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ANALYSIS OF ARC IN A VACUUM CHAMBER WITH AN AMF

ABSTRACT *Vacuum circuit breaker chambers* (*VCBC*) *are subject of a continuous study to optimize parameters of circuit breakers. The aim is to reduce the size and to increase the breaking ability in the whole range of rated voltages. In optimization attention is paid to reach a uniform distribution of the magnetic field over the contact plate surface. The influence of slits in the contact plates, and the rotation angle between contacts upon the magnetic field distribution* (*MFD*) *was analyzed.*
Field tests of different contact sets were made, using a dismountable vacuum chamber. The tests were conducted at short circuit currents up to 15 kA. A high speed video camera was used to monitor the arc developed between contacts.

Key words: *Vacuum circuit breaker* (*VCB*)*, vacuum chamber* (*VCBC*)*, short circuit tests* (*SCT*)*, axial magnetic field* (*AMF*)

1. INTRODUCTION

The vacuum circuit breakers are used in medium voltage networks and recently also at high voltages up to 145 kV and 40 kA. With the rise of the rated voltage the

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PROCEEDINGS OF ELECTROTECHNICAL INSTITUTE, Issue 269, 2015

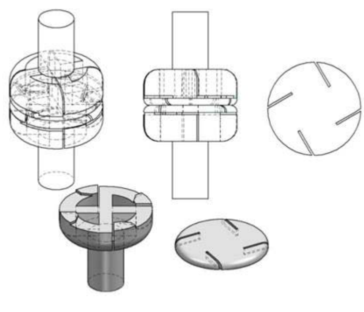
distance between contacts has to be increased. Therefore attention was paid to the MFD in the whole space between contacts. It is known [1] that by changing the slit shape in the contact plates it is possible to modify the MFD. An effective modification of the MFD is possible by rotating the contacts – one in relation to the other.

The contacts produced at present were modified to increase the magnetic flux density generated by the short-circuit current. One of the modifications consisted in cutting arc form slits in the contact plates. The other was to choose the best rotational position of one contact in relation to the other.

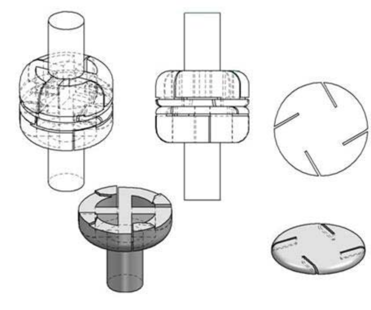
Using a high speed camera it was possible to observe the initiation of the arc between contacts and the evolution of the constricted arc into a diffusion arc as in [2]. Tests were made at different short circuit current values and the effects of overloading the contacts were observed. Further investigation of different contact solutions will define the limit breaking capacity of the vacuum chambers.

2. CALCULATION OF AXIAL MFD IN THE SPACE BETWEEN CONTACT PLATES

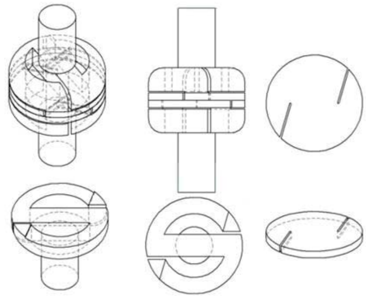
Calculations of MFD were made for unipolar contacts shown in Figure 1 when the contacts start to open (Fig. 2). The assumed short circuit current was 25 kA.



