Influence of value resistance contact units of switching devices on losses of the electric power in shop networks of low tension

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Abstract. The calculation of resistance tightening contact joints of switching devices allowing to consider technical condition of low-voltage switching equipment and to specify the value of the energy emitted in the switching device in the mode of operation electrical networks is presented in article.

1. Introduction

Electric power distribution in shop networks between receivers and management of work of power sources, transmission lines and receivers is carried out by means of electric devices. Though electric devices also do not perform directly working functions of units, but, nevertheless, are extremely important and integral parts of this device on which the correct, exact and reliable work of an execution part of the device to a large extent depends. Therefore to separate the electric device from all device, to represent it as independent unit it is possible only conditionally.

The concept «electric contact» means the reliable connection of two conductors allowing to carry current. Researchers were always interested in the processes happening on the surface of engagement when switching an electrical circuit [1].

The science about electric contact is based on studying of the mechanical, chemical, thermal and electric processes proceeding on the adjoining surfaces. Mechanical properties of contact materials cause first of all structure of surfaces and its influence on the area of engagement. Chemical properties are expressed by the fact that on the surface of contacts oxide, sulphidic or other protective films can be formed. Thermal and electrophysical processes on contacts are caused by a current flow just seeing the conductor to another and can be shown in the form of Lenz Joule, Thompson, Peltier's effects, the Colour, etc. [2].

The purpose of creation of any electrical connection consists in such contact of two conductors at which electrons of a crystal grid of one of them can freely pass into a grid of another. One of the main characteristics of metal surfaces is the roughness. Irrespective of a way of processing on the surface of metals there are always roughnesses. The nature of contact of two solid bodies substantially depends on roughness of the adjoining surfaces which, first of all, will concern each other in those places where the microoverhang of one surface will meet the corresponding microoverhang another. Intensive local pressure the mikrooblastyakh of contact points will cause deformation of metal in these. At further rapprochement of surfaces of the square of contact units will increase and create new contact spots in process of contact of other roughnesses. All process happens until resistance forces to crushing are not equal to the external applied force. But even then, when process is finished and there was already a considerable deformation of metal, the most part of the adjoining surfaces nevertheless is separated from
each other by the distances many times exceeding distances on which interatomic forces begin to act. Only the small platform provides the real metal tip at the expense of the available microroughnesses [3].

2. The calculation of the resistance of the contact groups of switching devices

At disconnection of contacts the surface area of contact begins to decrease owing to what current density in the field of tightening grows in process of discrepancy of contacts. The Joule heat which is selected in this area so quickly grows that microroughnesses manage to melt and form between contacts the liquid metal conducting bridge [4]. Under the influence of forces of surface tension the bridge at first has the barrel-shaped form which, in process of discrepancy of contacts, turns into hyperbolic with the col approximately in the middle of the bridge. These forms of the bridge were considered by Frank Llevelin Jones at slow cultivation of contacts. Jones experimentally confirmed for many metals justice of the formula of Ragnar Holm received on the basis of G. Wiedemann's law - R. Franz L. Lorentz [5, 14]:

\[ \alpha(T_p^2 - T_0^2) = \frac{U^2}{4}, \]

where \( T_p \) – bridge temperature before its destruction; \( T_0 \) – temperature of the opposite end of contact; \( U \) – voltage drop on the bridge; \( \alpha = 2.4 \cdot 10^{-8} \text{ V/degree}^2 \) – value of the constant which received a name of L. Lorentz. Its value specified by means of quantum statistics by A. Sommerfeld will well be coordinated with an experiment. This formula expressed dependence between temperature and voltage drop on any section of liquid throw, in this case on the melted bridge.

Some types of low-voltage switching devices, despite the seeming simplicity, in some cases represent very complex technical system, the main requirement to which is normal functioning according to specific assignment. The general provision defining functional suitability of the device assumes satisfaction in the course of its operation of predefined and absolutely certain criteria requirements, and according to contents and rigidity they can strongly differ depending on type of the device, the modes and conditions of its operation [6].

For example, characteristic of time cut-outs is the possibility of long finding of their contacts in the closed status, besides in the conditions of action of aggressive environments, moisture, the increased temperature, etc. It, in turn, causes strict requirements to stability and level of transition resistance of contact joints.

