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INVESTIGATION OF UNIPOLAR CONTACTS WITH AXIAL MAGNETIC FIELD

ABSTRACT *The paper presents test results of contacts generating axial magnetic field. The distribution of the magnetic field was measured in a stand enabling investigation of different contact construction. Short-circuit tests were made in a dismountable vacuum chamber on two contact types generating axial magnetic field. The test circuit and the equipment used were described as well as the oscillograms and pictures of the diffusion arc of the interrupted short circuit currents recorded by means of a high speed camera are shown.*

Keywords: *distribution of the magnetic field, electric arc, vacuum circuit breaker, unipolar contacts*

1. INTRODUCTION

A few models of contacts generating axial magnetic field (Axial Magnetic Field, AMF) were made taking into account results of the previous researches [1, 3-11].

The distribution of the magnetic field in the model contacts was measured. The short-circuit tests were made in a dismountable vacuum chamber. During the tests pictures of the arc evolution were recorded with a high speed camera.

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2. MEASUREMENTS OF THE MAGNETIC FIELD DISTRIBUTION

Measurement of the magnetic field components distribution was performed in a test stand that enabled testing of different contact constructions (Fig. 1).

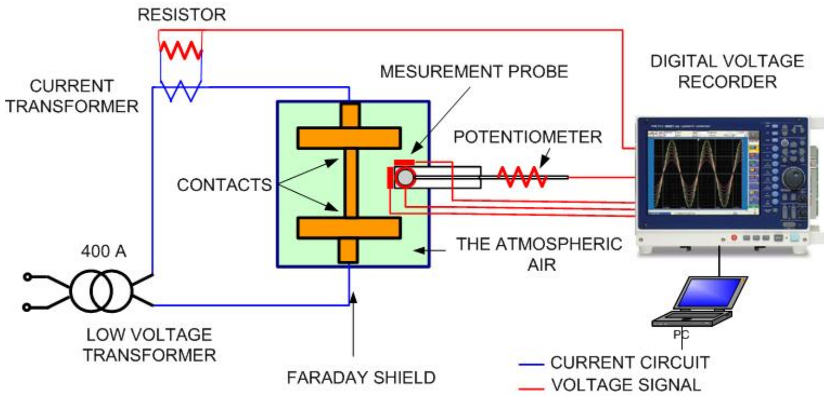


Fig. 1. Diagram of the measuring arrangement

The contacts conduct current of 400 A, 50 Hz supplied from a high-current transformer. A cylinder Ø10 mm, 17 mm high is introduced between contacts to close the circuit. Three measuring coil probes were mounted on a potentiometer slider thus allowing measuring their position. The voltage induced in the measuring coils was in the range from 0.1 mV to 20 mV at current of about 400 A. To reduce the influence of external fields, the contacts and coil probes are located in a Faraday's cage (Fig. 2).

Fig. 2. Experimental circuit with contacts installed

The coils and the potentiometer were rotated around the contact axis in the range from 0º to 180º. The measurements were taken every 5º. The three measuring coils were moved with a small electric motor along the contact radius.

The current between contacts and the voltages in the measuring coils as well as their position were recorded. This allows calculating the distribution of the radial, azimuthal and axial components of the flux density between contacts. The measurement results were recalculated for current 25 kA.

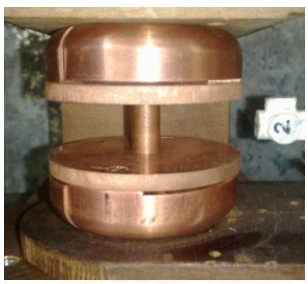
3. RESULTS OF THE MAGNETIC FIELD MEASUREMENTS

The diameter of the contacts was 65 mm (Fig. 3). The contacts were made of electrotechnical copper. The contact plates made of CuCr composite were of two types: without slits and with radial slits. The contact system was cut with “waterjet”. The use of this technology reduced the costs of the contact systems.

