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New contact material for reduction of arc duration for dc application

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Abstract. The phenomenon of arcing is the major cause of electrical contact degradation in electrical switches. Degradation involves contact erosion and/or welding. The use of special contact material and that of specific material processing may permit contact erosion to be reduced, in particular by shortening the arc duration. A short review of these approaches is presented in the first part of this paper. In the second part, the development of a new self-blowing contact material is described. This material has been tested under dc voltages from 14 V to 42 V. A reduction of the arc duration by a factor of 4 approximately was obtained as was a concomitant reduction of the extinction gap to less than 2 mm. This material will contribute to achieving better reliability in high current-high voltages breaking devices, and will aid in their miniaturization, e.g. in relays.

1 Introduction

The technical and economic reasons to increase the power levels of electrical circuits have been discussed in numerous papers. The associated voltage and/or current increase supported by the circuit results, in turn, in an increase in the arc duration, and subsequent extinction gap, during the breaking operation. Breaking devices have been developed with having original designs or conception, which permit reduction in the arc duration, with consequent reduction in its deteriorating effects. In this paper, we show that it may also be possible to introduce an innovative material which generates an intrinsic magnetic field in the extinction gap, thus promoting blowing of the arc and a consequent reduction in its duration. After a brief review of what is an arc and well-known solutions (mechanical, electronic, material...) to reduce it, we present a self blowing material as a possible answer.

1.1 Why break higher electrical power levels with usual break devices?

The manufacturers of breaking devices (CB, relays, etc.) have cost reduction policies and try to reduce the range or size of their apparatus. One consequence is that each device must have a wide breaking capacity. Therefore, it is subjected to longer electrical arcing, which are more damageable for contacts materials. Moreover, these devices are submitted to increasingly severe constraints, such as reduced sizes and weight, in order to limit fuel consumption in automotive or aeronautic applications. The automotive sector also seeks to raise the voltage of the circuit on board to increase the capacity of electrical power and to supply a growing number of electrical devices. All these changes submit breaking devices, and especially the electrical contacts materials, to more severe electrical conditions.

1.2 What are the consequences of an increase in current and/or voltage on breaking devices

When the current is switched off by a breaking device, it generates an electrical arc which is broadly a neutral plasma consisting of ionized species coming from the contacts material and from the surrounding environment (atmosphere, plastic parts...). It is a dynamic and unstable phenomenon. The main characteristics of this arc (duration and gap extinction, arc voltage and arc current) depend on the parameters of the electrical circuit, the parameters of the opening system (speed, design) and the nature of the elements close to the arc plasma which are able to come into the plasma and modify its composition (contact material, nitrogen or oxygen from atmosphere or materials from the case).

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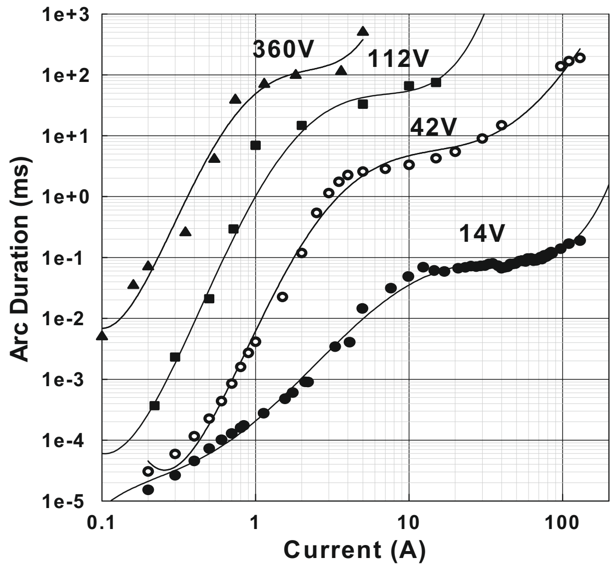

Fig. 1. Arc duration versus current in a range from 0.1 to up to 100 A at four circuit voltage (14, 42, 112 and 360 VDC).

