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Main Technical Characteristics of Low-voltage Electrical Devices

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***Abstract*—The paper studies the technical parameters of low-voltage switching devices. The main factors influencing the technical characteristics of devices are given. The dependence of the contact heating temperature of the apparatus on the loading factor is revealed. It is proved that with the increase of loading of devices the temperature of heating of contacts is within the permissible limits. The main factors influencing the resistance of contact connections - current flowing through the contacts, their sizes and heating temperature - are shown. According to the results of researches approximating functions of dependences of resistance of contacts and contact connections of switching devices on the current flowing through the device are developed. The obtained dependences are necessary for determination of equivalent resistance of lines of networks of intra-plant power supply. This will further allow to obtain reliable values of losses in such networks and most accurately predict the technical condition of electrical equipment.**

Keywords—low-voltage switching devices, magnetic starter, switch, contact resistance, heating of contact connections, failure factors, losses in low-voltage networks

I. INTRODUCTION

Low-voltage switching devices is an essential part of all electrified industrial facilities. Therefore, high demands are placed on the quality of their functional characteristics. Switchgear is exposed to one or more influencing factors simultaneously during operation, storage and transportation. Some of them can be considered as destabilizing factors, both internal and external [1]. The aggregate of such influences leads to decrease of reliability parameters, reduction of mechanical strength, false alarms and, finally, can lead to failure of the device [2]. Reliability level of devices mainly depends on the wear rate of switching contacts.

One of the main contact wear criteria for most contact connections is the amount of contact failure. Another important factor affecting the wear of contacts and contact connections is the arcing that occurs during the on-off cycle. The processes occurring during arcing cause melting and vaporization of the contact material [3]. The degree of wear of contacts of switching devices in the process of switching depends on the value of current flowing through the device, the material of contacts, as well as design and mass-dimension features of the device [4]. The rate of wear of contact connections and further possible failure of devices is determined by the following factors presented in Fig. 1.

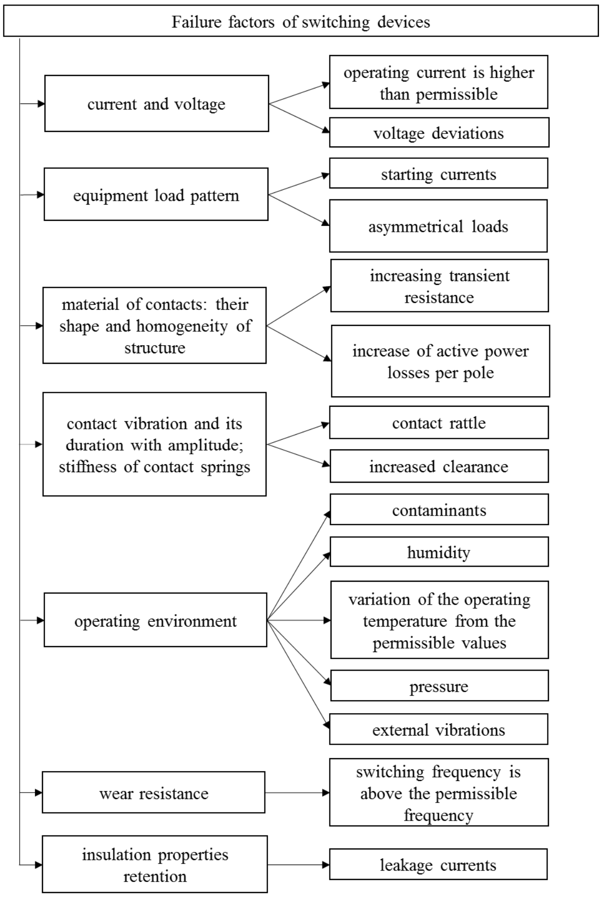

Fig. 1. Failure factors of low-voltage switching devices

During operation there should be no inadmissible overheating of the apparatus as a whole and its individual elements, this requirement should be observed throughout the entire service life of the apparatus [5, 6]. As it is known, contact resistance of apparatus represents an additional source of losses. Permissible excess temperatures of apparatus contacts are determined by operating conditions and depend on ambient temperature, pressure, operating mode and materials used. Heating of the contact connections of the apparatus occurs under the influence of various heat sources, the intensity of which varies depending on the mode of operation and load of the apparatus [7-9]. Different parts and units of the apparatus are heated unevenly when current flows, so the temperature of the contact connections is usually higher than the temperature of the adjacent conductors [10, 11].