The measurements show the influence of slits in the contact plates on the magnetic flux density distribution between contacts. It was already shown [1, 2] that to provide the necessary switching ability of the vacuum chamber the axial component of the magnetic flux density should be uniformly distributed over the contact plate surface and its value should be over 4 mT/kA. Because of the contact symmetry the measurements were taken over half of the contact surface.

Fig. 3. Unipolar ½ turn contact system, the coil part and the complete contact; the contact plates without slits

Fig. 4. Setup of the contact system without slits in the contact plates for the flux density measurement (the slits of the two coil parts aligned facing each other)



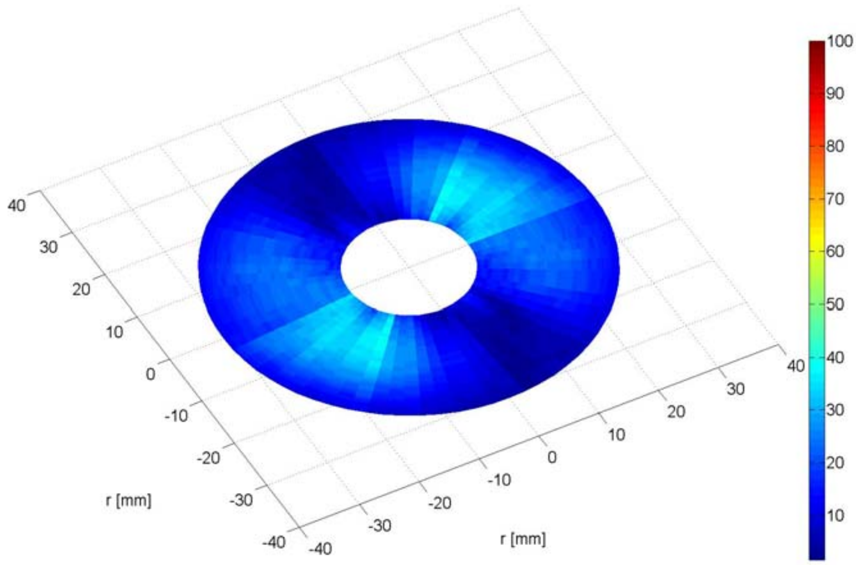


Fig. 5. Radial component distribution of the flux density between contacts The contact setup shown in Fig. 4

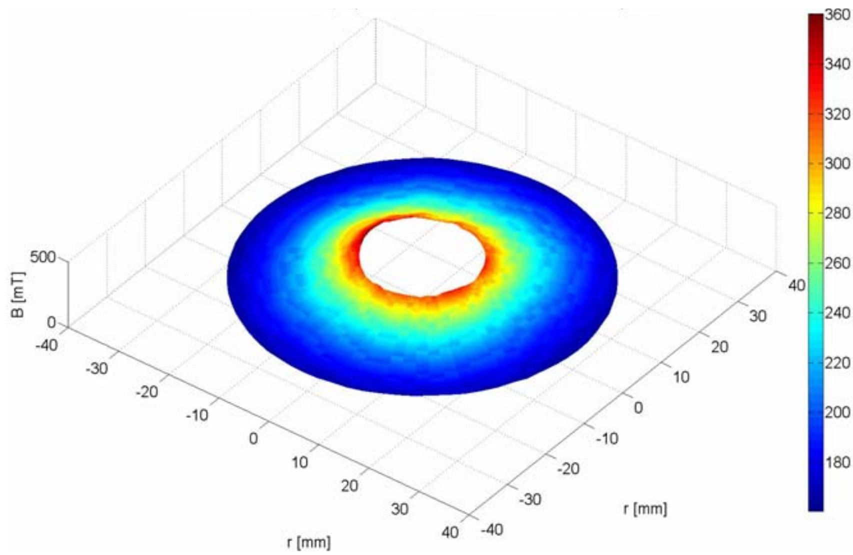


Fig. 6. Azimuthal component distribution of the flux density between contacts The contact setup shown in Fig. 4

