PROTECTION BY FUSES OF MECHANICAL SWITCHING DEVICES

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SUMMARY   A weighty risk of injury by overcurrents in mechanical switching devices concerns their contacts; overcurrents may give rise to stresses leading them to weld together or to arcing, if large enough.

Fuses are suitable for limiting such stresses by limiting both duration and peak value of the overcurrents, and their protective action meets the most severe conditions within a definite range of overcurrents.

For larger overcurrents the severity does not increase any more, or it even decreases.

Experimental results are given to confirm this behaviour.

GENERAL   An overcurrent flowing through the closed contacts of a mechanical switching device for a definite duration causes a thermal stress of the contacts, which corresponds to the amount of energy $\int_{t_d} r_c i^2 \, dt$, if t_d is the duration, r_c the contact resistance and i the overcurrent.

The electro-dynamical force acting between the contacts is proportional to i^2 and co-operates with the heating in increasing the contact resistance, until it succeeds, if the case may be, in moving the contacts so causing their separation and arcing thereby. If this occurs, the energy acting between the contacts during their separation is expressed by $\int_{ta} v_a \, i \, dt$, if t_a is the arc duration and v_a the arcing voltage between the moved contacts.

A value of overcurrent may be individuated for a definite mechanical switching device, starting from which the separation of the contacts by electro-dynamical force initiates since such a force prevails on the contact force. Larger overcurrents for unaltered durations produce larger repulsion forces for longer durations.

CURRENT-LIMITING FUSES FOR CONTACT PROTECTION   The use of current-limiting fuses is of most practical interest for protection of mechanical switching devices.

An apparently prominent condition takes place when the fuse is such as to initiate its current-limiting effect (cut off) with currents around the value, for which contact separation by electrodynamical force starts [1]. By such values of overcurrent the movement of the contacts does not take place,

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or it is negligible, but the increase of contact resistance due to reduction of the resulting contact force, as a consequence of the electro-dynamical repulsion, gets its maximum.

With larger overcurrents, the maximum duration allowed for them by the fuse operation decreases, since the condition of substantially constant I^2t maximum total let-through with increasing prospective currents is approached.

On the other hand, the ratio between the duration of the time, for which the instantaneous values of the overcurrent exceed the value by which electro-dynamical repulsion initiates prevailing, and the total duration permited by the fuse for the overcurrent increases with increasing prospective currents. As a consequence, the amount of energy acting between the displaced contacts is expected to increase for overcurrents moderately exceeding the value by which electro-dynamical repulsion starts to prevail, but it stops increasing and even it starts decreasing with larger and larger prospective currents. In fact the condition of constant I^2t maximum total let-through for the operation of the fuse implies decreasing of $\int_{t_a} v_a\, i\, dt$, v_a being not too variable with increasing currents.

Figure 1 shows the maximum duration of the time, for which the force due to electro-dynamical repulsion prevails on the mechanical contact force, as a function of the prospective current, for a mechanical switching device defined by the current causing an electro-dynamical repulsion equal to the mechanical contact force, and protected by a fuse of the current-limiting type. It is assumed that the current is made with a making instant, suitable to allow its maximum possible value to be attained, and that the cut off effect initiates to take place at the current for which electro-dynamical repulsion equals the mechanical contact force. The diagram shows a well definite maximum.

The conditions of maximum stress for the contacts are to be expected to occur within a range of overcurrents included between a value around that for which electro-dynamical repulsion equals the mechanical contact force and the value to which the maximum duration of arcing between displaced contacts corresponds.

If contacts are liable to welding, the most favourable conditions for getting the contacts welded, within the above range of overcurrents, depends upon the parameters governing the movement of the contacts back to touch together, when the repulsion force has subsided, then upon the time required for that, with reference to the duration of the current.

The behaviour of this phenomenon can be predicted with adequate accuracy by calculation with reference to specific defined conditions, among which the parameters of the mechanical system bearing the contacts have to be taken into account together with the parameters governing the behaviour of the current in the electric circuit protected by definite fuses [2, 3, 4, 5]. Within the scope of this paper, the consideration is limited to the behaviour of fuses in the particular application.

EXPERIMENTAL RESULTS As an experimental confirmation of the above considerations, tests have been carried out taking as typical mechanical switching device contactors of ordinary construction and of different current ratings, protected by standard fuses of current-limiting type and of different ratings.

For testing, fuses were replaced by an appropriate special device [6], suitable for reproducing the intended operating characteristics of fuses with appropriate accuracy, i.e. within a tolerance appreciably more restricted than that admitted by the Standards on fuses (IEC Publ. 269-1/2).

