# FUNDAMENTAL PRINCIPLES OF CURRENT LIMITING FUSES PROTECTING MOLDED CASE CIRCUIT BREAKERS

JOHN M. ACKERMANN
Bussmann Div. Cooper Industries, Inc.,St. Louis, MO 63178 USA

Abstract-In the past one method of coordinating circuit breakers and fuses has been accomplished through testing according to test agency standards. Fuse-circuit breaker combinations are subjected to a short-circuit without a clear understanding of the outcome of the test. The fuse rating was determined by a process of trial-and-error, that is, the fuse ampere rating was decreased until a combination of fuse and circuit breaker was found that would protect the circuit breaker from damage.

A critical time in the circuit breaker's performance has been identified and it will be shown that the circuit breaker will be protected at any available current if the selected fuse melts prior to the critical time in the breaker's operation. A desired level of protection of a circuit breaker by a fuse will thus be determined by a method other than trial and error.

Circuit breakers with a 10,000 ampere interrupting rating were tested with a series fuse with an available current of 100,000 amperes. All of the circuit breakers were successfully protected at 100,000 amperes by the fuse selected by the methods given in this paper.

## Introduction

This paper addresses the relationship between current limiting fuses and 125 volt molded case circuit breakers when the combination is applied beyond the circuit breaker's marked interrupting rating. The ratio of the instantaneous potential across the circuit breaker and the current through the circuit breaker when the circuit breaker is subjected to a short-circuit is defined as the instantaneous circuit breaker resistance. A point in time has been identified from the graph of instantaneous circuit breaker resistance that is critical to the performance of the circuit breaker and has been labeled as the "critical time". The success or failure of the circuit breaker is determined by its behavior after the critical time. The critical time is a function of the current rating of the circuit breaker, available current and the closing angle of the circuit.

It is common practice to insert a series fuse on the line side of the circuit breaker for the purpose of applying circuit breakers in systems where the available short-circuit current exceeds the breakers interrupting capability. The purpose of the circuit breaker is to protect the load side conductors and the load while the purpose of the fuse is to protect the breaker and down stream equipment. The reason for using fuse-breaker combinations is to obtain higher interrupting ratings at lower cost. The interrupting rating of the combination is determined by the interrupting rating of the fuse when fuses and breakers are applied in series properly. It has been determined that the relationship between the time for the current carrying element of the fuse to melt and the critical time for the circuit breaker is the determining factor for the successful protection of the circuit breaker.

The melting time of the fuse is a function of the ampere rating of the fuse, the available current and the closing angle. The critical time for a circuit breaker and the melting time for a fuse can be represented by a time-current characteristic. When the melting time-current characteristic for a fuse lies below the critical time-current characteristic for a circuit breaker, the circuit breaker will be protected at all levels of fault current, up to the interrupting rating of the current limiting fuse.

Current practice is to use a fuse with a large current rating. A combination of fuse and circuit breaker is tested at the maximum available current for which protection is desired. A small number of tests are conducted without a clear understanding of the outcome of the test and without any knowledge of the margin of protection.

The level of confidence in the coordination of the combination of circuit breakers and fuses selected for circuit protection is increased by the principles given in this paper. The outcome of subsequent fuse-circuit breaker tests can be predicted once the characteristics for the circuit breaker critical time and fuse melting time is determined.

## Procedure

Experiments were performed with circuit breakers rated at 30 and 60 amperes. All measurements were performed at 125 VAC, 60 Hz. The interrupting rating of the circuit breakers was 10,000 amperes (RMS). Test currents ranged from 11,800 amperes (36% P.F.) to 25,200 amperes (21% P.F.). Data was collected for closing angles of 0, 30 and 60 degrees for each of the test circuits. The critical time for a circuit breaker was determined with circuit breakers tested alone. One test was conducted for each circuit breaker rating for each circuit.

