BREAKING CAPACITY OF MINIATURE FUSES AND THE TESTING OF A HOMOGENEOUS SERIES

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ABSTRACT

The closing angle is specified in the breaking capacity test in IEC Publication 127. The tests analysed in this paper demonstrate that this situation is unsatisfactory for ratings above a critical level. The arcing angle should be specified. Alternatively, the correct closing angle is shown to be calculable if suitable pre-arcing data are provided when fuses are submitted for test.

The proposed introduction of homogeneous series testing of miniature fuse-links makes it more necessary to correct this situation, because a successful breaking capacity test on the highest rating is then considered to be proof that lower ratings of the same design are also satisfactory.

1 INTRODUCTION

IEC Publication 127 specifies breaking capacity tests for miniature fuse-links which are carried out at a prospective current of 1500 A ac rms 50 Hz at a power factor of 0.7 for high breaking capacity fuse-links, and 35 A or 10 times rated current (whichever is the greater) for low breaking capacity types. To attempt to ensure repeatibility of the tests, a closing angle of 30 ± 5 degrees on the voltage wave is specified.

In the United States, no closing angle is specified, random switching being employed. The tests described below verify the long held suspicion that neither of these methods of breaking capacity testing is completely satisfactory.

It is well established for other types of fuse-link that the arcing angle is the factor which determines the severity of a test on a fuse-link, and the results outlined below verify that this is also the case for miniature fuse-links. A fuse which successfully clears the circuit when arcing commences at an angle near to the next voltage zero will not necessarily perform satisfactorily when arcing commences just before voltage maximum.

Miniature fuse-links are a low-cost item. This is a reason why the cost of testing must be kept to the minimum consistent with safety, and there are at present moves to reduce these costs by introduction of the principles of homogeneous testing of series of fuse-links of similar construction, differing only in the dimensions which determine the current rating. In this technique the maximum number of tests is carried out on the highest rating in a series, and the results are considered to apply to lower ratings without further test. This development has focussed attention on the breaking capacity test which is most unreliable for the larger ratings in the low breaking capacity types.

The present test specification requires the breaking capacity test to be performed on every rating, and thus unsatisfactory designs can be eliminated when they fail to complete the breaking capacity test on ratings less than the maximum in the series, where the arcing commences near voltage maximum.

For fuse-links of very low ratings (eg up to 100 mA) the arcing angle is extremely close to the closing angle, and thus there is no need to depart from the practice of specifying a closing angle. The range of ratings over which this applies varies with the type of fuse-link, and can be calculated, as is shown below.

2 RANGE OVER WHICH THE PRESENT SYSTEM IS SATISFACTORY

The range may be assessed by consideration of the maximum values of pre-arcing I^2t specified in Publication 127 calculated from the gates specified at 10 times rated current. This will give a margin of safety, since the pre-arcing joule integral tends to be lower at higher prospective currents. The mathematical problem is then to find the arcing angle corresponding to the given closing angle for the value of joule integral thus determined.

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The problem was solved by consideration of the equation for the I^2t dissipated in an inductive circuit which is given by the following equation:

$$\int i^2 dt = 2I_p^2 \int_{t_1}^{t_2} \{\sin(\omega t_2 - \phi) - \exp(-R(t_2 - t_1)/L).\sin(\omega t_1 - \phi)\}^2 dt \qquad (1)$$

Where I_p = rms prospective current

ω = the angular velocity

t_1 = closing instant after voltage zero (sec)

t_2 = instantaneous time from voltage zero (sec)

ϕ = phase angle

R = resistance

L = inductance

The solution to this equation is as follows:

$$\int i^2 dt = I_p^2[t_2 - t_1 - (\sin(2C_2) - \sin(2C_1))/2\omega + (4\omega L^2/Z^2.\sin(C_1) . (F_2 - F_3) + F_4)] \qquad (2)$$

Where C_1 = $(\omega t_1 - \phi)$, $C_2 = (\omega t_2 - \phi)$ and $Z^2 = R^2 + \omega^2 L^2$

F_2 = $\exp(-R(t_2 - t_1)/L)).(R/\omega L.\sin(C_2) + \cos(C_2))$

F_3 = $R/\omega L \sin(C_1) + \cos(C_1)$

F_4 = $L/R.\sin^2(C_1).(1 - \exp(-2R(t_2 - t_1)/L))$

With the aid of a computer, the arcing angle was evaluated from equation (2) by means of an iterative program which identified the conditions for the nearest match to the given joule integral. It is proposed below that the same technique be used to predict the correct closing angle when the higher levels of current rating are being tested and thus obtain the desired arcing angle.