Diagram of figure 2 shows the results of tests on a contactor rated 50 A, for which the current (r.m.s. value) causing electro-dynamical repulsion substantially equal to the mechanical contact force is 5 kA. The contactor is protected by a standard fuse rated 125 A, for which the maximum total let-through I^2t in adiabatic conditions of operation is about 95 kA^2s.

The instantaneous values of the current through the contactor and of the voltage across the contacts, the final values of I^2t let-through, resulting by $\int_t i^2 dt$, of energy stressing the contacts, resulting by $\int_{t_a} v_a i\, dt$, and $\int_t r_c i^2\, dt$ were recorded at each test by the appropriate application of a computer [7]. The amount of this energy is reported in ordinate of the diagram, where the prospective test current is in abscissa. The making instant of the test current was pre-determined for each test with the aim at attaining the maximum expected total I^2t let-through.

When welding of contact occurs, it may result in a definite reduction of the amount $\int r_c i^2 dt$, for unaltered total I^2t let-through, due to the reduction of the contact resistance following the welding. In other cases the end of the let-through current leaves the contacts welded together, but the amount of energy required for this result is appreciably higher, as corresponding to $\int v_a i\, dt$. In such cases welding has occurred when contacts have come back to touch together, after a time of arcing due to repulsion. In many other cases, with higher currents, the arcing energy $\int v_a i\, dt$ did not give rise to welding.

CONCLUSIONS It may be stated as a conclusion:

a) when contacts are liable to welding, the most appropriate fuse [1] for protection is that, for which the current-limiting effect (cut off) initiates with currents approaching the value, by which electro-dynamical repulsion starts prevailing on the mechanical contact force.

According to the ratio between such a current and the rated current of the mechanical switching device, the above criterion may imply (and it implies in general for mechanical switching devices of particular design, as are contactors) de-rating of them with regard to normal service current, since fuses of rated current less than the rated current of the protected mechanical switching device are required.

Appropriate design of the mechanical switching device may reduce this inconvenience or overcome it at all. If contacts are less liable to weld ing, fuses of larger rated current can be used, but they allow for higher deterioration due to arcing during overcurrents.

b) tests for checking suitability of co-ordination between fuses and mechanical switching devices to be protected are to be made with currents around the value, which initiates contact separation by electro-dynamical repulsion, in moderate excess to this value.

Test at higher currents, up to the prospective current for which the combination of the mechanical switching device with the fuses is required to be suitable, are not strictly required when the above specified tests are passed successfully, since stresses on contacts and likelihood of welding, if the case may be, do not increase or even they substantially decrease with increasing currents, when fuses are characterized by operation with maximum total I^2t let-through being constant at large overcurrents.

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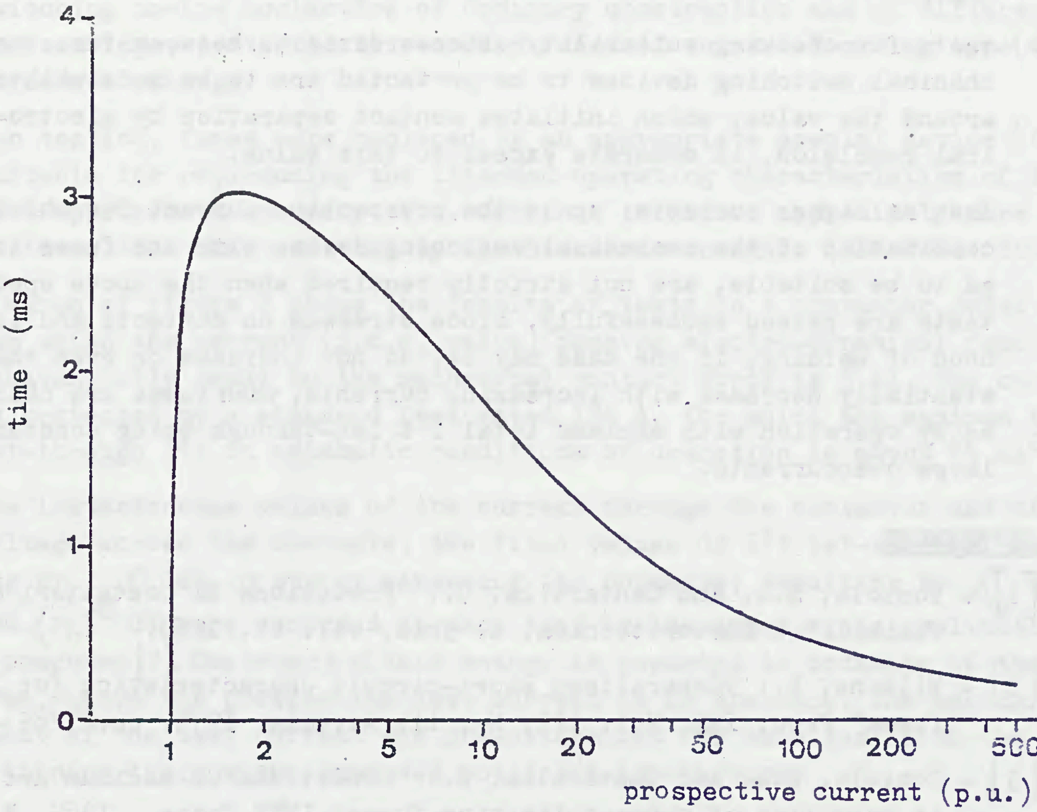

