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ALMATY UNIVERSITY *OF* POWER ENGINEERING AND TELECOMMUNICATIONS

Department of Power supply and renewable energy sources

ELECTRIC DEVICES

Lecture notes for specialty
5B071800 - Electrical power engineering

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Lecture notes for bachelor-students by speciality 5B071800- Electrical power engineering.

Reviewer: Candidate of Economic Sciences, Tuzelbayev B.I.

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The electric devices

Contents

1 Lecture 1. Introduction to a discipline course[1]

Content of lecture:

classification of electric devices. The main requirements imposed to electric devices. The main materials applied in an instrument -making. Literature.

Lecture purpose:

to acquaint students with appointment and the place taken by electric devices in power industry, terminology and literature at the course.

The electrotechnical devices used in power industry can be broken into three big groups conditionally:

- electrical machines;
- electric networks;
- electric devices.

Electric devices are the integral component in system of creation, distribution and use of the electric power.

Purposes of teaching course electric devices:

- to give to future experts in the field of power industry basic knowledge about electric devices, understanding of physical bases and provisions of the general theory of electric devices;
- on the basis of the general theory studying of designs of the main devices of common industrial appointment.

The electric device it is accepted to call the electrotechnical device intended for management, regulation and protection of electric chains and cars and also for control and regulation of various not electric processes.

1.1 Classification of electric devices

For convenience of studying, devices are classified by various signs.

a) to destination devices are subdivided into the following groups:

1) switching, intended for inclusion and shutdown of electric chains;

2) protective, intended for protection and disconnection of electric chains from overloads, currents of short circuit and other abnormal modes;

3) starting and regulating, intended for start-up and regulation of speed of electrical machines;

4) controlling (relays), intended for control of the set parameters of an electric chain;

5) regulating, intended for automatic continuous stabilization or regulation of the set parameter of an electric chain or system;

b) by the principle of work devices share on contact and contactless devices.

[1] On a lecture subject see [1, c.5-31], [2, c.11-13]

The first have mobile contact parts, and impact on the operated chain is carried out by short circuit and disconnection of these contacts. Existence of contact system is a weak link of such devices. Contactless devices have no the disconnected or sliding contacts. These devices exercise control by change of the electric parameters;

c) contact devices can be automatic and non-automatic.

The first come into action from the set operating mode of a chain or the car. Non-automatic devices – on will of the operator.

Within one group or type devices are distinguished:

a) on tension – a low voltage (to 1000B) and a high voltage (over 1000B);

b) by the nature of current - a direct current, alternating current of industrial frequency and alternating current of the increased frequency;

c) by the nature of protection against environment - open execution, splash-proof, explosion-proof, etc.;

d) on a way of action – electromagnetic, magnetoelectric, thermal, induction, etc.;

e) on some other factors (speed, to a way of clearing of an arch, etc.).

1.2 The main requirements imposed to electric devices

Requirements imposed to electric devices are rather various and depend on appointment, conditions of application and operation of the device.

Except the specific requirements relating to concrete type of the device, all electric devices have to meet the general requirements:

a) each device as a result of course on it electric current during the work heats up. Device temperature thus should not surpass some certain admissible size established for this device and its details;

b) in each electric chain can be abnormal (overload) or an emergency (short circuit) operating mode. The current proceeding on the device in these modes can exceed rated current of the device considerably. The device is exposed thus to big thermal and electrodynamic influences. However it has to sustain these influences without any deformations interfering its further work;

c) each electric device works in a chain with a certain tension where can also take place and an overstrain. However electric isolation of the device has to ensure reliable functioning of the device and at preset values of retension;

d) contacts of devices have to be capable to include and disconnect all currents of operating modes, and many devices and currents of emergency operation;

e) these or those requirements are imposed to each electric device from the point of view of reliability and the accuracy of work, and also a certain speed;

e) any electric device has to, whenever possible have the smallest dimensions, weight, cost, to be simple on the device, convenient in service and technological in production.

1.3 The main materials applied in an instrument-making

The materials applied in an instrument-making can be broken into the following groups:

a) conduction materials – mainly copper, aluminum, steel, brass, etc.;

b) ferromagnetic materials – different became also alloys for magnetic conductors;

c) insulating materials – for electric isolation of current carrying parts from each other and from the grounded parts;

d) arc-resistant insulating materials – asbestos, ceramics, plastic for arc-?gasitelny chambers;

e) alloys of high resistance – for production of various resistance;

e) contact materials - silver, copper, metal ceramics for ensuring high wear resistance of contacts;

g) bimetals – are applied in the automatic devices using linear lengthening of bodies when heating by electric current;

i) constructional materials – metals, plastic, insulating materials for giving to devices and its details of these or those forms and for production of details which primary value is transfer and perception of mechanical efforts.

Technical progress in an instrument-making considerably is defined by quality of the listed materials.

2 Lecture 2. Electrodynamic efforts in devices[2]

Content of lecture

calculation of electrodynamic efforts on the basis of Biot-Savart's law and on change of a stock of electromagnetic energy of a contour. Electrodynamic efforts in rounds and coils of devices. Electrodynamic efforts between the conductor with current and ferromagnetic weight. Electrodynamic efforts in conductors of variable section.

Lecture purposes:

to acquaint students with the electrodynamic efforts operating in electric devices and the existing methods of their calculation.

2.1 Basic concepts

At short circuit in a network through current carrying parts of the device the currents which are repeatedly exceeding rated current of the device can proceed. At interaction of these currents with a magnetic field of other current carrying parts of the device electrodynamic efforts (EDU) are created. These efforts seek to deform both conductors of current carrying parts, and insulators on which they fasten. This circumstance demands carrying out calculation of the device on electrodynamic firmness, i.e. on ability of the device to sustain passing of current of KZ without damage. Calculation of EDU is conducted usually or on the basis of Biot-Savart's law, or on change of a stock of magnetic energy of system. Let's consider application of the specified methods for calculation of EDU.

It is known that the conductor with the current located in a magnetic field is affected by the mechanical force which can be found from expression

$$\mathbf{F = I \cdot L \cdot B \cdot Sin\beta} \qquad (2.1)$$

where **I** - the current proceeding on the conductor;

L - length of the conductor;

In - induction of a magnetic field;

ß - a corner between the direction of induction and the direction of current.

The direction of action of force can be found:

a) by the rule of the left hand;

b) by method of a lateral raspor? and tyazheniye? of magnetic lines;

c) in a contour with current the direction of force is defined from the following general provision: forces operating in a contour with current seek to change a contour configuration so that the magnetic flux covered by a contour increased.

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[2] On a lecture subject see [1, c.31-58], [2, c.13-33]

2.2 Calculation of EDU on the basis of Biot-Savart's law

Let the task be set for us: to find forces operating on the conductor with current, being in a magnetic field, created randomly by the conductors located in space with currents.

To use a formula (2.1) and to find forces operating on the conductor with current it is necessary to find previously value of the induction created by sources of a magnetic field in the location of our conductor. Value of induction is also defined on the basis of Biot-Savart's law, known from a course of physics.

According to this law, in the absence of ferromagnetic environments the elementary induction created by an element of a linear wire of dL on which current of I flows at distance ρwill be equal in the point remote from a current element

$$\mathbf{dB} = \frac{\mu_o \cdot \mathbf{I} \cdot \mathbf{dL} \cdot \mathbf{Sin\alpha}}{4 \cdot \pi \cdot \rho^2} \qquad (2.2)$$

where α- a corner between a vector ρand the direction of current.

The resulting induction in the considered point from all wire

$$\mathbf{B} = \frac{\mu_o \cdot \mathbf{I}}{4 \cdot \pi} \cdot \int_L \frac{\mathbf{dL} \cdot \mathbf{Sin}\alpha}{\rho^2} \ . \ (2.3)$$

Similarly define induction in the space point interesting us from all available conductors with currents.

After definition of induction on a formula (2.1) EDU is calculated.

The method of calculation of EDU described above is universal. However, in some cases, it is simpler to apply the second method which carries the name of the power to finding of electrodynamic forces.

2.3 Calculation of electrodynamic forces for change of a stock of electromagnetic energy of a contour

The electromagnetic field round conductors and contours with current possesses an energy stock. Electromagnetic energy of the contour which is flowed round by current of I is equal

$$\mathbf{W} = \mathbf{L}\frac{\mathbf{I}^2}{2} \ . \ (2.4)$$

In turn electromagnetic energy of two contours which are flowed round by currents of i1 and i2 is equal

$$\mathbf{W} = \mathbf{L}_1 \cdot \frac{\mathbf{i}_1^2}{2} + \mathbf{L}_2 \cdot \frac{\mathbf{i}_2^2}{2} + \mathbf{M} \cdot \mathbf{i}_1 \cdot \mathbf{i}_2 \qquad (2.5)$$

where L-inductance of a contour;

M - mutual inductance of contours.

Any deformation of a contour or change of a relative positioning of contours leads to change of a stock of electromagnetic energy.

As it is known work of forces is equal in any system to change of a stock of energy of this system

$$\mathbf{A} = \mathbf{F} \cdot \mathbf{dx} = \mathbf{dW} \qquad (2.6)$$

where **dW** - change of a stock of energy of system at its deformation in the direction of axis X under the influence of **F** force.

The second method of definition of EDU in contours which received the name of a power method of calculation of EDU is also based on the specified law - the law of energy conservation.

When using this method electrodynamic force in a contour or between contours, acting in the direction of axis X is equal to the speed of change of a stock of energy of system at its deformation in the same direction, i.e. its derivative in this direction.

$$\mathbf{F} = \mathbf{dW} / \mathbf{dx}\,. \qquad (2.7)$$

It is convenient to apply this method when the formulas connecting inductance and mutual inductance of contours with their geometrical parameters i.e. in rounds and coils of electric devices and transformers are known.

2.4 Electrodynamic efforts in a round, the coil and between coils

As showed researches force operating in a round with current proportionally to a square of current and diameter of a round. This force affects a rupture of a round. If the coil consists of ωthe rounds which are flowed round by one current, inductance and the breaking-off effort will increase by ω2 times. Forces in the coil are directed so that its flux linkage increased. They seek to squeeze the coil on height and thickness and to increase its average diameter.

2.5 EDU between the conductor with current and ferromagnetic weight

At approach of the conductor with current to a ferromagnetic wall the magnetic field is distorted, magnetic power lines seek to become isolated on weight and there are forces seeking to attract the conductor to this weight i.e. there are attraction forces which are not depending on the direction of current in the conductor.

This property is used for retraction of an electric arch in the dugogasitelny steel lattice applied in many low-voltage devices in which there is an effective clearing of an arch.

2.6 Electrodynamic efforts in conductors of variable section

If the section of the conductor changes that always happens in a place of contacts of conductors, in a place of change of section owing to a curvature of lines of current there are longitudinal EDU (see fig. 2.1) seeking to break off a transition place along an axis of the conductor and directed towards bigger section. These forces reduce force of pressing of contact springs of devices that leads to increase in transitional resistance of contacts and at big currents of KZ to their svarivaniye.