The ratio of the instantaneous potential difference measured across the circuit breaker and the current through it yielded the instantaneous circuit breaker resistance. The critical times for each of the tested circuit breakers were determined by graphing the instantaneous resistance for the circuit breaker as a function of time. The critical time can be determined from the instantaneous resistance characteristic regardless of the success or failure of the circuit breaker. The nature of the circuit breaker failures were: ruptured cases, loosened rivets or failure to reclose at the conclusion of the test. There was no attempt to verify the calibration of the breakers at the conclusion of the experiments.

The melting time for fuses in series with circuit breakers were determined at currents ranging from 11, 000 amperes to 25,200 amperes, the same circuits that were used for the circuit breaker tests. A melt time-current curve was generated for the fuses by graphing the time for the fuse to melt versus the available current for each of the closing angles. In most cases more than one fuse was tested for each of the test conditions.

## Results

A critical time was found for each of the circuit breakers as a function of available current and closing angle. The time for a fuse to melt while in series with a circuit breaker was used to construct a melt time-current characteristic for fuses with circuit breakers. A time-current characteristic was determined from the critical time data obtained from the tests of circuit breakers. The proper coordination of fuses and circuit breakers can be determined by graphing the melt time for a fuse in series with a circuit breaker and the critical time for a circuit breaker on the same axis.

The instantaneous resistance for a successful and unsuccessful circuit breaker test is shown in Fig. 1. The critical difference between the successful and unsuccessful circuit breaker performance is determined from the data from these two tests. The point of departure of the two graphs has been identified as the critical time for the circuit breaker. The inflection point, identified as the critical time, can be found from the instantaneous resistance graph regardless of the performance of the circuit breaker.

