STARTERS PROTECTED BY FUSES

THERMAL STRESS ON OVERLOAD RELAYS DURING SHORT CIRCUIT CURRENTS

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SUMMARY : As well known, the stress and damage that short circuit currents can cause to contactors and their thermal overload relays are directly connected to the rating of the protective fuses.

In this study, a particular attention is paid to the phenomena which concern the thermal overload relays when the rating of the protective fuses is much higher than that of the relay, until 4 times.

1. - PRELIMINARY

On determining the co-ordination between starters and protective devices against short circuit, the Italian rules (CEI 17.7) and the International ones (IEC 947.4) supply the parameters which enable to verify, either experimentally or theoretically, the correctness of the combination. They are the tripping characteristics of the thermal overload relay in the range of the overload currents that the contactor is capable of breaking and that of the short circuit protective device when higher currents occur.

The protection of the starters against short circuit currents is entrusted to fuses or circuit-breakers; however, fuses represent the protective device which is used still today in the majority of the cases.

For example, in figure 1 the average time/current characteristic of a thermal overload relay of a starter having a current setting range 38-60A, set at 50A, and that of a 80A fuse type gG are compared.

The intersection point Ic_1 of the two characteristics marks the boundary of the respective breaking ranges of the two devices, and has to correspond (according to the prescriptions of the above mentioned rules) to the maximum breaking capacity of the contactor of the starter : in this case to the value of 650A.

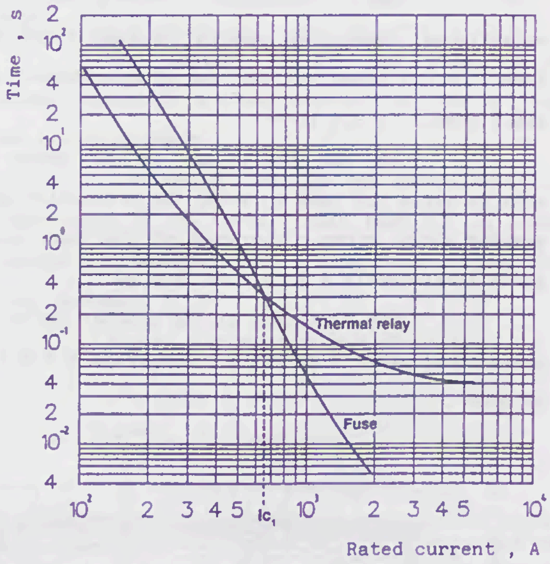

Figure 1 - Average time/current characteristic of a thermal overload relay having a current setting range 38-60A, set at 50A, and that of a 80A fuse type gG.

The subject of this study are the applications in which the rating of the fuses is much higher than that of the thermal overload relay, which is, therefore, submitted to particularly heavy stresses when fault overcurrents occur.

The study has a fair interest because these applications are specifically provided for in the co-ordination requirements of some International standards, such as those of CSA C22.2-14 and UL 508. One of the conditions prescribed by the above standards is the non-damage of the relay in order to consider the co-ordination as valid.

To this scope, according to the European practice, fuses type aM are chosen with a rated current equal to that of the motor full load current, while fuses type gG are sized from 1,5 to 2,5 times the motor current.

CSA and UL standards establish, on the contrary, the use of delayed fuses sized 2,25 times the motor current, and non-delayed fuses sized 4 times, for the verification of the co-ordination.

This last value can decrease to 2,25 times, but this degrading has to be shown in the nameplate of the starter including the data of the thermal overload relay.

The Canadian Electrical Code establishes, then, the use of delayed fuses sized from 2 to 2,5 times and the use of non-delayed fuses sized from 3 to 3,5 times.

In the following, it is taken into consideration the case in which the protective device against short circuit currents of the same starter above mentioned is a 200A fuse type gG.

The contactor of the starter has a rated operational current of 63A in categories AC3 and AC4, at 500V .