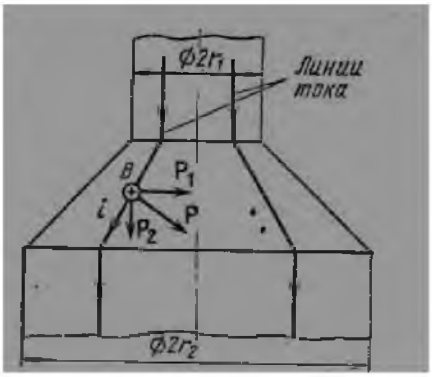


Figure 2.1-EDU in conductors of variable section

3 Lecture 3. Thermal calculations of electric devices[3]

Content of lecture:

bases of thermal calculations. Losses in conductors. Return is warm a heated body. Heat conductivity, convection, radiation. A thermolysis in the set mode.

Lecture purpose:

to acquaint students with bases of thermal calculations of electric devices.

3.1 Bases of thermal calculations

3.1.1 Losses in the conductors which are flowed round by current

The power P lost when passing on it electric current is equal in the conductor

$$\mathbf{P} = \mathbf{I}^2 \cdot \mathbf{R}$$

where **I-**effective value of current;

R – resistance of the conductor.

At a direct current of R corresponds to ohmic resistance

$$\mathbf{R}_0 = \frac{\rho \cdot \mathbf{l}}{\mathbf{s}}.$$

At alternating current of loss turn out big, than at a direct current. This increase of losses happens due to superficial effect and effect of proximity and is considered by coefficient of additional losses of CD> 1. Resistance at alternating current due to the called effects is more ohmic also carries the name of active resistance.

$$\mathbf{R} = \mathbf{R}_0 \cdot \mathbf{k}_{Д}.$$

Active resistance is the some fictitious resistance of the conductor which, being multiplied by a square of effective value of current, gives the losses which are really available at alternating current.

3.1.2 Superficial effect

The variation magnetic field covering the conductor with current induces in this conductor of EMF, directed towards to the enclosed tension. As the central layers of the conductor are crossed by a big magnetic flux, than external, and EMF, will be the greatest on a wire axis.

This EMF leads to reduction of density of current in the central layers of the conductor in comparison with current density in external layers. Influence of this phenomenon can be perceived as reduction of effective section of the conductor and respectively increase in resistance. Influence of superficial effect

[3] On a lecture subject see [1, c.59-64], [2, c.33-37]

grows with growth of frequency of current, conductivity and magnetic permeability of material of the conductor.

3.1.3 Effect of proximity

In this case change of distribution of current on the section of the conductor and change of resistance arises due to influence of a magnetic field of the next conductors with current.

3.2 Return is warm a heated body. Heat conductivity. Convection. Radiation.

Transfer of heat always goes from more heated bodies to less heated bodies and happens until temperatures of bodies are not made even. The temperature of a heated body is higher, the more intensively there is a process of transfer of heat.

Distinguish three types of transfer of heat: heat conductivity, convection and radiation.

3.2.1 Heat conductivity

Process of transfer of heat from one particle of a body to another or from one body to another when these particles or bodies adjoin with each other is called as heat conductivity. Heat conductivity in metals is carried out thanks to the thermal movement of electrons, and in other cases – molecules. Heat conductivity is characteristic for solid bodies. A necessary condition of heat conductivity is the difference of temperatures.

At calculation of transfer of heat through a body due to heat conductivity often apply expression

$$\tau = \mathbf{\Phi} \cdot \mathbf{R_T}$$

where τ- a difference of temperatures on an internal and external wall of material;

ö - the thermal stream passing through walls of the adjoining bodies; RT - the thermal resistance of a body.

$$\mathbf{R_T} = \frac{\boldsymbol{\delta}}{\boldsymbol{\lambda} \cdot \mathbf{S}} \qquad (3.1)$$

where λ- the heat conductivity coefficient, is in number equal to amount of heat transmitted through a surface by the area 1m2 for 1 sec. at temperature drop in 10 °C

The equation (3-1) is similar to the law of Ohm for electric chains and is called as the thermal law of Ohm. Thermal resistance in direct ratio to length of a way of a thermal stream δand in inverse proportion to the section of this way and coefficient of heat conductivity.

As appears from (3-1) amounts of heat allocated from one body to another due to heat conductivity in direct ratio for a difference of temperatures between them τand in inverse proportion to the thermal resistance of Rt of that body through which heat is transmitted. If the thermal stream passes through a number of walls with various thickness and coefficient of heat conductivity, the resulting thermal resistance of all walls will be equal to the sum of these resistance.

3.2.2 Convection

Process of transfer of heat by movement of particles of liquid or gas is called as convection. At natural convection the movement of the cooling gas or liquid occur at the expense of a difference of density of heated and cold volumes. At artificial convection the cooling environment is set in motion by means of fans or pumps.

Amount of heat given by a body due to convection

$$\mathbf{Q} = \alpha \cdot \tau \cdot \mathbf{S}$$

where α- the thermolysis Coefficient at convection determined by heat which is removed for 1 sec. from a surface in 1kv. m at a difference of temperatures in 10 °C;

τ - A difference of temperatures between a heated body and the cooling gas or liquid environment;

S - Body surface.

3.2.3 Thermal radiation

The part of energy gives a heated body to surrounding space by the radiation of electromagnetic waves (ultra-violet, infrared).

This way of a thermolysis is called as the thermal radiation, emission or radiation.

Heat given by a heated body at the expense of radiation decides on the help of the equation of Stefan-Boltzmann

$$\mathbf{Q} = \mathbf{k} \cdot \left[\left(\frac{\mathbf{T}_2}{1000} \right)^4 - \left(\frac{\mathbf{T}_1}{1000} \right)^4 \right] \cdot \mathbf{S}.$$

The amount of the given heat depends on a difference of the fourth degrees of absolute temperatures of its heated surface and environment.

The total amount of heat given by all types of heat exchange with difficulty depends on body temperature and its geometrical sizes. Therefore in each case previously estimate intensity of all types of heat exchange and those from them which prevails consider. For example, for the conductors shipped in oil consider only convection; for long tires neglect heat conductivity and consider only convection and radiation.

3.3 A thermolysis in the set mode

The thermolysis from a surface of a body occurs at the same time convection and radiation. Thus it is difficult to divide, what part of heat is transferred to environment by convection, and what part – radiation. Therefore enter concept of coefficient of a thermolysis of Kt which defines the amount of heat given to environment for 1 sec. all types of a thermolysis with 1kv.m. surfaces at a difference of temperatures of a heated body and surrounding space in 1grad. Celsius. The thermolysis coefficient (or heat exchange) is in the empirical way.

Then the amount of heat given by a heated body to surrounding space will be equal

$$\mathbf{Q} = \mathbf{k}_T \cdot \boldsymbol{\tau}_y \cdot \mathbf{S}.$$

In the set mode when all losses of P allocated in the conductor are sent to surrounding space it is possible to write down

$$\mathbf{P} = \mathbf{k}_T \cdot \boldsymbol{\tau}_y \cdot \mathbf{S}.$$

From where there is an excess of temperature of a heated body over ambient temperature Θ_o

$$\boldsymbol{\tau}_y = \frac{\mathbf{P}}{\mathbf{k}_T \cdot \mathbf{S}}.$$

And then and temperature of a heated body

$$\Theta_T = \Theta_O + \boldsymbol{\tau}_y.$$

Lecture 4. Operation of devices in the transitional modes[4]

Content of lecture:

heating and cooling of devices at a long operating mode. Heating and cooling of devices at a short-term operating mode. Heating and cooling of devices at a repeated and short-term operating mode.

Lecture purpose:

to acquaint students with features of heating and cooling of electric devices depending on duration of an operating mode of the device.

4.1 Heating and cooling of devices at a long operating mode

4.1.1 Equation of heating of the device

After turning on of the device temperature of its elements reaches not at once the established values. Heat allocated in the device partially is sent to surrounding space, partially goes for increase of its temperature.

The equation of thermal balance has an appearance

$$\mathbf{P \cdot dt = k_T \cdot S \cdot \tau \cdot \cdot dt + C \cdot d\tau} \qquad (4.1)$$

where P - the power of thermal losses in a body;

With - a body thermal capacity $\mathbf{C = M \cdot c}$

where with - specific heat;

M - body weight.

In the equation (4.1) left member of equation is the energy consumed by the device from a network during dt. The first member of the right member of equation is the amount of heat given by a body to surrounding space during dt. The second member is the amount of heat perceived by a body at change of its temperature on dτ

The solution of the differential equation (4.1) is relative dτ will be equal

$$\tau = \tau_Y \cdot (1 - \mathbf{e}^{-t/T}) \qquad (4.2)$$

where $\boldsymbol{\tau}_y$ - the established excess of body temperature over ambient temperature, is on a formula

$$\boldsymbol{\tau}_{\mathbf{Y}} = \frac{\mathbf{P}}{\mathbf{k_T \cdot S}}$$

The t - a constant of time of heating of a body, is determined by a formula

[4] On a lecture subject see [1, c.75-85], [2, c.40-44]

$$\mathbf{T} = \frac{\mathbf{c} \cdot \mathbf{M}}{\mathbf{k_T} \cdot \mathbf{S}}$$

The heating time constant physically represents itself time for which the body will heat up to the established temperature in the absence of a thermolysis in environment.

4.1.2 Equation of cooling of the device

For a cooling equation conclusion in the equation (4.1) we will put

$$\mathbf{P} \cdot \mathbf{dt} = 0.$$

In this case the equation will assume an air

$$0 = \mathbf{k_T} \cdot \mathbf{S} \cdot \tau \cdot \cdot \mathbf{dt} + \mathbf{C} \cdot \mathbf{d}\tau$$

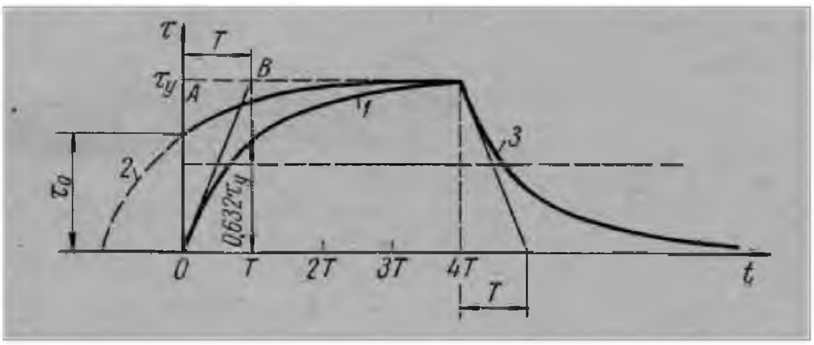
from where

$$\tau = \tau_0 \cdot \mathbf{e}^{-t/T}$$

where τ_0 – excess of body temperature at the time of the beginning of process of cooling.