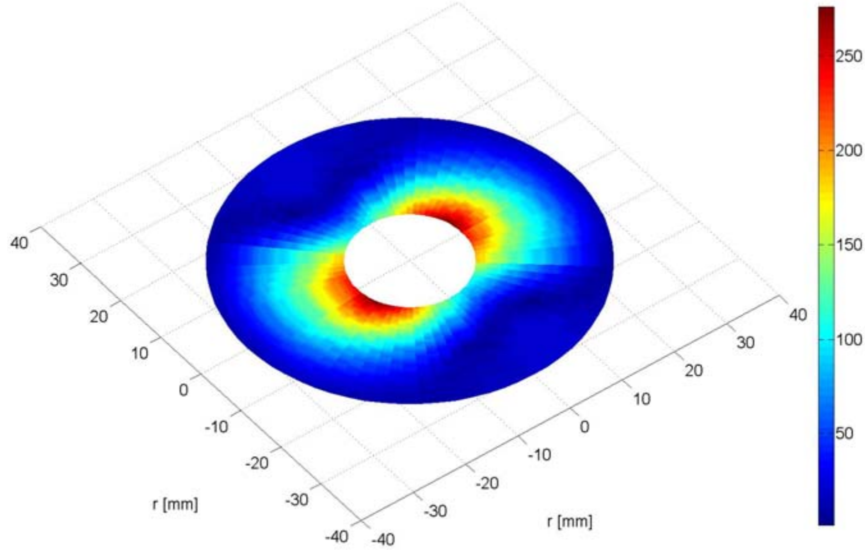


Fig. 7. Axial component distribution of the flux density between contacts The contact setup shown in Fig. 4

Figs. 5-7 show the measurement results of the magnetic flux components: radial, azimuthal and axial at the surface of the contact plates without slits. The axial component assums high values in two areas near the centre of the contact plates and is symmetrical relative to the axis of the contacts (Fig. 7). Its maximum value is 274 mT. The azimuthal component changes from 153.6 mT at the edge of the contact plates to 381.3 mT near the centre of the plates (Fig. 6). The radial component changes from 0.2 mT to 41 mT respectively (Fig. 5). Radial component values are much lower then those of the other components. (Due to the sensitivity of the coil probes the measurements of the magnetic flux density below 10 mT are taken with a rather large uncertainty). The results are summed up in Table 1.

TABLE 1
Comparison of the minimum and maximum values of the magnetic flux density components at 25 kA. The contact plates without slits

Axial		Azimuthal		Radial	
Min [mT]	**Max [mT]**	**Min [mT]**	**Max [mT]**	**Min [mT]**	**Max [mT]**
0.2	274.1	153.6	381.3	0.2	41.0

Fig. 8. Setup of the contact system with slits in the contact plates (the slits of the two coil parts aligned facing each other)

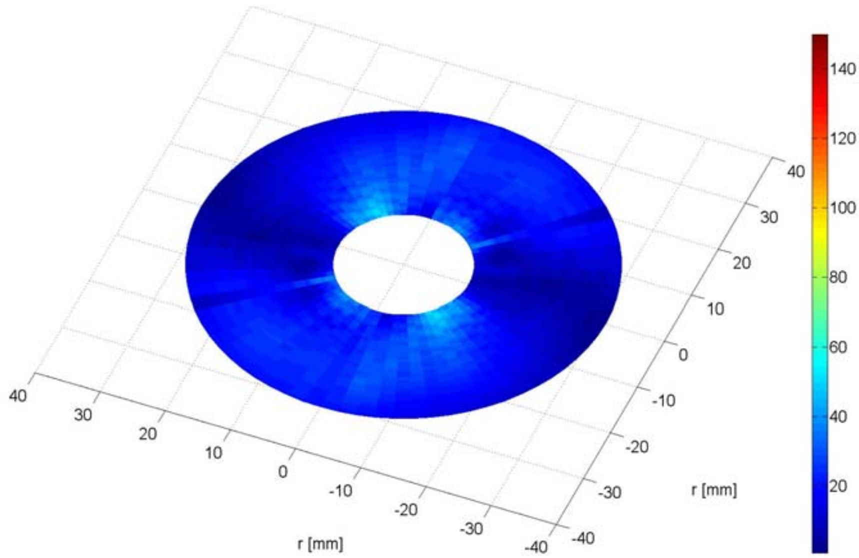


Fig. 9. Radial component distribution of the flux density between contacts
The contact setup shown in Fig. 8