On the basis of tests on all types of miniature fuses, confirmed by the tests described below it can be seen to be desirable that the arcing angle should be between 30 and 90 degrees in the breaking capacity tests, if the present specification of a 30 degree closing angle is sustained.

Miniature fuse-links are classified in IEC 127 in four different types, details of which are given in the standard sheets of the specification. For the standard sheet I fuse-links the maximum rating is 6.3 A with a maximum pre-arcing time of 0.02 sec at 63 A. This implies a maximum pre-arcing joule integral of 79 amp squared seconds under these conditions. By substituting the above value in equation (2) we found that on the basis of the criterion of an arcing angle below 90 degrees, there is no problem with the high breaking capacity types. However the results of tests (Fig. 1 is an example) showed that the arc energies peaked at arcing angles near voltage maximum, and there could thus be an argument for some increase in the specified closing angle. Comparability between different sources and current ratings is however very good with the 30 degree closing angle.

Standard Sheet II fuse-links are low breaking capacity types having a maximum pre-arcing time of 20 milliseconds at 10 times rated current. The pre-arcing joule integral is thus equal to 2 x (rated current)^2 amp squared seconds. Substituting this value in the equation and putting the prospective current at 35 A we find that on the basis of the above arcing angle criterion, no problem is likely for rated currents of 1.6 A and below.

Standard Sheet III fuse-links are time-lag types with a pre-arcing time of up to 0.3 seconds which corresponds to a joule integral of thirty times the square of the rated current. Substituting in the equation as before, we see that problems are only likely to arise for rated currents exceeding 400 mA.

All the above fuse-link types are of the 5 x 20 mm dimensions, but Standard Sheet IV is a 6.3 x 32 mm type with a maximum of 0.08 sec at 10 times rated current. Similar calculations reveal that on the basis of the above criterion, there should be no problem for fuse-links of ratings below 800 mA.

3 TEST RESULTS

The test results indicate the extent of the problem at present.

Figure 2 is a graph of the arc energies measured for a range of fuse-links 5 x 20 mm of European manufacture of rated currents from 0.63 A to 4 A tested at their breaking capacity current and rated voltage. The current was set by adding resistance to the test circuit. The test source was a large laboratory test transformer, but of lower power than that normally used in standard testing, so that the severity of the test was slightly greater than that specified for type testing.

It can be seen that the arc energy peaks in the region around 90 degrees and that all the failures were at arcing angles between 55 and 120 degrees.

On the basis of these tests, and the criteria applied in testing other types of fuse-link we propose that the arcing should commence near 90 degrees on the voltage wave.

4 MEANS OF ACHIEVING THE CORRECT ARCING ANGLE

The expense of measuring and recording arcing angles has been quoted as a major objection to specifying arcing angle in the past. However if the average pre-arcing joule integral is stated by the manufacturer (or obtained from the test of time/current characteristic at 10 times rated current), then equation (2) gives adequate accuracy for the calculation of the correct closing angle to obtain arc initiation in the desired range.

Figures 3, 4 and 5 illustrate the degree of accuracy obtained using this technique, for typical fuse-links to standard sheets I, II and III. The circles represent the calculated values using the average value of pre-arcing joule integral for each type and the crosses show the experimental results, with a solid line which was drawn through the experimental points before the calculations were made.

5 CONCLUSIONS

1) The breaking capacity test specified in the present IEC Publication 127 based upon a specified closing angle will not always produce the most onerous conditions particularly for fuse-links of higher rated current of low breaking capacity.

2) Calculations show that there is likely to be no problem of this kind for fuse-links below 400 mA rated current, and that for fast acting fuse-links 5 x 20 mm there is no problem up to ratings of 1.6 A.

3) The arcing angle should be specified instead of the closing angle.

4) The closing angle corresponding to the required arcing angle may be readily calculated if the average value is known of the pre-arcing joule integral corresponding to the test current, and calculation of the closing angle from the average joule integral gives a result sufficiently accurate for miniature fuse breaking capacity tests.

