CONTACTORS PROTECTED BY FUSES: RISK OF CONTACT WELDINDG

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Summary

The risk of contact welding of contactors protected by fuses, when a short circuit occurs, is strictly dependent on the electrodynamic force acting on the contacts of the contactor, the rating of the protective fuses and the value of the prospective short circuit current.
The phenomenon has been dealt with by many authors; some papers on the subject are herewith quoted.
In this paper the results are reported of numerous short-circuit tests performed on contactors protected by fuses, which confirm the considerations made by the above authors.

A brief description of the test carried out on 70 types of contactors, made by 16 different manufacturers with overcurrent up to 50 kA (r.m.s.) at 418 V (1.1 x 380), 50 Hz, is presented.
The results of the tests are illustrated by comprehensive diagrams. In particular the diagrams show:

- the instantaneous value of the current for which the separation of the contacts by electrodynamic effect occurs on each type of contactor;
- the maximum rating of the protective fuses that prevented the tested contactors from contact welding, as a function of the rated operational current of the contactor, for utilization category AC 3;
- the minimum rating of the protective fuses which produced contact welding as a function of the above rated operational current of the contactor.

At last, a comparison is made between the shown test results on contactors protected by fuses and the prescriptions of the new IEC Standards 947-4 (IEC Standards 947-4: Low-voltage switchgear and controlgear. Contactors and motor starters).

1. General

In most application, contactors and motor starters are protected by fuses against short circuit currents.
Fuses are suitable for preventing excessive damage to the contactor or its parts. In particular they are capable of limiting the thermal and electrodynamic stresses which can cause the contact welding of the contactor. In the present paper for contact welding is intended a stable union of the contacts, which cannot be easily broken by repeated operations of the contactor control circuit. In other words a welding is meant, which requires the use of a tool for the contact separation, although it also is not always effective.

2. Test carried out and relevant methods

The tests were made on 80 types of contactors of 16 different manufacturers and current ratings in accordance with the following table no. 1.
The tests were carried out with alternating current at 418 V (1.1 times the rated voltage), 50 Hz, on a single phase circuit, with overcurrents up to 50,000 A (r.m.s. value of the symmetrical component of the prospective current). The power factor was 0.5 up to 10,000 A, 0.3 from 10,000 to 20,000 A and 0.25 from 20,000 A up to 50,000 A.
The circuit comprised one pole of the contactor in series with a protective fuse, as shown in figure 1. The contactor was in the closed position before the initiation of the overcurrent. The supply source of the electromagnet of the contactor was independent of that of the test circuit.
The tests were repeated under the same conditions on all the poles of the contactor.

Table 1

Manufacturers of contactors	Rated operational current of the contactors tested, for utilization category AC3 (amperes)																						
a				12			25		40		63		100		160		250		400		630		
b		8		12			25			50		80		125		200	250						
c					16	20		32	40		63		100		160		250		400				
d					16	20			40			80		125		200							
e		8				20			40			80			160			315			630		
f								32		50		80			160		250		400				
g			10			20	25	32	40	50		80	100		160		250				630	800	1000
h							25			50				125									
i				12								80						315					
l	6		10		16		25		40	50		80	100										
m															160		250		400		630		
n					16		25	32	40		63	80	100	125	160		250			500	630		1000
o		8		12	16	20		32		50	63	80											
p										50	63	80		125	160		250						
q									40		63			125		200		315				800	

Before any test were carried out, 100 opening and closing cycles were made on each contactor at the rated current and voltage, rated frequency and power factor approaching unity, in order to standardize the initial conditions of the contacts. It has been intended, in such a way, to minimize any accidental differences existing on new contacts which could reduce the reliability of the results.
The instantaneous value of the minimum current for which separation of the contacts by electrodynamic effect occurs was first determined on each individual pole of each contactor.
The importance of the knowledge of such a current

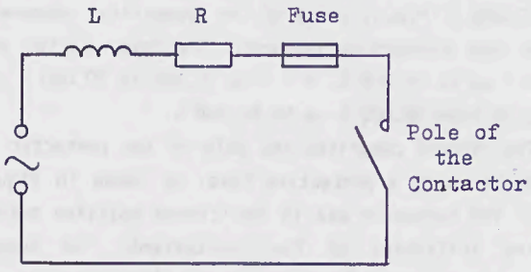

Fig. 1 - Test circuit comprising one pole of the contactor under test and the protective fuse.

