THE EFFECT OF FUSE-ELEMENT SHAPE ON BREAKING PHENOMENA IN a.c CIRCUITS

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ABSTRACT

Description is given of the results of comparative tests on interrupting parameters by fuse-links having an aM time-current characteristic. The tests were carried out at alternating current of 1180 ± 20V on fuse-link models with 0,20mm wide, single and parallel, copper strip elements. The active length of the fuse-elements was 96 mm. The fuse-link insulation bodies were made of Al_2O_3 and had an inside diameter of 43 mm. They were filled with quartz sand of a 0,2 to 0,5mm granulation. The results obtained permit to determine the dependence of the interrupting arc energy and the energy needed for melting $1mm^3$ of the fuse-element upon the width of the element as determined by the number of modules. The analysis comprises the interruption of I_2 critical currents and overload currents selected so that the prearcing times amount to from 20 to 200 sec.

1. INTRODUCTION

Progress in the construction of fuses continues to be dependent on incessant research and development work. Nevertheless, quantitative advantages following from the application of several parallel fusible strips instead of one strip having their summary width are still unknown. Thus, attempts have been made at clarifying this matter partially and tests carried out pertaining to the effect of the strip fuse-element construction on the process of interrupting short circuits and overloads. The interrupting capability of model links with single fusible strips, from 2 to 8 modules wide, was compared with the results obtained with single-module parallel fusible strips arranged in the link so that distances between their surfaces amounted to 5mm approximately. The arc energy, length of the melted elements and the energy needed for melting 1 mm^3 of the element mass were used as criteria for the comparison. The tests were limited to interrupting critical short circuit current I_2 and breaking overload currents selected so that their prearcing time amounted to from 20 to 200 sec. The measurements were taken at alternating current of 1180 ± 20V on copper fuse-elements having a thickness of 0,2 mm and an active length of 96 mm.

2. GENERAL CONSIDERATIONS REGARDING INTERRUPTION BY FUSES

Correctness of interruption by means of fuses is decided, above all, by the amount of energy appearing in the arc and by the fuse-element melting rate. This refers especially to fuses for rated continuous currents of several hundreds of amps and for rated voltages of more than 600 V. Special technical difficulties are encountered at working out designs for high-voltage full range fuses . This is so becasuse of the lack of appropriate information in references, and the available descriptions of the phenomena which accompany the interruption of currents by fuses are in general confined to short circuit conditions and usually they refer merely to fuses with single fusible strips or wire elements. Parallel fusible strips find application nowadays in actual fuses for higher rated currents. In fuses of such a design, howerer, progressive destruction of the fuse is found to take place at interruption in such cases when, because of any reasons, the parallel fusible strips do not take the same part in the process connected with interrupting the current. The strip at which the largest fulgarite appears, will also have the lowest arc impedance and it will quickly take over the whole interrupting task while the arcs at other elements extinguish. In such cases the arc usually comes up to the end caps, in many cases burning out holes in them, which results in a failure of interrupting the current. Such kind of faulty operation is, according to Rosen [5] , is typical in fuses having their elements of an insufficient length or it takes place when the test is carried out with a smaller current than the minimum fuse-link interrupting current.

3. TEST CONDITIONS

The tests were carried out on fuse-links composed of typical metal element as used in low voltage industrial links with second size blade contacts and with Al_2O_3 bodies, 100mm long, inside diameter 43mm. Quartz filler was used as arc-quenching material having a granulation of 0.2 to 0,5mm and the following basic chemical composition: 99.25% SiO_2; 0.21% Al_2O_3 + TiO_2; 0.05% Fe_2O_3 and 0,1% CaO. While being filled the links were subjected to shaking in order to ensure lowest possible porosity [4] . The tests comprised 340 models of fuse-links with copper strip element having an active length of 96 mm, a thickness of 0.2 $\pm^0$0.005 mm and a module width of 3 $\pm$ 0.02mm. The fuse-elements were composed of single strips having n = 1; 2; 3; 4; 5; 6; and 8 modules /Type B/ and of single-module strips /Type C/ placed in the links in parallel with their centre line and welded at both ends to the copper contact blades /Fig.2/. The distances between the single-module strip planes amounted to 5 $\pm$ 0,5 mm each. The melted element length was determined on the basis of X-ray photographs by suming up the particular lengths melted in the fusible strips. While evaluating the melted length areas of the cut-outs for forming restrictions as shown in Fig.1 were taken into account. The test circuit in compliance with the IEC requirements [7] was supplied form a single-phase transformer, 15kV/1kV; 3 MVA. Resistors and air-core reactors were used for presetting the values of the current and power factor. The voltage and tests current were measured with an accuracy