For contactors these requirements can be softened as at frequent operational switching of current perhaps periodic updating of contact surfaces. But in that and other case availability of information on value of resistance of contact joints as because of the big extent and branching of factory networks of low tension with a set of consecutive nodes with contact joints the share of resistance of the last in the general equivalent resistance of intra shop networks is rather high is necessary. Therefore when determining losses of the electric power in factory networks up to 1000V it is necessary to consider resistance of a contact system of switching devices. The power consumed actually by the device at its functioning and disseminated in it should be minimum. The low-voltage apparatostroyeniye begins to develop quite intensively recently. There is a replacement of outdated switching devices by devices of new generation to high current limiting capacity, on the devices providing higher reliability and profitability [7].

It is known that the electric wear resistance and operability of contacts of devices depend on many factors: material of contacts; working conditions – frequencies of cycles of inclusion shutdown, values of current and tension; from parameters of devices – speeds of discrepancy of contacts at shutdown, time and amplitudes of vibration of contacts at inclusion; Wednesday in which there is a switching of current contacts, etc.

Low-voltage switching devices, especially those types which have mobile contacts of bridge and lobe type should is long to be in the closed status under different external conditions. It causes strict requirements to stability and level of transition resistance of a contact joint.

In reference books there is practically no information on resistance of contact units of switching devices. Therefore there is a need for definition of utilization properties of devices.
It is considered that contact resistance consists of two components [8]:

\[ R_c = R_b + R_t, \]  

(2)

where \( R_b \) – resistance a body of contacts; \( R_t \) – the transition resistance places of engagement.

\( R_t \) resistance in difference from \( R_b \) has considerable variations on an absolute value and is capable to cause the unpleasant phenomena connected with failure of contacts. The detailed research shows that transition resistance, in turn, consists of two components:

\[ R_t = R_s + R_c, \]  

(3)

where \( R_s \) – resistance of superficial films; \( R_c \) – tightening resistance.

Earlier it was specified that the superficial films which are formed on contact surfaces can interfere with course of current. The component of \( R_c \) is caused by the fact that the contacts connected end-to-end adjoin not on all seeming surface, and only in separate points.

The valid contact points in different degree promote courses of current. On conductivity they can be divided into three groups [9]:

- the metal adjoining surfaces;
- the quasimetal adjoining surfaces covered with thickness absorbed by a gas film in several molecules;
- the bearing superficial films with high \( R_s \) resistance.

Resistance of metal surfaces leads to the fact that lines of current are pulled together to places with good conductivity, at the same time current density can reach \( 10^7 \) A/cm\(^2\). Introduction of this concept gave the chance to set quantitative ratios between the contact resistance, physical properties of contact materials, a geometrical form of a surface of engagement and contact effort [10].

The nature of the deformations happening on two adjoining surfaces has a huge impact on characteristics of contact. It is usually supposed that the isolating films which are available on a surface collapse only in case of plastic deformation of metal at contact and therefore a large number of researches for the purpose of definition of the factors influencing the mechanism of deformations was conducted. Ways of the description of the nature of mechanical contact in which mechanical properties of surfaces and their microrelief were considered were developed. Information on detailed structure of surfaces was processed on a computer. This research showed that some parameters of a relief, such as radiuses of curvature of surfaces of microoverhangs and distribution of the last on heights, were not always correctly evaluated earlier. For example, it was revealed that for many surfaces distribution of roughnesses on heights precisely corresponds to the normal distribution law [11].

Thanks to these data, calculation of a ratio of loading and the area of contact of two surfaces and also definition of the conditions leading to plastic deformation of separate roughnesses became possible. As a result of experiences it became clear that irrespective of a type of deformation, plastic or elastic, emergence of contact areas is defined not only the loading attached to two solid bodies, and, generally by roughness of their adjoining surfaces. This output is according to the general direction which arose recently at a research of physics of the adjoining surfaces. The size of each contact point is \( 10^{-5}-10^{-4} \) cm.

In terms of a current flow it is clear that engagement happens through the thin isolating barrier to a small amount of far remote spots in it which provide passing of electrons. Chemical, mechanical and thermal nature of microscopic areas of contact on the adjoining surfaces as it was already specified, manages all characteristic of contact.

Let’s evaluate the value of resistance of tightening of contact units of low-voltage devices. Electrical conductance between two contact elements is formed as a result of action of mechanical effort of \( P_c \) called contact which presses these elements to each other. One of the major characteristics of the closed electric contacts is the value of the conducting platform between them [12].