The curve of cooling is the mirror image of a curve of heating.

Curves of heating and cooling of the device are given in figure 4.1. Time of t is taken in T shares. The established body temperature usually is reached through time equal (35) T÷.



Drawing 4.1-Curves of process of heating and cooling of the device at a long operating mode

4.2 Heating and cooling of devices at a short-term operating mode

At a long operating mode the permissible load of Rd gets out so that the established excess of temperature τ_{at} was to equally admissible excess τof. Excess of temperature in this case changes on a curve 1 (see figure 4.2).

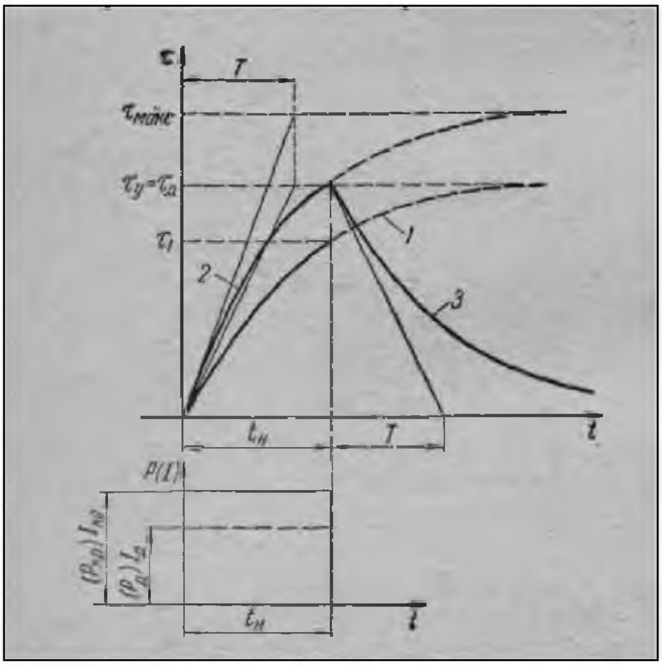


Figure 4.2 –Curves of process of heating and cooling of the device at a short-term operating mode

At the same loading in a short-term operating mode in time $\mathbf{t}_{\text{Н}}$ excess of temperature would reach value τ_1, i.e. the device would not be completely used on heating.

Therefore at the short-term mode it is possible to increase loading so that excess of temperature changed on a curve 2 and by the end of the mode (in time $\mathbf{t}_{\text{Н}}$) reached admissible temperature. For the characteristic of the short-term mode the concept of coefficient of an overload is entered

$$\mathbf{p} = \frac{\mathbf{I}_{\text{кр}}}{\mathbf{I}_{\text{дл}}},$$

which shows, in how many time it is possible to increase a permissible load on current at the short-term mode in comparison with the long mode

$$\mathbf{p} = \frac{1}{\sqrt{1 - \mathbf{e}^{-\mathbf{t}_{\text{кр}}/\text{T}}}} . \quad (4.3)$$

The analysis (4.3) shows that the coefficient of an overload grows with increase in a constant of time. In this regard in the devices, household devices working in the short-term modes it is recommended to increase time constant that allows to raise loading on current. The increase in a constant of time is reached generally at the expense of increase in mass of the material participating in heating process.

4.3 Heating and cooling of devices at a repeated and short-term operating mode

The operating mode is called repeated and short-term, at which loading periods $\mathbf{t}_{\text{Н}}$ alternate with pauses $\mathbf{t}_{\text{П}}$. Full period $\mathbf{t}_{\text{Н}}+\mathbf{t}_{\text{П}}$ is called as a cycle $\mathbf{t}_{\text{Ц}}$.

The mode by duration of inclusions of PV of % and frequency of inclusion - number of cycles in an hour is characterized.

PV of % represents the loading duration relation to duration of all cycle expressed as a percentage.

$$\mathbf{ПВ}\% = \frac{\mathbf{t}_{\text{н}}}{\mathbf{t}_{\text{Ц}}} \cdot 100\%.$$

Curves of process of heating and cooling of the device are represented in figure 4.3.

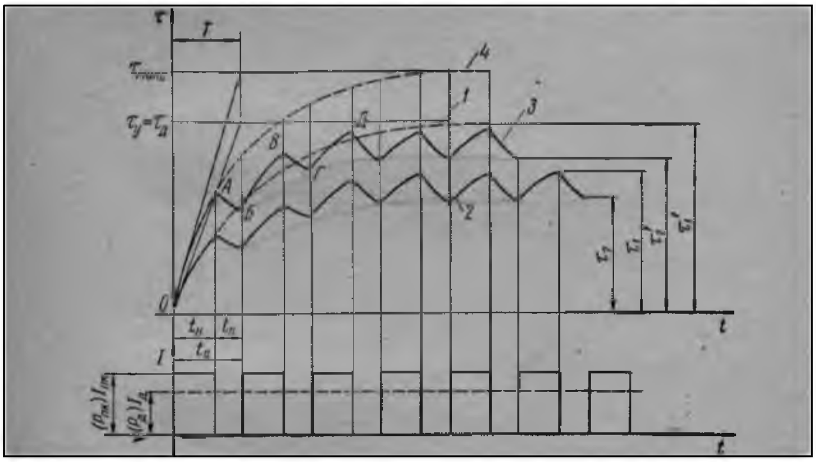


Figure 4.3 – Curves of process of heating and cooling of the device at a repeated and short-term operating mode

In this mode the periods of heating and cooling alternate and, since some moment, there comes the state when excess of temperature fluctuates between some maximum τ_1 and a minimum τ_2. If to load the device with the current corresponding to device % PV, excess of temperature will be to equally admissible excess of temperature (a curve 1). If at this current the device to leave included for a long time, excess of temperature will be more admissible and the device will fail.

5 Lecture 5. Thermal stability of electric devices[5]

Content of lecture:

heating of devices at short circuit. Thermal stability of devices. Extremely allowed temperatures of heating of conductors and devices. An indirect method of definition of the established excess of temperature and a constant of time of heating of the device.

Lecture purpose:

to study communications between rated currents of elements of the device (or the conductor) and their extremely allowed temperatures.

5.1 Heating of the device at short circuit

Short circuit is characterized by big current and the small duration determined by reaction time the maximum current protection. As showed researches if duration of heating does not exceed 0,1 T, it is possible to neglect return of heat in surrounding space and to believe that all energy emitted at KZ goes for heating of the device.

The equation of thermal balance (4-1) will have in this case an appearance

$$\mathbf{P \cdot dt = k_T C \cdot d\tau}$$

from where

$$\mathbf{d\tau = \frac{P \cdot dt}{C}}$$

then

$$\tau_{\text{КЗ}} = \frac{\mathbf{I}^2_{\text{КЗ}} \cdot \mathbf{t}_{\text{КЗ}} \cdot \mathbf{R}}{\mathbf{C}} + \tau_0$$

where τ_0 – excess of temperature of the device at the time of the beginning of KZ.

Heating of the device at KZ happens practically in a straight line (see figure 5.1)

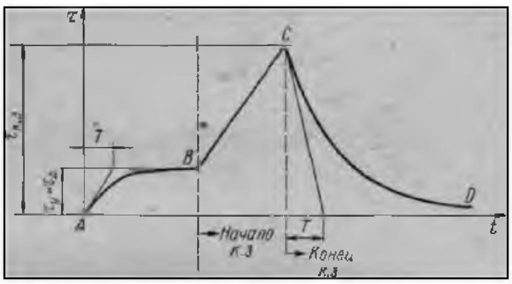


Figure 5.1 - Heating of the device at short circuit and its cooling after shutdown

5.2 Thermal stability of devices

Understand its ability to sustain without damages and an overheat above norms thermal action of currents of KZ of a certain duration as thermal stability of devices. For offices of firm - producers provide current of thermal stability and time during which the device can pass this current in the catalogs, without overheating and without being damaged.

The devices and electric networks protected by the safety locks having small endurance of reaction time (less 5ms) usually do not check for thermal and electrodynamic stability.

5.3 Extremely allowed temperature of heating of conductors and devices

For ensuring reliable operation of the device temperature of its conductors and details should not surpass some certain value. Temperature at which reliable operation of the device both which influence conductors and devices can sustain without decrease of the electric and mechanical properties is guaranteed is called as the limit allowed temperature.

Two admissible temperatures are normalized: - at the nominal long mode;

- at short circuit.

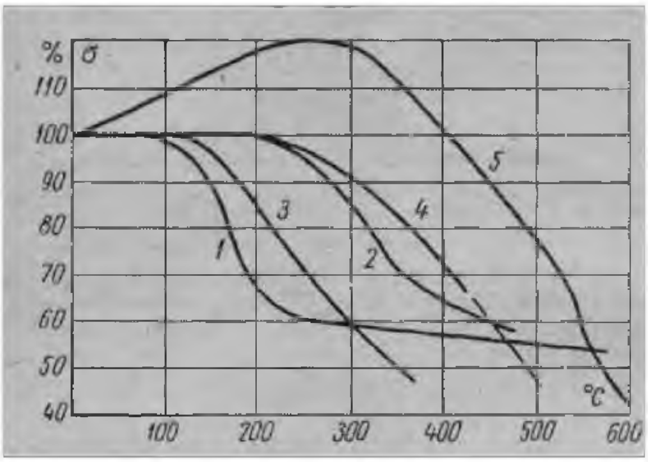
Short circuit is the short-term mode therefore having heated currents of KZ it is possible to allow higher, than at the long mode. However, this heating should not lead to decrease of electric and mechanical properties of isolation and wires.

For aluminum maximum permissible temperature for the KZ mode is accepted equal 2000C, and for copper 3000C.

Maximum permissible temperature for the isolated conductors is defined by properties (an isolation class) to which the conductor adjoins.

Maximum permissible temperature for uninsulated (naked) conductors are defined by the mechanical durability of conductors which sharply decreases with growth of temperature (see figure 5.2).

1,2 - aluminum; 4-



copper; 3 - ;;;;;;; 5 - steel.

Figure 5.2 - Dependence of strength metals at stretching from temperature heating.

Maximum permissible temperature for the conductors having contact connections sharply decreases in comparison with the whole conductors and is defined by temperature of the beginning of intensive oxidation of contact surfaces. As practice if temperature of contact connections does not exceed 70 degrees showed, reliable and their long-term functioning is ensured. And, on the contrary, if temperature of the wire having contact connections exceeds 70 degrees, as a result of oxidizing processes resistance of contacts increases, also thermal losses at the same time increase in them. Contacts overheat and collapse. Reliability of power supply worsens.

Maximum permissible temperature for not current carrying details: bearing, fixing, protective, etc. is defined from service safety conditions (an exception of burns at contact with them).

5.3 An indirect method of definition of the established excess of temperature and a constant of time of heating of the device

Often in practice it is required to find value of a constant of time of heating and the established excess of temperature of the device which skilled receiving demands a long time (10 — 20 hours) that causes, naturally, big inconveniences.