The purpose of the work is to study and evaluate the value of resistance of contact connections of apparatus by

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experimental and calculation methods. The obtained research results will allow to determine the values of power losses in networks with voltage up to 1kV with high reliability.

II. Materials and Methods

As practice shows, taking into account the resistance of devices allows to increase the accuracy of determining losses in low-voltage power supply networks and to determine the most "problematic" sections of the network from the point of view of energy efficiency. Failure to take into account such network parameters as conductor heating temperature, ambient temperature and apparatus resistance leads to significant errors in determining power losses in networks up to 1 kV.

For effective functioning of apparatus, the power consumed by the apparatus during its operation and dissipated in it should be minimal. Therefore, the issue of studying losses in switching devices is an urgent task for reliable modeling of the main technical characteristics of low-voltage networks.

Analysis of the majority of passport and catalog data of devices shows that they do not provide all the main technical characteristics. Resistance values of the most part of apparatus elements are not presented, for example, there is no data on resistances of power circuits and contacts of apparatus. At the same time, as studies of statistical data of magnetic starters failures show, the weakest elements of the apparatus are its power contacts. The data presented in catalogs, as a rule, are of approximate character, in this connection there is a necessity to study the laws of change of resistance of contact connections of apparatuses.

Table I presents the main catalog data of magnetic starters and switches produced by Kursk Electrical Apparatus Plant (KEAZ).

TABLE I. Main Catalog Characteristics of Switching Devices

Type of apparatus	**Rated current, A**	**Switching wear resistance, cycles**	**Mechanical wear resistance, cycles**	**Power losses ΔP, W**
Magnetic starter	6 - 63 80 - 95	$1\cdot10^6$ $1\cdot10^6$	$10\cdot10^6$ $5\cdot10^6$	0.2 - 4.2 5.1 - 7.2
Switch	100 250 - 630	no data	$25\cdot10^3$ $10\cdot10^3$	1,4 5.4 - 26.2

The resistance of contact connections of apparatus depending on the rated current and loading factor according to the expression:

$$R = \frac{2\sqrt{\lambda \cdot F \cdot k \cdot S}}{I^2} \cdot \left(\theta - \frac{I^2 \cdot \rho \cdot (1 + \alpha \cdot \upsilon)}{F \cdot k \cdot S} \right) \qquad (1)$$

where λ - thermal conductivity of contact material; F - cooling surface of conductor length unit, m^2; k - heat transfer coefficient; S - cross-sectional area of contacts, m^2; I - current through contacts, A; υ - temperature of contact pads, °C; θ = 45 °C - permissible temperature difference of contact relative to ambient temperature; ρ - specific electrical resistance, Ohm · m; α - temperature coefficient of resistance.

Let us determine the steady-state value of the contact temperature from the condition of equality between the heat power allocated in the contact and the heat power removed from its surface

$$\upsilon = \frac{I^2 \cdot \rho + \upsilon_0 \cdot F \cdot k \cdot S}{F \cdot k \cdot S - I^2 \cdot \rho \cdot \alpha} \qquad (2)$$

where υ_0 - ambient temperature.

According to expression (1) for magnetic starter with I = 40 A, loading factor 1, resistance of contact connections R

$$R = \frac{2 \cdot \sqrt{390 \cdot 2 \cdot (8.1+8.1) \cdot 10^{-3} \cdot 16 \cdot (8.1 \cdot 8.1) \cdot 10^{-6})}}{40^2} \times$$

$$\times \left(45 - \frac{40^2 \cdot 1.7 \cdot 10^{-8} \cdot (1 + 0.0043 \cdot 35.9)}{2 \cdot (8.1+8.1) \cdot 10^{-3} \cdot 16 \cdot (8.1 \cdot 8.1) \cdot 10^{-6}} \right) = 6{,}34 \text{ mOhm}$$

where υ according to (2):

$$\upsilon = \frac{40^2 \cdot 1.7 \cdot 10^{-8} + 35 \cdot 2 \cdot (8.1+8.1) \cdot 10^{-3} \cdot 16 \cdot (8.1 \cdot 8.1) \cdot 10^{-6}}{2 \cdot (8.1+8.1) \cdot 10^{-3} \cdot 16 \cdot (8.1 \cdot 8.1) \cdot 10^{-6} - 40^2 \cdot 1.7 \cdot 10^{-8} \cdot 0.0043} = 35.9 \text{ °C}$$

III. Results and Discussions

The results of calculations of resistance of contact connections and temperature of contact pads for the investigated apparatus are given in Table II.

