THE DISTRIBUTION OF CONSTRICTIONS IN CORRUGATED FUSE-ELEMENTS

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SUMMARY

The paper presents preliminary experiments results of an effect of constrictions positioning in the h.v. corrugated strip tape fuse-elements on the overload current breaking process

1. INTRODUCTION

The fuse-elements in h.v. fuse-links, with ratings above 100A, consist of several parallel silver (Ag) or, rather rarely, copper (Cu) strips. For the reason of interrupting phenomena these fuse-elements are usually longer than the fuse-body. A rate of both lengths reaches up to 5 and generaly depends on the voltage ratings as well as on the fuse design. The lengtheing of a fuse-element can be obtained by a winding of the fuse-strips on a ceramic support or by corrugating them. In the case of corrugated fuse-elements a lengthen rate is no more 1.8.

The main draw-back of the first (winding) design is the space inside of a fuse-body is not effectively used (with regard to arc quenching phenomena). On the other hand in the design of parallel corrugated strips it is of rather limited rigidity. A thermo-mechanical endurance when ageing during the multiple overloads was one of the problems intensively investigated up to now. One of the latest publication [1], by Namitokov, Ilyina, and Shklovsky, gives in this matter, a very important theoretical approach, which shows that with respect to ageing the best positioning of constrictions shall be on flat parts located between bent sections. But a thermo-mechanical endurance of the elements, mentioned above, is one aspect of the proper distribution of the constrictions only. Not the less there is also important the question how this distribution impacts on the breaking capacity. That is why authors decided to search this problem experimentally because there are no test data sufficient enough to analytical approach.

For the being time our tests were limited to the interruption of overloads corresponding to the pre-arcing time of about 0.1 to 120 seconds.

The paper gives results of model test of h.v. motor-protection fuses, with rating 7.2 kV a.c., containing 6 parallel copper currugated strips, which are fixed, each to the separate insulation support.

2.TEST CONDITIONS

The test were carried out on a model h.v. fuse-link 292 mm long, outer diameter 82 mm. As the fuse-elements were used corrugated copper strips with constrictions as shown in Fig. 1. The rigidity problem of corrugated model strips was partially solved by fixing, in several points, of each strip to the separate support. Quarc sand of granulation of 0.2 to 0.5 mm was applied as an arc quenching medium. Its basic chemical composition was: 99.24% SiO_2, 0.22% Al_2O_3+TiO_2, 0.05% Fe_2O_3 and 0.1% CaO. When filling with sand, the fuse-links were subjected to shaking to provide minimum porosity [2]. Two types of the copper corrugated strip-elements were investigated. The distinction between each type depends on a location of the constrictions on the folds of a fuse-element [Fig 2] An active length of the fuse-elements was of 450 mm and a thickeness of $0.18_{-0.006}$ mm. The elements were composed of six strips, each $6_{-0.05}$mm wide. Every strip contained 43 constriction rows, the constriction rate was 1:6.7. The distance between every next constriction axis was of 10 mm. The formed fuse-elements were placed inside the fuse-body uniformly so, that the minimum distance between the near edges of adjacent strips as well as the minimum distance from the inside part of insulation body were at least 6mm. This

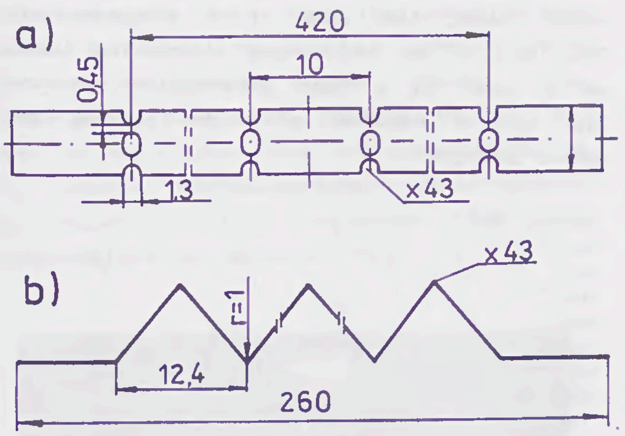

Fig. 1 Tested fuse-elements. a) shape, b) corrugation

arranging of strip-elements inside the fuse-body [4] allows to reach relatively low overload breaking capacity, at which the pre-arcing time is around 200s as well as to reach relatively high breaking capacity, at least of 50kA.

