INFLUENCE OF CONTACT DIAMETER ON ARC EROSION OF POLARISED CONTACTS AT HIGH CURRENT CONDITIONS

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Abstract: The article presents research conducted by the authors, concerning the influence of contact diameter on the arc erosion of polarised contacts made of materials of W-Ag50 type, at 4 kA current breaking. The investigation results can be used for constructing low-voltage circuit breakers.

Keywords: arc, high current, contact erosion.

1. INTRODUCTION

Investigations into electrical properties of contact materials under model testing conditions constitute a basis of all research and development work in the field of contact materials engineering. Investigation results are also valuable information for designers of electrical switches.

Among different electrical properties, the knowledge of arc erosion is of basic significance. Contact erosion determines the short-circuit breaking capacity of a circuit breaker. The capacity depends on many constructional, circuital and switching parameters. So far, a lot of researchers have concentrated on estimating the influence of such circuital and switching parameters as current, integral ∫idt and arc energy on arc erosion. Such investigations have been conducted for different contact materials [1-8]. Research on arc erosion has been carried out for many years in the Institute of Electrical Apparatus [9-15], in an automated and computerised test stand.

Among constructional parameters that have influence on arc erosion, contact dimensions and especially the operating surface of contacts should be stressed, and in the case of contacts with a circular section – contact diameter. The influence of contact diameter on contact erosion at high currents range has been noticed so far by a few researchers [9, 10, 16-18].

The subject of this paper are the authors' own investigations into the influence of contact diameter on arc erosion of polarised contacts made of materials of W-Ag50 type, at 4 kA current breaking.

2.EXPERIMENT PREPARATION

2.1. Test system

The investigation into arc erosion was conducted under model conditions of contact loading, in a test system equipped with a control and measurement system controlled by a computer [19]. A model of a unipolar circuit breaker constitutes a testing device in which the tested contacts are placed symmetrically and vertically. The lower contact is mobile. The adjustment of mechanical parameters of the contact is ensured. Figure 1 shows a simplified block diagram of the test system. The high current circuit is powered from a short-circuit current generator with 550 V_{AC} voltage and a big short-circuit power. The circuit comprises a contactor C, a load resistor R, a thyristor switch TS, a measuring shunt S and the tested contacts. The testing device TD consists of a pneumatic drive closing the contacts, a ball lock and a fast tripping device powered from the batteries of a capacitor ETCBD. The thyristor switch limits the current flowing through the tested contacts to one sine half-wave of 50 Hz frequency. Contacts open at a phase angle adjusted in the thyristor switch control TSC.

The control and measurement system consists of an input measuring device ID, a controlling device CD, a digital voltmeter V, a digital balance B and a personal computer PC with a measuring card MC. The measurment of contact resistance is performed with the technical method at 5 A current from a direct current source DC.

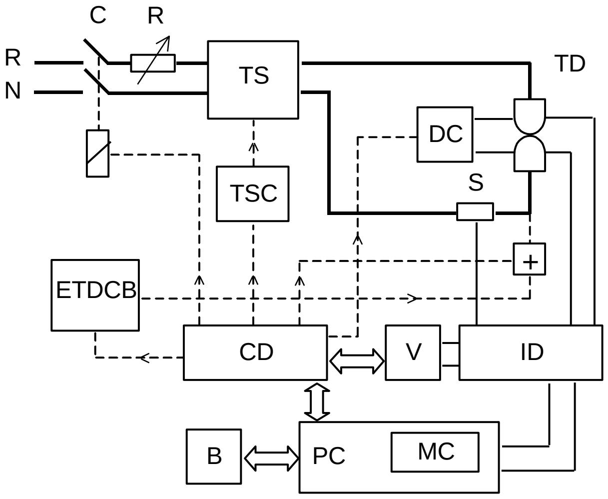

Fig. 1. A block diagram of the test system

The test system works under the control of *Eroja 2.1* program. Electronic devices of the system comprise only an interface between the testing device and the computer. The computer program has access to all controlled objects and ensures automatic testing according to the adjusted measuring sequence. During testing time, the system records the transients of current and arc voltages on the tested contacts. The transients constitute a basis for establishing time transients and the value of the integral ∫idt, arc energy, etc. Contact resistance is measured automatically after each current switching operation.