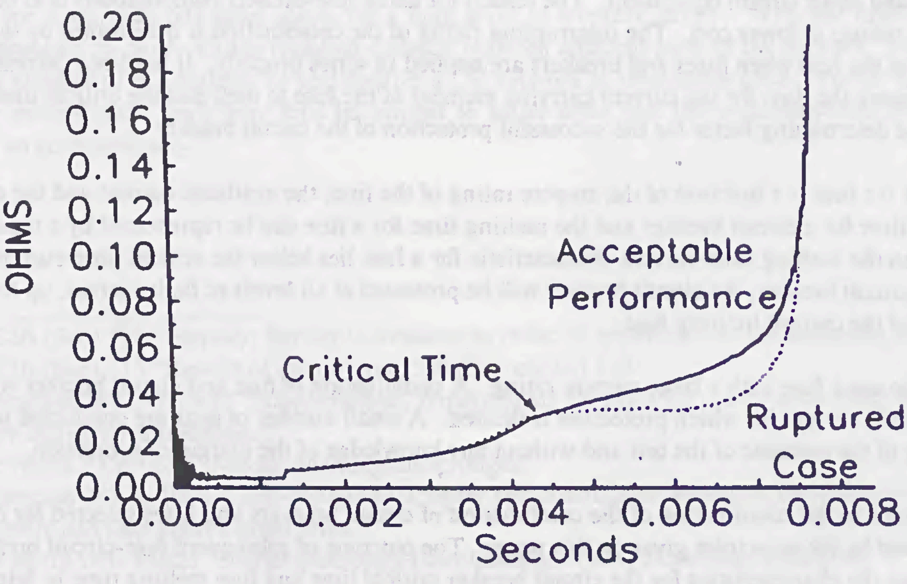


**Fig. 1 Instantaneous resistance versus time for a successful and an unsuccessful breaker test.**

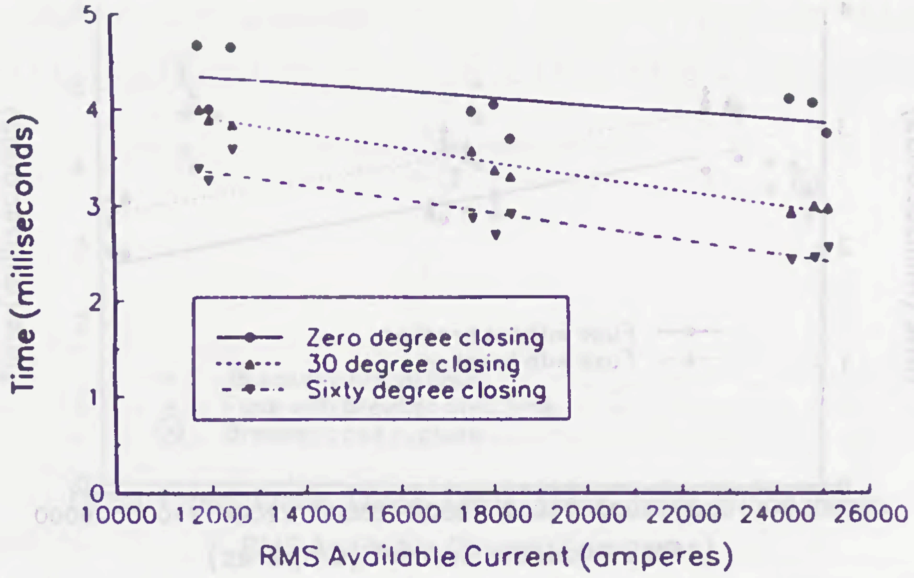


Fig. 2 Critical time versus available current for a 30 ampere circuit breaker.

A graph of critical times versus available current for a 30-ampere circuit breaker is shown in Fig. 2. Results for a 60-ampere circuit breaker are shown in Fig. 3. Both were tested at closing angles of 0°, 30° and 60°.

The time for fuses to melt was determined with a fuse in series with a circuit breaker because of the influence of the circuit breaker on the available current. The contacts of a circuit breaker separate a short time after current initiation resulting in an added impedance to the circuit and as a consequence the rate of rise of current is less than with a fuse alone. The time for a fuse to melt when it is in series with a circuit breaker is a function of the available current.

The time for a fuse to melt is shown with and without a series circuit breaker in Fig. 4. The time for a fuse to melt with a series circuit breaker is longer than the time to melt without a series circuit breaker.

The melt time for a fuse in series with a circuit breaker is also a function of closing angle. Melt time for a typical 200 ampere Class RK1 [1] fuse in series with a 30 ampere circuit breaker is shown in Fig. 5 at three closing angles.

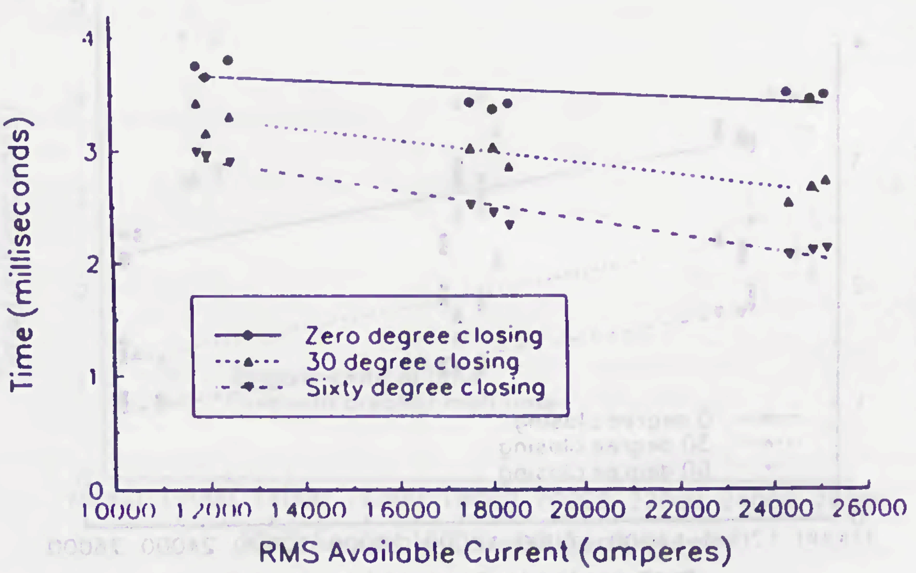


Fig. 3 Critical time versus available current for a 60 ampere circuit breaker.