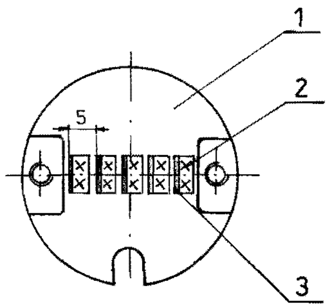

Fig.1. Fuse-link blade contact with arrangement of 5 strips shown. 1-blade contact; 2-fuse-element welding points; 3-fusible strip.

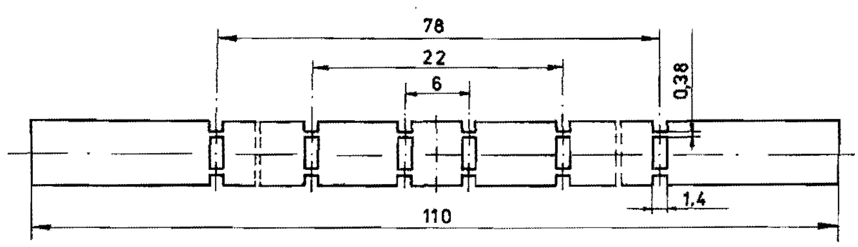

Fig.2. Two-module strip element with an aM characteristic.

of 1,5%, and the Joule's integral $/I^2t/$ and arc energy /A/ by means of special meters with an estimated accuracy of 5%. The measured values were recorded by a loop oscillograph, in which loops with a resonance frequency of 5 kHz were applied. The recording tape moving speed amounted to 5m/sec. at the short-circuit tests, and 0,5 m/sec. at the overload tests.

Ten measurement were taken per each point of the characteristic, and in doubtful cases even up to 30.

4. INTERRUPTION OF SHORT-CIRCUITS

The tests were carried out at alternating current of 1180 $\pm$ 20V in a circuit with a power factor of 0.22 $\pm$ 0.02. The test current $/I_p/$ was selected so that the cut-off current $/i_o/$ values amounted to /0,65 to 0,75/ $\sqrt{2}.I_p$ The current making angle was 0° to 20°el. Subjected to the tests were 60 models with single-strip elements /Type B/ containing 1; 2; 3; 4; and 5 modules respectively and 50 models with elements composed of single one-module strips /Type C/. The dependense A=f /n/ appears to have a straight line form for single and parallel strip elements

$A = a_0 + a.n$ /1/ The coefficients in this equation as determined by the above mentioned minimum square deviation method take such values as given in Table 1.

Table 1. Values of the coefficients in equation/1/

Fuse-link model type	a_0 /J/	a /J/	r^2
B	0,31	2,44	0,994
C	0,13	2,66	0,993

As this may be seen the linear correlation coefficients r^2 are very high in both the cases. This means that the correlation degree between the results calculated according to dependence/1/ and the results of measurements is very high. Thus, it may be concluded that equation /1/ describes the dependence A = f/n/ correctly. In order to check whether are any essential differences between the straight lines 1 and 2 /Fig.3/, the results of the arc energy measurements in the model groups with 2; 3; 4 and 5 module fuse-elements were subjected to a test of essential differences of the mean "t" values. It appeared that it is possible to determine with a 99% probability that there are no essential differences between the results in both these groups. The tests carried out on 110 models of fuse-links at interrupting I_2 currents made it possible to determine at a 0.98 cofidence level the energy which is necessary for melting the specific mass of a copper fuse-element. On both the types of element models practically the same value of 53 ± 3,7 J/mm3 was obtained. For the sake of comparison. Table 2 shows the value of energy needed for damaging 1 mm^3 of a copper element as given by several authors.