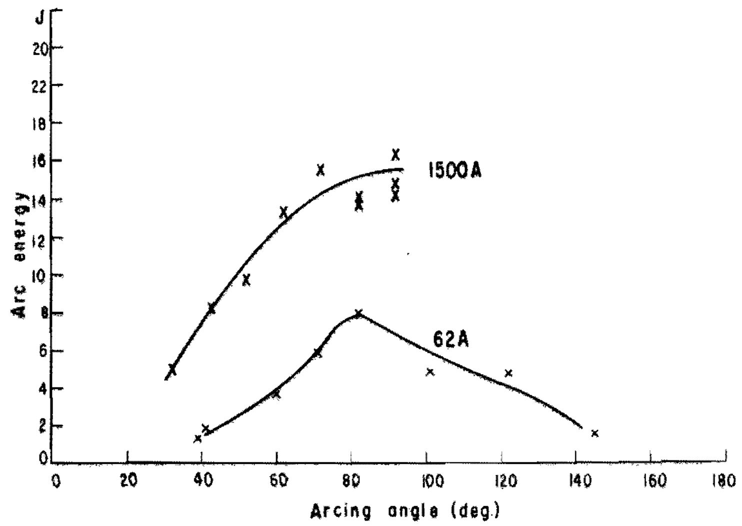

Fig. 1 Arc energy as a function of arcing angle for Standard Sheet I fuse-links I_n = 0.63 A. Tested at 62 A prospective current (no added inductance) and at maximum breaking capacity.

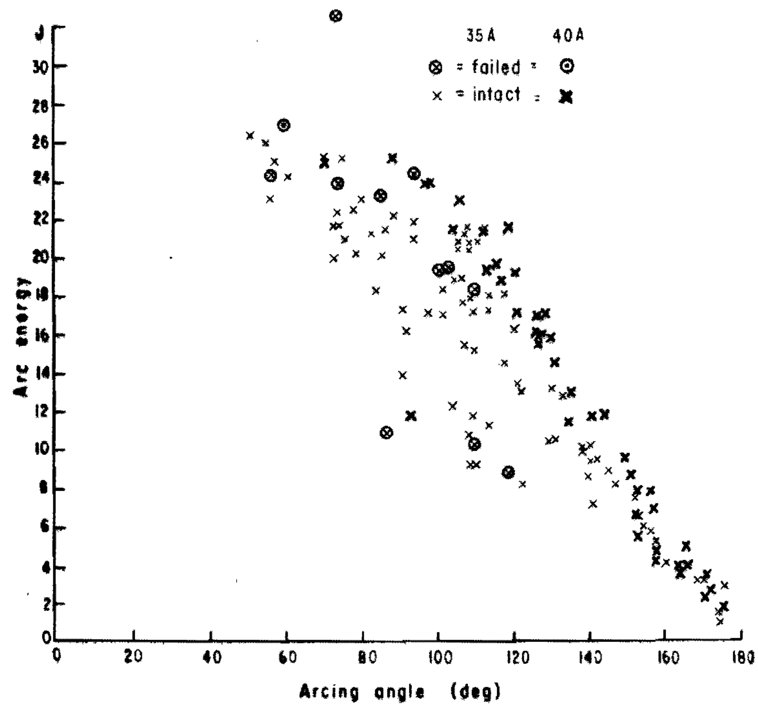

Fig. 2 Arc energy as a function of arcing angle for low breaking capacity fuse-links of differing current ratings, designs and time delay characteristics. Tested at 35-40 A with no added inductance.

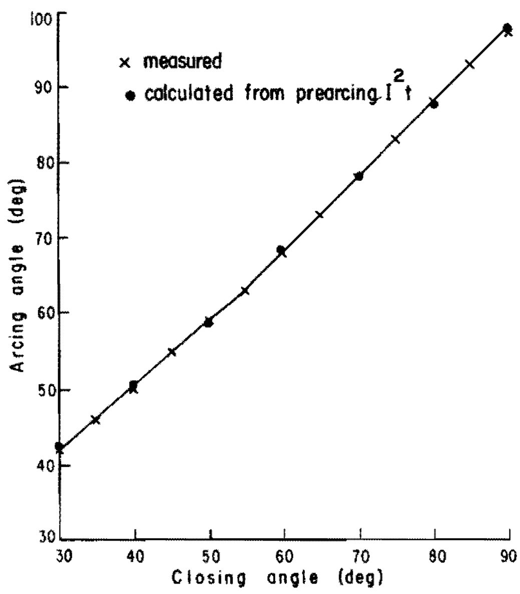

Fig. 3 Arcing angle as a function of closing angle for Standard Sheet I fuse-links I_n = 6.3 A.