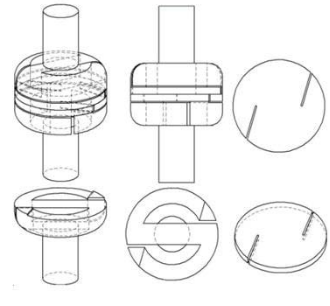
a) Unipolar ¼ turn coil contact



b) Unipolar ¼ turn coil contact rotated by 45°



c) Unipolar 1/2 turn coil contact



d) Unipolar 1/2 turn coil contact rotated by 90°

Fig. 1. Unipolar contacts considered

The results of calculation for the modified contact structure after rotating one contact in relation to the other by 45° (see Fig. 1b) are on Fig. 2b and for contacts as on Figure 1d are on Figure 2d respectively. After contact rotation the MFD is modified. In case of ¼ turn coil contacts a reduction of the intensive magnetic field and its area takes place. In case of ½ turn coil contacts a rotation of the contacts by 90° results in an increase of the area of a higher magnetic field. The high magnetic field does not fully cover the whole area of the contact plates; it decays in the lateral contact portions. Final conclusion is that the rotation angle between contacts should be selected to reach the best MFD over the whole contact surface.

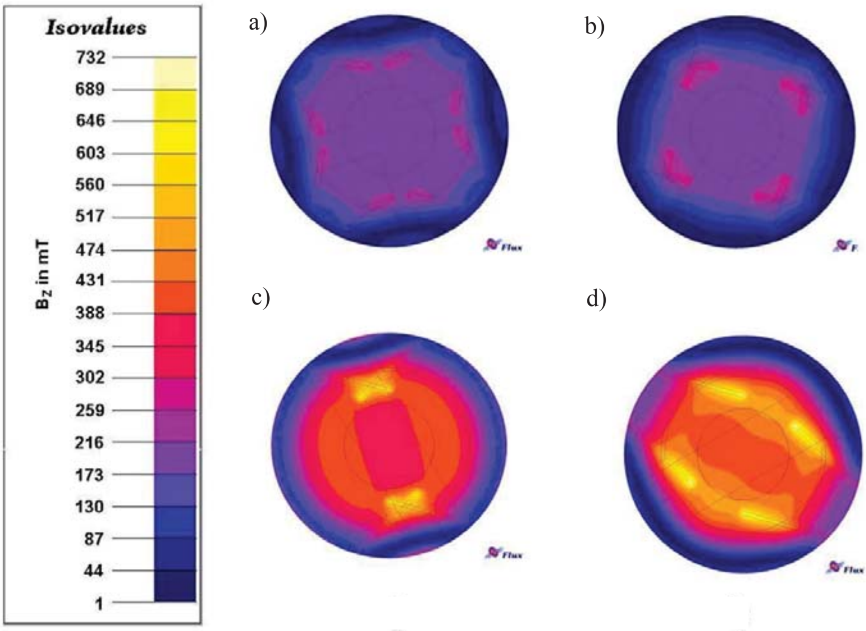


Fig. 2. Axial MFD in unipolar coil contacts at 25 kA:
a) ¼ turn coil contacts; b) contacts rotated by 45°; c) ½ turn coil contacts; d) contacts rotated by 90°

For medium voltage circuit breakers the contact gap is usually from 9 mm to 12 mm depending on the rated voltage. Considering ¼ turn coil contacts and 12 mm contact gap MFD in the whole space between contacts was calculated. For the calculations it was assumed that the space between contacts has a uniform conductivity, corresponding to the arc voltage drop. The magnetic flux density (see Fig. 3) changes from 180 mT at the contact plate surface (z = 6 mm) to 148 mT at the center plane between contacts (z = 0 mm).

The reduction of the magnetic field intensity at the center plane between the contacts was also observed in the other contact design, for ½ turn contacts. This effect can explain a reduction of the diffusion arc diameter during tests made in a dismountable vacuum chamber (see Fig. 7). Similar effect was analyzed in [3] for contacts for 123 kV.