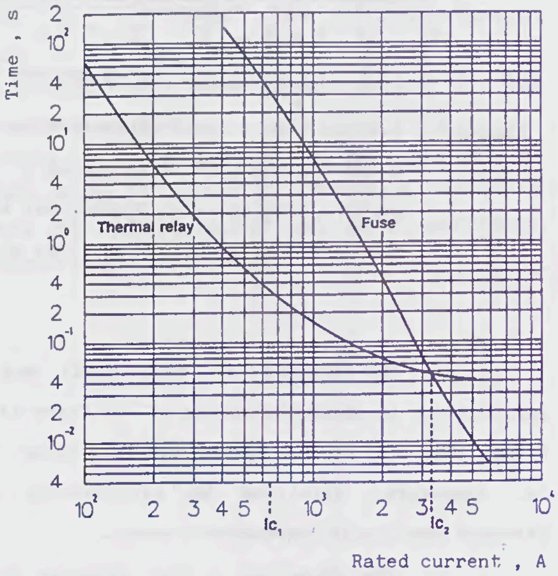

Figure 2 - Average time/current characteristic of a thermal overload relay having a current setting range 38-60A, set at 50A, and that of a 200A fuse type gG.

From the comparison of the time/current characteristics of the thermal overload relay and that of the fuse, represented in figure 2, it clearly results that the contactor is required to operate before the fuse when fault currents higher than 650A, i.e. higher than its breaking capacity, occur.

We shall distinguish two conditions of behaviour of the contactor when fault currents included between the value corresponding to its breaking capacity (650A, point Ic_1 of figure 2) and the intersection point Ic_2 (3300A, figure 2) flow through it .

The conditions which can prolong the duration of the fault current are the following :

(a) **Welding of the contactor contacts** : phenomenon which can happen as soon as it manifests a fault current enough to cause the repulsion of the contacts owing to the electrodynamic effect.

This value of current differs from contactor to contactor and rises with the contactor's size.

With reference to the above contactor of the starter, this possibility can occur beginning from a current of 2500A (instantaneous value), corresponding to a current of 1500A (r.m.s value) with power factor 0.5.

This result is drawn from a previous experimental study (6), carried out on 120 contactors of different type and rated current, which enables to establish statistically the value of the repulsion current as a function of the contactor's size, as it can be observed in figure 3, drawn from this study.

(b) **Persistent arc between the contactor contacts** : phenomenon which can happen during breaking operations, if welding does not occur prior, controlled by the thermal overload relay with fault currents higher than the breaking capacity of the contactor itself.

This risk is as much higher as the fault current is near enough to the value Ic_2 of figure 2.

In both the above-mentioned cases, the thermal overload relay is no longer capable of protecting itself.

The fault current will continue to flow in the circuit until the operation of the fuses.

The thermal stress, due to the persisting current, may cause remarkable damages to the thermal overload relay and even cause the melting of it in case the I^2t let through is higher than the one tolerable by the temperature sensitive element of the relay itself.

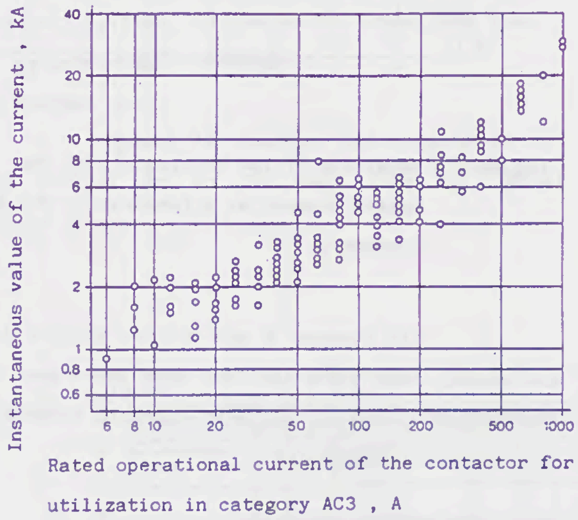

Figure 3 - Current causing contact separation by electrodynamic effect as a function of the rated operational current of the tested contactors .

The melting I^2t of the temperature sensitive element is a parameter that is clearly definable at level of project, but its definition in an experimental way allows to acquire in addition to the confirmation of the design calculations, further data like as: reliability of the construction, presence of weak parts, imperfection of the weldings or the connections to the incoming and outcoming terminals.