Figure 1 shows the arc duration curves for silver contacts versus wide current range (0.1 to 130 A) at 14, 42, 112 and 360 VDC in resistive load. These results were obtained with the experimental electrical testing device described in previous papers [1,2] and briefly reminded in Section 2.1.2. Each curve has two parts: a first segment obeys to a power law with a high slope I^4 and is followed by a flat section. Let us consider the curve for 42 VDC. Up to 2 ms, the arc duration versus current characterizes an arc in metallic phase (regime 1 or anodic arc) whereas at longer time it characterizes an arc in gaseous phase (regime 2 or cathodic arc) [3,4]. These effects were extensively discussed in previous publications. It is interesting to note that except at 14 VDC, the slopes of the first regime are parallel the ones to the others. It can be concluded that the same phenomena determine the arc behaviour in the whole voltage range from 42 VDC to 360 VDC.

These results show that the arc durations can reach important values needing a wider extinction. If the contact gap, imposed by the design of the device, is smaller than the natural extinction gap of the arc, it may stagnate almost indefinitely until the contact materials totally melt. That can lead to the destruction of the device and cause fires for its direct environment. Beside this, when the natural extinction gap of the arc increases (because the arc is getting longer), the phenomena of transfer between contacts pass through the above mentioned anodic and cathodic regimes and thus, material loss is becoming increasingly large [2,5–8].

Due to these various reasons, if the next generations of breaking devices have to withstand harsher electrical arcs, they should be equipped with arc reduction (or suppression) systems.

1.3 What are the most common arc suppression systems?

By modifying certain parameters of the breaking device, it is possible to control the arc duration and gap extinction. The electrical parameters of the circuit being imposed, we can only act on the physico-chemical parameters of the breaking device. The following (but non-exhaustive) list enumerates such actions and their principles that help to minimize the consequences of arcing.

1.3.1 Atmosphere

The atmosphere of the breaking can be ambient air, vacuum or a protective gas, such as SF6. Alternatively, the contacts environment may be filled with oil. In the earlier instants of the arc, the plasma consists of species that come from the ionization of the contact material. The pressure of the plasma is tremendous (several tens of bars). As the contacts separate, the pressure decreases and the gas from the atmosphere enters into the plasma and becomes ionized. This supplementary source of electrons maintains the electrical conductivity of the plasma and slows down the decrease of the current. Depending on the nature of the atmosphere, its components are more or less ionizable: specific atmospheres other than ambient air are sometimes used because they promote the extinction of the arc by providing a lack of electrons (ex: SF6). Under vacuum, the contact material only feeds the plasma. Therefore, its intensity decreases as the two contacts are moving away. In this case, the extinction gap and arc duration are reduced.

1.3.2 Kinematics

It is well admitted that for a resistive ac or dc circuit, increasing the speed of contacts separation (e.g. for certain appliances, by changing the stiffness of the springs), reduces the arc duration and associated damages as well. Various physico-chemical processes compete during the opening of the contacts. Some of them act in favor of the stabilization of the current in the plasma and others work against this state of equilibrium. Beyond these phenomena, opening the contacts contribute to the decrease of the current by increasing the plasma lenght. The faster the separation, the stronger the current decrease. However, care should be taken in inductive load where the time constant of the inductance plays an opposite role and may increase the arc duration at high speed [1,9].

1.3.3 Horn arc contacts or sacrificial contacts

These techniques reduce erosion on the main contacts. They limit their degradation and ensure good conduction (at the closed state) by limiting their temperature rise. Arc duration is not reduced but arc is deported in areas designed to withstand it.

1.3.4 Arc chamber

As it is the case in the circuit breaker, the developing arc moves to an arc chamber consisting of splitting plates where it is divided into multiple serial arcs. This promotes the arc voltage to increase and leads to rapid extinction.

1.3.5 Double break

In the design of the breaking devices, it is not uncommon to connect two pairs of contacts in series that will open simultaneously and will form two electric arcs. The energy of a single arc is almost divided by two and the damages are significantly reduced on the electrical contacts.

1.3.6 Electronics systems

It is possible to implement electronic systems, which detect arc ignition and provoke earlier arc extinction in the breaking devices. Some solid or electromechanical relays have been suggested in the literature [10].

All these specific features introduced in the design of devices involve the addition of arc suppression systems and/or a sealed box to contain atmospheres. They have a significant impact in terms of cost, size and weight.

1.3.7 Material

The choice of specific contact materials is complementary to the development of arc suppression systems. The influence of the contact material, though limited, reduces the extinction gap or the arc erosion regarding to the circuit parameters (ac/dc, voltage or current level), also the application of the circuit (protection or control). Because the influence of contact material occurs at the beginning of the arc, it is easy to compare different materials according to electrical circuit conditions.

