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SWITCHING–OFF BEHAVIOUR OF CONTACT MATERIALS AgCdO 15, AgNi 30 AND Cu+ UNDER CONDITIONS OF CATEGORY AC–4.

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The paper deals with the switching-off behaviour of contact materials AgCdO 15, AgNi 30 and Cu+. The switching-off behaviour was investigated experimentally under conditions of category AC-4, at supply voltage 230 V, in a current zone 400 to1200 A. The switching-off behaviours are characterized with two types of dependencies. The dependencies of the maximum arcing time versus interrupted current at which the interruptions were realized at first current zero. The dependencies of the maximum arc energy versus interrupted current at which the interruptions were realized at first current zero, too. All dependencies have been found for the velocities of a moving contact $v = 0.8\,\mathrm{ms}^{-1}$, $0.6\,\mathrm{ms}^{-1}$ and $0.38\,\mathrm{ms}^{-1}$.

K e y w o r d s: interruption, switching-off behaviour, contact material

1 INTRODUCTION

In low voltage switches an electrical arc burns during interruption, the time of which can be divided into two intervals. The first interval starts with contacts separation and it finishes when the current passes through the first current zero. The second interval follows immediately after the first interval and it finishes when the arc is quenched in the quenching chamber. Current interruption can be realized at the first current zero, that means at the end of the first interval, or after arc quenching in the quenching chamber. A very important fact is that the first interval must occur at every interruption, while the second interval need not occur at all.

The switching-off procedure depends on the deionization processes that take place in the contact space. After the arc quenching at the first current zero, the deionization processes will be influenced by the recovery voltage, contact system, velocity of moving contact and by contact materials. The contact material has a significant influence on the deionization processes.

For the same recovery voltage and contact system, dependences can be found for describing only the influence of the contact material (on deionization processes), parameter of which is the velocity of the moving contact. It can be stated that each material has its individual switching-off behavior. As the switching processes depend on many parameters and have non-linear characteristics, they have been investigated experimentally. Investigations were carried out on the contact materials: AgCdO15, AgNi30 and Cu + under condition of category AC-4, IEC 947 standard.

The other aim of the investigation has been to find the influence of the moving contact velocity on the switching-off properties. The switching-off properties are significant characteristics of the contact material. Their determining can contribute to design optimization of contactors working with a high number of switching cycles.

2 INFLUENCE OF CONTACTS ON THE SWITCHING PROCESS

The influence of contacts on the switching process is significant especially in the first interval which starts with the contact separation and ends during the first current pass through the current zero. Characteristic diagram can bee seen in Fig.1.

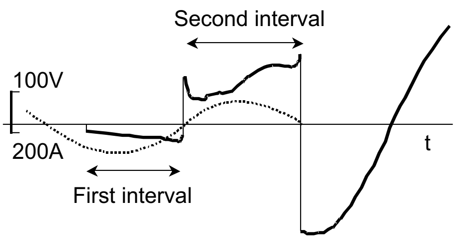

Fig. 1. Typical arc voltage during interruption

During the first stage of contact separation, a bridge of liquid materials is formed. After the break of the bridge the arc starts to burn. If some rests of the bridge keep staying on the contact surfaces, they deform the electrical field after arc quenching. That causes the decrease of the breakdown voltage in between the contacts. This is one of parameters that decteriorates the switching-off properties of contacts. An apparent deformation can be seen on Cu contacts by switching-off currents of 200-300 A. [1]. The appearance of a Cu contact deformed by the bridge rests can be seen in Fig.2.

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Another parameter with major influence on switching-off properties of contacts is the temperature rise of the contact surface. From the spots with temperature rise up to the boiling temperature electrons are radiated out (thermoemission) after arc quenching. The electrons decrease the break down voltage of the gap between the contacts and this causes worsening of the switching-off behavior of contacts. The number of electrons emitted is proportional to the surface and its temperature. Both are dependent on the value of interrupted current, arcing time, recovery voltage, moving contact velocity and on the properties of contact materials. In the case of heterogeneous contacts the number of parameters increases.