In this case the established excess of temperature is defined on the basis of partially removed heating curve.

The method is based that dependence $\tau = f\left(\frac{d\tau}{dt}\right)$ represents itself a straight line.

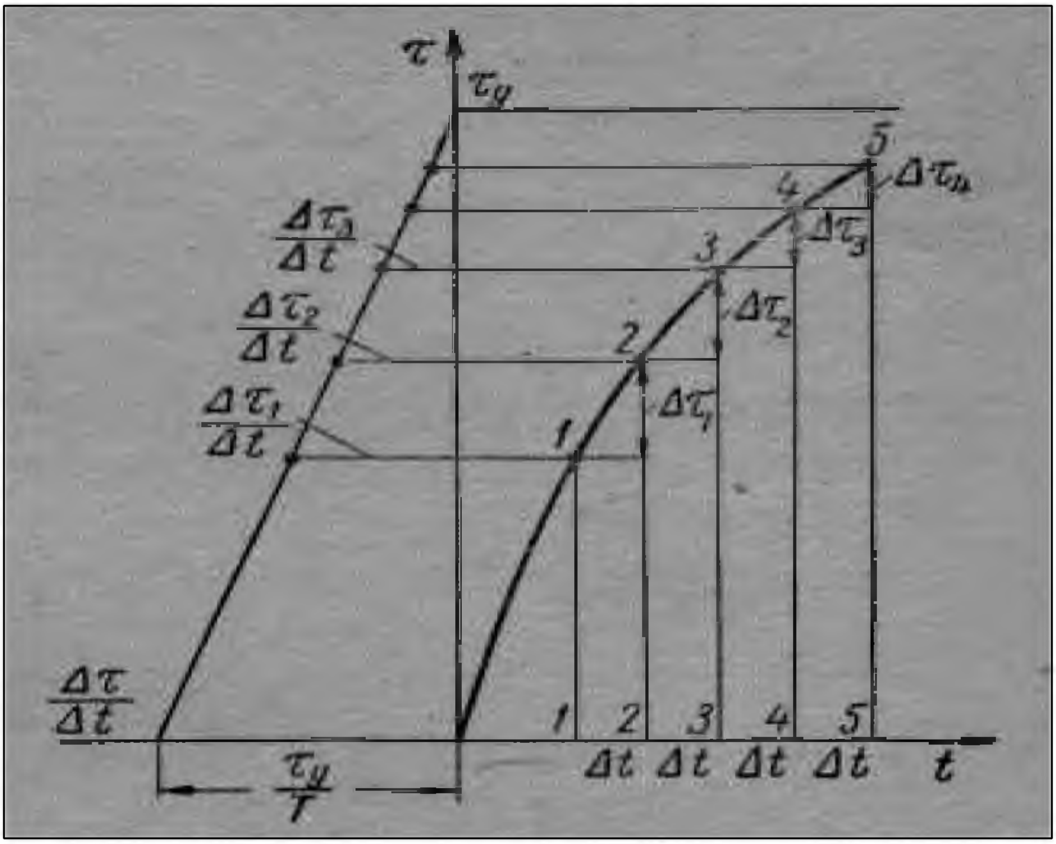
Construction is conducted as follows (see figure 5.3):

a) for identical, rather small periods Δt find temperatures corresponding to them excess $\Delta\tau$;

b) to the left from an axis of coordinates postpone in randomly chosen scale at the level of the corresponding value τ pieces $\frac{d\tau_i}{dt_i}$;

c) the ends of pieces connect a straight line.

The straight line point of intersection with ordinate axis will define the established excess of temperature τ_y, and the piece on crossing with abscissa axis will be equal to the relation $\frac{\tau_y}{T}$. Thus, it is possible to determine the necessary values by a site of a curve of heating τ_y and T.



Drawing. 5.3 - To definition of a constant of time and the established excess of temperature by an indirect method

Lecture 6. Electric contacts [6]

Content of lecture:

basic concepts. Terminology. Transitional resistance of contact. Temperature of a contact platform. Dependence of transitional resistance on a condition of contact surfaces.

Lecture purpose:

to study the basic concepts about contacts, to estimate an important role which play contacts in ensuring reliable operation of electric devices and electric networks.

6.1 Basic concepts. Terminology

Electric contact call both a place of metal contact of conductors, and conductors. Purpose of contact – to continue a way of current from one conductor to another.

On a way of connection of conductors among themselves contacts share on 3 groups:

a) not disconnected contact connections;

b) the disconnected contact connections;

c) the sliding contact connections.

The conductors which are rigidly connected among themselves concern to the first. Treat them: bolted connections of tires, accession of conductors to plugs, etc. The conductors intended for switching of electric chains concern to the second. Switches, knife switches, etc. concern to them. Brush contacts of electrical machines, rheostats, etc. concern to the third.

At electric contacts it is necessary to distinguish the seeming and physical areas of contact.

As contact surfaces will be carefully ground, they will always have microscopic hillocks or roughnesses therefore physically two surfaces will adjoin not all seeming area, and only separate microscopic platforms (see figure 6.1).

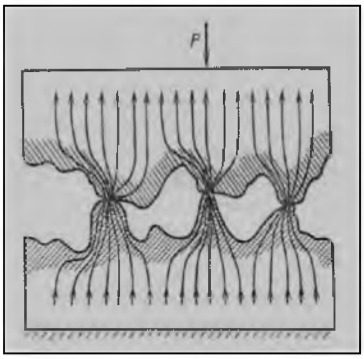


Figure 6.1 – Contact of surfaces of contacts

[6] On a lecture subject see [1, c.88-94], [2, c.55-75]

The quantity of contact platforms depends on geometrical forms of the adjoining contacts.

In a form of contact distinguish 3 types of contacts:

a) dot contact – contact is provided only in one microscopic platform – a point. For example: sphere, sphere plane, etc.;

b) linear contact - the seeming contact happens on the line. For example: the cylinder - the plane, a round, etc. Physically contact happens on a number of the platforms (at least two) located on the line;

c) superficial contact – the seeming contact happens on a surface, and physically on a number of the elementary platforms (at least three) located on this surface.

The sizes of elementary platforms of contact are proportional to force squeezing contacts and depend on resistance of material of contacts a smyatiya

$$\mathbf{S}_э = \frac{\mathbf{P}}{\sigma} \tag{6.1}$$

where P - force squeezing contacts;

σ - temporary resistance of material a smyatiya (from the reference book).

However with growth of force of compression growth of the sizes of platforms is slowed down because of shrinkage of the area of contact.

6.2 Transitional resistance of contact

In a zone of transition of current from one conductor in another there is big electric resistance called by the transitional resistance of contact.

Physically – the nature of transitional resistance is an electric resistance of microscopic hillocks on which there is a contact of conductors among themselves. Transitional resistance of contact can be presented as result of sharp increase of density of current in contact platforms in comparison with current density in a contact body.

The size of transitional resistance of contacts is determined, using skilled data, on the following expression

$$\mathbf{R}_{пер} = \frac{\varepsilon}{\mathbf{P}^{n}} \tag{6.2}$$

where ε- some size depending on material, a form, a way of processing and a condition of a contact surface;

P - force squeezing contacts;

n – the exponent characterizing type of contact and number of a common ground.

The values εdefined by practical consideration considerably depend on a condition of a surface of contacts, nature of their processing and, especially, on oxidation level.

As showed experiments, the transitional resistance of contacts quickly decreases with growth of force of compression of contacts (see figure 6.2).

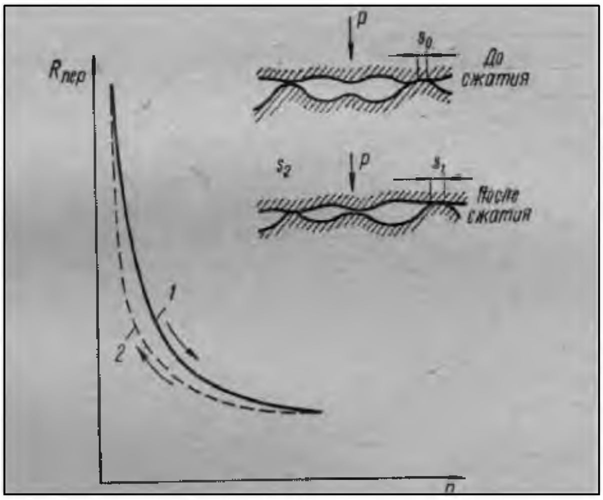


Figure 6.2 - Dependence of transitional resistance of contact at most pressing

6.3 Dependence of transitional resistance on temperature

As contact resistance this resistance of metal of the conductor therefore it also increases with growth of temperature.

However with increase in temperature the structure of hillocks and elementary platforms of contact due to change of size of specific resistance a smyatiya changes. Therefore with growth of temperature transitional resistance grows in the beginning (see figure 6.3), and then there is a sharp falling of mechanical durability of material, for example, at copper at the 200th hail. and transitional resistance also sharply falls. With a further growth of temperature transitional resistance again linearly increases up to the material melting temperature at which contacts cook, and transitional resistance reduces almost to zero.

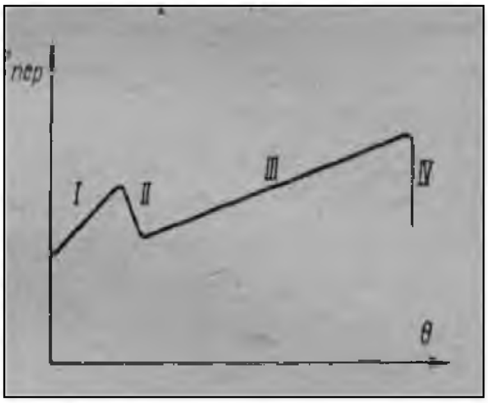


Figure 6.3 – Dependence of transitional resistance on temperature

6.4 Dependence of transitional resistance on a condition of contact surfaces

Results of the executed pilot studies showed that the transitional resistance of contacts extremely sensitively to oxidation of a surface.

Oxidic films are especially dangerous to contacts on small currents when forces of pressing are small. Process of formation of a film begins right after contact of the smoothed-out surface of contacts with the air surrounding them. Transitional resistance thus can increase in tens of thousands of times. In this regard contacts on small currents (small pressing) are produced from the precious metals which are not giving in to oxidation (gold, platinum, etc.). In silnotochny contacts the film collapses or thanks to big pressing, or due to slipping of one contact concerning another.

In the course of work the transitional resistance of contacts does not remain to constants. Under the influence of oxygen, other aggressive gases, the increased temperature intensity of formation of a film grows. Thus the transitional resistance of contact, power failure on it and its temperature increase. At certain values of tension and temperature there is an electric breakdown of a film then resistance of contact falls. This phenomenon is called as a fritting.

7 Lecture 7. Operating modes of contacts[7]

Content of lecture:

operating modes of contacts at inclusion and shutdown of an electric chain. Work of contacts in the included state in the nominal mode and in the KZ mode.