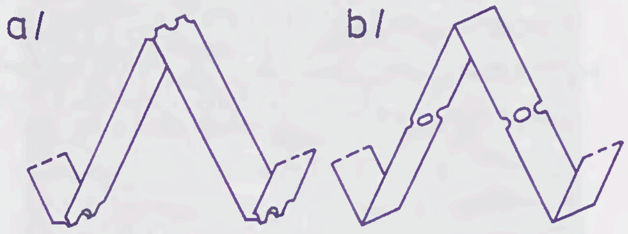

Fig. 2 Constrictions distribution

In consideration of costs, preliminary experiments were carried out on model fuse-links 70mm long inside of which single copper strip fuse-elements 100mm long of cros-section 6x0.2mm^2 were inserted. The fuse-element constrictions were distributed on the eight V-shape folds giving the constriction ratio of 1:7. Two utmost distributions were investigated on an every top and in the middle of the V-shape. Test currents were done 2 and 10kA; voltage 1250V; 50Hz; p.f.=0.2.

The overload interruption tests were carried out in synthetic circuit [5]. The test current, of $3.8I_n$ to $8I_n$, was selected to obtain the pre-arcing time of 3 to 120s. For this purpose the fuse under test was pre-heated with a test current at 50V a.c. This current was maintained up to the moment when its value sharply decreased. It meant that melting process of the fuse-element has started. Next, this current was switched of automatically and a power supply at full value of the test voltage was switched on. The change-over time was of 0.2s. Interruption tests of the current of $16I_n$ (2560A) were carried out in the circuit shown in Fig.3. Resistors and air-cored reactors were applied for the pre-setting the current and power factor values. The tests were performed at 7.2±0.15kV a.c. The test p.f. was 0.5±0.03 and 0.13±0.02 at the current of $8I_n$ and $16I_n$ respectively. In these both tests the making angle was 0 to 10 electrical degrees. The test current and voltage were measured with an error evaluated at ±5%. The measured values were recorded by means of two channels transient recorder.

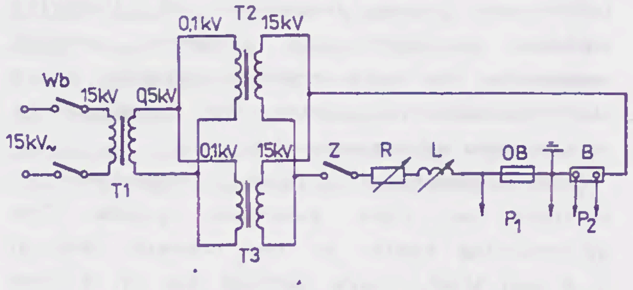

Fig. 3 Test circuitry for test current $16I_n$. Wb - master breaker, T_1,T_2,T_3 - trans formers 3x3MVA, Z - making switch, R - resistor, L - reactor, OB - fuse model under test, B - shunt, P_1 - re- -covery voltage measurements, P_2 - current measurements

3.EFFECT OF THE CONSTRICTION ARRANGING ON THE BREAKING CAPACITY OF A CORRUGATED FUSE-ELEMENT

The breaking capacity of a non-corrugated strip-element depends on geometrical dimensions of this element but first of all on the constriction number and the distance between themselves [3,4]. There is also additional factor which brings an influence on the breaking capacity of a corrugated fuse-element i.e. the way of constrictions arranging on a fold. If a constrictions number is equal to a fold number, that two extreme cases can be distinguished, respecting to the distance between two next constrictions i.e.: constrictions on fold tops (Fig.2a) and constrictions in the flat sections middle of the fuse-element (Fig.2b) In the course of an arcing, initiated by an arc ignition in every constrictios, being lengthned arc columns interact. This interaction is the greater if these arcs are closer [4].It is a result that the heat transfer from the arc column is worsening, hence decreasing of the arc voltage gradient. When these arcs ignite in the fold tops an electrodynamic current effect, in short-circuit breaking conditions, causes additionally the pushing-out the arc column outside the element fold. It causes that the voltage gradient in the arc column increases and in this way the arc column cooling process improve itself.

The voltage, current, arc-energy, breaking Joule's integral records at the voltage 1250V and visual inspection of fulgurite enabled to draw the following general conclusion: the best breaking capacity prove the fuse-elements having the constrictions on the tops of corrugations.