value has been discussed in previous papers (1). (2): here is sufficient to remind that the contact welding of the contactor is more probable for short circuit current values near to that for which separation of the contacts by electrodynamic effect occurs, than for greater prospective currents.
The determination was made by means of a suitable equipment causing a sinusoidal half wave of current of given amplitude, at 50 Hz, to flow through the contacts of the pole of the contactor.
The current amplitude was gradually increased, test by test, in successive tests and the voltage drop across the contacts was observed: contact separation is indicated by a sudden increase in the voltage drop, as can be seen in figure 2.
The found values differ, by a few percent, from pole to pole of the same contactor. In the diagram of figure 3, the minimum recorded for each contactor is reported as a function of its rated operational current for utilization category AC 3.
The reported data of the same diagram were smoothed by the least squares method and represented by a dashed straight line statistically equivalent.
The behaviour of each contactor protected by fuses under short circuit conditions was then examined.
The values of prospective test currents were selected for each contactor in the range comprised between a minimum current value slightly lower than

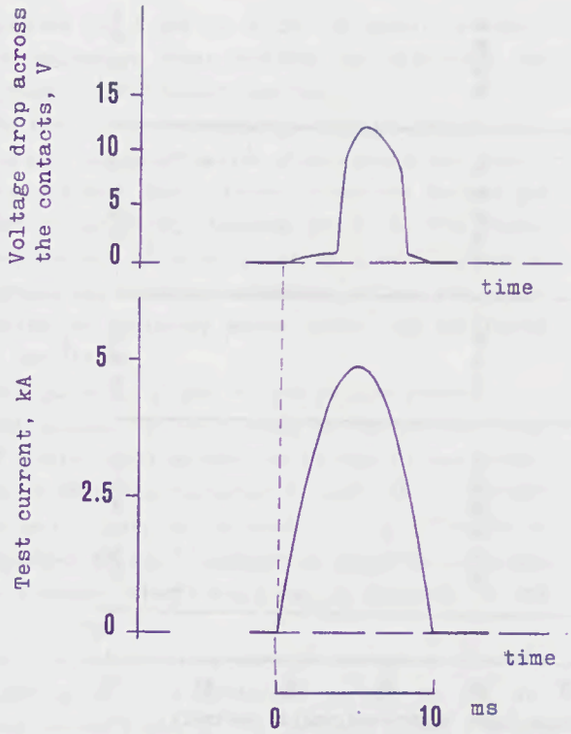

Fig. 2 - Test current and voltage drop across the contacts of a contactor which separate and then return to touch.

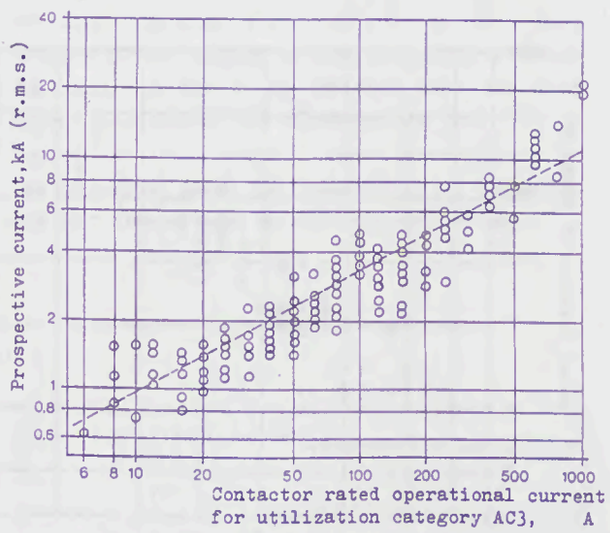

Fig. 3 - Current causing contact separation by electrodynamic effect as a function of the rated operational current of the contactors tested.

that which starts separating the contacts of the contactor by electrodynamic effect and a maximum current value stated in 50,000 A (r.m.s. value of the symmetrical component of the prospective current).

The fuse-links put in series with the contactors were of current limiting type, general purpose application, in accordance with IEC Standards. Their rated current was selected according to the instructions of the contactor manufacturer for a first series of tests, which were carried out in the above range of prospective currents. The fuse rating was then increased or decreased dependently on the results of the first series of tests, for making further series of tests under unaltered remaining conditions.

As a common, general result it can be stated that:

- for prospective currents not causing contact separation by electrodynamic effect no contact damage occurred;
- in the range of prospective currents within which contact welding was expected (1). (2), this occurred;
- for larger prospective currents only erosion of contacts occurred.