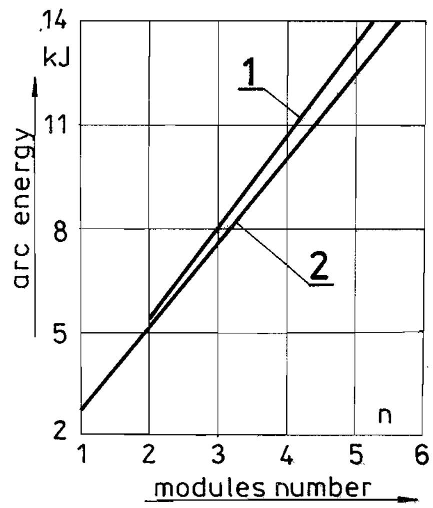

Fig.3. Dependence of short-circuit current interruption arc energy on fuse-element width. 1-single strip element, 2-multi-strip element.

Table 2. Energy needed for damaging $1mm^3$ of copper-element

Source of information	Element melting energy /J/mm^3/
Kohlrausch [2]	53
Johann [1]	46,3
Turner [6]	53,4
author	53 ± 3,7

The relatively high scatter of results obtained by the author is explained by the effect of restrictions on the arc burning prosess.

5. INTERRUPTION OF OVERLOADS

These tests were carried out at an alternating voltage of 1180 ± 20V in a circuit having a power factor of 0.5 ± 0.05. The test current I_p was selected so that a current value of 75A with a tolerance of 2% corresponded to one module i.e. the test overload to 75·n+2% Amps. This corresponded to the prearcing time, in dependence on the dimensions and shape of the fuse-element, from 20 to 2000 seconds.

Fig.4.shows the dependence of the fuse-element melted lengths on the number of modules in the element as calculated on the basis of measurements. Line 1 /Type B fuse-links/and line 2 /Type C fuse-links/show the courses X = f/n/ as calculated by the minimum square deviation method. Vertical lines have been applied for marking the mean arithmetic values deviation ranges calculated on the confidence level of 0.98. As it may be seen the dependences X = f/n/ have the shape of a straight line. $X = X_0 + a . n$ /2/ Nevertheless, the linear correlation coefficients r^2 given in Table 3 have small values, which may be an indication of a relatively low probability of describing correctly the obtained results X = f/n/ by means of the equation /2/.

Nevertheless, it may unambiguously stated that the application of parallel fusible strips in a fuse link instead of one strip with a summary width for interrupting overload currents having a prolonged arcing time from 20 to 200 sec.diminishes by 3 to 3.2 times the mean melted length of the fuse-element. This has a considerable significance in practice in the case of high voltage fuse-links.

Table 3. Values of coefficients in equation /2/

Fuse-link model type	X_o /mm/	a /mm/	r^2
B	78,43	-0,02	0,01
C	30,3	-1,56	0,12

Fig.5. shows the dependences of energy /A/ emitted in the arc at interruption on the number of modules in the fuse-element as calculated on the basis of measurements. Lines 1 and 2 show the courses of A=f/n/ calculated by the minimum square deviation method. The vertical lines have been used for marking the mean arithmetic value deviation ranges, calculated on the confidence of 0.98. It may be easily seen that the dependence A=f/n/ has the shape of a logarithmic curve

$$A = A_o + A_1 \cdot \ln . n \qquad /3/$$

The coefficients in equation /3/ as determined by the above mentioned minimum square deviation method have such values as given in Table 4.

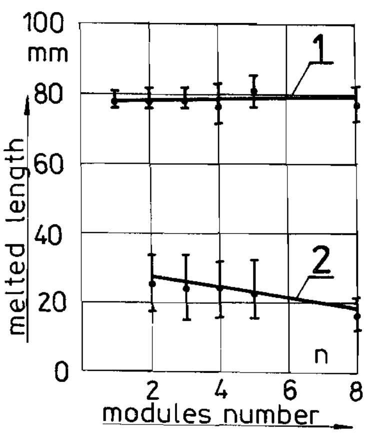

Fig.4. Dependence of the fuse-element melted lengths at interruption of I_2 current on their length.