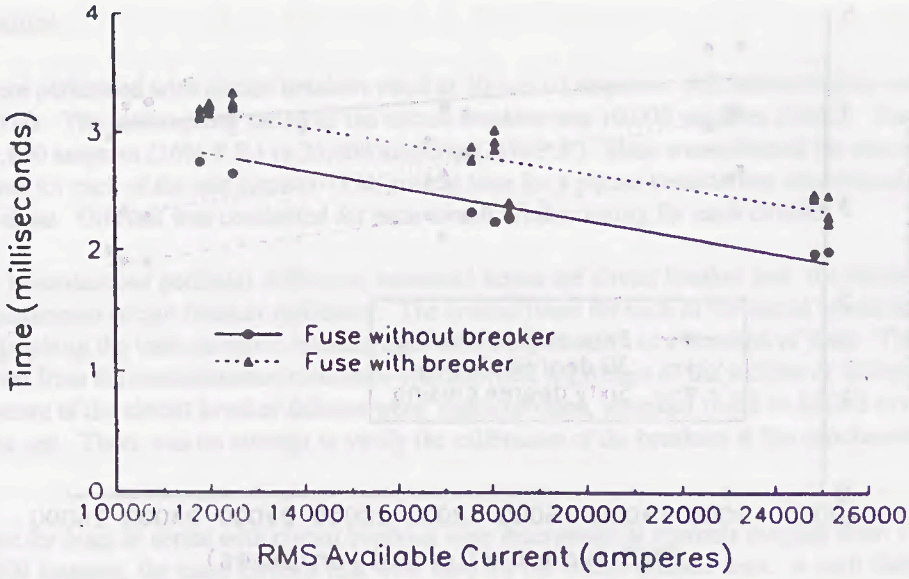


Fig. 4 Comparison of the melt time for a fuse in series with and without a series circuit breaker.

If the critical time-current characteristic for a circuit breaker and the melt time for a series fuse are plotted on the same graph, the level of coordination of the fuse and circuit breaker can be determined. Fig. 6 shows the melt time current characteristic for a 400 ampere Class J [1] fuse in series with a 30 ampere circuit breaker.

The time-current characteristics for the fuse and circuit breaker together shows that the melt time for the fuse is not well separated from the critical time for the circuit breaker. At the 25,000 ampere level (with zero degree closing) a breaker failure (breaker case ruptured) was encountered in this series of experiments. Fig. 6 shows that there are cases in which the fuse melted before the critical time for the circuit breaker. There were also cases in which the circuit breaker opened before the fuse melted. Note that two of three breakers reclosed, did not have loosened rivets and did not rupture the case at the conclusion of the test at the 25,000 ampere. The result of a test with a 400 ampere Class J fuse and a 30 ampere circuit cannot be predicted because there is no clear separation of the fuse melt times and the circuit breaker critical times.

Melt time-current characteristics for a 200 ampere Class RK1 [1] and a 30 ampere circuit breaker are shown in Fig. 7. The graph clearly shows separation between the critical times for the circuit breaker and the melting times for the fuse.