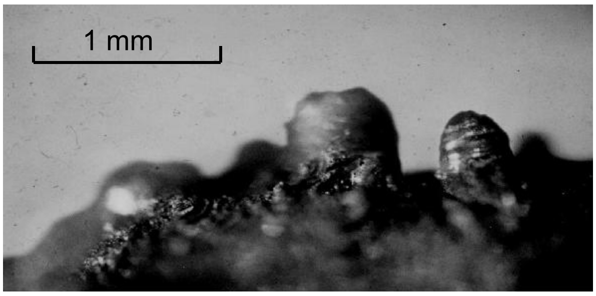

Fig. 2. Appearance of Cu contact with rests of bridges

Beside all the parameters listed so far, the temperature rise is influenced also by the time of arc immobility, or the time of reduced arc motion. In the first stage of its existence the arc is immobile or its motion is reduced ($v < 0.3\,\mathrm{ms}^{-1}$). This time depends on the blow out magnetic field, length of the arc, switched current, on the material and actual appearance of contact surface.

In the contact systems used for contactors the time of immobility and the time of reduced arc motion, for new AgCdO12 contacts, is approximately 1 to 4 ms, for current range 0 to 1500 A. [2].

3 INFLUENCE OF RECOVERY VOLTAGE ON THE SWITCHING PROCESS

Another parameter influencing the deionization processes after the first current zero pass is the recovery voltage. The electric field created in the gap between the contacts influences the deionization processes mainly in these ways:

a) it increases the number of electrons emitted from the negative contact,

b) it accelerates the electrons that may ionize neutral particles by collision.

The increased number of electrons may cause arc reignition. With an increased rate of rise and magnitude the probability of arc reignition grows up. For the given recovery voltage and given contact material it is possible to find a limit dependence of the arcing time on the interrupted current for which the interruptions occur at the first current zero.

4 INFLUENCE OF CONTACT SYSTEM AND VELOCITY OF MOVING CONTACT ON THE SWITCHING PROCESS

The contact system influences the switching process as follows:

- The form of contact system gives the capability of blowing out the magnetic field created by switched current. [3]. The moving arc causes a lower local temperature rise than the immobile arc.
- The increased number of mechanical breaks in the contact system causes a decrease of the electric field intensity in the contact gap. The decrease of the intensity has a positive influence on the switching-off contacts properties.
- The velocity of the moving contact has an influence mainly during the first interval. It is the velocity of the moving contact that influences the distance between contacts, causing an individual character of temperature distribution over the contact surface. See Fig. 3.

Using the same contact system for all the tests it is possible to eliminate its influence. However, the velocity of a moving contact can not be eliminated in this way. This is why its influence has been investigated.

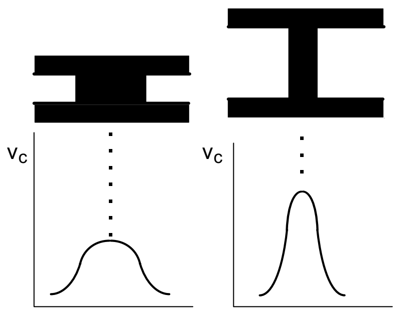

Fig. 3. Temperature distribution on contact surface at various contact distance

5 TEST CONDITIONS AND MEASUREMENTS

Tests were carried out under conditions of category AC-4, by IEC 947, at supply voltage 230 V and currents 400, 500, 900, 1000, 1200 A. Conditions under AC-4 are as follows [4]:

- Power factor of test circuit $\cos\varphi = 0.35 \pm 0.05$
- Factor $\gamma = 1.10 \pm 0.05$
- Frequency of transient recovery voltage for test currents is given in Table 1.

Table 1.

I (kA)	0.4	0.5	0.8	0.9	1.0	1.2
$f_{\rm id}$ (kHz)	85.5	89.4	98.2	100.6	102.7	106.5

All the tests were carried out in a contact system that is frequently used in contactors, see Fig. 4.

The tests were carried out so that for every adjusted current the maximum arcing time $t_{a\,\max}$ was investigated at which the current interruptions still occurred at the first current zero. For every current, series with 25 interruptions were realized with the same arcing time. The arcing time of individual series was prolonged from about 1 ms with a step of about 1 ms until a series with maximal time was found at which all the interruptions were realized at the first current zero. The equal arcing time was adjusted by synchronizing the instant of contact separation with respect to the current time change. The current and voltage time curves were registered by a storage tube scope. Beside the arcing time, also the average value of the arc voltage was measured and used for arc energy calculation. The polarity of contacts was random.