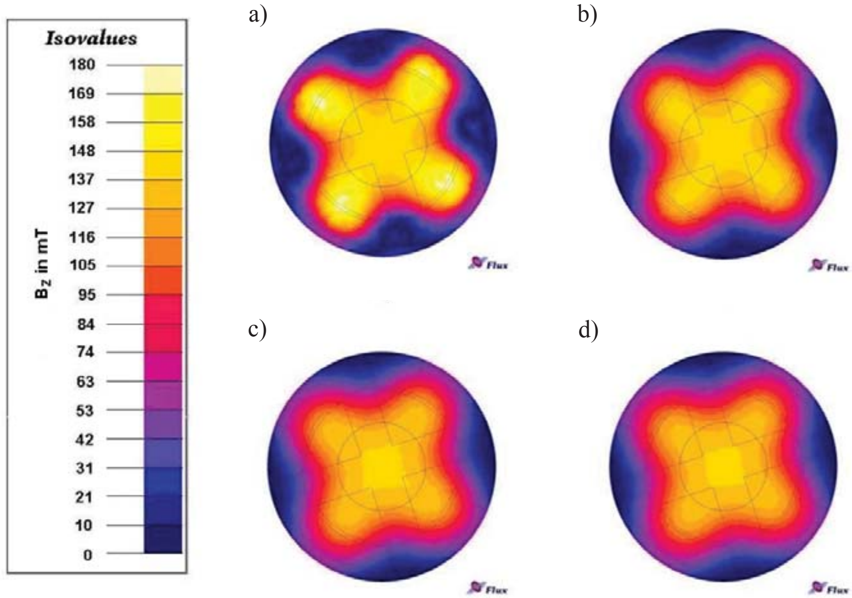


Fig. 3. Axial MFD on different planes between contacts at 25 kA. Contact gap 12 mm. Contact arrangement as in Fig. 1a: a) contact plate surface $z = 6$ mm ($B_{max} = 180$ mT); b) plane at $z = 4$ mm ($B_{max} = 152$ mT); c) plane at $z = 2$ mm ($B_{max} = 148$ mT); d) center plane, $z = 0$ mm ($B_{max} = 148$ mT)

3. MEASUREMENT OF THE MFD FOR DIFFERENT CONTACT SLITS

Measurements of the MFD distribution between contacts were made for ¼ turn coil contacts (see Fig. 1a). The current conducting element, a cylinder of 10 mm diameter to short-circuit the contact plates was used. The cylinder was placed at the center of the contact plates and the contacts were not rotated. Three measuring coils have been arranged to measure axial, radial and azimuthal components of the magnetic field. The results of the measurements of the axial MFD and the comparison with the calculated values are presented on Figure 4. On Figure 5 the MFD of the same contact arrangement was measured for different slits in the contact plates.

The contact arrangement, as in Figure 1a, with slits inclined at an angle of 30° to the radius (see Fig. 5a) gives the highest magnetic field density over the whole surface of the contact plate.

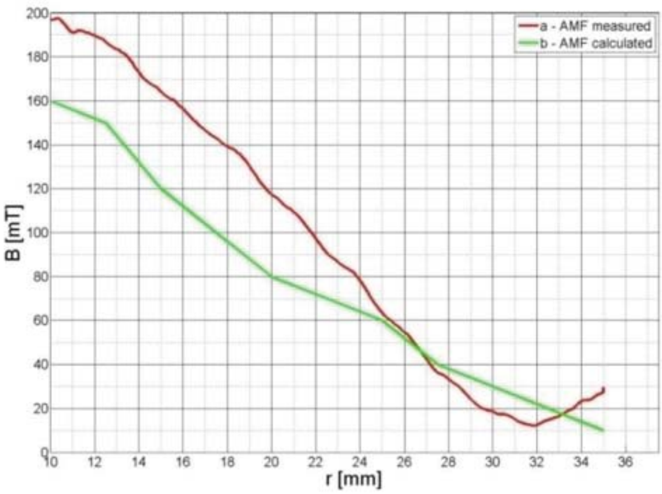


Fig. 4. Axial magnetic flux density distribution over the contact plates without slits: a) measured; b) calculated. Measured field values were recalculated for 25 kA