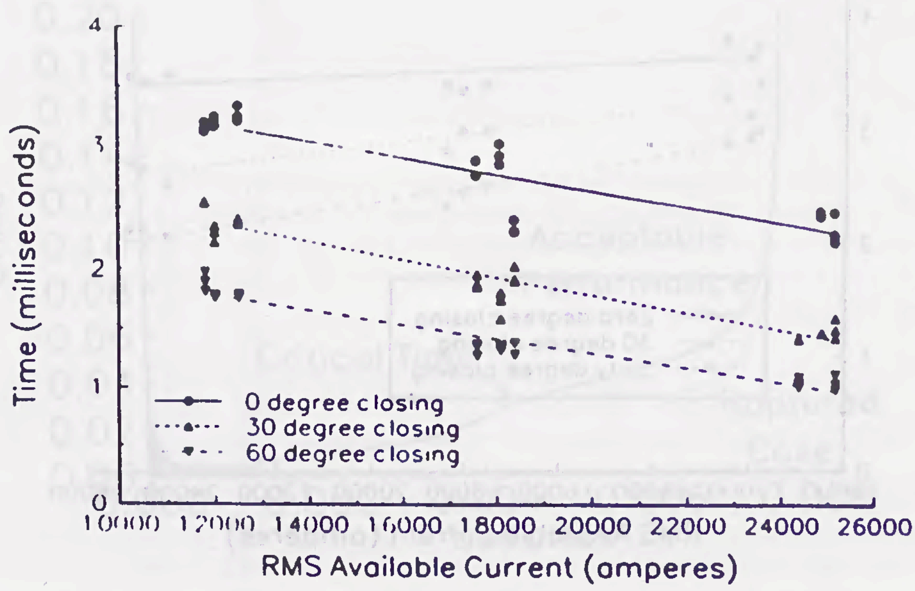


Fig. 5 Melt time versus available current for a 200 ampere Class RK1 fuse.

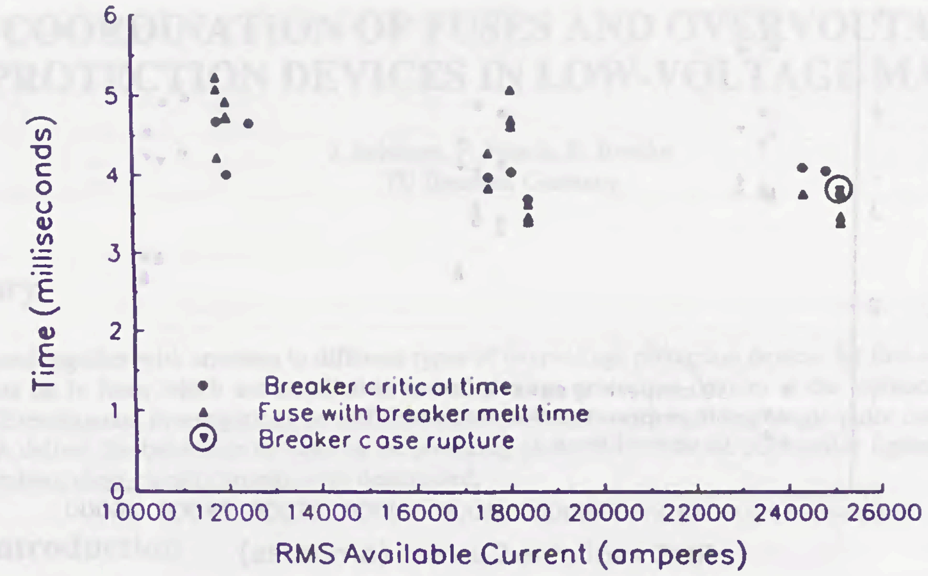


Fig. 6 Critical time for a 30 ampere circuit breaker and the melt time for a 400 ampere Class J fuse.

A comparison of the critical times for a 30 and 60 ampere circuit breaker with the melting time for a 200 ampere Class RK1 [1] fuse are shown for a 0° closing angle in Fig. 8. The definite separation between the melt time for the fuse and the series circuit breaker's critical times can be seen from this graph.

## Conclusions

The trend of the graphs of the critical times for the 30 and 60 ampere circuit breaker suggest that the critical times for those breakers will always be greater than the melt time for a 200 ampere Class RK1 [1] fuse. As a test of the hypothesis, circuit breakers rated at 15, 30, 60 and 70 amperes were tested in series with a 200 ampere Class RK1 [1] fuse with an available current of 100,000 amperes. The assumption was made that the critical time for a 15 ampere circuit breaker was near the critical time for a 30 ampere circuit breaker and the critical time for a 70 ampere circuit breaker was near the critical time of a 60 ampere circuit breaker. 100,000 ampere tests were conducted at closing angles of zero degrees and sixty degrees. At the conclusion of the test all of the circuit breakers were in tact, reclosed and showed continuity.

