LIQUID-FILLED FUSES FOR THE PROTECTION OF THYRISTORS

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INTRODUCTION A high-speed fuse at strong prospective currents in sub-cycle operation is readily characterized by

$$\tau_F = (I^2t)_F / I_R^2, \qquad (^x)$$

where $(I^2t)_F$ is the total I^2t let-through of the fuse-link and I_R is fuse-link's rated current. For fuses of one and the same type, but having various rated currents, τ_F is hardly dependent on rated current. If arc-quenching in the parallel branches of the fuse-link element is assumed to be taking place independently, the above expression is usable to determine τ_F for fuses of different rated currents from the total I^2t let-through of a single branch.

A similar expression for the thyristor may be written as

$$\tau_s = (I^2t)_s / I_{RS}^2,$$

where $(I^2t)_S$ is the total I^2t withstand capability of the thyristor in sub-cycle operation and I_{RS} is the effective value of rated current for the thyristor.

τ_S is likewise shown to be hardly dependent on thyristor's rated current as, for example, in (1), where $\tau_S = 0.3 \pm 0.1$ s over a wide spectrum of rated currents.

In the simplest case, where the fuse is connected with the thyristor in series, the protection requirement in sub-cycle operation can be described approximately in the following way

$$\tau_F \leqslant k\,\tau_S, \qquad (xx)$$

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where k is the factor of safety.

A considerable increase of I_R is achieved if the quartz filler is substituted by a liquid as proposed in (2) and (3).

However, simple liquid-filled fuses with no special quenching means, initially tested for arc quenching, showed poor characteristics, the values of $(I^2t)_F$ being high and hazardous transient overvoltages observed. That is why we have put forward a combined (heterogenous) filler, consisting of quartz sand and a dielectric liquid (4).

<u>EXPERIMENTAL SET-UP</u> The experimental set-up is shown schematically in Fig. 1. The capacitor battery C was first charged to a definite voltage of U and then, upon closing the circuit breaker CB, the current was passed through a laboratory model of the fuse F. The circuit parameters were L=2.42 mH; R=0.223 Ω; C=80,000 μF.

The values of $(I^2t)_F$ were measured by an electrodynamic milliammeter, set in ballastic behaviour (5). The milliammeter was coupled with the circuit via current transformer CT.

The fuse mockup is shown in Fig. 2. The fuse element 1 (Fig. 3), made of 0.028 mm thick silver foil, was placed in the cylinder grid 2 filled with quartz sand 3. The sand consisted of more than 98 per cent of SiO_2, the grain size being from 0.2 to 0.5 mm. The lower dielectric piston 4 had a circular groove filled with liquid under test 5.

Capillary forces made the liquid saturate the quartz sand 3, thus forming a heterogenous filler containing a 60 per cent (approximately) volume of quartz sand and 40 per cent of dielectric liquid.

As arc quenching is largely dependent on pressure in the sand, as pointed out in (6), the latter was maintained constant throughout the experiment. To achieve it, prior to testing a pressure of 10 kG/cm^2 was built up in the sand by means of the upper piston 6 and then the piston was fixed by the screw 7. The path of the test current was through piston 6, fuse element 1 and lower contact 8.

EXPERIMENTS AND RESULTS In arc quenching tests, the values of $(I^2t)_F$ obtained for dry quartz sand were compared with those obtained for the combined filler. As shown by the curve (a) in Fig. 4, the values of $(I^2t)_F$ were low, which is due to the fact that the thickness of the fuse element was very small and that a definite pressure existed in the sand. Heterogenuous fillers made up of quartz sand and carbon tetrachloride, as well as of sand and chloroform, are shown by the same curve to be as good arc quenchers as dry quartz sand. Ethylene-glycol-containing fillers were found to possess $(I^2t)_F$ values (curve b), which are 20 to 30 per cent greater than those offered by dry sand.

Overvoltages during arc-quenching in the heterogenous fillers were shown by electron oscillograms to be of the same order as in dry sand.