Figure 4 shows, for example, the behaviour of the above listed contactors rated 400 A made by four different manufacturers. As the current rating of the protective fuse increases the range of prospective currents within which contact welding occurred becomes wider.

In the diagram the values can be seen of:

- the maximum rating of the fuse which prevented contactors from contact welding under short circuit currents;
- the minimum rating of fuse which produced contact welding of the contactors.

Figure 5 shows, as a compendium, the maximum rating of fuses which prevented the tested contactors from contact welding as a function of their rated operational current for utilization category AC 3. Note that for many contactors, especially the larger ones, the rating of the protective fuse may become lower than that of the contactor. This fact leads to a certain derating of the operational current of these contactors when a significant reduction of the risk of contact welding is desired.

Figure 6 shows, comprehensively, the minimum rating of fuses which produced contact welding of the tested contactors as a function of their rated operational current for utilization category AC3.

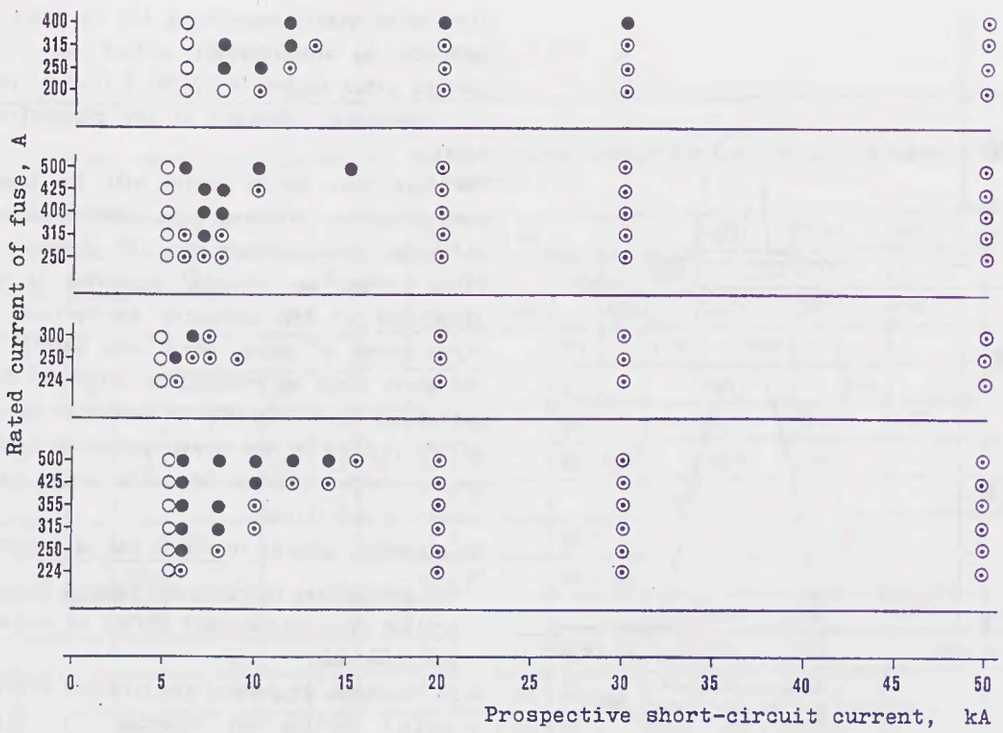

Fig. 4 - Results of tests carried out on 4 types of contactors rated 400 A and protected by fuses of various current rating:

- ○ no damage to contacts
- ● welding of contacts
- ⊙ erosion of contacts

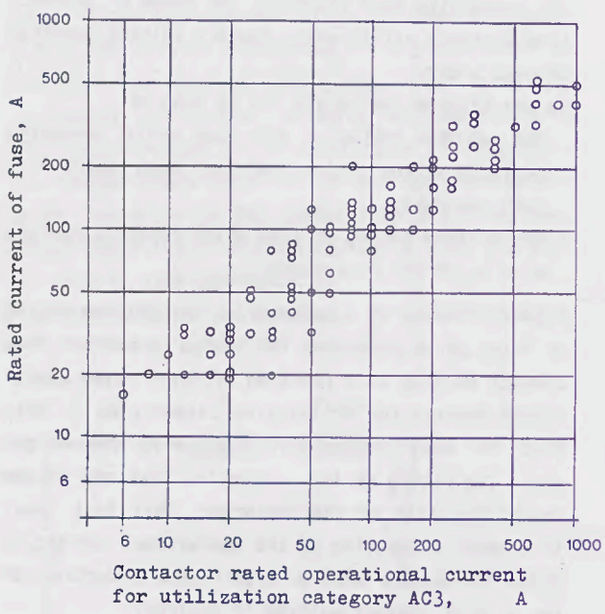

Fig. 5 - Maximum rating of fuses which prevented the tested contactors from contact welding as a function of the rated operational current for utilization category AC3 of the contactors tested.

