source to the combustible medium that will be heated to the point of ignition. The heat transfer process can take place through:

- radiation from the flame to the fuel medium;
- radiation from the pyrolyzed fuel to the combustible environment;
- thermal conduction through the fuel medium;
- thermal conduction outside the fuel environment;
- convective heating of the fuel medium by the hot gases from the flame;
- radiation from the heated part of the fuel medium;
- convective cooling of the environment.

The effect of conduction manifests itself over a very short period of time. For a fire propagating with velocity *u* in a fuel of thermal conductivity ÿ, density ÿ and specific heat c, the temperature in the fuel (due to conduction) drops exponentially ahead of the fire of the form ÿ/(ÿ,u), which is less of 0.001 m in almost all practical cases. So that, usually, the phenomena of thermal conduction through the combustible environment and outside environment can be neglected.

The speed of fire development mainly depends on:

- type of combustible material;
- initial temperature;
- pressure;
- system geometry;
- environmental humidity;
- the presence of air currents.

The air currents in the fire area have an important weight in determining the speed of fire propagation, determining both the acceleration of radiative heating and the increase of convective cooling. To a large extent, the effects depend on the way the air currents develop: linear, gusts, turbulent, intermittent.

Figure 23 shows the influence of air currents on fire development.

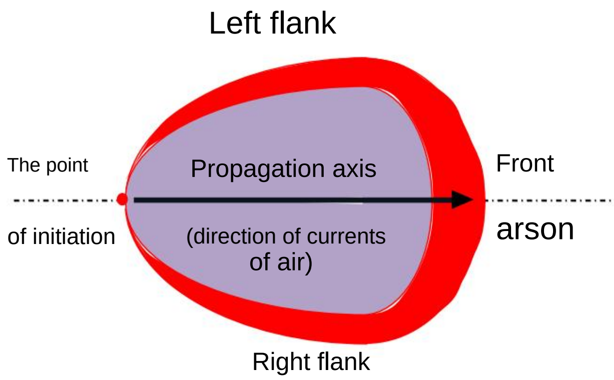


Fig. 23 Fire propagation under the influence of air currents.

Based on a large number of observations, the propagation speed *R* [m/s] of a fire on a flat surface can be determined from the empirical relationship:

= 4.36 ÿ ÿ f( ) ÿ e 0 , (12)

where *W* is the mass of the combustible material per surface unit [kg/m2], *v* ÿ air current speed [m/s], v0 = 6.9 m/s ÿ reference speed, *M* [%] ÿ relative humidity.

The function *f(M)* has the expressions:

( ) = e ÿ0.0897ÿ , for < 18.8%;
= 0.127 ÿ (30 ÿ), for 18.8% < < 30%; (13)
= 0, for > 30%

As an example, consider the usual case of a space where the combustible material has a density of 4 [kg/m2], the humidity of the material is 15%, and the speed of the air currents is 10 [m/s]. Result: R=19.35 [m/s].

Of course, the obtained value is informative, the propagation being determined by a complex of factors, primarily by the concrete conditions at the place where the fire occurred. The high speed of development of fires caused by electrical causes and the rapid increase in temperature can lead to serious damage to firefighters in the area.

Methods and procedures used in the investigation of the causes of fires

In order to solve the problems that arise in connection with the investigation of the cause of fires, a wide range of methods, procedures and techniques from different fields are used. They can be grouped as follows:

1. Logical reasoning methods, such as: identification, deduction, analysis and synthesis, comparison, assumption and exclusion, etc.
2. Measuring traces or objects, determining their shapes and examining their structure with optical means (magnifying glass, microscope, etc.).
3. Technical-scientific (physico-chemical) research and expertise procedures and means, which mainly allow:

- determination of the burning parameters of materials using the calorimetric bomb, the furnace for determining incombustibility, the incandescent block and other devices for determining the ignition and ignition temperature of solid materials and combustible liquids, the radiant panel, the thermodifferential analysis using the thermoderivatograph, the determination of the oxygen index, etc. .;

- establishing by calculation the energy balance of the materials and substances at the scene of the fire;
- identifying the presence in the ash, slag, soot, melts or materials taken from the fire site of some substances (especially combustion initiators or accelerators) or of some components in their structure. This can be achieved by applying the procedures: illuminescence emitted under the action of ultraviolet radiation, X-ray or other types of exciting radiation, spectral analysis, chromatography,
radioactive activation, polarimetry, electrophoresis, etc.;
- determination of the changes that occurred in the structure of metals and other materials, following the thermal stress and the physico-chemical phenomena to which they were subjected during the fire (metallographic analysis, electron microscopy, etc.);
- analyzing and comparing the surfaces and contours of objects (surface displacement method).