Lecture purpose:

consideration of the physical phenomena occurring during the work of contacts of electric devices.

Let's consider the processes connected with work of contacts in the following modes:

a) work of contacts at inclusion of a chain;

b) work of contacts in the included state;

c) work of contacts at shutdown of a chain.

7.1 Inclusion of a chain

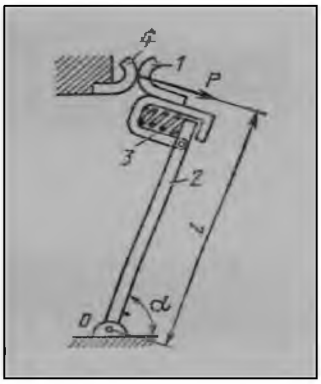
At turning on of electric devices in their contact systems the following processes can take place:

a) vibration of contacts;

b) erosion of a surface of contacts.

7.1.1 Vibration of contacts

The processes arising at vibration, we will consider on the example of contact system of the contactor which simplified scheme is given in figure 7.1.



Drawing 7.1-Contact system of the contactor in the course of inclusion

Mobile contact 1 is connected with the contact lever 2 and a contact spring 3. Motionless contact 4 is rigidly fixed on a support.

At inclusion of the contactor his electromagnet affects the lever 2 which movement leads to contact of contacts 1 and 4. At the time of contact of contacts

[7] On a lecture subject see [1, with. 95-110], [2, c.76-89]

there is a blow as a result of which occur deformation a smyatiya of contacts and отброс contact 1 to the right. Between contacts the gap is formed and under the influence of tension attached to them there is an electric arch. The movement of contact 1 will stop to the right when the energy received by it at blow turns into energy of compression of a spring 3. After that contact 1 under the influence of a spring 3 will start moving to the left. There will be a new blow and new отброс contact. This phenomenon is called as vibration of contacts.

Vibration of contacts leads to repeated formation of an electric arch which results in their strong wear because of an oplavleniye and dispersion of material of contacts.

For reduction of vibration preliminary deformation of a contact spring 3 is created.

In this case, at the time of a contact of contacts the effort of pressing increases not from scratch, and from previously established pressing size $\mathbf{P}_{\text{нач}}$. The preliminary tightness of a contact spring is created by a failure of mobile contact.

The failure of contact is understood as distance on which mobile contact will move if to clean the motionless.

Then

$$\mathbf{P}_{\text{нач}} = \mathbf{c} \cdot \Delta\mathbf{l}_{\text{пров}}$$

where with - rigidity of a contact spring;

$\Delta\mathbf{l}_{\text{пров}}$ - contact failure size.

With creation of a failure of contact and increase in initial pressing of a contact spring decreases as the transitional resistance of contact, and that is very important, vibration. However at excessively big initial effort vibration can sharply increase at the insufficient power of the including electromagnet.

At the same time the increase in the traction moment leads to increase in speed of mobile contact, its kinetic energy that conducts to growth of amplitude of an otbros. It is necessary as we see, an optimum ratio of power of the including electromagnet and size of a failure of contacts.

At inclusion of contacts on the existing short circuit vibration of contacts amplifies because of emergence of the rejecting electrodynamic forces in contact points. In order that there was no oplavleniye of contacts at the time of their contact, the effort of a preliminary tightness of a contact spring has to compensate electrodynamic forces of an otbros and create such pressing by which tension on transitional resistance will not lead falling to an oplavleniye of a point of a contact and a svarivaniye of contacts.

7.1.2 Erosion of a surface of contacts

In the course of inclusion in process of approach of contacts to each other between them intensity of electric field increases, and at a certain distance (the 100-th shares of millimeter) there is an electric breakdown of an air interval between contacts. At breakdown electrons bombard the anode, and its material passes to the cathode, being postponed on it in the form of thin needles.

Wear of contacts as a result of transfer of material from one contact on another, i.e. evaporation of material in surrounding space without change of composition of material is called as physical wear or an erosion.

7.2 Work of contacts in the included state

In this mode we will consider 2 cases:

a) passes rated current through contacts;

b) passes KZ current through contacts.

7.2.1 Mode of rated current

As it was noted on the previous occupation, for the transitional resistance of contacts two temperature points are characteristic:

Temperature of a softening of material and temperature of melting.

It is necessary for reliable work of contacts that at rated current power failure on transitional resistance was equal

$$\mathbf{I}_{\text{ном}} \cdot \mathbf{R}_{\text{кон}} = 0{,}5 \div 0{,}8) \cdot \mathbf{U}_{\text{конт1}} \qquad (7.1)$$

where $\mathbf{U}_{\text{конт1}}$ - power failure in contact at which temperature of contact is equal to contact material softening temperature (it is brought in reference books).

At calculations of contact systems of devices at the set rated current and to known power failure for contact material from a formula (7.1) transitional resistance is defined, and then on a formula (6.2) there is a necessary contact pressing of River.

7.2.2 Mode of short circuit

At short circuit passes current through contacts at 10-20 times the exceeding nominal rates. Because of a small constant of time of heating temperature of a contact platform rises almost instantly and can reach melting temperature.

It is necessary, also to mean that at short circuit, at the expense of forces of pushing away arising in contact platforms, contact pressing weakens, transitional resistance thus increases, thermal losses and heating of contacts that can lead to their svarivaniye increase.

7.3 Shutdown of a chain

In the course of disconnection of contacts contact pressing decreases, transitional resistance increases, and at the expense of it temperature of points of a contact grows. At the time of separation microledges of contacts heat up to melting temperature, and between contacts there is a bridge from liquid metal. At the further movement of contacts the bridge breaks and depending on parameters of the disconnected chain (tension and current) there is an arc or smoldering category, the followed high temperature.

High temperature leads to intensive oxidation and dispersion of material in surrounding space, to transfer of material from one electrode on another and to education on contacts of an oxidic film. All this involves wear of contacts.

The wear connected with oxidation and education on contacts of films of chemical compounds of material of contact with Wednesday is called as chemical wear or corrosion.

The erosion and corrosion of contacts reduce service life of devices. The direction of an erosion and a form of wear of contacts depend on a type of the category and value of current. It is necessary for emergence of the arc category that values of tension and current exceeded some minimum U0 and I0 values, characteristic for this material of contacts. For example for U0 copper = 12,3B, and I0 = 0,43A. If current in a chain is less I0, between contacts there will be a smoldering category or a spark if it is more - the arc category.

Service life of contacts depends on material of contacts, their weight, number of kommutation and size of the switched chain current.

Apply the following measures to fight against an erosion of contacts:

a) reduction of duration of burning of an arch by means of dugogasitelny devices;

b) elimination of vibrations of contacts at inclusion;

c) use of arc-resistant materials for contacts.

8 Lecture 8. Materials of electric contacts[8]

Content of lecture:

materials for contact connections.

Lecture purpose:

studying of physical properties of the main conduction materials applied as contact connections in an apparatostroyeniye.

8.1 Materials for contact connections

Its service life and reliability of work, and respectively reliability of operation of devices and power supply of consumers in general considerably depends on contact material.

The following requirements are imposed to contact materials:

- they have to possess high conductivity and heat conductivity;
- to be steady against corrosion and to have a conducting oxide film;
- to be arc-resistant, i.e. to have high temperature of melting and evaporation;
- to be firm for reduction of mechanical wear at frequent inclusions and shutdowns, mechanically strong and it is easy to give in to machining;
- to have the high values of current and tension necessary for a dugoobrazovaniye;
- to have low cost.

The listed requirements sometimes are inconsistent, and it is impossible to find material which would meet all requirements.

Apply to contact connections:

- copper;
- silver;
- aluminum;
- tungsten;
- metal ceramics.

Let's consider merits and demerits of these materials.

Copper

The most widespread contact material.

Copper meets almost all requirements except for a korroziostoykost. Oxides of copper have bad electric conductivity.

Treat positive properties of copper:

a) high specific electric conductivity and heat conductivity;

b) sufficient hardness that allows to apply at frequent inclusions and switching off;

c) quite high values of current and tension necessary for a dugoobrazovaniye;

d) simplicity of technology and low cost.

It is necessary to carry to shortcomings of copper:

[8] On a lecture subject see [c.106-110], [2, c.89-90]

a) at an outside work copper becomes covered by a layer of the strong oxides having high electric resistance;

b) demands big forces of pressing.

For protection of copper against oxidation the surface of contacts becomes covered by an electrolytic way a silver 20-30 microns thick layer. In contacts on big currents sometimes put silver plates. (In the devices which are switched on rather seldom).

Because of low arc resistance application in devices of the inclusions which are disconnecting a powerful arch and having a large number in an hour is undesirable. In the contacts which do not have mutual sliding because of a film of oxides use of copper is not recommended.

It is applied both for not disconnected, and to the disconnected contact connections.

In not disconnected connections apply corrosion-resistant coatings of contact surfaces, namely: silvering, a tinning, nickel plating and galvanizing, and also a covering of the smoothed-out copper contact by neutral greasing with the subsequent seal of seams.

Silver

Treat positive properties of silver:

a) high electric conductivity and heat conductivity;

b) the film of oxide of silver has small mechanical durability and quickly collapses when heating a contact point;

c) contact of silver is steady thanks to small tension on the smyaty;

d) small pressing are sufficient for work.

Stability of contact and small transitional resistance of contact – characteristic signs of silver.

It is possible to refer small arc resistance and insufficient hardness that interferes with its application in the presence of a powerful arch and frequent inclusions and shutdowns to shortcomings of silver.

It is applied in the relay and contactors at currents to 20A.

At big currents it is used as material for the main contacts working without arch.

Most often silver is applied in the form of slips – in a place of the contact made of copper the silver slip and also as the second component at creation of contacts from metal ceramics is welded.

Aluminum

Treat positive properties of aluminum:

a) high electric conductivity and heat conductivity;

b) the small density of material that allows to reduce the weight and weight of the device.

It is necessary to carry to shortcomings:

a) education on air of films with a high resistance and with a high mechanical durability;

b) low arc resistance (temperature of melting is much less, than at copper and silver);

c) small mechanical durability.

Because of existence in air of moisture and oxides copper and aluminum contacts form a galvanic cell. Under the influence of the EMF of this element there is an electrochemical destruction of contacts (electrochemical corrosion).

In this regard at connection with copper aluminum has to become covered in the electrolytic way by a thin layer of copper, or both metals have to be covered with silver.

Aluminum and its alloys (duralumin, alpax) is applied mainly as material to tires and constructional details of devices. As the disconnected contacts it is not applied.

Tungsten

Treat positive properties:

a) high arc resistance;

b) big firmness against an erosion and a svarivaniye;

c) high hardness allows to apply it at frequent inclusions and shutdowns;

d) high temperature of melting.

And shortcomings are:

a) high specific resistance;

b) small heat conductivity;

c) formation of strong oxidic and sulphidic films.

Due to the formation of films and their high mechanical durability tungsten contacts demand big pressing.