Table 4. Values of coefficients in equation /3/

Fuse-link model type	A_o /kJ/	A_1 /kJ/	r^2
B	3,8	8,8	0,5
C	0,78	1,05	0,16

As it may be seen the energy emitted at overload interruption by a type B fuse-link with a single element is from 6.1 to 85 times higher than the energy emitted in the C link with an element composed of single one-module strips. This is confirmed to some degree by the arcing times as calculated by the dependence from which it follows that virtual arcing times /t_{Va}/ are in the case of type B models from 4.3 do 7.5 times longer than the times obtained on type C models. The shortening of the arcing time obtained due to division of the strip element into n parallel strips seems to be caused by the fact that the arc usually melts only one of the strips. This means that in the process of interruption migration of the arc takes place. The taking over of the interrupted current by one of the parallel strips in the cause of a current density in that strip, and consequently of a considerable shortening of the arcing time. The arc migration lasts until conditions for the its extinguishing appear. The more so because, according to Onufhrienko's investigation [3], the penetration of the arc plasma into the inside of the sand filler does not exceed in practice 2mm at strip thicknesses of not more than 200 μm. The advantages following from subdividing the module strip element in n parallel single-module strips are shown in Fig.6 which gives the dependences of the arc energy magnitude, related to a single module $A' = /\frac{A}{n}/$, on the number of modules in the fuse-element. Another criterion for evaluating the effect of the fuse-element construction on the interruption of overloads consists in a comparison of the energy needed for melting/damaging/ 1mm^3 the fuse-element in type B and type C fuse-element. The results of measurement and calculation indicate that the values of the energy involved are dependent on the construction of the strip fuse-element and also to same degree on the magnitude of the test current.

$$t_{Va} = \frac{\int i^2\,dt}{I_p^2} \qquad /4/$$

Fig.7 shows the results of measurement and calculation of the energy E needed for damaging /melting/ 1mm^3 of, copper strip elements placed in models of the B-type /curve 1/ and C-type /curve 2/. The lines 1 and 2 show the dependence E = f/n/ as determined by the minimum square deviation method. The vertical lines are used for marking the mean value deviation ranges calculated on the confidence level of 0.98. It may be concluded from Fig.7 that the dependence E=f/n/ has the form of an exponential curve for both the curves.

$$E = C_0 - C_1 \cdot \ln \cdot n \qquad /4/$$

The coefficients in the above equation as determined by the minimum square deviation method, have such values as compiled in Table 5.

Table 5. Coefficients in equation /4/

Fuse-element type	C_0 /J/mm3/	C_1 /J/mm3/	r^2
B	116,85	21,65	0,18
C	46,15	3,53	0,03

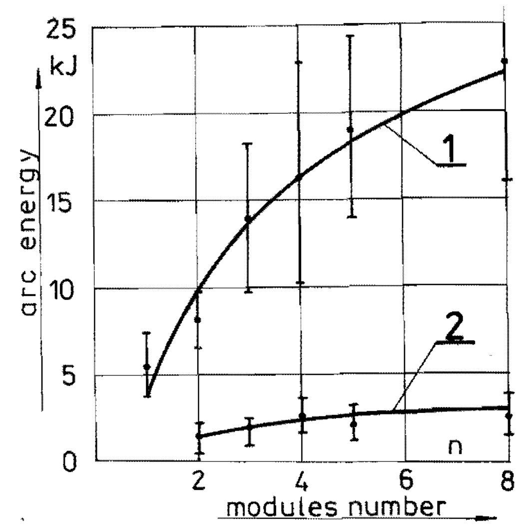

Fig.5. Dependence of overload current interruption arc energy on fuse-element width.
1-single-strip element; 2-multi-strip element

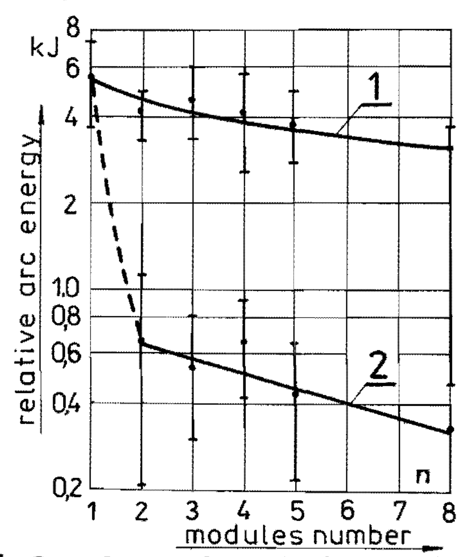

Fig.6. Dependence of overload current interruption arc energy related to a single module upon the width of the fuse-element.
1-single-strip element;
2-multi-strip element