This conclusion was experimentally verified on 7.2kV fuse-link models. The interrupting tests, at the current (3.8, 4, 5, 8 and 16)xI_n, were carried out on 3 fuse samples with both types fuse-elements. It was found, that the fuse-links of which elements are with constrictions in the middle of flat section (Fig.2b) only in abt. 20% interrupted satisfactorily a test current. So high percentage of interrupting failures related to the whole overload test current range, (3.8-16)xI_n. In the basis of the visual inspection of fulgurites as well as the analysis of interrupting records it can be pointed out two main reasons of interruption failures. The first one is, just mentioned, thermal interaction of the next arcs when they ignite in the middle of the flat section of a corrugated strip. A relatively short distance between next arc centres (approx. 5.5mm) makes difficult a cooling down of these arcs. On this way relatively low arc voltage gradient is obtained. It leads to an increasing of an arcing time and consequently a fulgurite cross-section increases reasonably. This increasing causes the arcs coming close together up to the moment of converting them in a single arc. This single arc develops itself along the axis of a strip-element. This kind of an arc length shortening leads, as a rule, to a fuse interruption failure. The typical records of such failures are shown in Fig.4.

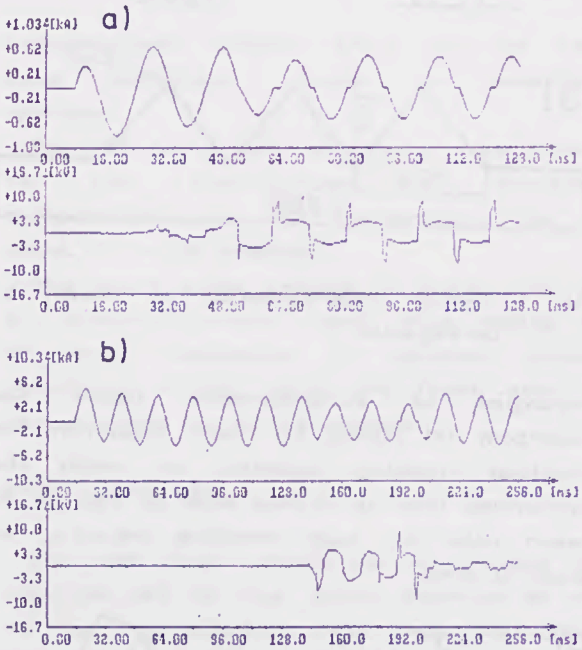

Fig.4 Exemplary records of interruption failure. a) U_p=7050V, I_p=614A, b) U_p=7050V, I_p=2560A

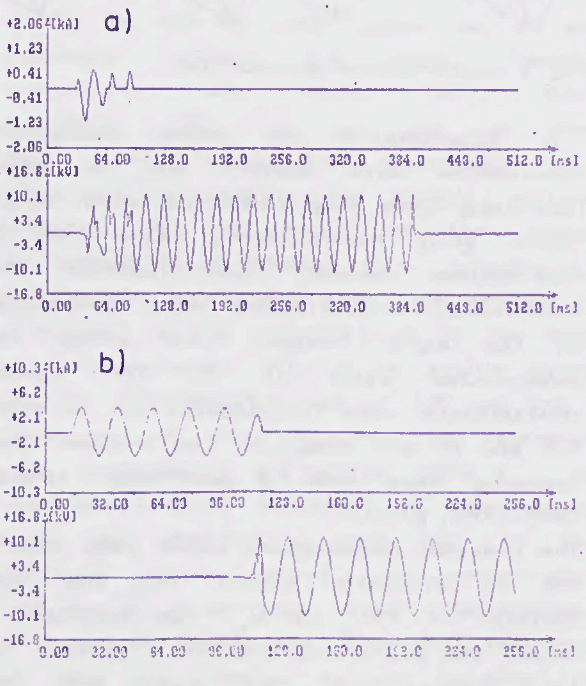

Fig. 5 Exemplary records of interruption. a) U_p=7380V, I_p=630A, b) U_p=7450V, I_p=2560A

On the other hand all the fuse samples of which elements were with the constrictions on a fold top interrupted satisfactorily. The highest arcing time values, when interrupting the test current up to $5I_n$, were no more than 50ms and respectively at $16I_n$: within 10-20ms.Exemplary interruptions are shown in Fig.5. Fulgurites from this interruptions are shown in Fig.6.