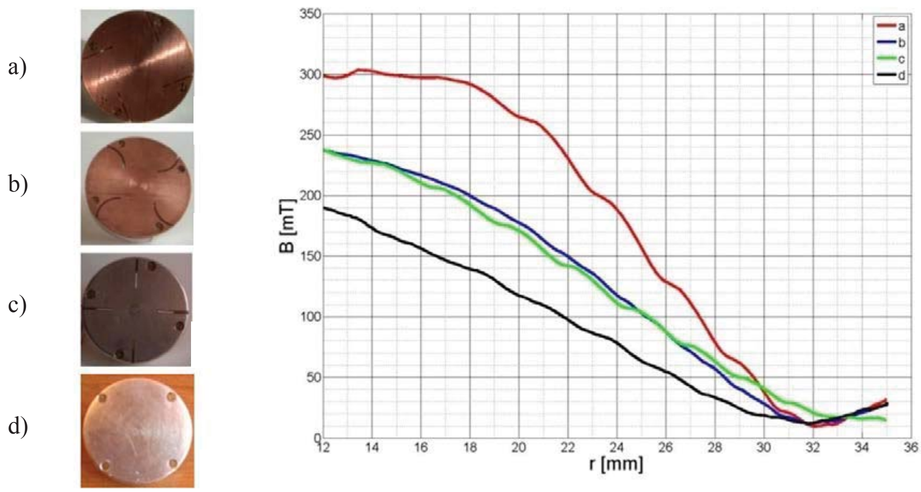


Fig. 5. Axial magnetic flux density distribution over the contact plates with different slits (measured): a) slits inclined at angle 30 degrees to the contact plate radius; b) arc slits; c) radial slits; d) without slits. Contact arrangement as in Figure 1a. Field values along the radii with maximum field, recalculated for 25 kA

4. TESTS OF UNIPOLAR CONTACTS IN A DISMOUNTABLE VACUUM CHAMBER

The test stand is shown on Figure 6. Tests were made using ¼ turn coil contact with the radial slits Figure 6a. During tests the vacuum arc was recorded by a high speed camera. The arc current and the contact velocity were also measured and recorded.

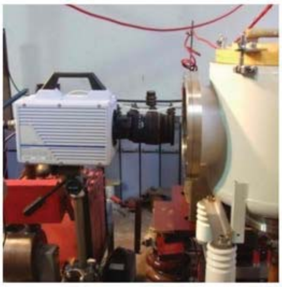


Fig. 6. Test stand with a dismountable vacuum chamber and a high speed camera

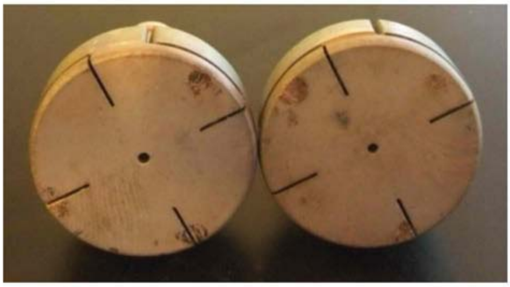


Fig. 6a. Contact surface after the short-circuit tests

The AMF contacts (see Fig. 1a) of 65 mm diameter were used during the tests. The contact stroke was set to 12 mm. Recorded videos have been filtered with an image processing algorithm. With the rise of the short circuit current a constriction of the diffusion arc appears on the cathode side at the center part of the contacts (see Fig. 7 and 8). With the decay of the current, the diameter of the concentrated arc plasma reduces. The thermal load of the contact surface can be much higher and this can cause changes in the contact geometry. The arc spots at the cathode can be seen all over the contact surface (see Fig. 8).