The results of measurement and calculation indicate that value of energy E needed for melting 1 mm^3 of copper in a 0.2mm thick fuse-element surrounded by quartz sand is dependent on the magnitude of the test current and on the construction of the fuse-element. Thus, when interrupting critical fault currents I_2, at alternating voltage, the energy is approximately equal to the values given in references [1, 2, 6] , amouting to abt. 53 J/mm^3. At the interruption of overload currents corresponding to prearcing time of from 20 to 200 sec. the values of that energy is dependent on the construction of the fuse-element to a great degree. For instance, in order to melt 1mm^3 of a 0,2mm thick cooper fuse-element /Fig.1/ composed of from two to eigth single-module strips, 3mm wide each, the values E is nearly completely independent from the number of the strips, amounting to 50 J approximately.

This is a lower value than of 53 J given in references [1, 2, 6] . On the other hand, in the case of a single fuse-element n-module strip the values E is considerably dependent on the width of that strips. Thus, abt. 115 J are needed for melting 1 mm^3 cooper in a 3mm wide single-module strip, and abt. 70 J for a 24mm wide eight - module strip respectively. The explanation is a simple one. The prearcing times are in this case several times longer than at parallel strips, amounting to abt. from 160 msec. for a single-module strip up to abt. 80 msec. for an eigth-module strip. At such long prearcing times a considerable portions of the energy emitted in the fuse-link at interruption is absorbed by the arc-quenching material. Further, the shorter prearcing time as measured in fuse-links having wider elements follows also from the arc does not burn equally at the total length, and only in points moving on the cathode and anode i.e. on the whole width of the strip. The migration of the arc accelerates the melting process i.e. legthening of the arc, and in consequence it results in shortening the arcing time.

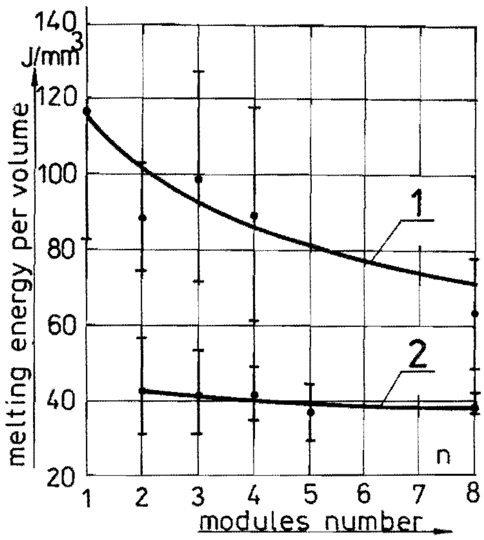

Fig.7. Dependence of copper fuse-element melting energy at interruption of overload current upon the width of fuse-element.
1-single-strip element,
2-multi-strip element.

CONCLUSIONS

The model tests that had been carried out on fuse-links with single and parallel strip elements at alternating voltage of 1180 ± 20V for interrupting critical I_2 short-circuit and overload currents selected so that the prearcing times amounted to from 20 to 200 sec. permit to draw the following conclusions:

/a/. The measured value of energy needed for melting 1mm³ of a copper strip element at interrupting a critical short-circuit current amounts to 53 ± 3.7 J/mm³, being in practice the same for single as well as for parallel elements having identical cross-sections.

On the other hand, at interruption of overload currents the value of the energy involved amounts to abt. 40 J/mm³ for parallel strip elements and in the case of single elements it is dependent on their width, amouting to abt. 115 J/mm³ for a single-module element and abt. 70 J/mm³ for an eight-module element.

/b/. The melted length of strip element at the interruption of overload current is 3 to 3.2. times higher in the case of single strip elements than that in the case of parallel elements of the same cross-section.

/c/. The energy emitted at the fuse-link at the interruption of an overload current is 6.1. to 8.5 times higher in the case of links with single-strip elements than in the case of links with parallel strip elements of the same cross-section.

Further, the virtual arcing time time is 4.3 to 7.5 times higher respectively.

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Session IV

ARCING AND DISRUPTION PHENOMENA 2

Chairman: Dr. J. E. Daalder