4. Experiments to determine how some materials burn at the place of the fire and the phenomena accompanying the combustion processes.
5. The reconstruction of some aspects regarding the situation before the fire, which can be done at the burned object, in other similar objects or in the laboratory. This presents some limits, giving positive results only in some cases, because there are many difficulties in fully reproducing the conditions that existed at the time of the fire initiation, which cannot always be known in full.

In order to carry out a scientific investigation of the causes of fire, a classification of fire traces is necessary, because only through thorough knowledge of them can the desired result be reached. This classification is perfectable and can be completed with new data. Next, a variant of the classification of these traces is presented, a classification that takes into account the general principles of forensic tactics and techniques.

In principle, the damages *D* caused by fires can be calculated from the general relationship:

$$= ÿÿ\ ÿ\ ÿ_{=1} \quad _{=1} \quad , \qquad (14)$$

where *ÿi* is the probability of occurrence of fire *i , pji* ÿ damage to equipment *j* during the fire i.

Of course, the probability *ÿi* can be determined for fire hazard areas following long-term studies.

NUMERICAL SIMULATION OF FIRE

A current and particularly important topic from the point of view of the design of constructions and installations with regard to the fundamental requirement of fire safety is the part of fire modeling.

Considering the existence of a large number of victims and the material damage resulting from fires, even surpassing those due to earthquakes, by creating a fire modeling as correct as possible, compliance with the requirements of the legislation in the field regarding the rescue of users is sought. Thus, today three modeling methods are most often used:

- the mathematical model: in which the internal temperature is considered as the main parameter, having the same value at a given moment in the entire analyzed space as being unitary, but changing according to time;
- the zone model: in which the analyzed space is divided into two zones: a warmer one in the upper part and a colder one in the lower part, while respecting the condition of an identical temperature at an initial moment that varies according to time;
- the field model: represents the most realistic modeling of fires and which it involves solving the chemical and physical equations at each point of the analyzed space.

Thus, for modeling a fire using one, two or all of the methods presented above, the most used software program is called FDS (Fire Dynamic Simulator). The program is designed for the numerical solution of a particular form of the Navier-Stokes equations, analyzing low velocities of air circulation, with variations in heat and flue gases.

The physical laws that describe the propagation process of a fire as a gaseous fluid comprise a thermo-fluidodynamic system that defines a set of 6 differential equations with 6 unknowns: the three components of velocity, pressure, temperature and density.
This system of equations (which is known as the Navier-Stokes equations) is strongly coupled and sensitive: a small change in the initial conditions can lead to trajectories in the solution space that are completely different from each other.

ConCluSIonS

The first official version of the FDS, released in 2000, targeted large-scale simulations of smoke movement from prescribed, well-ventilated fires, ideal for design work where the rate of fire heat release is not predicted by the model but by the designer. Improved versions were implemented in versions 2 (2001), 3 (2002) and 4 (2004). Gradual improvements to these routines, along with the introduction of parallel processing and various fire-specific features, have led to versions that provide more realistic data.

During NIST's investigations of the World Trade Center collapse and the Station Nightclub fire, it became quite obvious what needed to be done with FDS to make it an effective fire reconstruction tool. Up until that point, FDS had been used by the FPE community for design applications and to some extent forensic work, but the scope of investigations pushed the model to its limits.

By 2005, it was clear that FDS would need a major overhaul, so a new version (FDS 5) had to be created to dramatically increase the flexibility and functionality of the model. The work was carried out on two broad fronts - the gas phase and the solid phase. In short, better combustion and better pyrolysis. Version 5 was released in 2007. It included a major revision of input parameters and constructs. Over the next three years, improvements were gradually added, and in 2010 work began on FDS 6, which began beta testing in the fall of 2012. FDS 6 was officially released in the fall of 2013. Improvements have been made since then. stepwise hydrodynamics, chemistry and multi-mesh calculations. The HVAC solution, a key addition to the model, was also included in version 6 and has been constantly improved.

GENERAL CONCLUSIONS

An important role in assessing the risk of fire in electrical installations is knowing the characteristics of the voltage and current curves in the analyzed area.

Modern electrical receivers, which use elements with non-linear characteristics, introduce harmonic distortions of electric current and voltage, respectively, into the supply network, causing an increase in active power losses, electric overcurrent in the neutral conductor of three-phase networks and heating of conductors, overvoltage in network nodes or equipment terminals and disturbances in their operation.

In a study of an industrial user in which a strong non-sinusoidal regime was found, accompanied by the pronounced heating of some electrical conductors in different areas, the author studied this phenomenon to highlight the disturbances and establish a methodology for calculating the additional thermal effect that is produced. The first recordings showed the presence of strong non-sinusoidal electric currents. Under these conditions, the need for long-term monitoring was established in order to have complete information.

Measurements were also made to analyze the shape of the absorbed electric current. The analyzed scheme comprises two departures, each of them feeding strongly nonlinear receivers.

The measurements were carried out on the low-voltage secondary circuit of the supply transformer of the analyzed section.