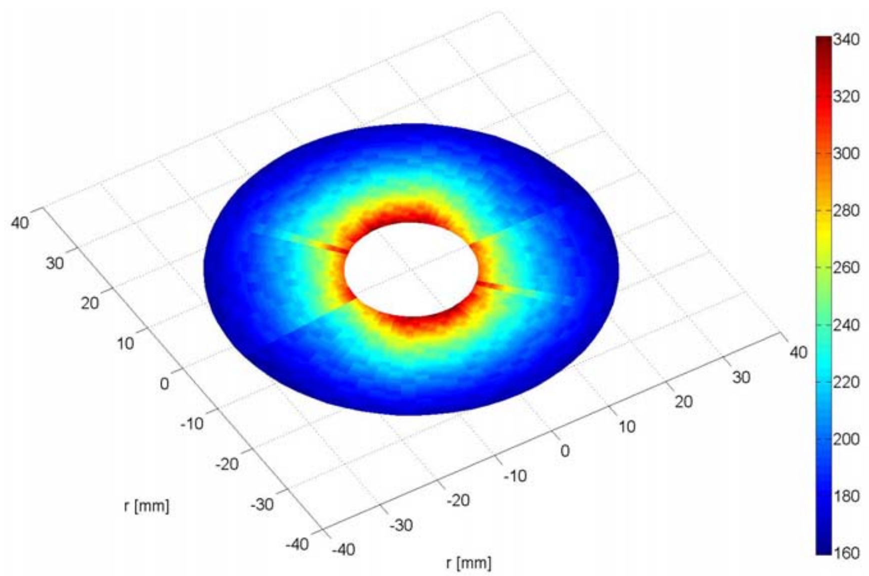


Fig. 10. Azimuthal component distribution of the flux density between unipolar contacts
The contact setup shown in Fig. 8

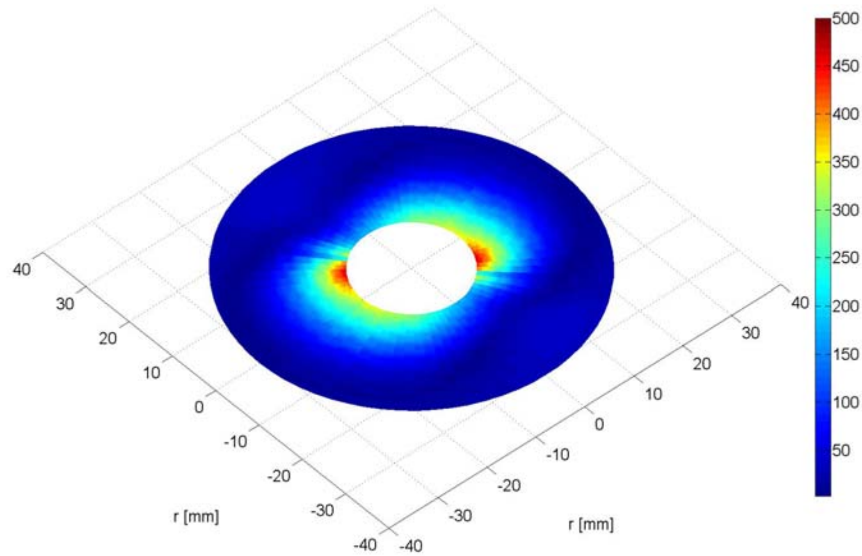


Fig. 11. Distribution of the axial component of the flux density between unipolar contacts Contact setup shown in Fig. 8

TABLE 2
Comparison of the minimum and maximum values of the magnetic flux density components at 25 kA. The contact plates with radial slits