In any case, it is a question of a non-negligible factor of knowledge in the set up of the prototypes and in the settlement of the co-ordination between starter and device for the protection against short circuit.

According to this point of view, an investigation was carried out on the whole line of thermal overload relays, manufactured with the conventional technics of the bimetal element and the heater element, in order to verify the melting I^2t for each element and to define by consequence the fuses which enable to exclude the probability of such melting, whatever the value of the fault current may be.

2. - TESTS CARRIED OUT

The above-mentioned relays were deprived of the tripping device before carrying out the tests.

The incoming and outcoming terminals of each thermal relay, mounted in its plastic housing, were supplied by a single-phase alternating current at 50Hz.

The testing current was made by an auxiliary equipment and switched off by the melting of the heater element.

The supply voltage was maintained, in the major part of the tests. lower than 60V in order to reduce conveniently the arcing time during the melting process.

Figure 4 shows the test circuit.

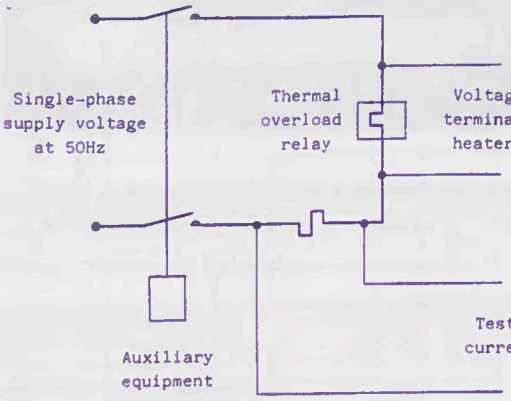

Figure 4 - Test circuit

For each type of heater element, several tests were carried out with values of current increased step by step.

Figure 5 shows a bimetal element complete with its heater element of wounded wire, before the test.

In figure 6, that shows the same element after the tests, the melting of the heater element can be seen.

In each test, the test current, the voltage at the relay terminals, the values of the prearcing time and of the energy which caused the melting of the heater elements were recorded by means of a data acquisition system and a transient recorder.

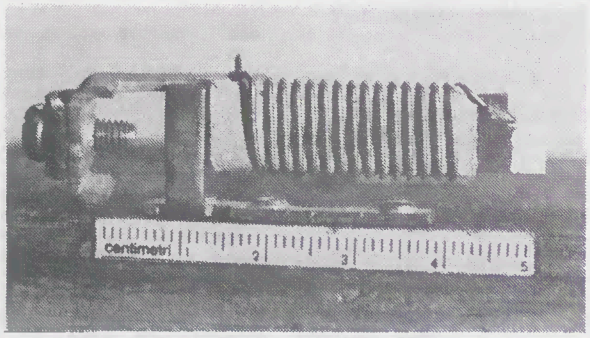

Figure 5 - Bimetal element complete with heater element of wounded wire, before the test .

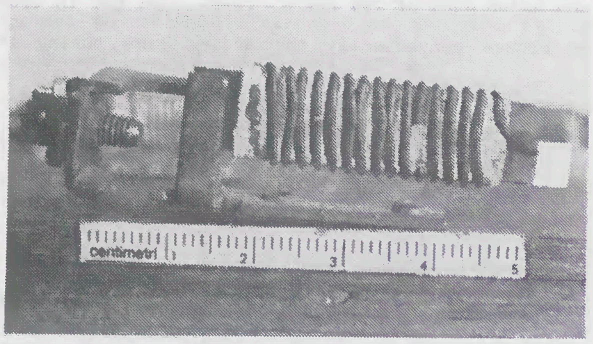

Figure 6 - Bimetal element complete with heater element of wounded wire, after the test. The melting of the heater element is evident .

From the examination of the test results, it was noticed that, at the rising of the test currents, the melting I^2t decreases progressively of intensity, so much that it reaches a value that remains pratically steady, as it can be seen, by way of example. in the graphic representation of figure 7, related to a thermal overload relay with current setting range 29-47A.

The same behaviour was found out in all the tested samples.

About 20 measurements of the melting I^2t at the changing of the test current were made on each of 22 tested samples.