In the analysis of the distortions of the voltage and current curves it is necessary to take considering the two notions of power factor differently. To analyze the operation of the data used, the following main electrical quantities were monitored: - the variation of the effective value of the phase voltages;

- the variation of the effective value of the electric current per phase;
- the variation of the voltage distortion factor;
- the variation of the level of the 5th and 7th harmonics;
- the variation of the asymmetry factor;
- the variation of the flicker indicator in the long term and the occurrence of transient situations.

Currently, fires caused by electrical installations represent an important part, over 25% of all fires, causing both significant destruction of material goods and loss of human life. At the same time, fires in electrical installations are also a hidden threat; they can flare up even when, apparently, things are in order. Consequently, constant attention is required for removing their causes, as well as for the development and use of effective and fast extinguishing means.

Frequent causes of fires in electrical installations are heating conductors and the appearance of electric arcs generated by contact imperfection.

Since the heating of the conductors is due to the increase in the intensity of the electric currents, either due to overloads or due to short circuits caused by their inadequate insulation, it is necessary for the maintenance personnel to constantly check the condition of the wiring and the power of the receivers connected to the network.

The most important thing, however, is the correct setting of the electrical circuit protection elements (switches) and the permanent control of their technical state of operation.

Another thing, just as important, is to constantly check the technical condition of electrical contacts, both fixed and mobile, especially sockets and switches, to avoid the formation of electrical discharges that lead to their overheating and ignition.

The essential condition for limiting the consequences of an electrical fire is its detection in the initial phase and rapid intervention to extinguish it. That is why it is necessary to permanently train all people who are or work in rooms where electrical household equipment works, so that they can observe any situations in which a fire could occur in the electrical installations and act quickly to prevent it.

Extinguishing media must also be on hand, loaded with the appropriate agents and checked for proper operation, to be used until qualified personnel respond. Since *water is forbidden to be used for extinguishing fires in electrical installations,* it has been shown that steam, but *especially water mist, is particularly effective for extinguishing fires whose causes of development are of an electrical nature.*

It is also very important to install fixed, automatic extinguishing and alarming means in permanently unsupervised areas, where there is electrical or electronic equipment in operation, under voltage.

Heat is a form of microscopic and disordered energy transfer (internal energy), due to temperature differences. This transfer occurs spontaneously from the system with the higher temperature to the one with the lower temperature, respecting the irreversibility postulated by the second principle of thermodynamics. The general objectives of heat transfer are important:

- determining or ensuring the thermal flow between two systems;
- determining or ensuring a temperature distribution compatible with safety rules;
- optimization of the specific processes of energy transfer in the form of heat.

Understanding the physical mechanisms through which the transfer modes are achieved, as well as the knowledge of the equations for quantifying the energy flow transported, are essential in applications.

The general conditions for carrying out heat transfer processes refer to specifying some material or process characteristics, such as:

- the body is homogeneous or heterogeneous;
- the body is isotropic or anisotropic,
- the body contains or not internal sources of heat with a given volumetric distribution;
- the thermal regime is stationary or transient;

- the propagation of the thermal flow is one, two or three-dimensional.

In electrical appliances in operation, heat is continuously developed by virtue the transformation of part of the electromagnetic energy into thermal energy.

As a result of the heat released in the device, the temperatures of its various parts rise up to the limit temperature, corresponding to the stationary mode, when all the released heat is given to the environment. In stationary mode, the device possesses a certain thermal load, energy that is kept in a potential state until the moment the device is disconnected, when it no longer receives energy from the source, the accumulated heat is fully dissipated, progressively, in the colder environment.

The main sources of heat in electrical devices are especially their active parts: the conductors traversed by the electric current and the iron cores traversed by magnetic fluxes varying in time. The higher the load on the device, the more important will be the electrical energy losses in the device and therefore, under equal cooling conditions, the overtemperatures in its different parts will be higher.

Allowing higher overtemperatures in the device, higher powers can be obtained from it, all other conditions remaining identical. Depending on the materials used and the operating conditions, the thermal demand must respect the maximum limits allowed for the steady-state temperature. The process of thermal transmission in the current paths traversed by alternating currents has a more complicated character.

In this case, due to the film effect and the proximity effect, the current density and respectively the specific losses do not have a uniform distribution in the section of the current paths. Solving the thermal stresses of the current paths, in such a complicated case, encounters great difficulties, therefore a series of approximations are made for the practical calculations. Thus, it is considered that the specific losses are uniformly distributed and are constants.

The change in the operating states of electrical devices is characterized by an unsteady working regime, which is accompanied by transient thermal stresses, determined by the heating and cooling processes.

Among the most characteristic transient thermal stresses of electrical devices, related to their working regime, we mention:

a) the process of heating the appliances during the network supply, until reaching the stationary thermal regime;

b) the cooling process after disconnection from the network;

c) the short-term load heating process;

d) the heating process at intermittent periodic regime, and

e) the heating process in the short-circuit regime.

