CYCLIC LOADING OF FUSES FOR THE PROTECTION OF SEMI-CONDUCTORS

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INTRODUCTION In some applications fuses used for the protection of semi-conductors are subjected to overload currents. These over-loads can either be occasional or cyclic and under extreme conditions the thermal excursions caused by the overload may result in undue stress being imposed on the fuse element. This would ultimately cause premature operation of the fuse.

Increasing interest is now being shown in the selection of fast acting fuses for cyclic loading duties. In many applications other factors which significantly affect the choice of type of fuse (ultra fast, fast) and the current rating automatically ensure that the fuse will be capable of withstanding the associated cyclic duty. These are ambient temperature, protection philosophy employed, allowance for mis-sharing between parallel paths etc.

The general U.K. practice for large steel mill drives and similar applications, is to ensure that the fuse only operates when a device fails, and the fuse characteristic is matched against the sum of the total withstand capabilities of all the devices connected in parallel in each arm. In addition it may also be required that in the event of a short circuit at the d.c. terminals or an interconvertor fault, circuit breakers and not fuses operate. The foregoing dictates the type of fuse required and normally fast fuses are employed rather than ultra-fast types. Since, generally speaking ultra-fast acting fuses are more susceptable than fast acting fuses to mechanical fatigue caused by cyclic loading conditions, the above philosophy ensures that the fuses are more capable of withstanding cyclic pulses of current.

It is probable that these factors coupled with element designs that embody a good pulse withstand capability have contributed to the exceptionally good service experience. The number of problems encountered in service has been extremely small. However as the present trend is to obtain greater utilisation of devices, this will in turn be reflected by higher pulsed currents being carried by the fuse. This means that in order to ensure that the past good service record is maintained more attention has to be paid to the pulse withstand capability of the fuse.

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SERVICE PROBLEMS In installed equipments the fatigue failure of fuses can present serious problems because of the necessity of replacement, or the fact that as each fuse operates it may remain undetected until the equipment finally ceases to function thereby causing a serious increase of downtime. Hence it can be seen that it is essential that the fuse selected has an adequate pulse withstand ability.

Outside the U.K. the tendency has been to use ultra-fast acting fuses the philosophy being to ensure that the fuse will protect the device under all fault conditions. It may be because of this fact that more withstand problems have been encountered on cyclic loading duties. Arising from this some equipment manufacturers include a pulse test in the fuse specification, which usually takes the form of subjecting the fuse to a specified number of pulses, in order to assess the suitability of the fuse to withstand the pulses in service.

EMPIRICAL RULES FOR OVERLOADS AND CYCLIC LOADS It must be appreciated that the rated current of a fuse is normally that value of current (r.m.s.) which the fuse can carry continuously without deterioration of the fuse elements occurring. It has been recognised that this test does not necessarily ensure that the fuse is capable of being continuously switched at rated current. In the Standard for semi-conductor fuses (IEC 269-4) the new method of determining rated current is based on the fuse being able to withstand the rated current being switched at least 100 times. In practice with the exception of one or two designs, fuses are capable of a much greater number of operations.

Based on the foregoing and also on service experience and knowledge the following empirical rules were determined.

OVERLOADS (OCCASIONAL) The time-current characteristic which is usually published is an operating characteristic, but it does give some indication of the ability of a fuse to withstand occasional overloads. There is no real difficulty in assessing the ability of a fuse to withstand occasional overloads and the following rule has proved to be a very useful method of selection.

> The r.m.s. current for the duration of the overcurrent must not exceed 85% of the time-current characteristic. If the overcurrent is due to a short circuit at the d.c. terminals, it is also necessary, because of assymetry to ensure that the r.m.s. current of the first pulse does not exceed 85% of the time-current characteristic.

In cases where the duration of the overcurrent is greater than or equal to 1 hour, the equivalent r.m.s. current should not exceed the rated current of the fuse.

For applications where the equipment is liable to frequent overcurrents as distinct from cyclic loads the above factor should be reduced to 70%.

OVERLOADS (CYCLIC LOADS) The selection of a fuse for these particular duties can be much more difficult because of the many variations which can occur. The present recommendations are as follows:-

> Ensure for the ON time being considered that the current pulse does not exceed 40/50% of the time-current characteristic for the same ON time.
>
> The equivalent continuous r.m.s. current should not exceed the rated current of the fuse.

The factor (40/50%) depends on the type of fuse e.g. fast or ultra-fast and also the element design. However there are some applications (highly repetitive duty cycles) where the above factors are inadequate. It is primarily for these cyclic loading conditions that the above rule requires modification and is the reason for the investigations described later in this paper.

BRIEF HISTORICAL REVIEW OF HIGH SPEED FUSES Generally speaking the faster acting a fuse is the more susceptable it will be to cyclic loading. In order to achieve an ultra-fast operation the reduced sections of the elements are smaller than those of the slower fuses. When subjected to a cyclic current pulse, these smaller reduced sections may be subjected to more stress during the heating and cooling periods, and hence have less ability to withstand cyclic pulses.