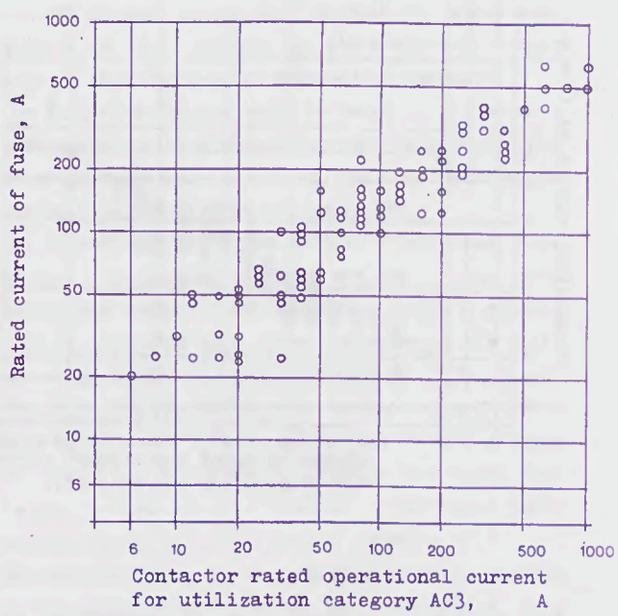

Fig. 6 - Minimum rating of fuses which produced contact welding of the tested contactors as a function of the rated operational current for utilization category AC3 of the contactors tested.

Diagrams no. 5 and no. 6 can be useful to choose the protective fuses suitable for preventing the contactors from contact welding.

The new (1990) international standardization dealing with the coordination of contactors and motor-starters with short circuit protective devices has been issued as IEC Standards 947-4. In this Standards methods of testing can be found intended to improve the contactor conditions of use and application for achieving better safety and continuity of service.

Test currents "q" and "r" aim at this purpose.

Test current "q" corresponds to the maximum value of short-circuit prospective current of the installation where the contactor is used. It is intended to verify that, during short circuit, there be no permanent arcing, flashover or ejection of flames or external effects which may be dangerous to the surroundings.

Test current "r" is a current related at discrete steps to the rated operational current for utilization category AC3 of the contactor. Test current "r" values are specified in the following table 2 and shown in diagram n.7.

Since the origins of the Standardization of contactors, test current "r" was intended as a short circuit current causing a high level of stress to the contactor protected by a given short-circuit protective device. With reference to the above considerations related to the protection afforded by fuses, it has to be reminded that the most severe stresses for the contactor are likely to be experienced for a range of these currents near to the current at which the contacts of the contactor are just thrown apart by electrodynamic effect.

Table 2

Rated operational current I_e (AC-3) (A)	Prospective current "r" (kA)
$0 \quad I_e \leq 16$	1
$16 < I_e \leq 63$	3
$63 < I_e \leq 125$	5
$125 < I_e \leq 315$	10
$315 < I_e \leq 630$	18
$630 < I_e \leq 1\,000$	30
$1\,000 < I_e \leq 1\,600$	42
$1\,600 < I_e$	Subject to agreement between manufacturer and user

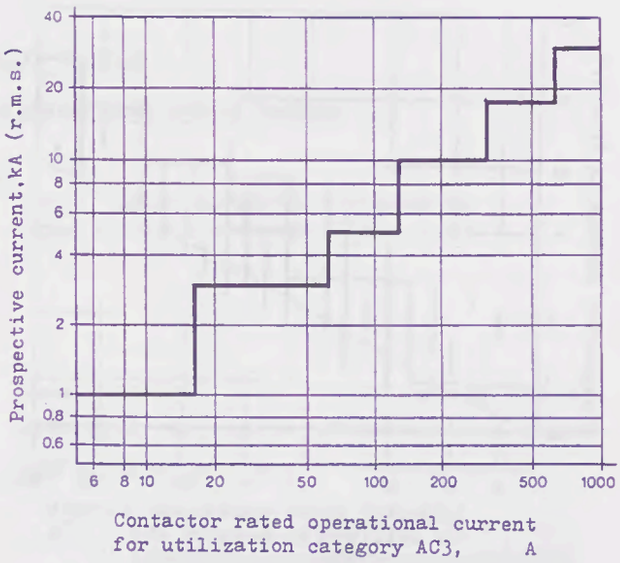

Fig. 7 - Test current "r" at discrete steps as specified in ICE Standards 947-4 as a function of the rated operational current for utilization category AC3 of the contactors tested.