Transient thermal stresses (often of a random nature) may also occur due to internal heat sources, related to the normal operation of the devices or in the event of a fault (the occurrence of an electric arc between the contacts or in the event of a fault due to the bypass arc, gases and vapors hot metal etc.).

In all the cases mentioned, the metallic and dielectric elements will be strongly thermally stressed, reducing the reliability of the device.

ANNEXES

Detailed calculations and demonstrations, as well as some case studies, were included in the thesis in some appendices presented briefly in the next chapter.

Heat transfer in a cylindrical bar

In stationary mode, the heat flow generated in the bar must equal the heat flow transmitted to the cooling fluid from the outside. This condition allows the bar surface temperature to be maintained at a constant value *ts.* The heat balance equation for the volume element of thickness *dx* and surface S is:

ÿ 2 ÿ ÿ ÿ ÿ = ÿ + ÿ ÿ ,[W] (15)

where:

ÿ = ÿÿ ÿ 2 ÿ ÿ ÿ — (16)

and

ÿ + = ÿ + ÿ/— = ÿÿ ÿ 2 ÿ ÿ ÿ — ÿ 2 ÿ ÿ ÿ ÿ ÿ — (ÿ —) ÿ . (17)

It is noted that, in the presence of internal heat sources, the thermal flow is no longer independent of the r coordinate. The flow ÿ transferred to the surface of the bar corresponds to *r=R* and represents exactly the thermal flow generated by the sources in the volume of the bar.

In the case of convective heat transfer to the outside of the bar, the thermal energy balance at the surface of the bar is:

ÿÿ ÿ — | = = ÿ ÿ (ÿ). (18)

Heat transfer in a cylindrical tube

In the case of the cylindrical tube with a thermally insulated inner surface, it is considered a thermally insulated tube on the inside, and on the outside it is in contact with a temperature fluid.
It should be noted that, under the assumption of a stationary thermal regime (constant over time), we can only speak of a cooling fluid (<) capable of absorbing the thermal energy generated inside the tube. If convective heat transfer is considered, the boundary conditions are expressed in the form:

— | = = 0;
(19)
ÿÿ ÿ — | = = ÿ ÿ [ÿ],

representing a zero unitary heat flux at the assumed perfectly insulated surface and, respectively, the equality between the unitary heat flux given by conduction to the cooled surface and that taken up by the fluid by convection.

The thermal , the external temperature is obtained, as well as the total drop of For = temperature ÿ . flux ÿ transferred through the outer surface of the tube is obtained from the temperature gradient at = (Fourier's law) or from the energy balance on the entire wall. According to the latter, the thermal energy generated in the volume of the wall must be completely evacuated (transferred to the outside environment) to ensure a permanent (constant) thermal regime in the wall:

ÿ = ÿ ÿ ÿ (2 2) ÿ =

= 4 ÿ ÿ ÿ ÿ ÿ ÿ ÿ (ÿ) ÿ (ÿ) 2 ÿ 1 / (ÿ) 2 ÿ 2 ÿ ln(ÿ) ÿ 1 [W], (20)

where *L* is the length of the tube.

Performing another energy balance, this time on the outer surface of the tube (=), it follows that the cooling fluid must take over the heat flow ÿ in its entirety:

ÿ = ÿ ÿ 2 ÿ ÿ ÿ ÿ (ÿ)[W], (21)

the coefficient of convective heat transfer between the wall and the fluid being specified by ÿ.

Thermal transfer through the cylindrical wall of a conductor carried by electric current

The analyzed model corresponds to a cylindrical conductor insulated by the current electric and located outdoors.

Radial geometries (cylindrical or spherical) are often exposed to a temperature gradient only in the radial direction and can therefore be treated as one-dimensional. In steady state and in the absence of internal heat sources, such systems can be analyzed either starting from the differential relation of conduction, or starting from the corresponding form of Fourier's relation. Next, the cylindrical systems will be analyzed by the first method, and the spherical ones by the second method.

It is considered a tubular cylindrical wall, with the inner diameter the outer diameter and the length 1 2 much greater than the radii. Heat develops inside the tube, defined by temperature, and outside is a cold zone, by temperature. The corresponding convective heat transfer coefficients (between the two zones and the surfaces of the cylindrical wall) are ÿ and ÿ In steady state, the differential relation of conduction in cylindrical coordinates has the form:

1 ÿ (ÿ ÿ) = 0 . (22)

The physical meaning of relation (22) becomes obvious if we consider the corresponding form of Fourier's law. Thus, the thermal flux ÿ transferred conductively (diffusively) for a cylindrical surface is given by the expression:

ÿ = ÿÿ ÿ ÿ = ÿÿ ÿ (2 ÿ ÿ ÿ ÿ) ÿ = ÿ2 ÿ ÿ ÿ ÿ (ÿ ÿ). (23)

where = 2 ÿ ÿ ÿ ÿ is the area of the surface perpendicular to the transfer direction of heat.