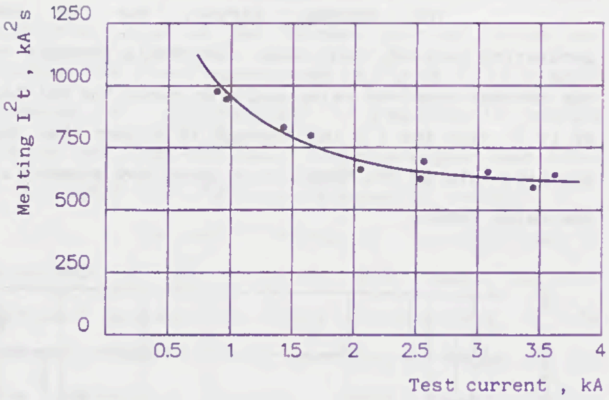

Figure 7 - Behaviour of the melting I^2t of the heater element as a function of the test current .

In figures 8 and 9, two typical tests are shown, that refer to the same above-mentioned thermal relay, carried out with currents of 950A and 3600A (r.m.s.) respectively.

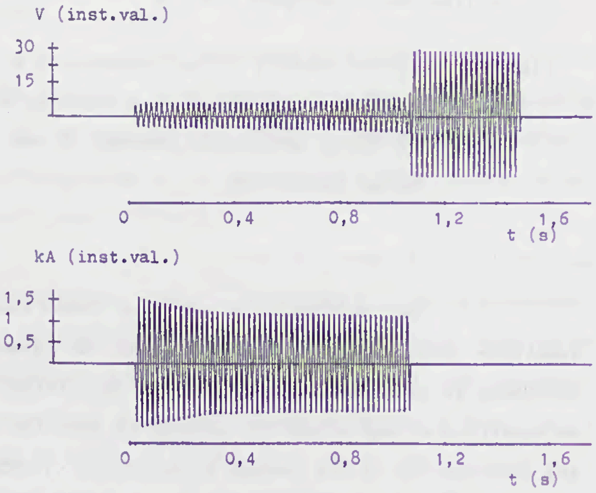

Figure 8 - Test carried out with current 950A

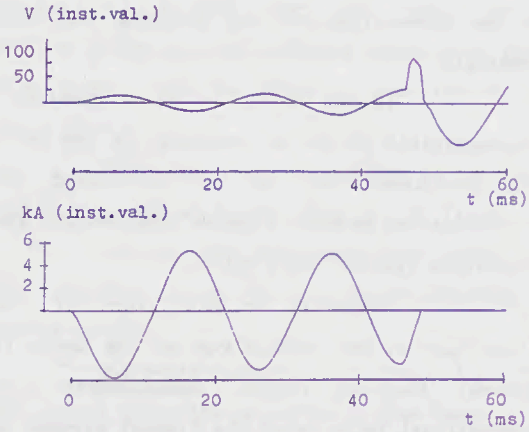

Figure 9 - Test carried out with current 3600A

The equivalent value of the test current was obtained from the relation :

$$I_{eq.} = \sqrt{\frac{I^2t}{t}} \qquad \text{where}$$

I^2t = thermal stress which caused the melting, experimentally determined

t = melting time, limited to the pre-arcing time, experimentally determined

Figure 10 sums up the results of the tests carried out on the whole line of thermal overload relays. .

Each thermal relay is represented by a thick line, parallel to the axis of abscissas, the extremes of which define the current setting range of the relay, while the value of the melting I^2t is plotted in ordinate.

In the same graph, the values of the melting I^2t of the fuses were plotted (pre-arcing I^2t + arcing I^2t at 500V), either of aM type or gG type, as a function of their rated current.

The above-mentioned values of the fuses were taken from catalogues of some European Manufacturers.