In Figure 2, six materials were tested on the laboratory bench described in Section 3.1.2. The experimental conditions were the following: 42 VDC, 20 cm/s, and resistive load. For our comparison, 10 wt.% MeO were added to silver. We see that $AgSnO_2$ has yielded the longest arcs, with a strong shift from 25 A, while the $AgZrO_2$ arc durations are lower. Besides $AgSnO_2$, other materials in this current range, such as AgNi and AgZnO, show a linear increase of the arc duration versus current. The additions of Gd_2O_3 and ZrO_2 are good alternatives to the today widely used $AgSnO_2$ [11].

1.3.8 Magnetic blowing

On some breaking devices, which should switch strong currents, magnetic blowing systems may be used. Most often, it is realized by introducing a serial coil on the circuit (close to the area of arc). Current flow in the coil produces a magnetic field oriented perpendicular to it and ensures arc evacuation from the contact area by producing a force orthogonal to both other directions, according to Lorentz law. Such magnetic blowing systems have been developed both for dc and ac applications depending on the targeted breaking capacity.

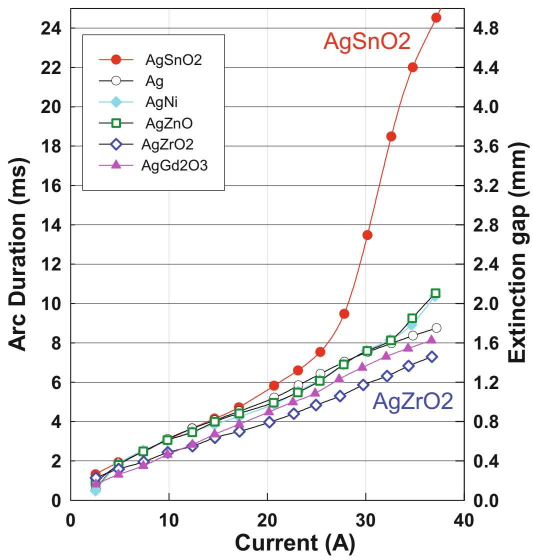

Fig. 2. (Color online) 42 VDC resistive, $t = f(I)$, Ag, AgNi, $AgSnO_2$, AgZnO, $AgGd_2O_3$, $AgZrO_2$.

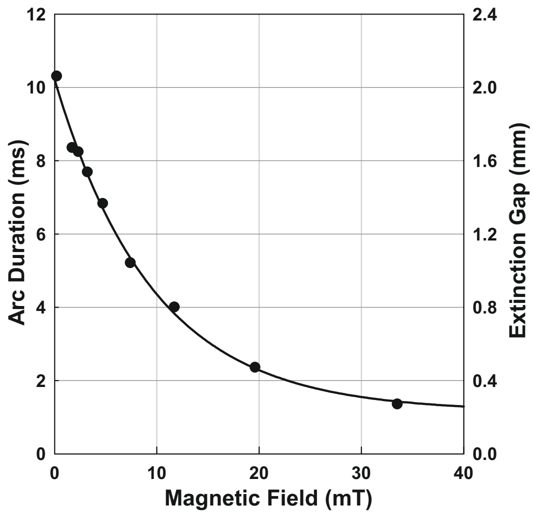

Fig. 3. Arc duration and extinction gap versus external magnetic filed for Ag at 42 VDC, 37.5 A at 20 cm/s.

Figure 3 shows the variation of the arc duration and extinction gap versus a uniform external magnetic field perpendicular to the current flow. These results were obtained on the electrical test device described in Section 3.1.2, on silver contacts at 20 cm/s under 37.5 A. Two magnets produced the magnetic field and it was varied by changing the gap between the two magnets. Its value was measured using a Hall probe (sensitivity around +/−0.2 mT) positioned in the magnet gap. In a second step, the Hall-effect probe was replaced by electrical contacts to obtain the data shown in Figure 3.