The comparison of relations (22) and (23) shows that the thermal flow ÿ is constant in the radial direction, which corresponds to a constant thermal energy for the considered wall (body). The constant thermal regime in the wall assumes an invariant temperature field ( ).

Heat transfer in the case of an electrically insulated conductor

Consider the case in figure A4.1 of a hollow cylindrical wall made of two concentric layers of different materials. The temperature distribution was represented in the hypothesis that the thermal contact resistance between the layers is significant. The wall separates a warm area having the temperature from a cold area having the temperature , , .

The convective heat transfer coefficients are ÿ , and ÿ , considered constant along the length *L* of the cylindrical wall.

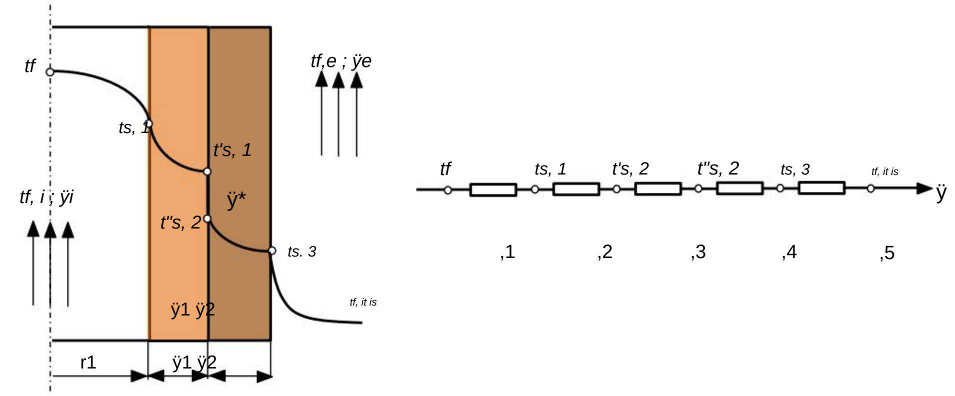


Fig. 24 Temperature distribution and equivalent thermal circuit for a multicomposite tubular cylindrical wall (inhomogeneous) with concentric layers.

The thermal flow ÿ transmitted from the hot zone to the cold zone is constant under the conditions a constant regime.

Heating of electrical conductors*

Non-insulated electric conductors passing through electric current represent a source of heat due to the thermal effects determined by the Joule effect.

In the present case, the acceptable hypothesis can be adopted that the radius *R* of the cylindrical conductor is much smaller than its length *L* and, therefore, for the calculation of the method of evaluation of the thermal field, a two-dimensional model can be adopted (the phenomenon being identical in any section along the conductor). Under these conditions, the thermal field in any cross-section of the conductor shows variations only in the radial direction according to Poisson's relation:

$$\frac{\text{ÿ}^2}{\text{ÿ}2} + + \frac{1}{} \cdot \frac{\text{ÿ}}{\text{ÿ}} + \frac{}{\text{ÿ}} = 0, \qquad (24)$$

where *t* is the temperature [K], *r* ÿ current radius [m] , *p* ÿ specific power dissipated in the conductor [W/m3], ÿ ÿ thermal conductivity [W/(mÿK)].

***Case study:**

Consider a copper conductor {ÿCu = 0.018ÿ10ÿ6 [ÿm]} with cross-sectional area *A* = 2.5[mm2] {*rc* = 0.892[mm]}, located in air with the ambient temperature *tf* = 20[ÿC], traveled by an electric current *I* = 25[A] {electric current density *j* = *I*/ *A* = 25/2.5 = 10 [A/mm2]} and the specific power *qv* = *j* ^{2}ÿÿCu = 1.8ÿ106 [W/m3] {ÿ/L = 4.5 [W/m]}, having an insulation with a thickness *ÿiz* = 0.5[mm] {*riz* = 0.00139 [m]}, under the conditions of a transmissivity coefficient between the insulation and the medium surrounding *ÿiz* = 10 [W/(m2ÿK)], the thermal conductivity of the insulating material *ÿiz* = 0.12 [W/(mÿK)], the temperature on the separation surface between the current-carrying conductor and the insulation will be:

= 2.20 + 51.52 + 20 = 73.72 [°C].

From relation (16) it follows that the temperature at the outer surface of the insulation is:

= 71.52 [°C].

In real cases, the temperature at the separation surface between the conductor and the insulation, as well as the temperature at the outer surface of the insulation can reach values that can generate sources of fire but also a degradation of the insulating qualities of the insulation.