2.2. Test parameters

The experiment was carried out on test contacts having the shape and dimensions given in Figure 2. A series of test contacts having a few different diameters within the range of D = 4÷14 mm was prepared. Contact tips made of composite materials of W-Ag50 type, with constant thickness 3 mm were soldered with the method of induction heating, with a hard solder of AgCu28P1 type.

Contacts were investigated as symmetrical (identical diameter) and non-symmetrical (different diameters). In the second case, one of the contacts had a constant diameter equal to 14 mm and the other contact had a variable diameter.

The tests were carried out at assumed values of mechanical and electrical parameters given in Table 1. During individual tests, these parameters underwent the changes of statistic fluctuation and will be precisely defined further on in the paper.

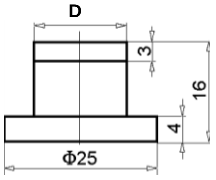

Fig. 2. Test contacts

Table 1. The assumed contacts testing conditions

Test parameters	Value
1. Mechanical parameters	
Contact opening	10 mm
Contact tilt	2 mm
Contact force	30 N
Force of the contact opening spring	50 N
2. Electrical parameters	
Conventional current (peak)	4 kA
Integral ∫idt	20 As
Phase angle of contacts opening	30 deg
Contacts polarisation:	
- upper contact	anode (+)
- lower contact	cathode (-)
Additional transwerse blast field	none
Number of switching operations	3÷100

3. EXPERIMENT RESULTS AND ANALYSIS

During measurements, transients of current and voltage on the contacts were recorded. After arc ignition the arc voltage was recorded. The experiment was to determine the characteristics of erosion, i.e. the variation of mass loss separately for the cathode and for the anode, in the function of the number of switching operations. Demonstration electrical transients are presented in Figure 3. Figure 4 shows demonstration characteristics of erosion obtained for two cases of contacts.