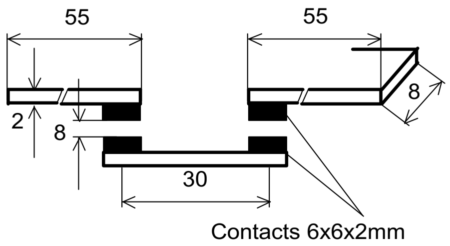

Fig. 4. Diagram of contact system

In this way $t_{a\,\max}$ as a function of current I at moving contact velocities $v = 0.8, 0.6 \ldots 0.38\,\mathrm{ms}^{-1}$ were found, [5]. They are given in Figs. 5, 6, 7.

The contact materials under tests were sized $6 \times 6 \times 2$ mm. AgCdO15 (15 wt % CdO) and AgNi30 (30 wt % Ni) are materials produced by conventional powder metallurgy. Cu+ is a Cu based and doped contact material. Samples of this material were developed at STU Bratislava, are verified and are going to be patented.

6 RESULTS AND DISCUSSION

From the measured dependences $t_{a\,\max} = f(I)$ it is obvious that the switching-off properties are non-linear functions. A significant result is the capability of all materials to interrupt currents up to 1200 A, at the first current zero under conditions of AC-4 category.

AgNi30 has the worst properties of all tested materials. Relatively worse switch off properties can be explained by its lower thermal conductivity. Due to a lower thermal conductivity the heat flow in the contact is lower, so that at the same arc energy a higher local temperature rise in the arc spot is caused. At a higher temperature of the surface more electrons are emitted. This causes a decrease of switching-off properties. This process is supported also by the fact that AgNi30 is thermally more resistant, what is caused by Ni particles with the boiling temperature 2900° C . That allows its heating up to a higher temperature.

Only with this material a new parameter has been found that limits the switching properties "from beneath". The arc was recovered after the first current zero when the contact distance decreased below an critical value, dependent on the interrupted current value. The arc recovery was caused by bridging the small contact distance with material released from the contact. At 1000 A current this critical distance has appeared to be about 0.5 mm, diminishing with the decreased current. Using a linear approximation

$$d_{cr} \approx 0.5 \times 10^{-6} \cdot I \qquad \text{(m;A)} \tag{1}$$

For every velocity of the moving contact an equation of minimal arcing time can be derived at which the current is interrupted at the first current zero. For individual velocities of the moving contact these relations can be expressed by equation

$$t_{a\,\min} = \frac{d_{cr}}{v} = \frac{0.5 \times 10^{-6} \cdot I}{v} \qquad (\mathrm{s;\ m,\ ms^{-1}}) \tag{2}$$

For particular velocities of the moving contact they have the forms

$$v = 0.8\,\mathrm{ms}^{-1}; \quad t_{a\,\min} \approx 0.625 \times 10^{-6} \cdot I, \tag{3}$$

$$v = 0.6\,\mathrm{ms}^{-1}; \quad t_{a\,\min} \approx 0.83 \times 10^{-6} \cdot I, \tag{4}$$

$$v = 0.38\,\mathrm{ms}^{-1}; \quad t_{a\,\min} \approx 1.3 \times 10^{-6} \cdot I. \tag{5}$$

In general, better properties has the AgCdO15 material. For velocities $v = 0.8$ and $0.6\,\mathrm{ms}^{-1}$ in the current region 400 to 800 A. A significantly better switching-off properties have been found than those for AgNi30. A still more significant improovement of the switching-off properties has been found at a velocity 0.38 ms^{-1} in the whole current range.

The better switching-off properties of the AgCdO 15 are given by the fact that in the same conditions the temperature rise of the contact surface is lower. There are more reasons, among them:

- CdO particles are decomposed at 933° C , which consumes some heat from the arc, hence the temperature rise on the contact surface is lower
- Created Cd and O and plasma jets expand the arc plasma to a large surface, hence the arc heat flows into the contact through a greater contact surface. This results in a lower local temperature of the contact surface.
- Higher thermal conductivity of AgCdO15 than of AgNi30.

Limitation of the switching-off properties "from beneath" has not been observed with this material. The best switching-off properties at all velocities of the moving contact has Cu+ material. The influence of the velocity of the moving contact upon the contact switching-off properties can be explained, in general, as follows:

With the decrease of velocity, the distance between the contacts decreases and at a smaller contact distance, under influence of higher pressure and plasma jets, plasma is displaced over a greater surface. That is why the surface is heated up to a lower temperature, hence the switching-off properties are getting better.