The maximum temperature in the center of the conductor can be determined based on relation (7):

$$MAX = + \frac{}{4 ÿ ÿWith} \cdot {}^2 . \qquad (25)$$

For *tR* = 73.72ÿC, *qv* = 1.8ÿ106 [W/m3]; *rc* = 0.000892 m and ÿCu = 400 =>:

$$MAX = 73.72 + \frac{1800000}{4 ÿ 400} \cdot (0.000892)^2 = 73.72[°C].$$

Heating of multi-wire cables

For a cable with *n* identical conductors, with electrical resistance *r,* traversed by the same electrical current I, a quantity of heat corresponding to the loss power ÿ is released:

$$ÿ = ÿ \cdot {}^2 , \qquad (26)$$

which determines a heat flow ql per unit length:

$$= \frac{ÿ}{} = ÿ \frac{ÿ}{ÿ ÿ^2} \cdot {}^2 \text{ [W/m]}, \qquad (27)$$

A cable for powering a three-phase receiver comprises 5 conductors, of which 3 are active (phases A, B and C), a neutral conductor (N) and a protective conductor (PE) (fig. A6.1). Normally, the N and PE conductors do not carry electric current and therefore do not contribute to the heating of the cable.

In practical calculations, the bundle of *n* conductors is represented as one equivalent conductor with rech radius having the same cross-sectional area as the *n* conductors:

$$echo = ÿ ÿ . \qquad (28)$$

Heating a 3-wire single-phase cable

Of the three conductors, only two are current-carrying, the third being the earth (PE) conductor. As a result, for n=2, the linear heat flow generated is:

$$= ÿ \frac{ÿ}{} \cdot {}^2 = 2 \cdot \frac{1.68 \cdot 10ÿ8}{1.5 \cdot 10ÿ6} 162 = 5.734 \text{ [Wÿm]}.$$

The current density is:

$$= = \frac{16}{1.5} = 10.66 \text{ [A mm2 ÿ]} = 10.667 \cdot 106 \text{ [A m2 ÿ]}.$$

The volumetric internal heat source has the size:

$$= ÿÿ^2 = 1.68 \cdot 10ÿ8 \cdot (10.667 \cdot 106)\ 2 = 1.912 \cdot 106 \text{ [W m3 ÿ]}.$$

Assuming that this cable is laid in the open air with temperature = 25 [°C], the value of the convection coefficient for quiet air, without currents, must be determined, considering the average diameter of the conductor sheath De=8.4 [mm].

The problem is solved by successive approximations, starting from an initial value of the convection coefficient, ÿ = 5 [W (m2 ÿ ÿK)], arbitrarily chosen.

Starting from this value, the temperature of the outer surface of the conductor is determined:

= + ÿ ÿ ÿ a = 25 + 5,734 / ÿ · 8.4 · 10ÿ3 · 5 = 68.46 [°C],

resulting in the average temperature calculation of the physical properties:

= 0.5 ÿ (+) = 0.5 ÿ (25 + 68.46) = 46.73[°C].

The calculation model of electrical contact

In the case of the sphere model of infinite conductivity, it follows that between two half-spaces, 1 and 2, which model the contact elements, electrical conduction is established by means of a sphere of radius *a* and infinite conductivity. Electric current lines are radial and equipotential surfaces are spherical. The electric current density is constant on the surface of a sphere of radius r.

In the case of the flattened ellipsoid model, imagined by Holm R., it turns out that the half-spaces 1 and 2, of infinite conductivity are in contact by means of a flattened ellipsoid, as in figure A8.1 b); equipotential surfaces are confocal ellipsoids, which have the flattened ellipsoid as their base ellipsoid.

To *calculate the electrical resistance between the equipotential surface of the basic ellipsoid (as a contact point)* and *the surface of another equipotential confocal ellipsoid,* the formal analogy is used, which exists between the relations that characterize the stationary electric field of the direct electric current in a conducting medium and the relations which characterizes the electric field in an uncharged dielectric.

The electrical resistance of the flat contact

In reality, in the case *of contact between two flat surfaces,* current conduction takes place at the metal contact through a large number of point contacts (which form micro contact surfaces). If the contact points are assumed to be identical, then the total contact resistance with *n* contact points *Rtn* will be *n* times less than the contact resistance corresponding to the point contact.

From a *phenomenological* point of view , in the first moments the touch takes place in a small number of contact points. Then the material of the contact parts is crushed, the areas of the elementary contact surfaces increase, the contact parts are brought closer together and, as a result, new contact points appear. The process of increasing *n* will continue as long as *the specified push:*

= = ÿ ÿ ÿ 2 , (29)

is less than the permissible crushing ÿ.

The electrical resistance of a linear contact

A linear contact is made of a flat piece 1 and a cylinder segment piece 2, in contact under the action of the pressing force F, as in figure 25.a).