TABLE II. Results of Calculation of Technical Characteristics of Switching Devices

Type of apparatus	**I, A**	**Contact dimensions, mm**	**Temperature of contact pads, °C**	**Resistance of contact connections, mOhm**
Magnetic starter PML	25	$r = 4$	35.6	12.6
	40	$a = 8.1$ $b = 8.1$	35.9	6.34
	63	$a = 12$ $b = 12$	35.7	4.35
Switch RE19	100	$a = 10$ $b = 16$	36.5	1.98
	250	$a = 20$ $b = 20$	37.4	0.61
	400	$a = 25$ $b = 25$	38.2	0.32
	630	$a = 35$ $b = 35$	37.8	0.22

Fig. 2 shows graphical dependences of temperature of contact pads υ on loading factor K for magnetic starter with rated current 25 A and 40 A.

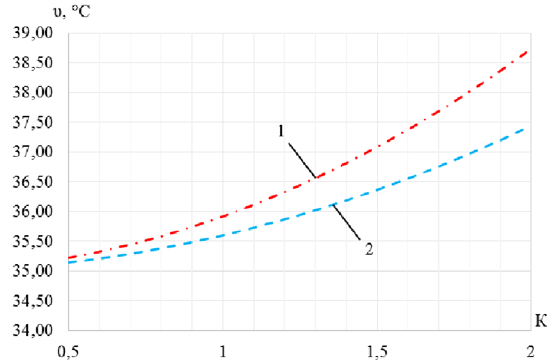

Fig. 2. Graphs of dependences of temperature of contact pads on loading factor for magnetic starter: 1 - $I = 40$ A; 2 - $I = 25$ A

Graphical dependences in Fig. 2 show that the temperature of contact pads of magnetic starters with rated current 25 A and 40 A increases insignificantly – at the coefficient of apparatus loading K = 0.5 temperature υ = 35 °C, and at overloading of apparatus K = 2.0 temperature υ rises to 38 °C. In the calculation expression of temperature increase υ does not take into account the influence of the elements of the equipment installed in the apparatus circuit. The calculation does not take into account the duration of overload current flow.

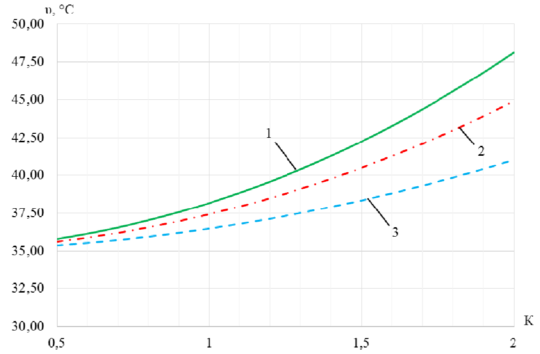

Fig. 3. Graphs of dependences of contact area temperature on loading factor for the switch: 1 - $I = 400$ A; 2 - $I = 250$ A; 3 - $I = 100$ A

Graphical dependences in Fig. 3 shows that for the switch for rated current 100 A the temperature of contact pads υ rises from 36.5 °C at rated value up to 41 °C at double overload with current of the device. At rated current of 250 A and loading factor of the switch K = 0.5 the temperature of υ was 35.6 °C, at loading K = 2.0 the temperature rises to 45 °C. Calculation of temperature υ for the switchboard for rated current 400 A showed that at increase of loading from K = 1.0 to K = 2.0 the temperature value increases from 38.2 °C to 48 °C.

The obtained values of the heating temperature of the contact pads meet the requirements of GOST. The maximum permissible temperature of copper contact connections for magnetic starters and switches should not exceed 95 °C, and the permissible excess temperature of contacts of switching devices at ambient temperature of 40 °C is 55 °C.

Table III presents the result of experimental studies revealed the dependence of contact resistance of switching devices on the rated current. The error of the obtained approximating functions does not exceed 5 %.