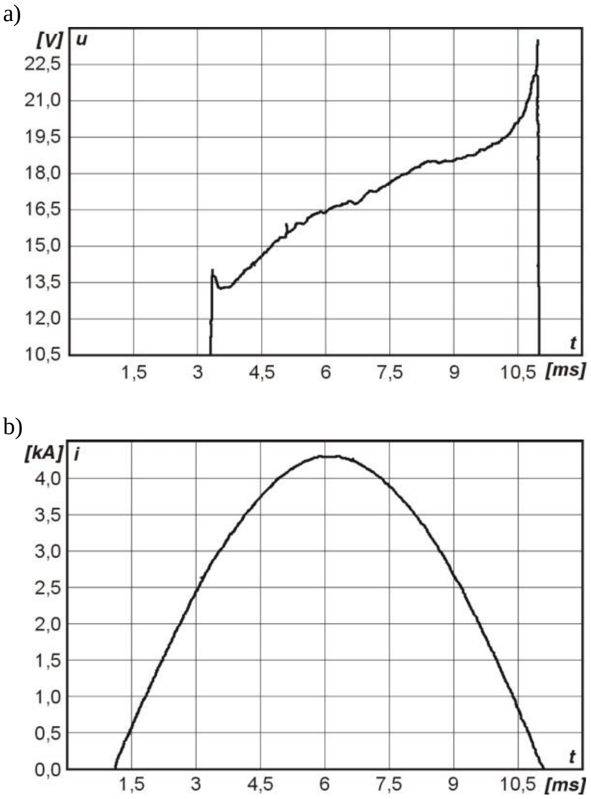

Figure 3. Demonstration current and arc voltage transients

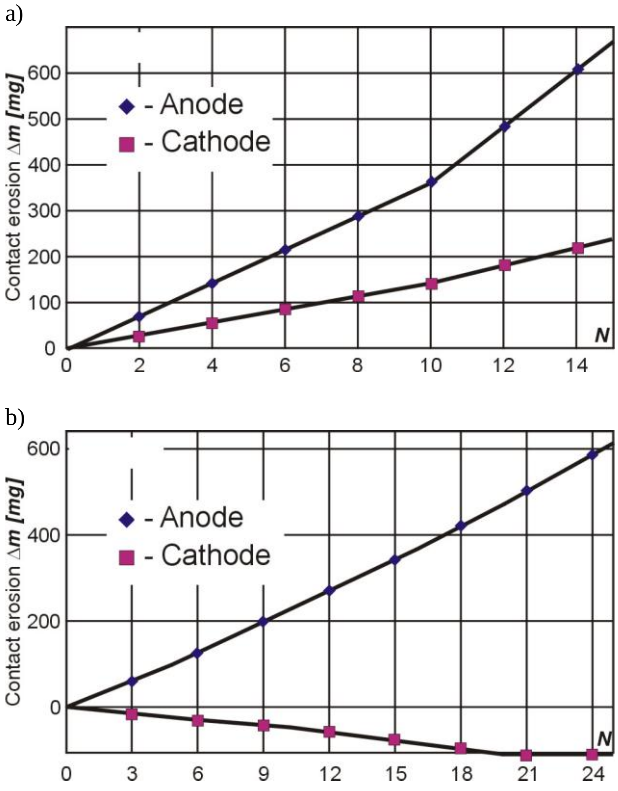

Figure 4. Demnonstration erosion characteristics Δm=f(N)

a) D_A=D_K= 6 mm
b) D_A= 6 mm, D_C= 20 mm

The results of investigations concerning the influence of contacts dimensions on contact erosion have been divided into three measuring groups:

- Group no 1 – a symmetrical contact (identical cathode and anode diameters) – Table 2.
- Group no 2 – a non-symmetrical contact with a constant anode diameter (upper contact) and a variable cathode diameter (lower contact) – Table 3.
- Group no 3 – a non-symmetrical contact with a constant cathode diameter (lower contact) and a variable anode diameter (upper contact) – Table 3.

In a general case, the characteristics of contact erosion can be expressed by a simple power function [10]:

$$\Delta m = a \cdot N^{b} \qquad (1)$$

which is correct for the number of switching operations $N<N_L$, where N_L denotes the contact live of the tested contacts.

Arc erosiveness of contacts has been defined as:

$$\Delta m^{*} = \Delta m \ / \ N \qquad (2)$$

where Δm is either anode or cathode mass loss, measured after performing N switching operations, with $N = 20$ for $N > N_L$ and $N = N_L$ for $N_L < 20$.

In tables 2-4, two values of erosiveness are given: the measured one Δm_{pom}^{*} and the calculated one Δm_{obl}^{*}. Δm_{obl} calculations were performed with the help of the least squares method. For many cases they differ little from one another (≤ 20%). Then, for further analyses and a graphic display, only Δm_{pom}^{*} calculations results will be assumed.

Table 2. The results of measurements and calculations for the case of a symmetrical contact $D_A=D_C$

Contact marking	D [mm]		Δm_{pom} [mg]		Δm_{obl} [mg]		Δm_{pom}^{*} [mg]		Δm_{obl}^{*} [mg]		N
	A	C	A	C	A	C	A	C	A	C	
G11	4	4	290	100	266	101.6	96.67	33.33	88.8	33.85	3[1)]
G16	5	5	410	160	399	169	34.17	13.33	33.26	14.09	12[1)]
G2.1	6	6	650	230	617.2	224	43.33	15.33	41.15	14.95	15[1)]
G15	8	8	390	140	345	139	19.5	7	17.25	6.95	20
G1	10	10	70	40	70	50	3.5	2	3.5	2.5	20
G3	14	14	80	60	82.3	47	4	3	4.11	2.35	20

[1)] Boundary value (the test was finished).