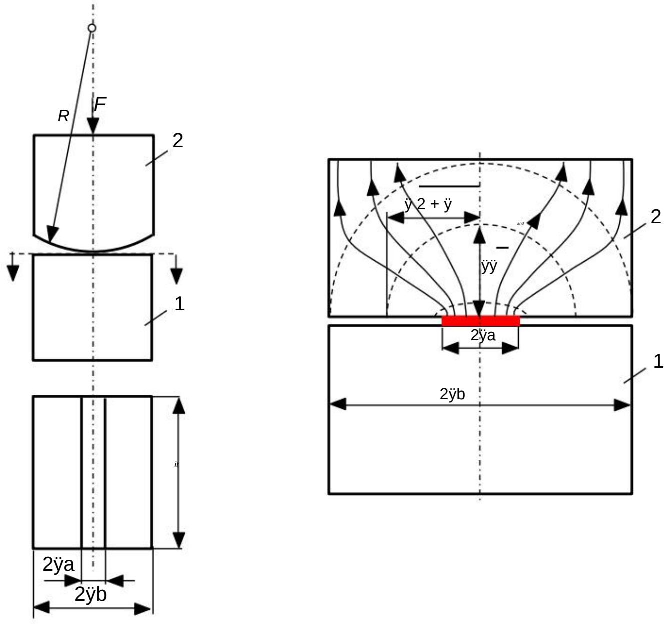
The mathematical model of the linear contact consists of a conductivity band *l* that establishes the electrical infinity and thickness with area 2 *A* conduction between parts 1 and 2.

The area of the strip of width 2 *a* and length *l* is obtained with the relation:

2 ÿ ÿ = . (30)

As with point contact, the radius *r* of the contact cylinder being relative large *(r* ÿ 50 ··· 60 mm) does not play a significant role in determining the contact resistance.

In figure 25 b) a cross section is presented in the linear contact calculation model. Equipotential surfaces are confocal eclipses; the base ellipse is a straight line of length 2 a. The electric current lines are hyperbolas orthogonal to the ellipse.



a) b)

Fig. 25 Linear contact: a) - contact surface; b) - the calculation model.

For the calculation of the constriction resistance, the analogy that exists between the relations that describe the electric field in a dialectic and the electric field obtained by passing the continuous electric current through a conductive medium is used.

The electrical resistance of a planar contact with deformation

Although in the technical field the planar contact is achieved with the plastic deformation of the material tips that come into contact, the number of contact points remains small (3 ... 20), and the occupied area is extremely small compared to the apparent contact area. Under these conditions, it can be considered in figure A9.1 that *d* >> *a.*

In the construction of electrical devices and installations, silver or tinned Cu parts are also used to make the surface contacts. In this case it is appropriate to consider the resistivity of the base material and the hardness of the protective material.

In table 2, the surface specific resistance = 10ÿ12[ÿÿm2] was considered , and the Prandtl figure ÿ = 0.45. It is worth noting that at a new contact with the surface of unaltered contact, the contribution of the constriction resistance is predominant, while in a contact with the altered contact surface, the contribution of the resistance of the superficial film is predominant, to the formation of the total resistance.

Table 2 Values for c, *m* and *e* - from relation (6) in the SI system

MATERIAL	*c*	*m*	*e*
Silver	0.842 ÿ 10-4	0.6	2.25 ÿ 10-4
Copper1	0.935 ÿ 10-4	0.6	2.48 ÿ 10-4
Aluminum 1.342 ÿ 10-4	1.35 ÿ 10-4	0.6	
Cu-W1 synthesis	1.972 ÿ 10-4	0.6	12.60 ÿ 10-4
Tinned copper	0.596 ÿ 10-4	0.6	0.225 ÿ 10-4
Silver-plated copper	0.918 ÿ 10-4	0.6	2.25 ÿ 10-4

Contact heating in long-term mode

For the analysis of the heating of the contacts during the passage of a long electric current are several calculation models are used:

a) model of the sphere of infinite conductivity (fig. 26);

b) the flattened ellipsoid model (fig. 27);

If the resistivity of the material of the two half-spaces is denoted by ÿ, the resistance electric field of a spherical half-space of thickness *dr* results:

$$ÿ d = \frac{ÿ}{2 ÿ ÿ ÿ^{2}}, \tag{31}$$

and the electrical resistance of the spherical half-space results:

$$= \frac{ÿ}{2 ÿ ÿ ÿ} \int^{ÿ} \frac{d}{^{2}} = \frac{ÿ}{2 ÿ ÿ ÿ}. \tag{32}$$

The electric contact resistance *Rc* of the two hemispheres touching the sphere of infinite conductivity is twice higher than the value indicated in relation (32):