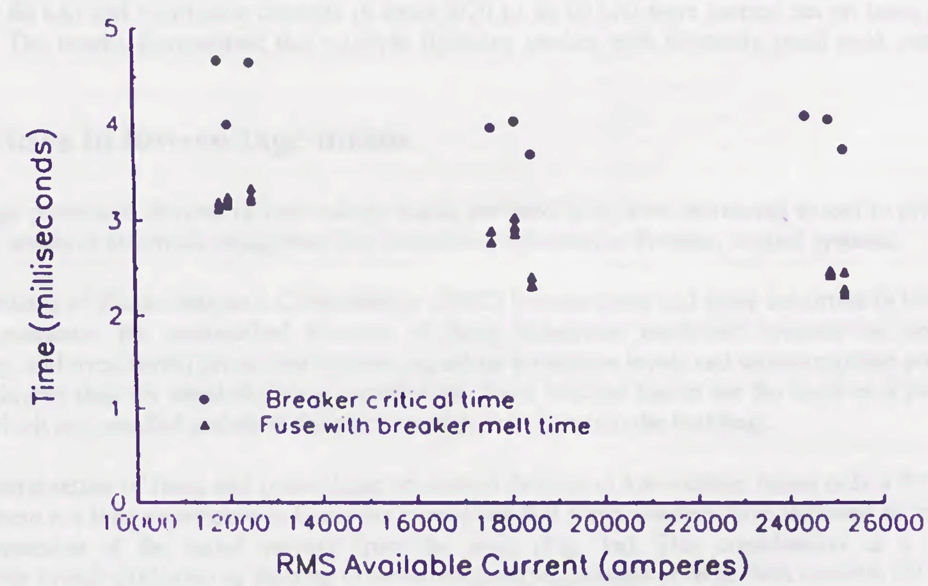


Fig. 7. Critical time for a 30 ampere circuit breaker and the melt time for a 200 ampere Class RK1 fuse versus available current.

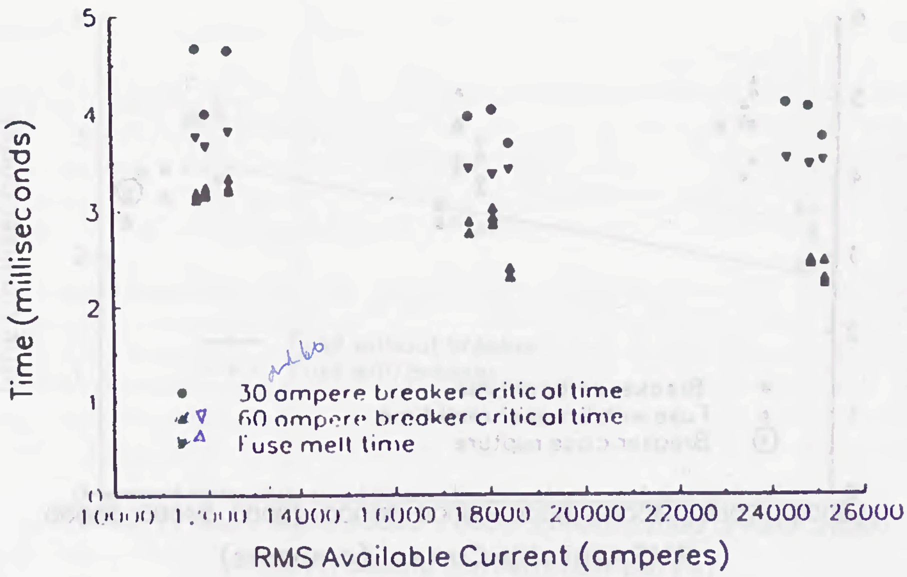


Fig. 8 Critical time for a 30 and 60 ampere circuit breaker and the melt time for a 200 ampere Class RK1 fuse.

This investigation was limited to a single model of circuit breaker from one manufacturer. Circuit breakers of different designs and manufacturers should be studied before applying the techniques described in this paper in general.

The purpose of this investigation was to find a guiding principle for the protection of circuit breakers by fuses when circuit breakers are applied beyond their interrupting capability. A critical feature in the instantaneous resistance characteristic for the circuit breaker proved to be useful when relating the interaction of fuses and circuit breakers. Relating the melt time of the fuse to the "critical time" of the circuit breaker allowed the correct prediction of desired performance at ten times the interrupting rating of the circuit breaker.

## References

[1] North American Harmonized Fuse Standards, Class J 248-8, Class R 248-12.