The metal tip is carried out not on all surface, and only in the few points. The film which is available on the surface of metal formed by these or those chemical compounds and having high electrical resistance in some cases can be pressed through under the influence of mechanical efforts, in others can be punched under the influence of electric potential difference. In the place of breakdown the metal isthmus carrying electric current [13] can be formed.
The main feature of a contact surface – its roughness. Only in the few points overhangs of the contacting sections adjoin. Increase in force of contact clicking leads to growth of number of such places. Under the influence of an electric spark and an arc intensively there take place chemical reactions as a result of which on the surface of contacts the different chemical compounds having high electrical resistance are formed. Besides, corrosion of contacts which in the wet environment has electrolytic character can be observed. Drastic remedies of fight against films on the surface of contacts is a mechanical grinding of contacts in the course of their inclusion or rather high pressure of one contact on another, capable to press through a film (for gold $P > 0.01$ H, for silver $P > 0.1$ H, for tungsten $P > 0.7$ H).

At the big sizes of films (tens of nanometers) there can come the mechanical wear of surfaces of the contacting metal details – the phenomenon called by a fritting. If on contacts with such film to lift tension, then transition resistance will quickly decrease.

In case of the plastic or elasto-plastic deformation observed in real contacts, the radius of a signal connect pad of $f$ decides on the help of a concept of the contact hardness $H_v$ entered by R. Holm. It is in number equal to average pressure in contact overhangs which approximately three times exceeds pressure corresponding to the beginning of plastic deformation [14].

In this case

$$f = \left( \frac{P_c}{\pi \xi H_v} \right)^{\frac{1}{2}},$$

(4)

where $\xi$ – the compressibility coefficient considering extent of processing of a contact surface on which its elasto-plastic properties depend; $P_c$ – contact effort of the electric device; $H_v$ – the contact hardness of material of contact of the switching device.

For purely plastic deformation $\xi = 1$, and for elasto-plastic $0.3 < \xi < 1.0$. At good polish of contacts when deformation has almost elastic character, the value $\xi$ can be reduced up to 0.02. As analytically it is very difficult to display coefficient $\xi$, we will use its mean value for devices on tens and hundreds of amperes $\xi = 0.4$.

For real plane contact quantity of signal connect pads of $n = 3$. Then the radius of a resultant signal connect pad will be defined as

$$f = \left( \frac{P_c}{n \pi \xi H_v} \right)^{\frac{1}{2}}.$$

Let's give several examples of calculation of radius of a signal connect pad of switching devices. Data for calculation of resistance of tightening are provided by design department of the Divnogorye plant of the low-voltage equipment (DZNVA) Divnogorsk Krasnoyarsk Krai.

For AE2040 series automatic machines on rated current 63 A where as material of contact the composition Ag silver (95%) - graphite C (5%) for which $H_v = 35$ kg/mm$^2$, $P_c = 0.5$ kg, we calculate $f = 0.67$ mm is used.

For automatic machines of the BA 57-35 series on rated current 250 A where as material of contact alloy Ag silver (85%) - CdO cadmium oxide (15%) for which $H_v = 55$ kg/mm$^2$, $P_c = 2.5$ kg, we calculate $f = 0.12$ mm is used.

For automatic machines of the BA 57-39 series on rated current 400 A where as material of contact alloy Ag silver (70%) - Hi nickel (30%) for which $H_v = 50$ kg/mm$^2$, $P_c = 4.0$ kg, we calculate $f = 0.16$ mm is used.

Thus, the received results allow to evaluate the value of resistance of tightening of time cut-outs in the general resistance of contact units of devices. So, for example, for the time cut-out of the VA 57-35 brand with $I = 250$ A, resistance of a power chain is 1.2 mOm, and tightening resistance – 0.12 mOm.
Let's estimate dependence of value of power losses of time cut-outs on the power which is passed via the device. The power transferred by one pole of the automatic machine is defined according to expression

\[ P = UI \cos \phi, \]  

(5)

here \( U \) – is the mains voltage; \( I \) - the current passing through the circuit breaker.

\[ \Delta P = I^2 k^2 R, \]  

(6)

where \( k^2 \) – automatic machine load factor square; \( R \) – resistance of a power chain of the switching device [15].

![Figure 1. Dependence of power losses on the passed power in time cut-outs.](image)

3. Conclusion

On the basis of the presented characteristics for different groups of time cut-outs dependences of power losses on the power (figure 1) which is passed via the switching device are constructed.

Course of current via switching devices causes losses in their pure resistance. The share of these losses is small in comparison with the passed power – 0.12-0.15%. But while the electric power reaches the electroreceiver, it passes several switching nodes and a share of losses from delivered power increases up to the value of 1.0-1.5% that is essential at an electric power loss estimate in shop networks. Therefore at an electric power loss estimate in shop networks it is necessary to consider losses in switching equipment.

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