Are applied as dugogasitelny contacts at the disconnected currents to 100 kA and more, on small and average currents as working contacts with the big frequency of shutdown.

Metal ceramics

Main properties of contact connection: high electric conductivity and arc resistance - cannot be received for the account of alloys of such materials as silver and tungsten or copper and tungsten as they do not form alloys.

Therefore apply a method of powder metallurgy to receiving the materials possessing necessary properties. Metal ceramics is received by agglomeration of mix of powders of various metals one of which possesses the increased electric conductance, and other increased arc resistance.

The materials received in such a way keep physical properties of the metals entering them. Arc resistance of metal ceramics is provided with such components as tungsten and molybdenum.

Low transitional resistance of contact is reached by use as the second component of silver or copper.

Metal ceramics unites high arc resistance with rather good conductivity.

The most widespread compositions of metal ceramics are: silver-tungsten, silver-graphite, silver-molybdenum, copper-tungsten, copper-molybdenum, etc.

Metal ceramics as dugogasitelny contacts on averages and the big disconnected currents and also as the main contacts on rated currents to 600 A in devices with a large number of kommutation is applied.

9 Lecture 9. Bases of the theory of burning and clearing of an electric arch [9]

Content of lecture:

the processes arising at ionization of an arc interval. Thermionic and autoelectronic issue. Shock and thermal ionization. The processes arising at a deionization of an arc interval. Recombination and diffusion of charged particles.

Lecture purpose:

studying of the physical phenomena occurring at emergence of an electric arch between the dispersing contacts of the device.

Disconnection of an electric chain at a little considerable currents and tension, as a rule, is followed by an electric discharge between the dispersing contacts. The air interval between contacts is ionized and becomes carrying out for some time. In it there is an arch leading to undesirable consequences for contacts and the device in general. For effective fight against negative influence of an electric arch it is necessary to have ideas of the modern theory of emergence of an electric arch, of the physical processes accompanying this phenomenon.

9.1 The processes arising at ionization of an arc interval

In usual conditions air is a good insulator: for example, for breakdown of an air interval in 1sm it is necessary to put voltage not less than 30 kV. In order that the air interval became carrying out, it is necessary that in it there was a certain concentration of charged particles: electrons and ions.

Process of separation from a neutral particle of one or several electrons and formation of free electrons and positively loaded ions is called as ionization. Ionization of air can happen under the influence of light, X-rays, high temperature, under the influence of electric field and some other factors.

For the arc processes taking place in electric devices the greatest value take: from the processes happening at electrodes – thermionic and autoelectronic issues, and from the processes happening in an arc interval, shock and thermal ionization.

[9] On a lecture subject see [1, c.123-129], [2, with. 92-97]

9.1.1 Thermionic issue

The phenomenon emission of free electrons from a surface of the cathode having high temperature is called as thermionic issue.

At a divergence of contacts the transitional resistance of contact and density of current sharply increases in the last contact platform. This platform is warmed before fusion and at a further divergence of contacts is torn, with formation of vapors of metal in air space.

On a negative electrode the cathodic spot (the heated platform) which forms the basis of an arch and the center of radiation of electrons at the first moment of a divergence of contacts is formed.

Density of current of thermionic issue depends on temperature and material of contact. It is small and can be sufficient only to start emergence of an arch, but not for maintenance of its burning.

9.1.2 Autoelectronic issue

The phenomenon emission of electrons under the influence of strong electric field is called as autoelectronic issue. In process of a divergence of contacts intensity of a field between them increases and passes through values the exceeding 109 V/m sufficient for a vyryvaniye of electrons from the cold cathode. Current of autoelectronic issue is also small and can serve only as the beginning of emergence of an arch.

Thus, the initial stage emergence of the arc category is explained by existence of thermionic and autoelectronic issues of free electrons in an arc interval the dispersing contacts.

After emergence of an arch and formation of positive ions and electrons each of them will direct to the electrode: positive charges to the cathode, and electrons to the anode.

At the expense of positive ions amplifies thermionic and autoelectronic issues:

Thermionic issue amplifies at the expense of increase in temperature of the cathode as a result of bombing of the cathode positive ions, and autoelectronic issue - due to strengthening of electric field between a layer of positive ions and the negative cathode.

9.1.3 Ionization by a push

If the free electron at the movement in electric field gets the sufficient speed and, respectively, kinetic energy, at collision with a neutral particle it can beat out from it an electron, i.e. ionize this particle. The new electron which can ionize the following neutral particle, etc. is as a result formed. There will be the avalanche increase of a stream of electrons in an arc interval.

Condition for shock ionization is existence of electric field and the sufficient length of free run necessary for acquisition by an electron of the demanded energy for ionization of molecules in an air interval. Speed of electrons depends on a potential difference on length of its free run. Therefore not the speed of the movement of electrons, but that minimum value of a potential difference what needs to be had on the end of a free way that the electron by the end of a way got necessary speed is usually specified. It is a potential difference carries the name of potential of ionization.

The pressure and density of gas, the less length of free run at an electron is higher and the less energy will get an electron. Ionization of an air interval will be complicated, Doug can not arise. Availability of vapors of the metals in an air interval having the potential of ionization is lower, than at air considerably reduces energy of ionization and facilitates formation of the arc category.

9.1.4 Thermal ionization

It is process of ionization under the influence of high temperature.

Maintenance of an arch after its emergence, i.e. providing the arc category with enough free electrons, is explained by almost only type of ionization – thermal ionization.

Temperature of a trunk of an arch reaches 4-7 thousand degrees Kelvin. At such high temperature quickly increases both number of quickly moving molecules, and their speed. At collision of quickly moving molecules and atoms their most part collapses, with formation of charged particles.

The main characteristic of thermal ionization is the extent of ionization representing the relation of number of the ionized atoms in an arc interval to total number of atoms in this interval. Vapors of metal are much quicker ionized, than air that is explained by their lower potential of ionization.

9.2 The processes arising at a deionization of an arc interval

Along with processes of ionization in an arch there are return processes, i.e. reunion of charged particles and formation of neutral particles. This process carries the name of a deionization.

At emergence of an arch ionization processes prevail, in steadily burning arch processes both processes are equally intensive, and at prevalence of processes of a deionization the arch dies away.

The deionization occurs, mainly, at the expense of a recombination and diffusion.

9.2.1 Recombination

Process at which variously charged particles, coming to mutual contact is called as a recombination, form neutral particles. Intensity of a recombination amplifies with reduction of temperature of an arch and increase in pressure. In the electric arch burning close surfaces of a dugogasitelny chamber a recombination of the main carriers of charges in an arch – electrons happens to positive ions the next way: Electrons load a chamber wall surface to some negative potential at which positive ions are attracted to this surface and, having attached an electron, form a neutral particle.

At a recombination, the part of energy is released in the form of the radiation of quanta of light (photons).

9.2.2 Diffusion

It is carrying out of charged particles from area of burning of an arch in environment. Thereby conductivity of an arch decreases.

Diffusion is caused by both electric, and thermal factors. Density of charges increases in a trunk of an arch from the periphery to the center. In a type of it the electric field forcing ions to move from the center to the periphery and to leave arch area is created. In the same direction also the difference of temperatures of a trunk of an arch and surrounding space works. The charged particles which left arch area as a result are recombined out of this area.

In freely burning arch diffusion plays is insignificant a small role. However its role amplifies in the arch blown by compressed air and in an open moving arch.

The dissociation (decomposition) of neutral molecules of gases on separate atoms belongs to number of the phenomena facilitating clearing of an arch.

The dissociation of molecules of gas is followed by absorption of thermal energy. Arch temperature thus goes down, process of a deionization will prevail over process of ionization and a condition for clearing of an arch improve.

As dugogasyashchy gas most often apply hydrogen. It is allocated in dugogasitelny chambers at decomposition under the influence of high temperature of an arch of transformer oil, a fiber, plexiglas.

10 Lecture 10. Conditions of clearing of an electric arch [10]

Content of lecture:

volt-ampere characteristic (VAKH) of an electric arch. Static and dynamic VAKH. Conditions of clearing of an arch of direct and alternating current.

Lecture purpose:

on the basis of the analysis VAKH arches to consider ways of clearing of an arch on direct and alternating current.

10.1 Volt-ampere characteristics of an arch

The most important characteristic of an arch is its volt-ampere characteristic (VAKH) representing dependence of tension on an arch from current.

With increase in current in a chain, and, therefore, numbers of electrons in an arc interval arch temperature at the same time increases, thermal ionization amplifies, the number of the ionized particles increases in an arch and, respectively, the electric resistance of an arch falls.

And, resistance of an arch falls so sharply that tension on it too falls, despite growth of current. Upon transition of current from one value of current to another the thermal condition of an arch does not change instantly as possesses thermal inertia. If to change current slowly, thermal inertia of an arch does not affect. VAKH, received at slow change of current, is called static. If to change current quickly, VAKH will depend on the speed of change of current. Such VAKH is called dynamic.

Static VAKH arches depends on length of an arch, material of electrodes, parameters of the environment and refrigerating conditions.

Power failure on an arc interval is equal

$$\mathbf{U_Д = U_Э + E_Д \cdot l_Д}$$

where $\mathbf{U_э}$ - sum of okoloelektrodny power failures;

$\mathbf{E_Д}$ - intensity of electric field in an arch;

$\mathbf{l_Д}$ - arch length.

$$\mathbf{U_Э = U_К + U_А}$$

where $\mathbf{U_К}$ - prikatodny falling tension, ravno10 – 20B;

$\mathbf{U_А}$ - prianodny power failure, is equal 5-10B.

[10] On a lecture subject see [1, c.127-157], [2, c.97-109]

Intensity of electric field in an arch depends on current and conditions of burning of an arch: than more intensively cooling of an arch and the is higher pressure of the environment in which the arch burns, the intensity of electric field in an arch is more and the above its VAKH lies. And rise VAKH as we will see further, promotes clearing of an arch.

Let's consider conditions of clearing of an arch of a direct current.

10.2 Conditions of clearing of an arch.

To extinguish an arch of a direct current, it is necessary to create such conditions under which in an arc interval at all values of current from initial to zero processes of a deionization surpassed ionization processes.

For the chain represented in figure 10.1a, containing R resistance, inductance of L and an arc interval with power failure $\mathbf{U}_Д$, to which U current source tension is enclosed, for any timepoint the equation will be fair

$$\mathbf{U = i \cdot R + L\frac{dI}{dt} + U_Д}$$

where $\mathbf{L \cdot \frac{dI}{dt}}$ - The EMF arising on inductance at change of current in a chain.