$$= \frac{ÿ}{ÿ ÿ} \tag{33}$$

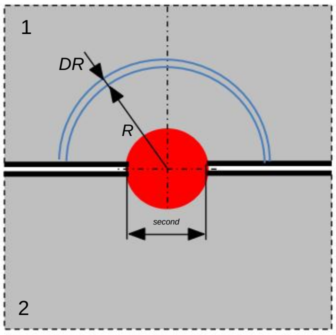


Fig. 26 The sphere model of infinite conductivity

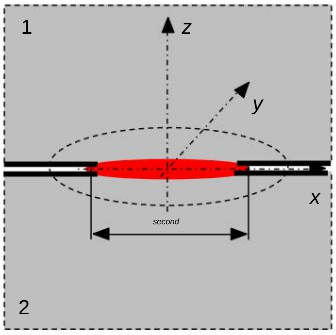


Fig. 27 The flattened ellipsoid model

If, for example, the spherical contact between the two *Ag* materials ÿAg=0.0165ÿ10ÿ6 [ÿÿm], and the contact sphere has a radius of 2[mm], a resistance of:

$$= \frac{0.0165 ÿ 10ÿ6}{ÿ ÿ 2 ÿ 10ÿ3} = 2.63 ÿ 10ÿ6 [ÿ].$$

Electric current tube

To perform the calculations, the following assumptions are made:

a) The heat flow developed in each tube is transmitted to the outside only through its own electric current tube. There is no heat transfer between neighboring points *m* and n, which are assumed to be at the same temperature.

b) The highest overtemperature is on the area ÿA0, which also defines a surface isothermal, as a result of the fact that in the contact zone there is the greatest constriction.

c) The contact elements are made of the same homogeneous and isotropic material.

By passing the electric current *I* through an electric current tube, equipotential and isothermal surfaces are defined, considering the surface ÿA0 with reference parameters regarding the electric potential V = 0, the overtemperature *ÿt* and the absolute temperature

T=Tt. An area ÿAÿ located very far away, theoretically at infinity, is characterized by V=U/2, where *U* is the contact voltage *ÿt* = 0, *T=T0.*

It is noted that *equipotential surfaces are also isothermal,* due to the fact that equal heat fluxes pass through equal thermal resistances. In fact the expression of the electrical resistances *R* and thermal *Rt,* for a segment of electric current tube between the base surface ÿA0 and the equipotential surface ÿA01 located at the distance *dn* from ÿA0, are:

= ÿ ÿ ÿ ÿ 01 ; (34)

= ÿ ÿ ÿ ÿ 01 . (35)

where:

ÿ ÿ - represents an average value of the area over the distance *dn;*

ÿ - electrical conductivity;

ÿ - thermal conductivity.

Influence of pressure force

For plastic deformation = ÿ ÿ(ÿ dependence between force *F* and) and results in the relation of temperature *Tt* is entered :

= 2 ÿ ÿ ÿ H / 16 ÿ ÿ 2 · 1 / (bow basket 0) 2 . (36)

Adiabatic heating regime

In the case of the adiabatic regime, to calculate the heating in this regime, it is considered the general relationship of conduction heating in media with sources:

— / ÿ = ÿ / 1 ÿ ÿ + ÿ1 / 1 . (37)

If we consider the spherical contact model and the physical process as adiabatic:

— / ÿ = ÿ1 / 1 , (38)

where ÿ1, the power developed in the unit volume is at the distance *r* from the center of the sphere contact:

ÿ1 = ÿÿ 2 = ÿ0 ÿ [1 + ÿ ÿ (+)] ÿ 2 / 4 ÿ ÿ2 ÿ 4 . (39)

In the case of the frontal power injection regime, the contact elements are fixed on electric current paths that have preferential extension, namely according to the length of the conductor. The heat relation can describe the heating process in the short-term regime under the following assumptions:

- heat propagates along a single spatial dimension;
- the heat source is concentrated on the front surface of the contact and comes from Joule effect of compressive strength. Apart from the tensile strength alone there are other sources of heat, so in the heat relation p1=0

The influence of overtemperature

The dependence relationship between the electric resistance *Rt* of the heated contact and the electric resistance R0 of the unheated contact is determined using the potential theory. With reference to this theory, two strictures are considered, namely:

- the restriction S(ÿ, ÿ), where ÿ and ÿ depend on the temperature;
- the restriction S0(ÿ0, ÿ0), where ÿ=ÿ0 and ÿ=ÿ0, and ÿ and ÿ do not depend on temperature;

For the two strictures the elementary potential variation is:

$$d = ÿÿ \frac{d}{ÿ} ; d_0 = ÿ0\, ÿ \frac{d}{ÿ} . \quad (40)$$

Since the dependence of resistivity with temperature is of the form ÿ = ÿ0 ÿ (1 + ÿ ÿ), from relations (40) it follows:

$$d = d_0\, ÿ (1 + ÿ ÿ). \quad (41)$$

Experimental data in industrial installations

For checking the heating conditions of electrical conductors, it was studied the distortion of electric current in industrial electrical installations. To begin with, the correctness of the voltage and current phasor sequence was checked

The strong distortion of the curves and the deviation from the sinusoidal form is determined by the large number of frequency converters used to supply electric motors, which are not equipped with systems for limiting the level of distortion.

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