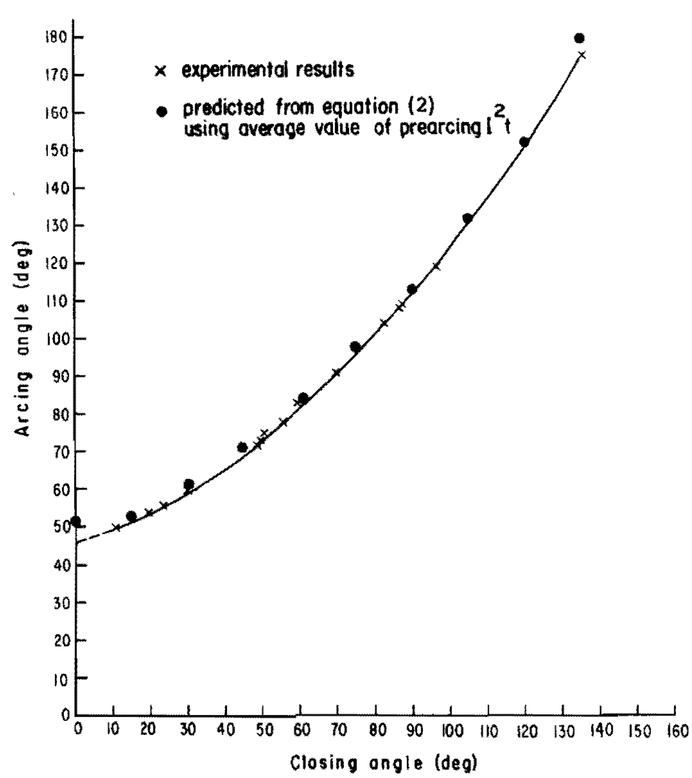

Fig. 4 Arcing angle as a function of closing angle for Standard Sheet II fuse-link I_n = 0.63 A. Tested at 35 A with no added inductance.

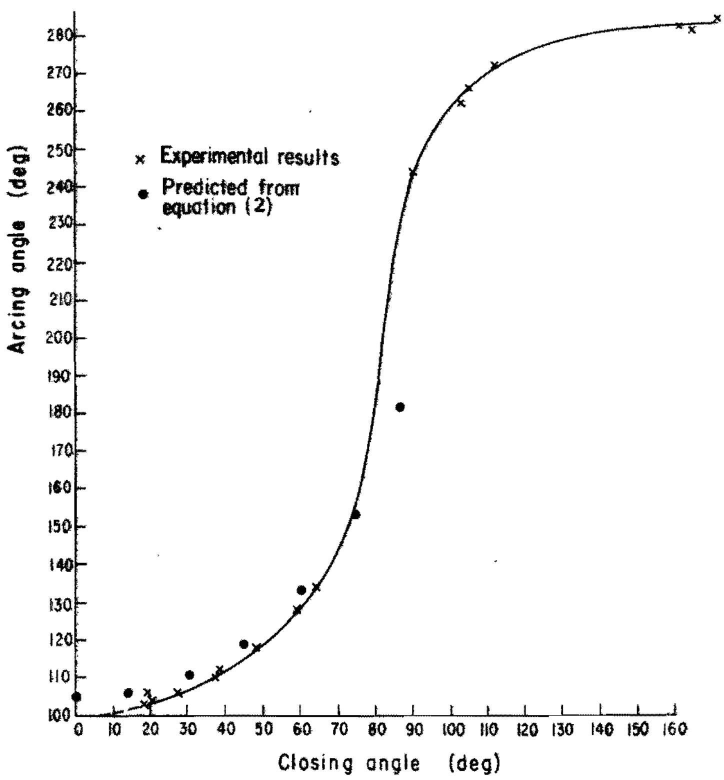

Fig. 5 Arcing angle as a function of closing angle for Standard Sheet III fuse-links I_n = 1 A. Note: The virtual impossibility of achieving arcing angles between 180 and 240 degrees (0-60 degrees).