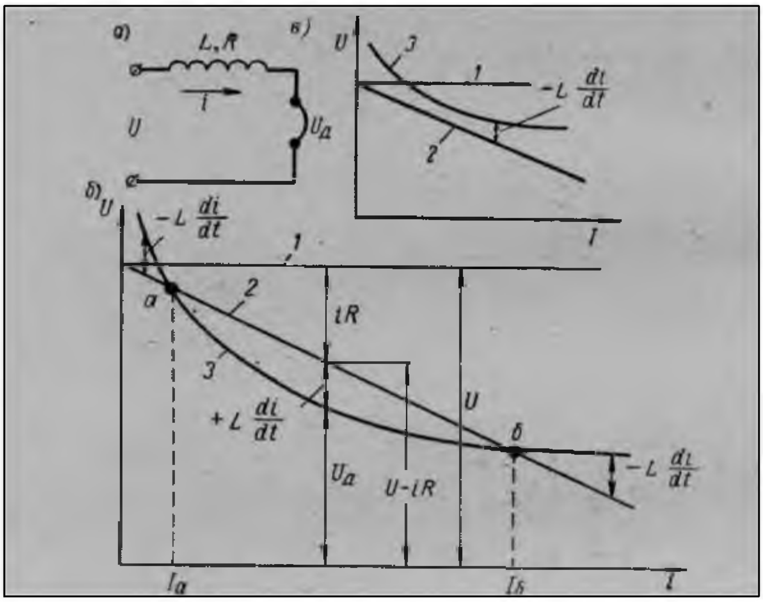


Figure 10.1-K to a condition of clearing of an arch of a direct current

At steadily burning arch when processes of ionization and a deionization are in an equilibrium state

$$\frac{dI}{dt} = 0 \quad \text{and} \quad U = i \cdot R + U_Д .$$

If $\frac{dI}{dt}$ > 0, in an arch process of ionization prevails over process of a deionization, i.e. the amount of again formed charged particles will be more quantities disappearing as a result of a recombination.

If $\frac{dI}{dt}$ <0, in an arch processes of a deionization prevail, the number of charged particles decreases and the arch dies away.

Therefore, it is necessary for blackout of an arch that current in it decreased all the time, i.e. $\frac{dI}{dt} < 0$, and, therefore

$$U_Д > U - i \cdot R \quad . (10.1)$$

Thus the inequality (10.1) has to take place at all values of current. The graphic solution of a task is shown in figure 10.1b.

In this drawing the straight line 1 represents U source tension, a straight line 2 - the rheostatic characteristic of a chain $U - i \cdot R$, and a curve 3 - VAKH arches. Prisoners between the rheostatic characteristic and VAKH pieces correspond $L\frac{dI}{dt}$. In points "And" and "B" is satisfied a condition $\frac{dI}{dt} = 0$, i.e. in these points the equilibrium state takes place. However in a point of "B" it is stable equilibrium, and in a point "And" – no.

At currents $I < I_A$, $U_Д > U - i \cdot R$ and on inductance there is negative tension $L\frac{dI}{dt} < 0$, testifying to increase of process of a deionization in an arch. Under the influence of this tension current will decrease to zero. If for any reason $I > I_A$, on inductance there will be positive tension $L\frac{dI}{dt} > 0$, testifying to ionization process increase, and current will increase to value $I_Б$.

The point of "B" is a point of stable equilibrium: at any changes of current under the influence of tension on inductance the system will revert to the original state.

In electric devices take all measures to that the arch died away in minimum short time. Obviously, for this purpose it is necessary, that $\mathbf{U_Д > U - i \cdot R}$. It is possible or at the expense of a raising VAKH, or at the expense of increase in resistance of a chain. VAKH can be lifted as a result of increase in length of an arch, intensity of cooling and increase of pressure of the environment in which the arch burns.

At the closed contacts the arch is absent and current is equal in a chain $\mathbf{I_K} = \frac{\mathbf{U}}{\mathbf{R}}$ (see figure 10.2). At cultivation of contacts between them there is an arch with current $\mathbf{I_2}$. If length of an arch and tension of a source are invariable, at increase in resistance current in a chain will start decreasing, accepting values $\mathbf{I_3}$, $\mathbf{I_4}$. At further increase of resistance conditions for clearing of an arch are created. Current and resistance at which there come conditions for clearing of an arch, are called critical.

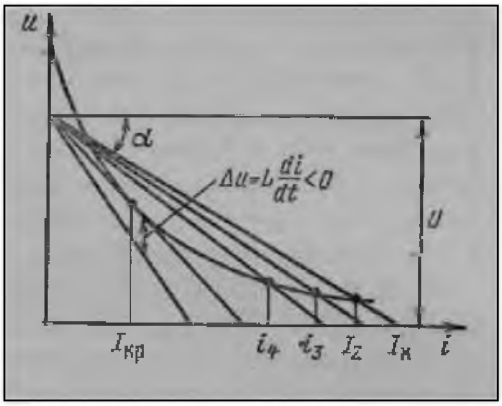


Figure 10.2 - Current in a chain at various resistance of R and existence of an arch

If at invariable current to increase tension or at an invariable tension to increase current, the rheostatic characteristic $\mathbf{U - i \cdot R}$ will rise up. But then for observance of conditions of clearing of an arch it is necessary to lift also VAKH arches. Therefore, with increase in tension of a source and with growth of the disconnected current of a condition of shutdown are made heavier.

10.3 Features of burning and clearing of an arch of alternating current

If for clearing of an arch of a direct current it is necessary to create conditions under which current would reduce to zero, at alternating current current in an arch irrespective of extent of ionization of an arc interval passes each half-cycle, i.e. each half-cycle through zero the arch dies away and is lit again. The problem of clearing in this case consists in creating conditions under which current would not be restored after passing through zero.

For clearing of an arch of alternating current at a voltage up to 1000B the phenomena occurring at the cathode upon transition of current through zero have crucial importance. At the time of transition of current through zero in prikatodny area in time about 0.1 microseconds isolation of an air interval is restored up to the size U0 = 150-250B i.e. in order that there was an arch it is necessary to put tension above the specified sizes.

11 Lecture 11. Ways of clearing of an electric arch[11]

[11] On a lecture subject see [1, with. 157-183], [2, c.109-147]

Content of lecture:

ways of clearing of an electric arch. Magnetic blasting. Clearing of an arch with a high pressure. Application of dugogasitelny lattices on direct and alternating current.

Lecture purpose:

consideration of the physical phenomena occurring when clearing an electric arch between the dispersing contacts of the device with various ways.

The problem of dugogasitelny devices of devices consists in providing clearing of an arch:

a) for small time with the admissible level of retension;

b) at small wear of current carrying parts of the device;

c) at the minimum volume of the heated gases;

d) with minimum sound and light effects.

It is necessary for clearing of an arch of a direct current that arches passed VAKH above a rheostatic straight line, i.e.

$$\mathbf{U}_{Д} > \mathbf{U} - \mathbf{i} \cdot \mathbf{R},$$

and as

$$\mathbf{U}_{Д} = \mathbf{U}_{Э} + \mathbf{E}_{Д} \cdot \mathbf{l}_{Д},$$

that can be received raising of the characteristic for the account:

a) increases in length of an arch $\mathbf{l}_{Д}$;

b) intensity of electric field in an arch column $\mathbf{E}_{Д}$;

c) uses of okoloelektrodny power failure.

Raising VAKH at the expense of increase in length of an arch ineffectively as demands significant increase in the sizes of devices.

To increase intensity of electric field in an arch $\mathbf{E}_{Д}$ it is possible:

a) by effective cooling of an arch;

b) due to rise in pressure of the environment in which the arch burns.

Cooling of an arch is carried out usually:

a) moving an arch concerning Wednesday in which it is, using a magnetic field (magnetic blasting) for this purpose;

b) exhausting by means of magnetic blasting an arch in a narrow crack of a dugogasitelny chamber which walls have high heat conductivity and arc resistance. The arch in process of retraction in a crack gets a zigzag form thanks to what length of an arch increases. Cooling of an arch is carried out as a result of close contact of an arch with ceramic walls of a crack, cold concerning arch temperature.

11.1 Movement of an arch under the influence of a magnetic field

Electric arch, being a peculiar conductor with current, can interact with a magnetic field. As a result the arch will be affected by force, the so-called magnetic blasting moving an arch.

Most often the magnetic field is created by the coil which is consistently switched on with the switched chain. Force operating per unit length arches is equal in a magnetic field

$$\mathbf{F} = \mathbf{I} \cdot \mathbf{H}$$

where I – arch current;

H - intensity of the magnetic field created by the dugogasitelny coil in a zone of burning of an arch.

As for the consecutive coil $\mathbf{H} \equiv \mathbf{I}$ that $\mathbf{F} \equiv \mathbf{I}^2$.

Thus, force operating on an arch is proportional to a current square.

At small currents this force is small therefore for obtaining force sufficient for clearing of small currents it is necessary to increase number of rounds of a winding and as the winding is flowed round by rated current of the device, and the section of its rounds has to correspond to this current. It leads to a big consumption of copper.

By means of magnetic blasting the arch with a force is exhausted in narrow cracks of the dugogasitelny lattices made of refractory materials. As a result the arch is sharply cooled on lattice walls. Quickly deionizatsionny processes accrue and the arch dies away. It is applied in contactors with a heavy operating mode at number of inclusions in an hour more than 600.

11.2 Clearing of an arch with a high pressure

Conductivity of an arc interval depends on extent of ionization of gas. At an invariable temperature extent of ionization falls with growth of pressure. It means that for carrying out the same current with a high pressure it is necessary to put more high voltage.

With growth of pressure also heat conductivity of gas that leads to strengthening of heat removal and cooling of an arch increases. Finally with growth of pressure tension on an arch increases.

Clearing of an arch by means of the high pressure created by the arch in densely closed chambers is used in fuses and some other devices. In these devices all energy emitted in an arch is given to the gas which is in limited volume

As a first approximation here the ratio is fair

$$\rho \cdot \vartheta = \frac{2}{3} \cdot \mathbf{W}_{Д}$$

where $\mathbf{W}_{Д}$ - energy of an arch;

υ - volume;

ρ - pressure.

As a result the arch manages to be extinguished in the small densely closed chambers and to make devices absolutely safe in the fire relation.

11.3 Clearing of an arch in a dugogasitelny lattice

The ways of clearing of an arch considered above were reduced to impact on its trunk.

The arch can be extinguished, using okoloelektrodny power failures. For the first time this essentially new way of clearing was offered by Dolivo-Dobrovolsky.

Over the dispersing contacts 1 and 2 devices (see figure 11.1) are installed the motionless metal plates 3 isolated from each other forming a dugogasitelny lattice. The arch arising at shutdown 4 is exhausted in this lattice where breaks into a number of consistently included short arches 5.

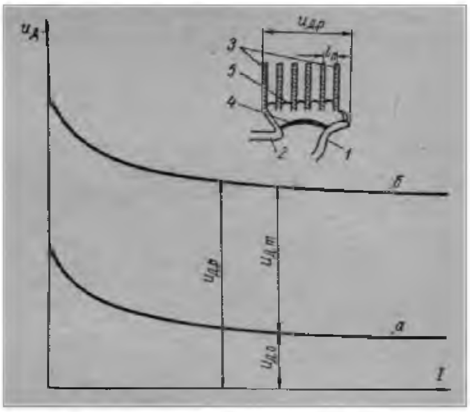


Figure 11.1 – Дугогасительная lattice and static volt the ampere characteristics of an arch: and - open; - in a dugogasitelny lattice

Each plate of a lattice has an okoloelektrodny power failure. Clearing of an arch happens at the expense of the sum of okoloelektrodny power failures.