Table 3. The results of measurements and calculations for the case of a non-symmetrical contact $D_A \geq D_C$

Contact marking	D [mm]		Δm_{pom} [mg]		Δm_{obl} [mg]		Δm_{pom}^{*} [mg]		Δm_{obl}^{*} [mg]		N
	A	C	A	C	A	C	A	C	A	C	
G12	14	4	810	270	1092	176.4	202.5	67.5	273	44.11	4[1)]
G19	14	4	50	160	50	150.6	10	32	10	30.12	5[1)]
G18	14	6	250	330	244.6	383.3	12.5	16.5	12.23	19.17	20
G10	14	8	220	270	220	300	11	13.5	11	15	20
G17	14	10	60	90	59.19	93.01	3	4.5	2.69	4.65	20
G9	14	14	70	60	72.97	56.76	3.5	3	3.65	2.84	20

[1)] Boundary value (the test was finished).

Table 4. The results of measurements and calculations for the case of a non-symmetrical contact $D_C \geq D_A$

Oznaczenie styku	D [mm]		Δm_{pom} [mg]		Δm_{obl} [mg]		Δm_{pom}^{*} [mg]		Δm_{obl}^{*} [mg]		N
	A	C	A	C	A	C	A	C	A	C	
G13	4	14	270		289.5		67.5		72.4		4[1)]
G22	5	14	410	10	402.7	13.31	27.33	0.67	26.85	0.89	15[1)]
G21	6	14	580	40	678.3	39.18	29	2	33.92	1.96	20
G20	8	14	140	10	130	10	7	0.5	6.5	0.5	20
G8	10	14	180	[2)]	181	[2)]	9	[2)]	9.05	[2)]	20

[1)] Boundary value (the test was finished).
[2)] A mass gain was obtained.