To express the switching-off properties, arc energy can be used too, as it takes into account both the arcing time and arc voltage. This is the reason why for $t_{a\,\max} = f(I)$ relations $W_a \max = f(I)$, expressing the maximal arc energy which the arc can have should the current be interrupted at the first current zero, were found. The arc energy can be expressed in general as

$$W_a = \int_0^{t_a} u_a(t) i_a(t) \mathrm{d}t \qquad (6)$$

where $u_a(t)$ - is the arc voltage, $i_a(t)$ - is the arc current and t_a - is the arcing time.

The time diagrams of the arcing voltage of all contact materials in the first interval were very close to linear diagrams, and the voltage drop over one break did not exceed approximately 25 V. A typical oscillogram is in Fig. 1. Under these conditions, the arcing voltage can be replaced by a linear function and an average value can be used for calculating the arc energy.

With respect to low values of the arc voltage, the influence of arc on the current can be neglected and the current can be expressed by the equation

$$i_a(t) = \sqrt{2}\, I \sin\omega t \qquad (7)$$

and the arc energy in the first interval is

$$W_a \approx \int_{t_1}^{t_2} U_{aa} \sqrt{2}\, I \sin\omega t \mathrm{d}t \qquad (8)$$

where t_1 is the instant of arc beginning, t_2 is the instant of arc quenching (first current zero), U_{aa} is the average value of arcing voltage and I is the interrupted current.

Solving equation (8)we get

$$W_a \approx U_{aa} \sqrt{2}\, I\, \omega^{-1} (\cos\omega t_1 - \cos\omega t_2) \qquad (9)$$

From equation (9) the arc energy was calculated for a set of currents under tests. For preset currents and $t_{a\,\max}$ and U_{aa} energies were calculated. Relations were calculated for 50 Hz supply frequency and are shown in Fig. 8, 9, 10. These relations indicate the energy of both arcs in series.

Conclusions drawn from the relations investigated:

- Contact material AgCdO15 compared with AgNi30 allows appoximately 2 times higher arc energy for interruption in the first current zero within the current range of 400 to 800 A and within the speed range of 0.8 to 0.6 ms^{-1}
- Maximal arc energy for AgNi30 generally decreases with increasing current at all velocities. At $v = 0.38\,\mathrm{ms}^{-1}$ it was roughly two times the value at 0.8 ms^{-1}.
- A significant increase of arc energy has been found for AgCdO15 for the velocity 0.38 ms^{-1} and currents above 800 A. The reason is the expansion of the arc plasma to a larger area.
- The highest value of arc energy was found for Cu+. It increased with an increase of current.
- With materials AgCdO15 and AgNi30 there were minima observed for current range of 800 to 900 A within the whole range of velocities. The minima were most probably caused by arc mobility. The arcing time and time of immobility were probably very close for the given current range. It caused a higher local temperature rise of contacts. Explanation of all nonlinearities and phenomena that occur between contacts needs further investigation.

7 CONCLUSIONS

The aim of the paper is to show results of experimental investigation focused on switching-off properties of contact materials AgCdO15, AgNi30 and Cu+.

The properties are characterized by two types of relations:

- maximal arcing time versus interrupted current at which the interruptions were realized at the first current zero
- maximal arc energy versus interrupted current at which the interruptions were realized at the first current zero.

Experiments were carried out under conditions of AC-4 category, given by IEC 947 Standard, at supply voltage 230 V, 50 Hz, within the current range 400 to 1200 A, at velocities of the moving contact 0.8, 0.6 and 0.38 ms^{-1}.

It was found out that:

- The switching-off properties are results of multi-parameter and non-linear processes.
- The best switching-off properties have been found for material Cu+, followed by lower ones for materials AgCdO15 and AgNi30.
- All three materials are able to interrupt currents up to 1200 A at the first current zero under conditions of AC-4, the arcing time and arc energy must not exceed the maximal values. This condition can be satisfied by synchronizing the instant of contact separation to interrupted current
- The switching-off properties are significantly influenced by the velocity of the moving contact.