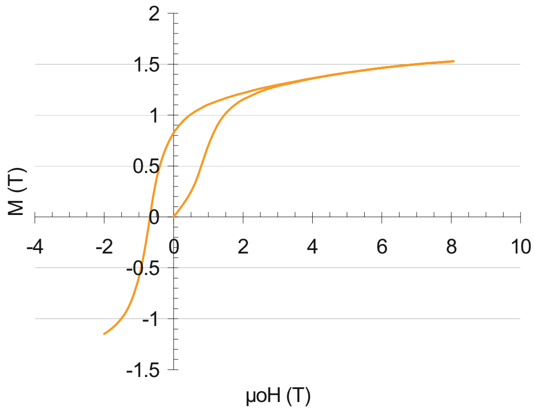

Fig. 4. (Color online) $M = f(\mu_0 H)$ for magnetic phase in electrical contact material.

Figure 3 shows that the arc duration at 0 mT is in agreement with data in Figure 2. The arc duration decreases drastically as the magnetic field is increased. At 10 mT it is already reduced by a factor of more than 2. At longer time, it tends towards a limit value of about 1 ms.

2 Self-blowing material

The purpose of this part is to present the study on the characteristics of a break arc, exploiting the self- blowing properties of a magnetic phase, introduced into the contact material. This new material permits higher breaking capacity to be reached than traditional materials without any change in the device design.

2.1 Equipment and procedure

2.1.1 Contact material preparation and magnetic characterization

Cylindrical samples with a diameter of 5 mm and a height of 5 mm were prepared by conventional powder metallurgy by mixing silver powder with magnetic material (for confidentiality reasons, we will not indicate here the physico-chemical properties of the material used: nature, shape and mass content).

The samples were magnetized at room temperature in a super-conducting magnet with a maximum applied field of $\mu_0 H = 7$ T (Oxford Company). The field was applied along in the direction perpendicular to the cylinder axis. Figure 4 shows the characteristic hysteresis cycle of the magnetic phase used in our electric contact material.

After magnetization, the surface induction of each sample, B_s was measured with a Hall probe (Lakeshore Company) placed at 1mm above the surface sample. The samples were magnetized at three different levels corresponding to surface inductions of 30, 55 and 100 mT respectively, as determined by the Hall probe. The samples were called AgMM1, AgMM2 and AgMM3, respectively.

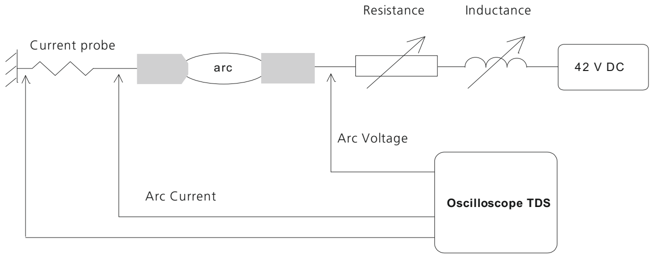

Fig. 5. Electrical test apparatus for break arc.

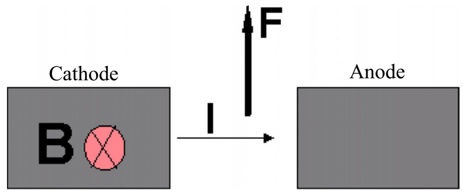

Fig. 6. (Color online) Sample geometry used during the electrical tests.

2.1.2 Electrical characterization by break arc duration

The IPR Laboratory is equipped with a fully automated device (Fig. 5), adapted to perform contact breaking under 14 VDC up to 360 VDC. In this paper, most experiments were performed under 42 VDC and with a resistive load, at opening speed of 20 cm/s, i.e. under conditions similar to those of automotive relays. Voltage, current, loads and opening speed were controlled, and a digital oscilloscope stored voltage and current characteristics of the arc during the break. The arc parameters, namely arc energy, arc duration and extinction gap were thus deduced.

For all the experiments, the magnetic material AgMM was placed at the cathode and pure silver at the anode: Figure 6 shows the position of the cathode and the anode in the electrical tests. The respective directions of the current, I, the magnetic induction of the sample, B, and the resulting Lorentz force, F are indicated in the Figure 6.

2.2 Results and discussion

Figure 7 shows the evolution of arc voltage versus time under 37.5 A, 42 VDC and a resistive load for the following contacts materials: $AgSnO_2$, pure Ag and AgMM3. The arc voltage increases slowly with time for $AgSnO_2$ and a little faster for silver. The total arc duration are 24 ms and 8 ms respectively. By contrast, with AgMM the arc duration is reduced down to 3 ms only. The reduction with respect to the case of silver contact illustrate the blowing effect of the magnetic field.