Axial		Azimuthal		Radial	
Min [mT]	Max [mT]	Min [mT]	Max [mT]	Min [mT]	Max [mT]
1.7	482.3	43.9	357.6	0.4	53.8

The maximum value of the azimuthal component is 357.6 mT (Fig. 10) and is lower than in other cases. The radial component reaches 53.8 mT (more than in the previous contact setup, see Fig. 9) and is concentrated near the slits in the contact plates. The slits in the contact plates of unipolar contacts affect the distribution of the magnetic flux density. Radial slits considerably increase the maximum axial component value, up to about 500 mT for 25 kA. The azimuthal component of the magnetic flux density is lower. The increased axial component helps to increase the switching ability of the vacuum chamber contacts.

4. TEST CIRCUIT FOR THE VACUUM ARC INVESTIGATION

Test circuit was supplied from a capacitor bank (Fig. 12). The overall capacity of the capacitor bank is 4.7 mF. The capacitors are switched on reactors of regulated inductance up to about 4 mH. The oscillatory circuit consisting of the capacitor bank and the inductive coils has a natural frequency of 67 Hz.

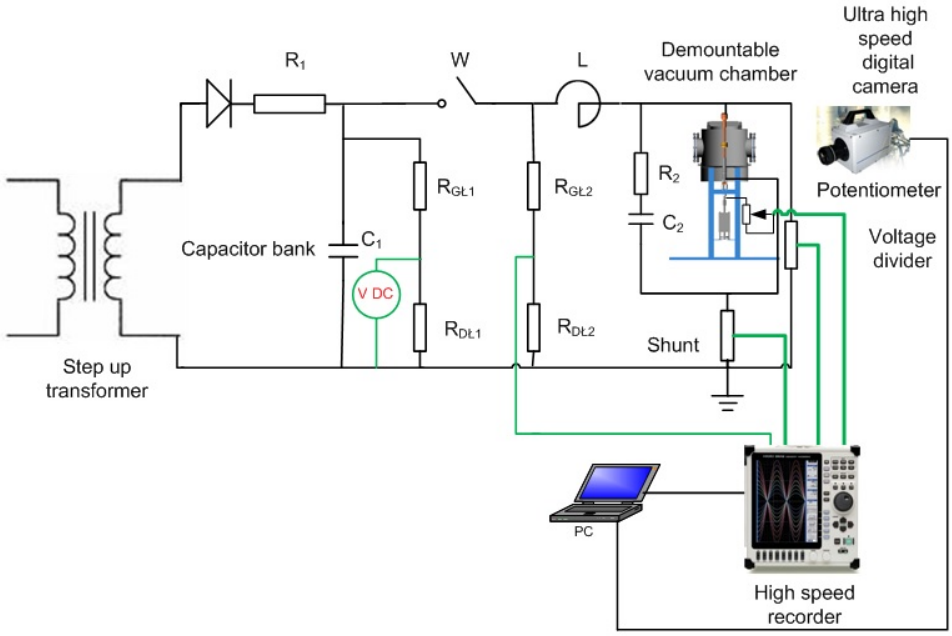


Fig. 12. Test circuit supplied from a capacitor bank

Description: L – Reactance of the reactor set 4 mH, C1 – Capacitor bank, 4.7 mF, C2 – Capacitor 0.23 μF for RRRV (Rate of Rise of Recovery Voltage), R1 – Current limiting resistor, R2 – Resistor for RRRV RGŁ1, RDŁ1, RGŁ2, RDŁ2 – Capacitor voltage divider

The capacitor bank was charged up to about 10 kV to obtain the alternating current of maximum value up to 16 kA and frequency about 67 Hz. The contact movement, the current supplied and voltage were recorded during switching. Contacts of different construction were installed in a dismountable vacuum chamber equipped with two viewfinders, allowing observation of arc between contacts.