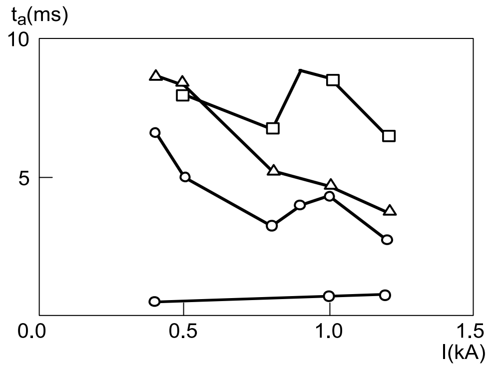

Fig. 5. Arcing time versus current at $v = 0.8\text{ms}^{-1}$

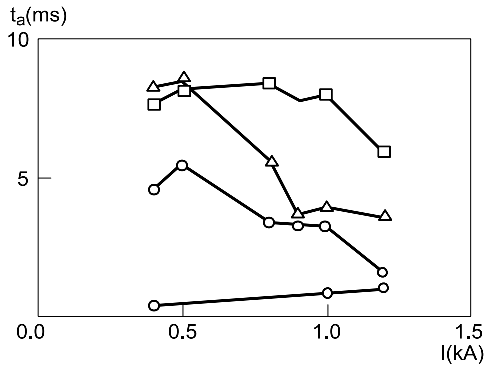

Fig. 6. Arcing time versus current at $v = 0.6\text{ms}^{-1}$

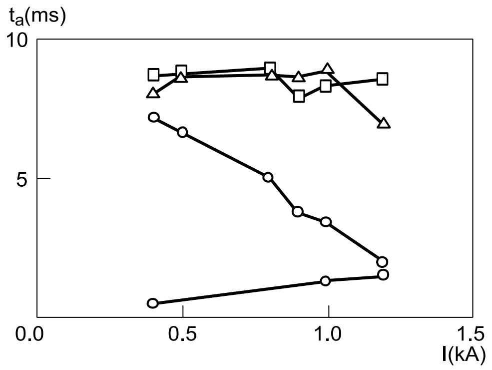

Fig. 7. Arcing time versus current at $v = 0.38\,\text{ms}^{-1}$
O AgNi30, △ AgCdO15, □ Cu+

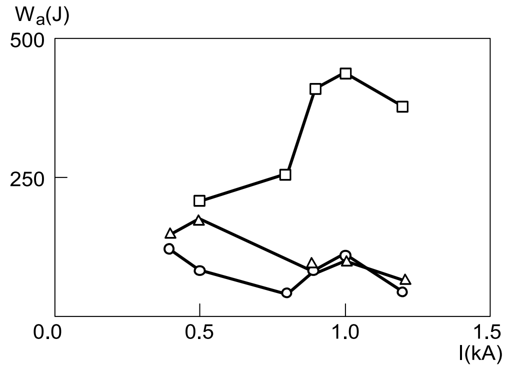

Fig. 8. Maximal arc energy versus current at $v = 0.8\text{ms}^{-1}$

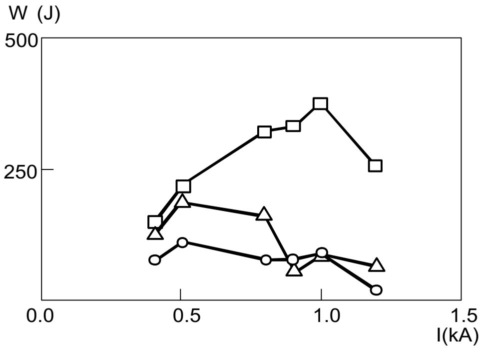

Fig. 9. Maximal arc energy versus current at $v = 0.6\text{ms}^{-1}$

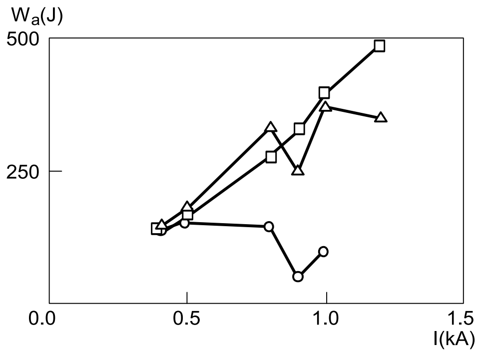

Fig. 10. Maximal arc energy versus current at $v = 0.38\,\text{ms}^{-1}$
O AgNi30, △ AgCdO15, □ Cu+

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