In the case of chloroform-, as well as thermex-containing fillers, the circuit was found,after the arc was quenched, to be passing considerable current. The fulguritesof these fillers appeared to possess a rather significant conductivity and, therefore, both chloroform and thermex were found to be unsuitable for forming heterogenous fillers.

Tests for rated currents were performed using the same model as in Fig. 2. A fuse element with an active length of l=48 mm and having four incisions was used instead of that shown in Fig. 3, all the other parameters being the same as in Fig. 3.

It is certainly possible for such a fuse element to break a circuit with considerably higher voltages as in the above tests for arc quenching, where a shorter fuse element having one incision was used.

The temperature of casing 9 was set at +25 ±0.5 °C by means of a thermostat.

Fig. 5 illustrates the dependency of fuse element resistance r upon steady current I. Curve (c) represents dry sand; curve (d) - heterogenous filler containing sand+carbon tetrachloride; (e) - heterogenous filler subjected to a high intensity electric field.

The electric field was provided by inserting into the fuse a high-voltage electrode, as described in (4), which was connected with a 4 kV 50 cps AC source. In the case of a heterogenous filler, the resistance r, as shown by curve (d) in Fig. 5, increases slowly, which is attributed to the cooling effect of the liquid.

The increase of r is even more slower under the influence of electric field, since the latter considerably intensifies heat dissipation from the fuse element (curve (e)).

Let us assume the fuse rated current to be of such a value that it elevates the fuse element temperature to a definite mean value of, say, +70 °C. Then the corresponding resistance will be r=21 mΩ in which case for dry sand I_R=10 - 11 A and 16 - 18 A for sand containing carbon tetrachloride, whereas, in the case of electric field, I_R is estimated to be between 21 and 22 A.

It is evident from Eq. (^{x}) that at $(I^2t)_F$ =idem the value of ϑ_F for the heterogenous filler decreased 2 to 3 times as compared with dry sand while the decrease for heterogenous filler was even three- to four-fold when it was under the influence of electric field, the satisfaction of (^{xx}) being thus considerably better.