Direct current

At number of plates $\mathbf{m}$ short arches will be $\mathbf{m}+1$ and as much will be prianodny $\mathbf{U}_А$ and prikatodny $\mathbf{U}_К$ power failures. Tension on all arch will be equal in a lattice

$$\mathbf{U}_{ДР} = \mathbf{U}_Э \cdot (\mathbf{m}+1) + \mathbf{E}_Д \cdot \mathbf{l}_Д$$

where $\mathbf{U}_Э = \mathbf{U}_А + \mathbf{U}_К$ - sum of okoloelektrodny power failures;

$l_Д = l_O \cdot (m+1)$ - arch length;

l_O - distance between lattice plates.

VAKH arches in a dugogasitelny lattice is expressed to the curve, same in a form, as VAKH of an open arch, but postponed for the sum of okoloelektrodny falling in area of higher tension.

In order that the arch went out it is necessary that number of plates of a lattice met a condition

$$m > \frac{U_C}{U_Э}$$

where U_C - network tension;

$U_Э$ - prielektrodny power failure.

Alternating current

When clearing an arch of alternating current in a dugogasitelny lattice the main role is played by the processes at the cathode which are that at the time of passing of current through zero the okolokatodny space instantly gets the electric durability of an order $U_Э = 150 - 250B$.

As on a direct current $U_Э = 20 - 25B$ that much less, than on alternating current, and the number of plates in a dugogasitelny lattice on alternating current is necessary respectively much less.

The Dugogasitelny lattice on alternating current acts 7-8 times more effectively, than on a direct current. Its broad application is explained alternating current and limited application on the constant by it.

The Dugogasitelny lattice allows to reduce strongly the sizes of an arch and to extinguish it in limited volume at small lighting and sound effect. It provided it broad application in dugogasitelny devices of contactors and automatic switches.

Plates of a dugogasitelny lattice make of magnetic material (steel). Arising between an arch and ferromagnetic plates of force of an attraction promote fast entry of an arch into space between plates and to splitting an arch into a number of consistently included short arches.

Lack of a dugogasitelny lattice is the burn-out of plates in the repeated and short-term mode at current 600 A and above. For reduction of corrosion of a plate cover with copper or zinc.

12 Lecture 12. Electromagnetic mechanisms[12]

Content of lecture:

electromagnet attraction force. Maxwell's formula. Electromagnets of alternating current. A short-circuited round as a measure of fight against noise and vibration in devices of alternating current. Delay and acceleration of action of an electromagnet.

Lecture purpose:

to supply to students with the main information on the electromagnets which are the electromechanical converter of energy in many devices.

Electromagnetic mechanisms apply to actuating of many devices. As we noted earlier, normal work of contacts of devices, existence or lack of vibration of contacts, possibility of a svarivaniye of contacts considerably depends on work of an electromagnet at KZ, etc. That, in turn, it is provided with creation of the electromagnet attraction force, necessary for normal operation of devices.

12.2 Electromagnet attraction force

In engineering calculations electromagnet attraction force is counted usually on Maxwell's formula

$$\mathbf{P} = \frac{\mathbf{B}_\delta^{\,2} \cdot \mathbf{s}_\delta}{2 \cdot \mu_0}$$

where $\mathbf{B}_\delta$ - magnetic induction in a working gap;

$\mathbf{S}_\delta$ - equivalent section of an air gap;

μ_0 - magnetic permeability of air.

The formula can use if the induction in an air gap is distributed evenly. It is sometimes convenient to find force of draft of an electromagnet through a magnetic flux

$$\mathbf{P} = \frac{\mathbf{\Phi}^{2}}{2 \cdot \mu_0 \cdot \mathbf{s}_\delta}.$$

12.3 Electromagnets of alternating current. Short-circuited round

At sinusoidal alternating current the stream changes under the law

[12] On a lecture subject see [1, c.211-240], [2, c.166 - 175]

$$\Phi = \Phi_m \cdot \sin\omega t.$$

Force of an attraction of an electromagnet will be in that case equal

$$P = \frac{\Phi_m^{\ 2} \cdot \sin^2 \omega t}{2 \cdot \mu_0 \cdot s_\delta}.$$

Let's designate
$$\frac{\Phi_m^{\ 2}}{2 \cdot \mu_0 \cdot s_\delta} = P_m.$$

Then

$$P = P_m \cdot \sin^2 \omega t = \frac{P_m}{2} \cdot (1 - \cos 2\omega t),$$

i.e. force of an attraction P pulses in size with a double frequency of a network, without changing thus the sign (see figure 12.1b)

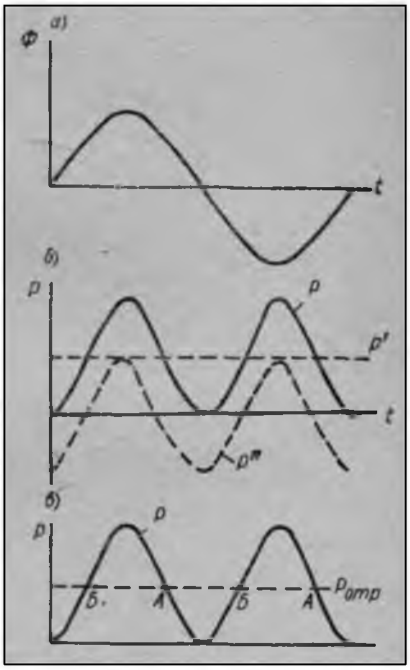


Figure 12.1 – Curve changes of force of an attraction of an electromagnet of alternating current without short-circuited round

Force of an attraction can be presented in the form of two components: a constant in time

$$P_1 = \frac{P_m}{2},$$

and the variable changing in time under the law of a cosine

$$\mathbf{P}_2 = \frac{\mathbf{P}_m}{2} \cdot \cos 2\boldsymbol{\omega}\mathbf{t}.$$

The average for the period value of force P will be equal $\mathbf{P}_m/2$.

If the detachable effort of an electromagnet is $\mathbf{P}_{\text{OTP}}$ (see figure 12.1v), twice for the period in a point "And" the anchor of an electromagnet will start disappearing, and in a point of "B" again to be attracted, i.e. will vibrate with a double frequency. Vibration results in wear of magnetic system and is followed by buzz.

For vibration elimination electromagnets of alternating current are supplied with the short-circuited rounds (see figure 12.2) from conduction materials (copper, brass) covering part of a pole of an electromagnet (about 70 — 80%).

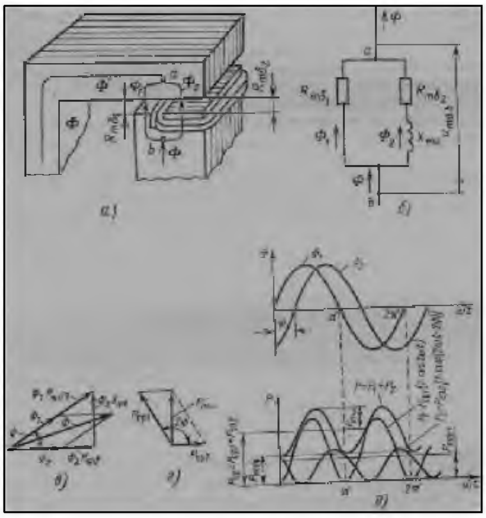


Figure 12.2 – To the principle of work of a short-circuited round

The principle of work of a round consists in the following.

The general stream of an electromagnet F branches on a stream of F1 which passes on not covered a round of part of a pole, and on a stream of F2 which passes through the part covered by a short-circuited round.

Thus in a round it is induced э. of page also arises current which creates a magnetic flux the covering short-circuited round and, together with part of the main stream, the forming F2 stream passing through the part of a pole captured by a round.

As a result the magnetic flux of F2 will be shifted in time in relation to F1 stream for some corner φ .

Force of an attraction of an electromagnet P will consist in this case of forces of P1 and P2 two pulsing, but shifted on a phase.

Each of forces of P1 and P2 can be presented in the form of two components

$$P_1 = \frac{P_{1m}}{2} - \frac{P_{1m}}{2} \cdot Cos2\omega t \quad \text{and} \quad P_2 = \frac{P_{2m}}{2} - \frac{P_{2m}}{2} \cdot Cos2\omega t ,$$

and full force

$$P = \frac{P_{1m}}{2} + \frac{P_{2m}}{2} - [\frac{P_{1m}}{2} \cdot Cos2\omega t + \frac{P_{2m}}{2} \cdot Cos(2\omega t - 2\varphi)] .$$

Thanks to shift of phases the resulting force P pulses much less, and the minimum value of this force remains above detachable effort Rotr, than and vibration of an anchor is excluded.

12.4 Delay and acceleration of action of an electromagnet

In some cases in practice it is necessary to slow down or accelerate action of an electromagnet.

Delay of action of an electromagnet of a direct current can be reached (see figure 12.3).

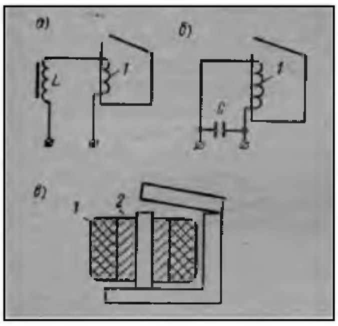


Figure 12.3 – Schemes of delay of operation of an electromagnet:

a) increase in a constant of time of the coil;

b) inclusion parallel to the capacity coil;

c) by means of the short-circuited round having small electric resistance.

The short-circuited round slows down increase of a stream at inclusion of an electromagnet.

At inclusion of capacity increase of tension on the coil happens gradually in process of condenser charging.

Acceleration of action of an electromagnet can be reached due to reduction of a constant of time.

In this case existence of a short-circuited round, the massive parts of a magnetic conductor, metal frameworks of the coil and any short-circuited rounds formed of the fixing and other details lying on the way of a stream is inadmissible as they will increase time of action of an electromagnet.

The Shikhtovanny magnetic conductor also leads to acceleration of action of an electromagnet.

Still bigger acceleration can be received at inclusion of an electromagnet according to the scheme presented in figure 12.4

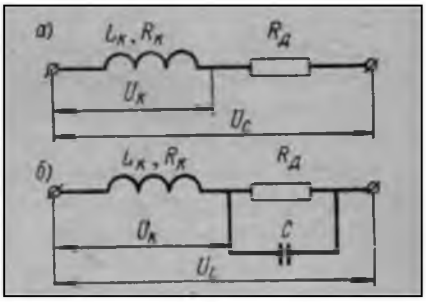


Figure 12.4 – Schemes of acceleration of operation of an electromagnet of a direct current

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