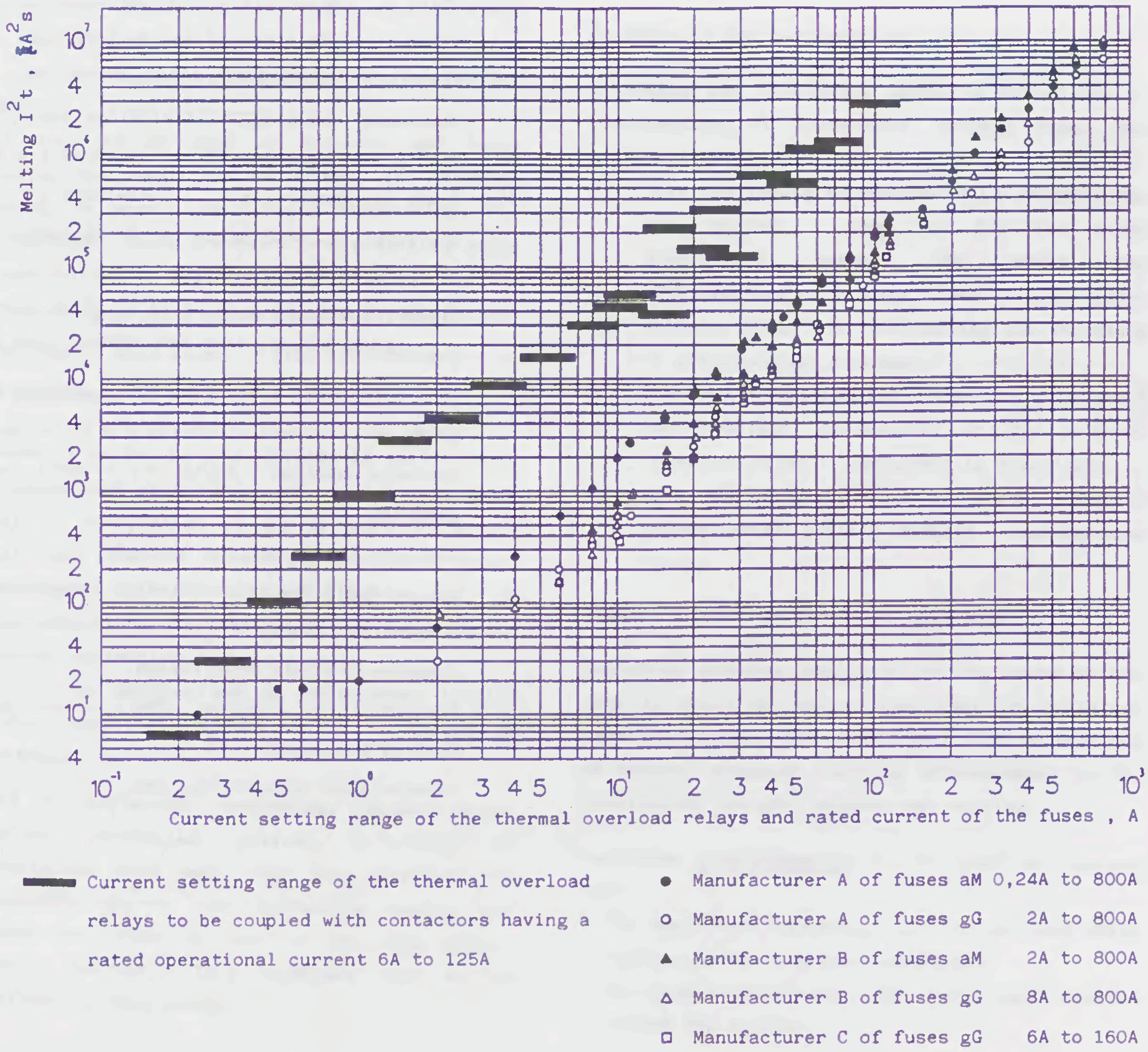

Figure 10 - Comparison of the I^2t causing melting of the heater element with the melting I^2t of the fuses

3. - CONCLUSION

With reference to the above mentioned considerations, it is possible to evaluate graphically the rating of the fuse which guarantees the non-damage of the thermal overload relay when conditions of particular stress occur in presence of the above-described fault currents.

The I^2t let flow by the protective fuse has to be always lower than the melting I^2t of the thermal overload relay.

The Authors wish to thank Prof. G. Cantarella and Dott. G. Farina for their valuable advices.

4. - REFERENCES

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