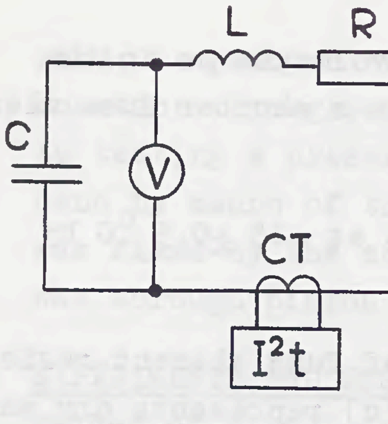

Fig.1

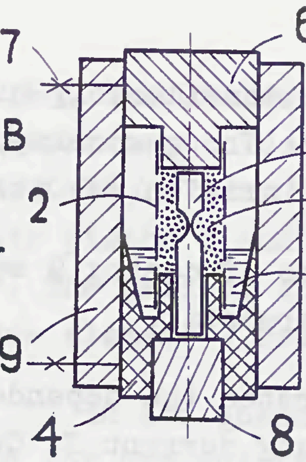

Fig.2

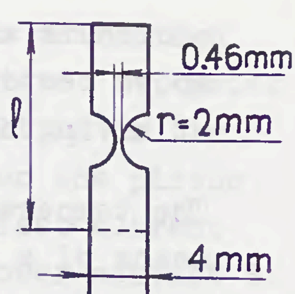

Fig.3

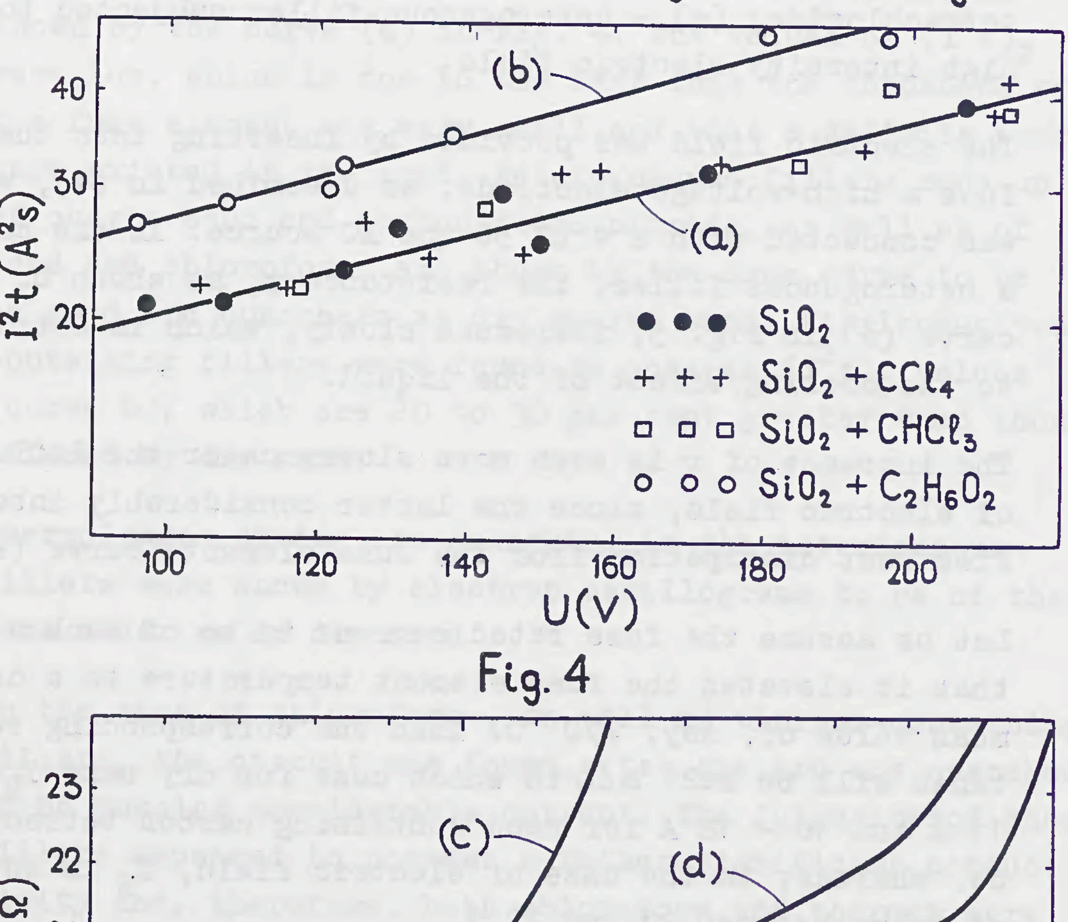

Fig. 4

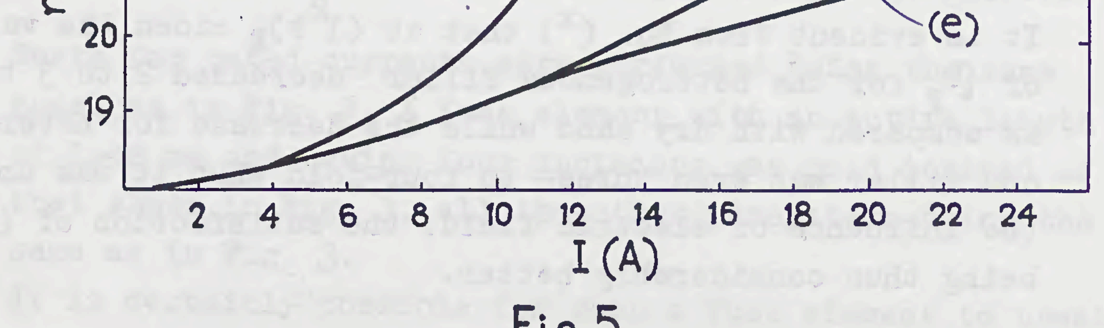

Fig. 5

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