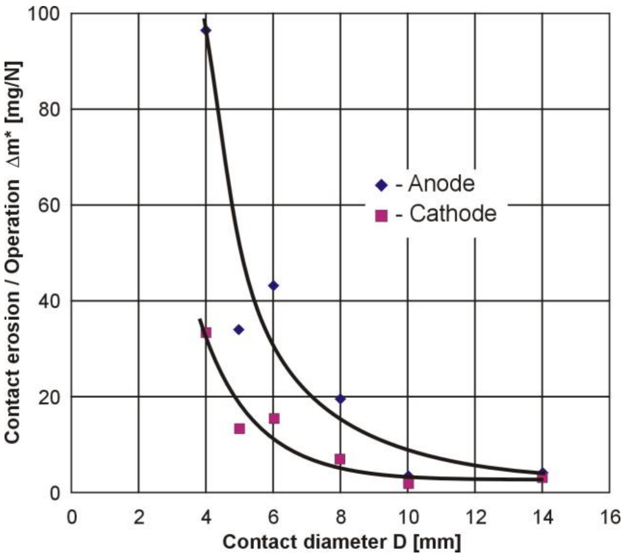

Figure 5. Erosiveness in the function of contact diameters for $D_A=D_C$

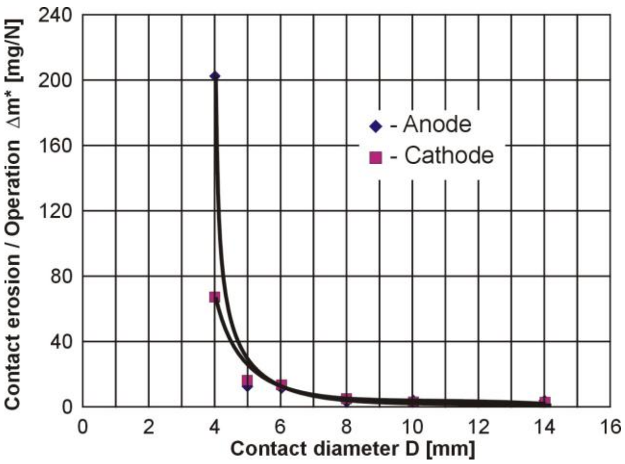

Figure 6. Erosiveness in the function of contact diameters for $D_A \geq D_C$

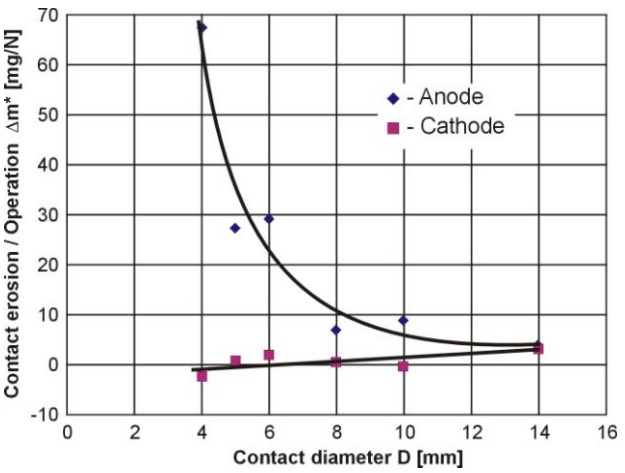

Figure 7. Erosiveness in the function of contacts diameters for $D_C \geq D_A$

Tables 5÷7 compile the results of measurements of electric quantities (values averaged for whole series comprising N switching operations) for a symmetrical and non-symmetrical contacts.

Table 5. Average values of electric quantities for a symmetrical contact - $D_A=D_C$

Contacts dimensions [mm]	**$\hat{I}$ [kA]**	**ψ_a [°]**	**U_m [V]**	**P_m [kW]**	**E [J]**	**$\int i^2dt$ [kA^{2}s]**	**N**
4/4	4,15	30,6	43,5	160	800	80	$3^{1)}$
5/5	3,88	30,6	30	108	494	64,6	$12^{1)}$
6/6	4,35	25,2	27,1	105	537	91	$15^{1)}$
8/8	4,24	31,1	17,5	73,8	375	77,4	20
10/10	4,30	19,8	24,5	78	472	88	20
14/14	4,33	23,4	22,4	76	461	90	20

Table 6. Average values of electric quantities for a non-symmetrical contact - $D_A \geq D_C$

Contacts dimensions [mm]	**$\hat{I}$ [kA]**	**ψ_a [°]**	**U_m [V]**	**P_m [kW]**	**E [J]**	**$\int i^2dt$ [kA^{2}s]**	**N**
14/4	4,05	31,7	32,5	128	601	71,1	$5^{1)}$
14/5	4,24	25,4	24,1	96,3	479,6	78,3	20
14/6	4,2	23,4	22,95	84,5	478	84,5	20
14/8	4,09	27,5	24,5	79,7	419,8	73,6	20
14/10	4,35	19,8	21,2	75,4	460	91	20

Table 7. Average values of electric quantities for a non-symmetrical contact - $D_C \geq D_A$

Contacts dimensions [mm]	**$\hat{I}$ [kA]**	**ψ_a [°]**	**U_m [V]**	**P_m [kW]**	**E [J]**	**$\int i^2dt$ [kA^{2}s]**	**N**
4/14	4,2	28,8	31,5	120	628	84	$4^{1)}$
5/14	4	21,9	25,9	95,6	468	68,3	$15^{1)}$
6/14	4,03	32	22	81,4	410,1	68,7	20
8/14	4,15	25,6	21,8	83,4	436,4	74,5	20
10/14	4,35	21,6	21,4	75	455	91,5	20

A high regularity of characteristics of arc erosion of contact tips $\Delta m=f(N)$ was obtained. They can be described by a power function (1). From the first switching, the anode was the more worn out electrode, which conforms with earlier investigations published in [10].