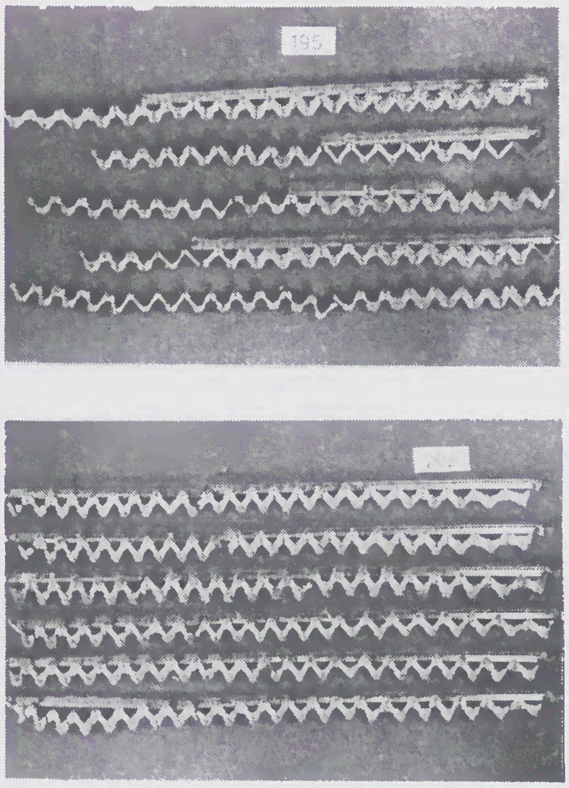

Fig. 6 Exemplary fulgurites of interruption 195 - U_p=7380V, I_p=630A; 202 - U_p=7450V, I_p=2560A

4. EFFECT OF FUSE-ELEMENTS CONFIGURATION ON THE MULTIPLE OVERLOADS ENDURANCE

As it was concluded in the paper [1] that due to the desired endurance on cyclic overloads it is advisable to have in the strip elements much folds being as close as possible to the constrictions. With regard to an interruption, however, most advantageous is if the constriction is in a top of the fold of a corrugated fuse-element. In the case when whole element is corrugated, there appears favorable tension distribution on particular constrictions, as a result of an expanding and contracting of the element subjected to the cyclic overloads variations. Amount of these variations can be evaluated by simple calculations, assuming that the temperature rise of an element by ΔT causes the every flat section length rise by Δl, of this element. Decreaasing of an angle between the flat parts of a fuse element is assumed by $\Delta\phi$ (Fig.6). The variation of the angle ϕ can be evaluated from the formula (1)

$$\sin\left(\frac{\phi}{2} - \Delta\frac{\phi}{2}\right) = \frac{a}{l(1 + \alpha\Delta T)} \qquad (1)$$

Assuming ΔT=300K, α=17exp(-6) 1/K for the copper, a=6.2mm, l=10mm, the variation of angle $\Delta\phi=0.33^{\circ}$ is obtained as the result when every flat section of the element lengthened itself by Δl=0.051mm. This lengtheing by Δl is several times shorter than a diameter of the smallest quarc sand granule used as an arc quenching medium. It seems that, at a normal packing density, these variations of Δl and $\Delta\phi$ do not cause yet creation in the element constrictions distinctly destructive tensions, which can change a fuse time-current characteristic.

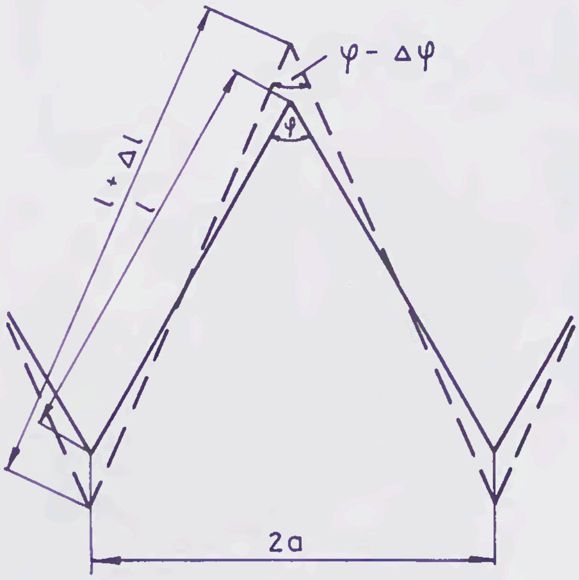

Fig. 7 Fuse-element geometry changes due to heating

Certain verification of the consideration above are endurance on pulse load test results performed on 7.2kV fuse-link models with fuse-elements of constriction on a fold top (Fig.2a). The pulse load endurance coefficient K, estimated for these models fuse-links (acc. IEC 644 [5]), is equal 0.72. Comparatively high value of the coefficient K (in spite the copper fuse-links were used) proves that the pulse load endurance of the copper corrugated fuse-elements with constrictions on the tops is absolutely satisfactorily.

5. CONCLUSIONS

Model overload interruption tests on h.v. fuse-links with corrugated strip fuse-elements prove that the most advantageus is a distribution of constriction on fold tops. By the corrugating of strip elements the tension in a fuse-element was reduced.

Constriction placed in fold tops do not make worse the fuse-links endurance on multiple overloads.

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