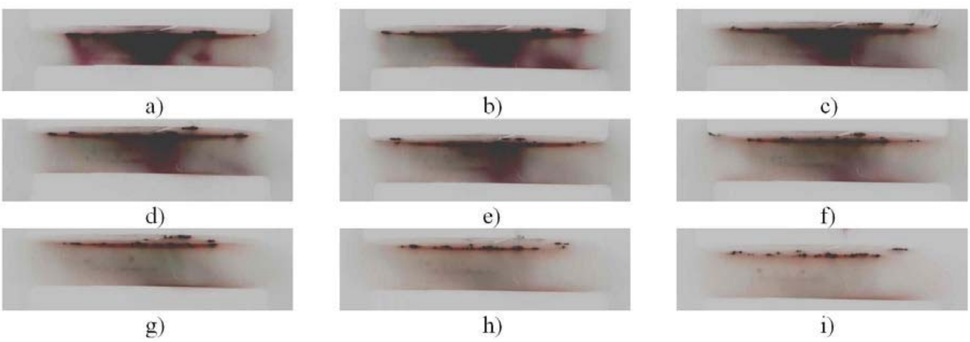


Fig. 7. Development of a high current vacuum arc between Cu-Cr contact plates:
a) 615,4 μs/5525 A; b) 653,9 μs/5950 A; c) 692,3 μs/6300 A; d) 730,8 μs/6675 A; e) 769,3 μs/6825 A; f) 807,7 μs/6800 A; g) 846,2 μs/6950 A; h) 884,6 μs/6700 A; i) 923,1 μs/6625 A

a) b)

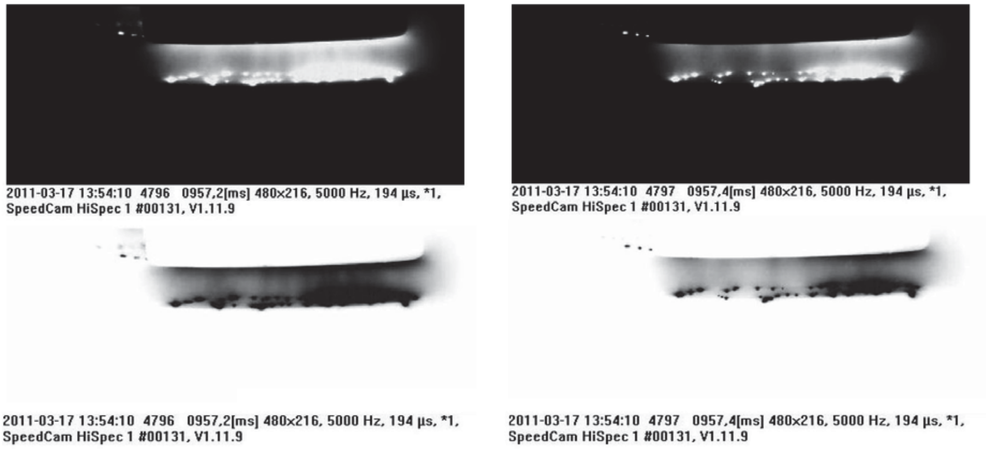


Fig. 8. Vacuum arc in an AMF dismountable vacuum chamber at current 15 kA peak:
a) frame No 4796; b) frame No 4797

The short circuit current was measured and recorded by means of a high speed camera at the terminals of the dismountable vacuum chamber. The arc at current 15 kA peak in an AMF dismountable vacuum chamber was recorded. Recorded videos have been filtered with an image processing algorithm to be able to observe the distribution of the arc spots. There is a concentration of the plasma at the central part of the contacts and a change of the position of the plasma concentration can be seen. This phenomenon may be due to the influence of the radial component of the magnetic field.

The records in Figure 8 show some fractions of arc which can appear between the contact coil and the contact plate.

5. CONCLUSIONS

The possible change of the area of a high MFD over the contact surface was analyzed. Results of calculation are presented for contacts ¼, and ½ turn coil contacts. The distance between contacts was 12 mm. The MFD was calculated for the contacts rotated one in relation to the other by 45° and 90° degrees. The effect of the rotation by 90° of the ½ turn coil contacts upon the MFD is well pronounced.

For contact stroke of 12 mm, as in medium voltage circuit breakers, the axial magnetic field density over different planes between contacts was calculated and the MFD presented. With increasing distance from the contact surface, the MFD in the central part of the contacts decreases.

The slits in the contact plates play an essential role upon the MFD in the contact gap. The measurements were made, to select the best slit shape, for which the magnetic field is the highest and covers the greatest area of the contact surface. Attention should be paid not to reduce the MFD at the assembly stage by inadvertently rotating one contact in relation to the other. The results received will be verified using the dismountable vacuum chamber and published in the next papers. The result of the research is intended for the manufacturers of the vacuum chambers.