Figure 8 shows the evolution of the extinction gap, as a function of the current, for pure silver contacts on the one hand and silver magnetic contacts on the other hand. The three magnetic materials differ only by the magnetic field they produce. The stronger the magnetic field, the lower the arc duration. Optimum properties are obtained with the arc length of AgMM3 which is the contact producing the highest magnetic field. Under 37.5 A, the arc duration

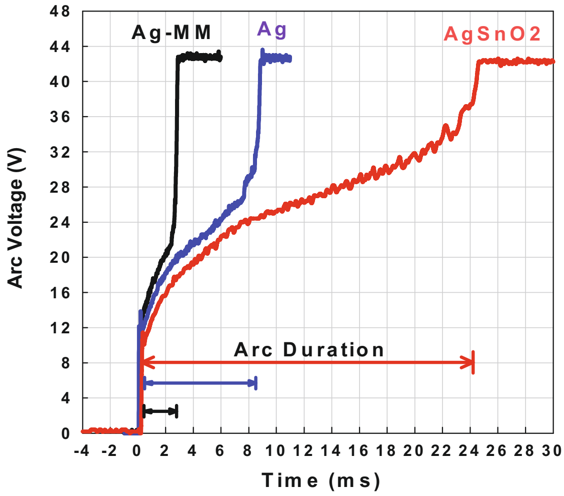

Fig. 7. (Color online) Arc voltage versus time for $AgSnO_2$, Ag and AgMM3 at 42 VDC, 37.5 A resistive.

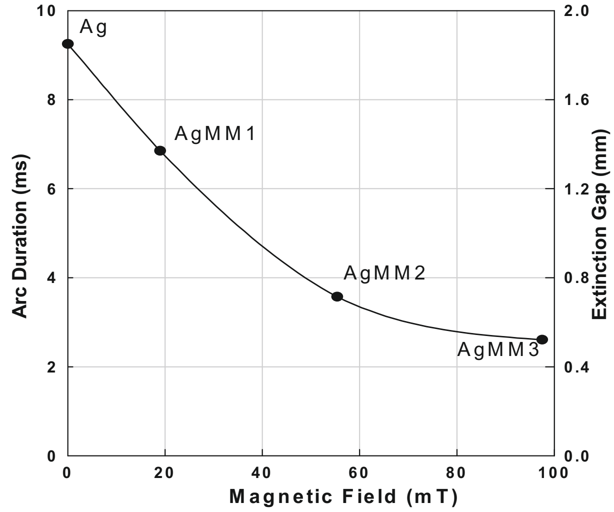

Fig. 9. Arc duration versus Magnetic field for Ag, AgMM1, AgMM2 and AgMM3 at 20 cm/s 42 VDC, 37.5 A at 20 cm/s.

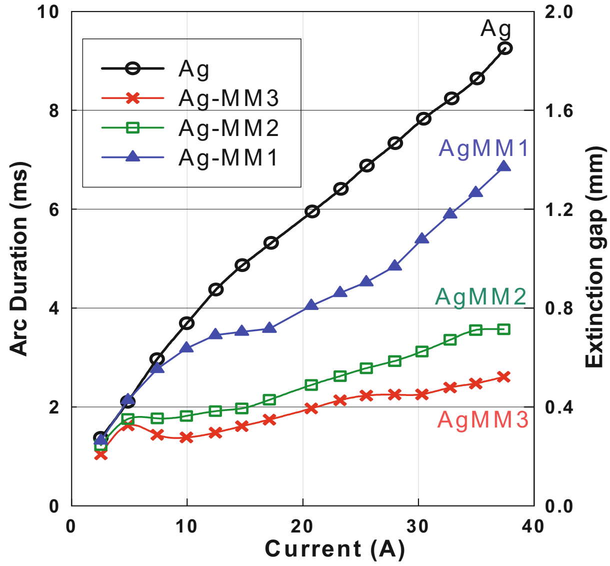

Fig. 8. (Color online) Arc duration versus Current for Ag, AgMM1, AgM2 and AgMM3 at 20 cm/s 42 VDC resistive.