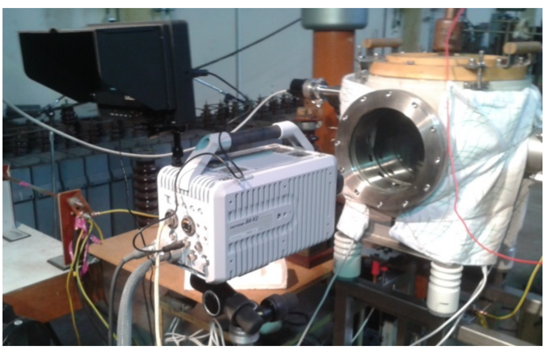


Fig. 13. Recording of the switching arc with a high speed camera

The dismountable chamber allows investigation of contact systems of diameter from 30 mm to 100 mm applied in medium voltage switches. The form of the discharge between the contact plates during the opening operation is recorded with a high speed digital camera (Fig. 13), 10 000 frames per second, resolution 768x768, shutter speed 1/270 0000s. The switching ability was investigated at vacuum about $3*10^{-6}$ mbar.

5. SWITCHING TEST RESULTS

Models of AMF contacts were installed in the dismountable vacuum chamber. The slits of the two coil parts were aligned facing each other (see Figs. 14, 15).

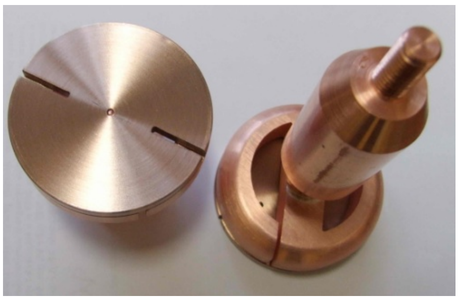


Fig. 14. Unipolar contact (2P) with radial slits

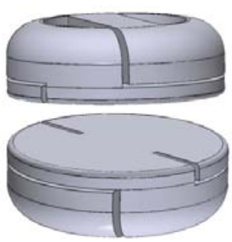


Fig. 15. Contact arrangement during switching tests

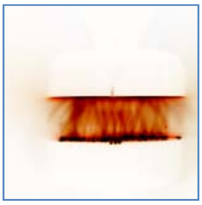
Currents, TRV and arc form during switching tests of contacts with radial and diagonal slits are shown in the following figures (see Figs 16, 17).

The photograms show the arc form corresponding to 50% and 100% of the maximum current value (the time step was 1/8 of the current period 15 ms).

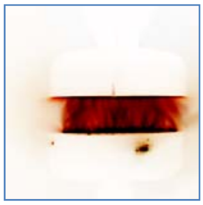
Photogram No.1-6.65 kA

Photogram No. 2-4.67 kA

Photogram No. 3-5.29 kA



Photogram No. 4 - 6.18 kA



Photogram No. 5 - 4.21 kA

Fig. 16. Photograms registered during the short-circuit tests at current 6.14 kA for contact plates with radial slits