Using a dismountable vacuum chamber and contacts as in Figure 1a the arc evolution, namely the constriction of the arc at the center part of the gap and the distribution of the arc spots on the contact surface were registered.

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Manuscript submitted 15.05.2015

ANALIZA ŁUKU W KOMORZE PRÓŻNIOWEJ W OSIOWYM POLU MAGNETYCZNYM

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STRESZCZENIE *Badania komór próżniowych są wykonywane w celu optymalizacji parametrów wyłączników. Głównym celem jest zmniejszenie wymiarów i zwiększenie zdolności łączeniowej w całym zakresie napięć znamionowych wyłączników. W artykule przedstawiono wyniki obliczeń rozkładu indukcji magnetycznej dla dwu rodzajów styków w dwóch konfiguracjach, tj. styków cewkowych typu ¼ zwoja w położeniu bazowym i po obróceniu styku jednego względem drugiego o 45°, jak i styków cewkowych typu ½ zwoja w położeniu bazowym i po obróceniu styku jednego względem drugiego o 90°. Obliczenia wykazały, że obrót styków względem siebie powoduje zmianę rozkładu indukcji na powierzchniach nakładek stykowych. W przypadku styku cewkowego typu ¼ zwoja indukcja magnetyczna maleje. Powierzchnia, na której wartość indukcji osiąga znaczne wartości również maleje dla tego układu stykowego. W przypadku styku cewkowego typu ½*

zwoja obrót styku o 90° powoduje powiększenie powierzchni, na której wartość indukcji przekracza 4 mT/kA. Indukcja bowiem rozłożona jest nierównomiernie na powierzchni nakładki stykowej i jej wartość maleje w kierunku krawędzi styku. Należy stwierdzić, że obrót styku jednego względem drugiego powinno się dobierać każdorazowo dla osiągnięcia największego natężenia pola magnetycznego.

W obliczeniach dotyczących styków cewkowych typu ¼ zwoja z odstępem międzystykowym 12 mm, założono, że przewodność w całej przestrzeni międzystykowej jest stała i wynika z napięcia łuku. Przy prądzie 25 kA maksymalna indukcja magnetyczna zmienia się od 180 mT na powierzchni nakładki stykowej do 148 mT w środku odległości pomiędzy stykami.

W celu zbadania rozkładu łuku pomiędzy stykami wykonano pomiary dla różnych ich typów w rozbieralnej komorze próżniowej przy prądzie zwarciowym do 15 kA. Rozwój łuku dyfuzyjnego badano przy użyciu kamery do zdjęć szybkich. Zmierzono rozkład osiowego pola magnetycznego dla modeli styków cewkowych typu ¼ zwoja z nakładkami o różnych nacięciach, tj. z nacięciami promieniowymi wykonanymi pod kątem 30° w stosunku do promienia styków, z nacięciami w kształcie łuku, oraz dla styków bez nacięć. Styki z nacięciami wykonanymi pod kątem 30° do promienia styku, miały największe na całej powierzchni styków natężenie pola magnetycznego. Podczas pomiarów styki były zwarte przy pomocy centralnego kołka przewodzącego.

Jak wynika z obliczeń podczas montażu należy zwrócić uwagę na wzajemne usytuowanie styków, aby zapobiec zmniejszeniu wartości pola magnetycznego.

W rozbieralnej komorze próżniowej zbadano rozwój łuku dyfuzyjnego w przestrzeni międzystykowej oraz rozkład stóp łuku na powierzchni styków.

Słowa kluczowe: *wyłącznik próżniowy, komora próżniowa, próby zwarciowe, osiowe pole magnetyczne*

IEl, Warszawa 2015. Nakład 80 egz. Ark. wyd. 8,46. Ark. druk. 6,25. Pap. off. Kl.III. 80 g.
Oddano do druku w czerwcu 2015 r. Druk ukończono w czerwcu 2015 r.
Redakcja – Wydawnictwo Naukowo-Techniczne
Indeks nr 37656