A great influence of contacts diameter on contacts erosiveness is easily seen in figures 5-7. The influence is different for the anode and the cathode. For small contact diameters of a symmetrical contact (Figure 5) contact mass losses are always bigger for the anode than for the cathode. The smaller the contact diameters, the bigger the difference. For diameters bigger than 10 mm the erosiveness of the anode and the cathode is the same.

In the case when the anode diameter is always bigger than the cathode diameter (Figure 6), within a wide range of anode diameter variation, the erosiveness of both contacts is practically the same. A considerable, ca. four times bigger difference was measured for D_A=4mm.

If the cathode is broad and the anode is narrow (Figure 7), then within the whole range of the tested anode diameters the anode was always more worn out, whereas the cathode was very little worn out. For a small anode diameter there even occurred a cathode mass gain.

The main reason of the visible scatter of measurement points, especially for the symmetrical contact, can be a significant difference between the measured current values and arcing time during testing of different contacts. Arc energy, as an energetic parameter of the arc, strongly influences arc erosion. It is a quantity which mathematically binds three quantities: arc current, arc voltage and arcing time. For example, for a symmetrical contact average current $I_{śr}$ = 4,2 kA, its minimum value is equal to 3,88 kA (-7,6%) and the maximum value reaches 4,35 kA (+3,6%). The consequence of this were also scatters of energy and integral $\int i^2dt$ values. For example, for a non-symmetrical contact the average energy value was equal to $E_{śr}$ = 523,2 J, its minimum value reached 375 J (-28,4%), whereas the maximum was 800 J (+52,9%). The scatters of current and arc voltage values fall within the range of accepted laboratory research limits. Contact diameter, on the other hand, has an influence on arc voltage.

The obtained results are similar to the results obtained earlier [10] for composite W-Ag contacts and a few different current values (Figure 8). It is easily seen that if contact diameter is big and the current relatively small, then the influence of diameter variation on erosion can practically be neglected. The influence increases and can be very big if the diameter of contact bases is comparable with contact dimensions at high current. It appears from Figure 8 that anode mass losses are much bigger than cathode mass losses, regardless of contacts dimensions.

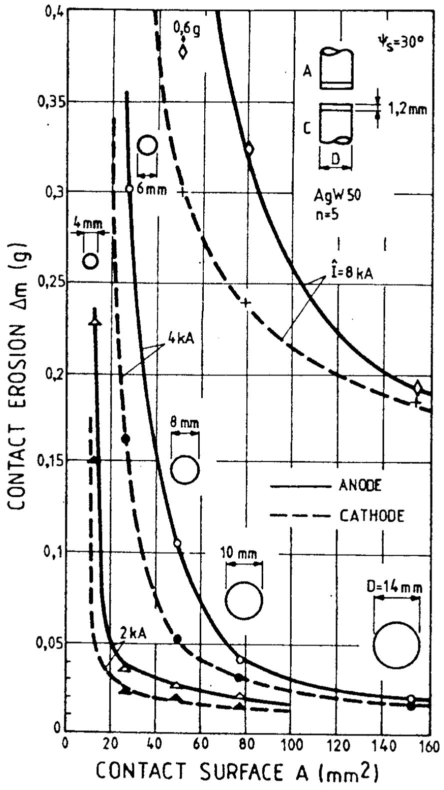

Figure 8. The dependence of arc erosion on the dimensions of contacts surface and the number of switching operations for W-Ag50 and W-Ag35 composites [10]

4. SUMMARY

The experimental results presented in the paper are interesting for designers of direct current circuit breakers. The findings broaden the knowledge of the influence of contacts dimensions on the arc erosiveness of high current contacts made of composites of tungsten-silver type. The experimental results can also be used in practice for the purposes of constructing low-voltage circuit breakers.

The obtained results need further elaboration and theoretical justification that will be the subject of next publications by the authors.

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