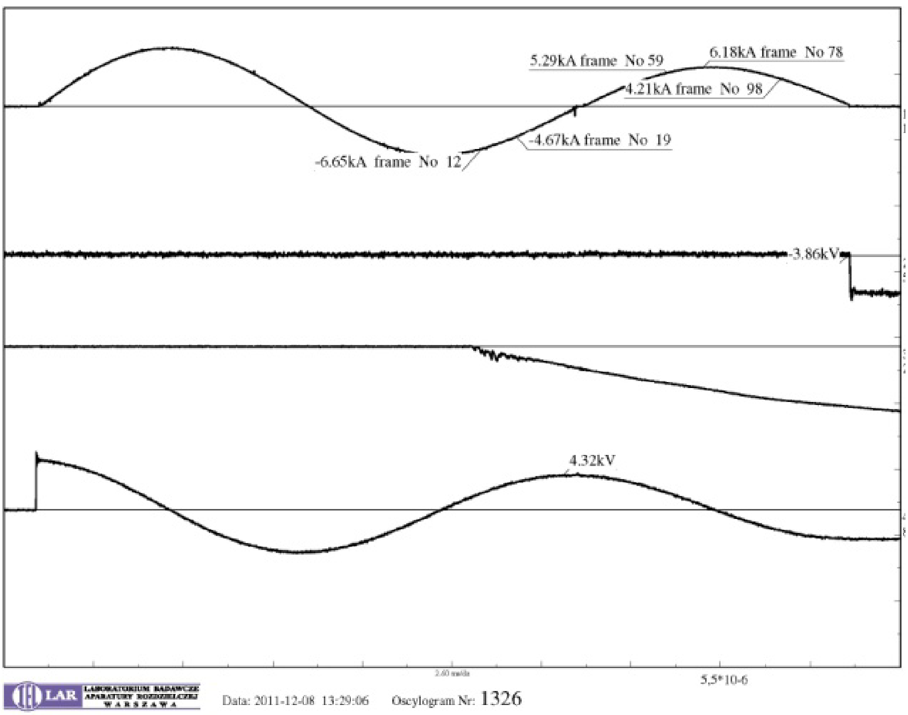


Fig. 17. Switching tests of contacts with radial slits

In the initial phase between 1 ms and 1.5 ms the arc is of constricted form and could damage the surface of the contact plates. In the second phase a diffusion arc is formed almost over the whole surface of the contact plates. Many cathode spots are formed at one of the contact plates. In the final phase the energy of the arc decreases and at current zero the switching occurs.

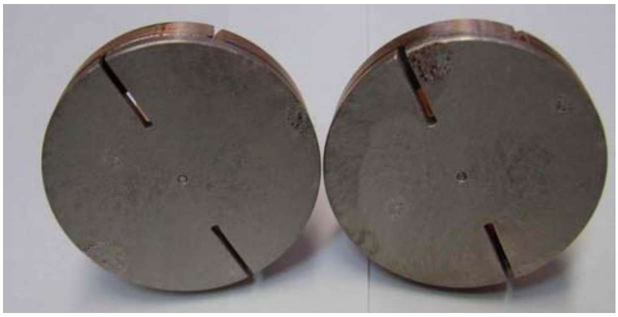


Fig. 18 Unipolar contacts after switching tests

6. CONCLUSIONS

Calculation and measurements show that the contact construction influences the magnetic field distribution and the form of the arc between contacts [12-13].

Using a dismountable vacuum chamber two AMF models of contacts were tested. A few short-circuit tests were made of the two models at currents from 1 kA to about 15 kA.

An arc discharge is initiated at the contact plate edge (Photogram No. 1 Fig. 16). The burns of the contact plates can be seen on Fig. 18.

The development of arc between the cathode and anode was registered using a high speed camera.

The photograms show arc spots and the place of arc initiation in the contacts with the axial magnetic field.

The burns were observed at the sharp edges of the contact plates. Conclusion – the sharp edges must be rounded.

When increasing the short-circuit current, the arc current tends to concentrate in the centre of contacts.

Numerous closing operations caused deformation of the contact plates and of the contact base. A mechanical reinforcement of the contact plates and the contact base is essential to increase the resistance to mechanical impacts.

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BADANIA STYKÓW UNIPOLARNYCH O OSIOWYM POLU MAGNETYCZNYM

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STRESZCZENIE *Artykuł zawiera opis badań wykonanych w Zakładzie Wielkich Mocy Instytutu Elektrotechniki. Badano dwa rodzaje styków generujących osiowe pole magnetyczne stosowane w komorach wyłączników próżniowych. Badania łuku łączeniowego wykonano rejestrując gaszenie łuku ultraszybką kamerą. W pierwszej części artykułu omówiono budowę stanowiska badawczego. Natomiast w dalszej części przedstawiono wyniki badań oraz oscylogramy i fotogramy zarejestrowane podczas prób zwarciowych w rozbieralnej komorze próżniowej. W konkluzji omówiono uzyskane wyniki badań.*

Słowa kluczowe: *rozkład pola magnetycznego, łuk elektryczny, wyłącznik próżniowy, styk unipolarny*