That is particularly true for the risk of contact welding, as can be seen in the above diagram of figure 4.

The opportunity originates from the above considerations of examining whether test current "r", as specified in IEC Standards 947-4, be significant also for the risk of contact welding.

That has been done in figure 8, by comparing the prospective current values for which contact welding were experimentally verified with test current "r" values as specified in the quoted international Standards.

Precisely, in diagram of figure 8, as a function of the rated AC3 operational current of the tested contactors, the following quantities have been plotted for easy comparisons:

- the ranges of the prospective currents of the tests in which contact welding was systematically experienced (the short circuit protective device being the fuse specified in the above diagram of figure 6);
- the test current values "r" at discrete steps as specified in IEC Standards 947-4 (already reported in figure 7);
- the dashed straight line of the above figure 3 statistically equivalent to the current values for which contact separation of the tested contactors occurs.

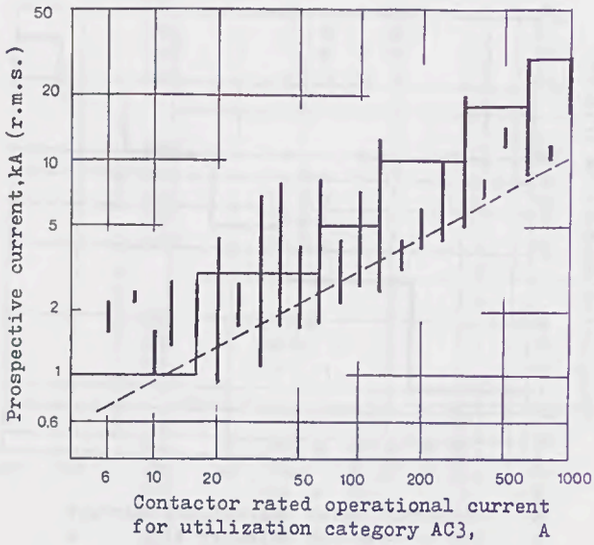

Fig. 8 - Comparison of the prospective current values for which contact welding was experimentally verified with the test current "r" values as specified in the quoted international Standards.

It can be observed that "r" prospective test current values practically comply with the above reminded condition of being near (slightly higher) to those values for which the contacts of the contactors are just thrown apart by electrodynamic effect. In addition, they fall in the prospective test current ranges where contact welding was experimentally verified.

Therefore, it can be deduced that the tests made by current values "r" give also significant results as regards the risk of contact welding of contactors in short circuit conditions.

REFERENCES

|1| Toniolo S.B., Cantarella G.: Protezione di contattori mediante fusibili. L'Elettrotecnica - No. 3 bis, vol. LV, 1968.

|2| Cantarella G., Farina, G., Tartaglia M.: Behaviour of contactors protected by fuses during short-circuit currents. Proceedings IEE, vol. 124, No. 12, 1977.

|3| Wright A., Newbery P.G.: Electric fuses. IEE Power Engineering Series 2. Peter Peregrinus LTD,, 1982.

|4| Bellato G., Buccianti R.,: Contattori di bassa tensione; indagine sul mercato italiano. - Elettrificazione, febbraio 1987. pag. 70 - 121.

|5| Arato D., Cantarella G.: Risultati di prove di corto circuito su contattori e rischio di saldatura dei contatti. Rendiconti della LXXXVIII riunione annuale dell'AEI - Catania 1987. Memoria 1.a.3..

|6| IEC Publication 269-1 Second Edition 1986 Low Voltage Fuses. Part. 1: General Requirements.

|7| Wilkins R.: Generalised short-circuit characteristics for h.r.c. fuses. Proc. IEE, vol. 122 No. 11, November 1975.

|8| Turner H.W., Turner C.: Phenomena relating to temperature rise and welding in high current electric contacts. 4th International Research Symposium on Electric Contact Phenomena. 1968.

|9| Turner H.W., Turner C., Williams D.J.A.: Critical parameters influencing the co-ordination of fuses and switching devices. Proceedings of the ICEFA 1987.