TABLE III. DEPENDENCE OF CONTACT RESISTANCE OF SWITCHING DEVICES ON RATED CURRENT

Type of apparatus	**Current limits**	**Type of analytical dependence of resistance on current**
Magnetic starter	$I < 70$ A	$R = \frac{825}{I}$
	$I \geq 70$ A	$R = \frac{760}{I}$
Switch	all I	$R = \frac{68}{I}$

Using the research data, a comparative analysis of graphical dependences of contact resistance on rated current, obtained experimentally and by calculation for the considered magnetic starters (Fig. 4) and switches (Fig. 5).

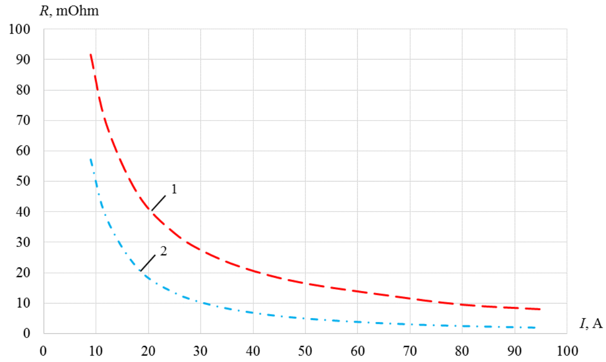

Fig. 4. Graphs of contact resistance dependences on rated current for magnetic starters: 1 - experimental data; 2 - calculated values

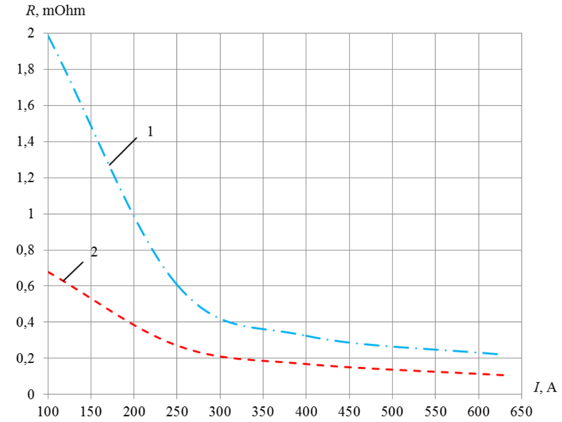

Fig. 5. Graphs of contact resistance dependences on rated current for switches: 1 - calculated values; 2 - experimental data

The conducted studies and graphical dependencies in Fig. 4, 5 show that the calculated and experimental methods of determining the resistance of contact connections of magnetic starters and switches have a significant difference in the obtained results. In this case, the most reliable is the experimental method of determining the resistance of contact connections. For magnetic starters the error of the calculation method is -57.55%, for switches the average error amounted to 118.94%. Therefore, the calculation method cannot be recommended for reliable estimations of technical parameters of the investigated devices.

Dependences of change of resistance of contacts and contact connections can be recommended for forecasting the technical condition of electrical equipment of in-plant power supply and specifying the value of power losses in low-voltage networks.

IV. CONCLUSION

As a result of the conducted researches the calculated dependences of the temperature estimation of the contact area temperature of magnetic starters and switches on the value of the apparatus loading factor are obtained. The models of estimated and experimental dependences of contact resistance values of magnetic starters and breakers on the value of rated current are developed. The approximating functions in Table IV allow estimating the values of contact resistances and contact connections of switching devices.

TABLE IV. APPROXIMATING FUNCTIONS OF DEPENDENCES OF RESISTANCE OF CONTACTS AND CONTACT CONNECTIONS OF SWITCHING DEVICES ON RATED CURRENT

Type of apparatus	**Current, A**	**Approximation function**	
Magnetic starter	$6 \div 630$	Calculated	$R = 1276{,}2 \cdot I^{-1{,}414}$
		Experimental	$R = 894{,}51 \cdot I^{-1{,}028}$
Switch	$100 \div 1600$	Calculated	$R = 521{,}9 \cdot I^{-1{,}218}$
		Experimental	$R = \frac{68}{I}$

On the basis of the conducted researches of technical characteristics of magnetic starters and switches, installed in the shop networks, it is proposed to take the parameter of resistance of contacts and contact connections as one of the criteria of energy efficiency of devices.

The developed dependencies can be used to calculate the values of equivalent resistances of shop-floor power supply networks when determining the value of power losses. Refining the values of losses in shop floor networks allows to plan energy saving measures in the most efficient way, as well as to control the technical condition of electrical equipment.

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