Fig. 1
Maximum duration of the time for which the force due to electrodynamical repulsion prevails on the mechanical contact force, as a function of the prospective current, for a given power factor (cosφ = 0.2). Prospective currents are referred to the r.m.s. value of the current for which these forces are equal

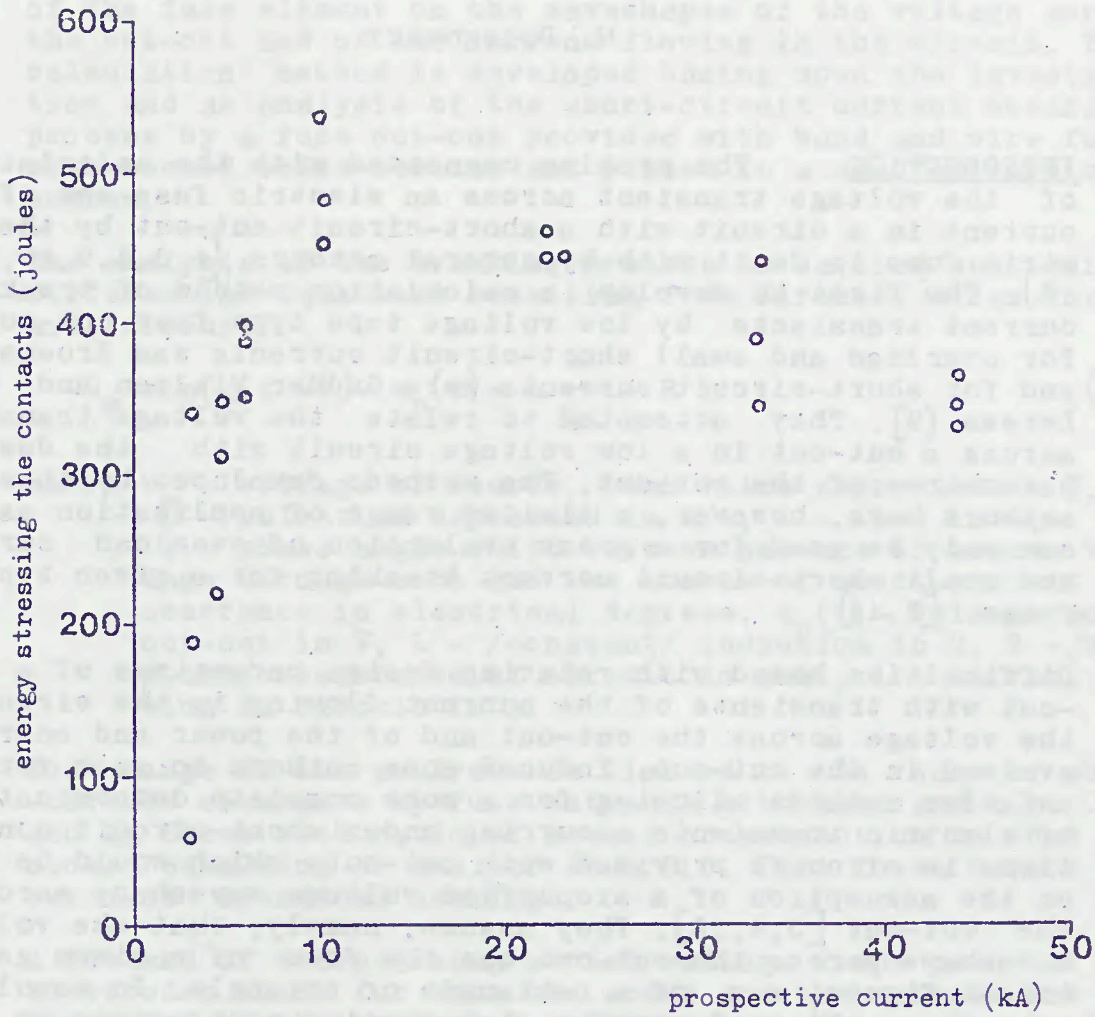

Fig. 2
Energy stressing the contacts of a contactor rated 50 A, as a function of the prospective test current