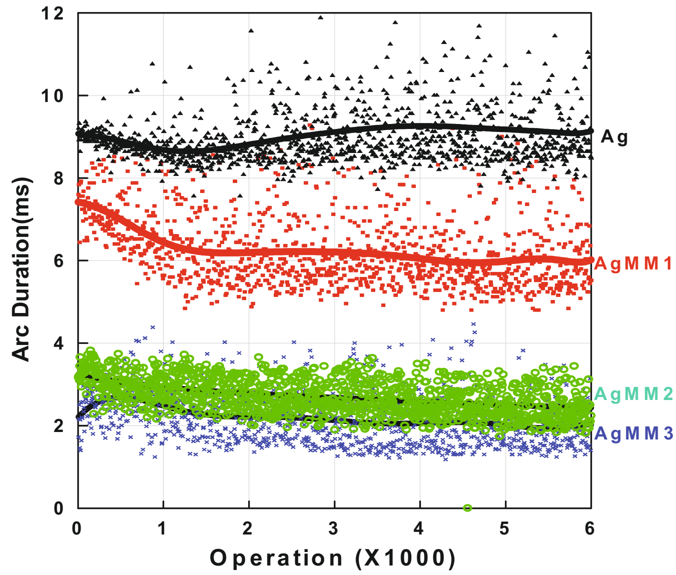

Fig. 10. (Color online) Arc duration versus number of break operations for Ag, AgMM1, AgMM2 and AgMM3 at 20 cm/s 42 VDC, 37.5 A at 20 cm/s.

is reduced down to 2.4 ms, 72.5% less than with pure silver. For AgMM1, which produces the weakest magnetic field, the blowing effect starts around 10 A only. In the case of AgMM2 and AgMM3, the blowing effect begins earlier. The reason is that for higher magnetic field, the curved radius of the trajectory of an electron is smaller.

Figure 9 shows the evolution of the arc duration as a function of the magnetic field. The value at 0 mT does correspond to the arc duration for pure silver.

Qualitatively, the curve is similar to the one shown in Figure 3. The magnetic field scales do not correspond one to the other. This is simply due to the fact that the field measured on the contact surface with the Hall probe (Fig. 9) is not the field measured in the gap (Fig. 3).

It remains that with AgMM3 a spectacular reduction in the arc duration is obtained at 2.4 ms which corresponds to ∼480 μm of extinction gap ($v = 20$ cm/s).

All together, the use of magnetic contact permits arc blowing through the Lorentz force, as it is the case in the classical systems using permanent magnets or coils.

Figure 10 shows arc durations versus number of operations at 42 VDC & 37.5 A for a resistive load. Results are compared for pure silver and the three types of magnetic contacts. In all cases, the average arc duration shows a slow decrease during the first thousand operations. Nevertheless, the efficiency of magnetic blowing was preserved up to final testing. This is very encouraging despite the fact that the maximum 6000 operations considered here is much less than the millions of operations, which a relay must usually undergo. It is also noticeable that the dispersion in arc duration is larger for pure silver than for all magnetic contact material including AgMM1, which produces the weakest magnetic field.

3 Conclusions and perspectives

A new contact material has been developed which generates an intrinsic magnetic field in the extinction gap and leads to much faster current breaking. With fully magnetized materials (generating the largest magnetic field in our conditions), the average arc duration was reduced by a factor of 4 compared to that obtained with silver contacts. The reduction in the arc duration was already very significant with non fully-magnetized materials. The decrease in the extinction gap under field tends towards a non-zero limit value (extrapolated to around 200 μm (and 1 ms) from Fig. 3). This implies that below a certain minimum distance the magnetic field blowing effect disappears (in our conditions). The dispersion in the blowing efficiency was characterized over at least 6000 operations, in the case of fully-magnetized materials. It is already planned to characterize further the material limits by increasing the severity of all electrical parameters during testing.

It is hoped, on the one hand, that the reduction in the extinction gap obtained with this new material will permit breaking device miniaturization. On the other hand, the reduction in the arc duration should lead to a strong reduction in contact erosion. Thus, an increase in the device lifetime and a reduction in the volume of contact material may be expected, leading to significant cost reduction.

Further studies have started, addressing the mechanism of arc breaking and the process of material erosion, as well as arc initial formation, contact heating and welding. The contact itself is being further optimized with respect to its shape and nature.

Finally, as the blowing efficiency is also dependent on the environment of the contact material, testing of this new material in real breaking devices is programmed.

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