The historical development of high speed fuses (naturally cooled) with which the author is familiar is shown in Fig.1. Comparing the 2nd and 3rd generations it can be seen that the difference in current density is not as significant as that between the 1st and 2nd generations. This is because by optimising the design parameters the increase in speed has been achieved not only by smaller element reduced sections, but also by improved element design and by enclosing each element in its own fuse barrel. 1)

Based on this fact it is apparent that the current densities in the reduced section cannot be further increased without jeopardising other parameters, and in order to obtain maximum utilisation of these ultra-fast fuses a fairly extensive Laboratory test programme was undertaken to investigate their pulse withstand capability.

LABORATORY TESTS In order to reduce the amount of testing time required particular duty cycles were chosen e.g. 5 seconds ON 5 seconds OFF. This cycle being repeated continuously.

Fast and ultra-fast fuses of various current and voltage ratings were connected in series, and then subjected to a particular repetitive duty cycle, the test being continued until all the fuses had operated. Individual fuses being replaced by copper links when they operated.

The tests were then repeated using different values of current during the ON period again until all the fuses had operated.

These results were then used to plot fatigue characteristics for a given duty cycle. A typical curve is shown in Fig.2. The results show, as expected, that the curve is not asymptotic i.e. silver has not fatigue limit.

A BASIS FOR ACCELERATED CYCLIC LOADING TESTS Obviously verification by test at the longer times on the fatigue characteristic is not a practicable proposition, and because of the shape of the curve it is difficult to predict the withstand capability of the fuse with accuracy.

However it can be stated that the test results approximate to a law of the form:-

$I = aN^{-\theta}$ where I = R.M.S. current for the ON period

a = constant for a given fuse current rating.

N = number of cycles

θ = slope of the characteristics (constant)

Taking logs we obtain:-

$\log I = \log a - \theta \log N$

which is of the form $y = mx + c$

hence re-plotting the test results on a log-log scale will in fact produce characteristics as shown in Fig.3.

Therefore for a particularly arduous cyclic duty it is not unreasonable to determine two or more points for relatively short times. Plot the results on a log-log scale and simply draw a best-fit straight line through the test points. Then by extending the straight line predict the number of cycles the fuse will withstand for a particular value of current during the ON time (Fig.4).

The Laboratory tests have shown quite clearly (Fig.5) that the life of a given fuse can be extended considerably by providing some stress relief bends in the element. The shape and number of stress relief bends being important factors in order to achieve the greatest improvement.

PRESENTATION OF THE CYCLIC WITHSTAND CAPABILITY FOR THE EQUIPMENT DESIGNER. There are so many variations which can occur in service that the information must be relatively easy to understand and use.

1) The information must be presented in such a manner that it is not unduly conservative and hence result in uneconomic designs or pose protection problems.

2) It should also be easy for the designer to equate the information to his particular application.

One way of achieving this is to present fuse characteristics as shown in Fig.6.

In order to take full advantage of the information the equipment designer must first decide on what is a reasonable service life for the fuse and then from a knowledge of the duty cycle, determine how many cycles the fuse will experience during its service life. Then using Fig.6 it is a relatively easy matter to determine, as a function of rated current, the highest pulse the fuse can withstand.

CONCLUSIONS The proposed method of conducting an accelerated cyclic load test should be useful for both the fuse manufacturer and the equipment designer. Using Laboratory test results that can be obtained relatively quickly it enables the life expectancy of a fuse to be predicted for a given cyclic pulse duty.

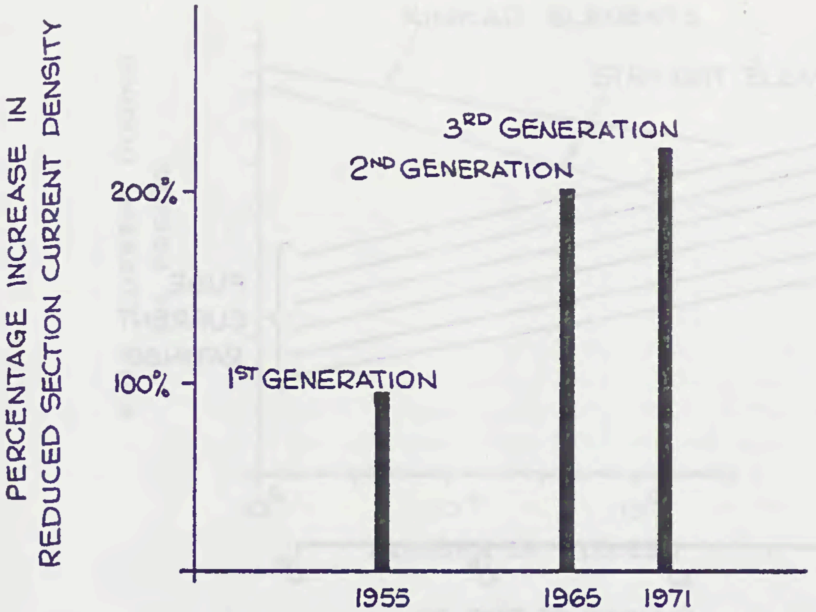
From a knowledge of the element designs for a range of various current ratings, it is possible to construct a family of life characteristics.

A more precise method than the existing empirical rules for selecting fuses to withstand cyclic loading conditions is outlined. Presenting the cyclic withstand characteristics for a range of fuses as shown in Fig.6 allows the equipment designer more scope and flexibility.

Although the withstand characteristics are nominally based on equal ON and OFF times, tests have been conducted with varying OFF times which demonstrate that for practical purposes allowances can be made for these effects.

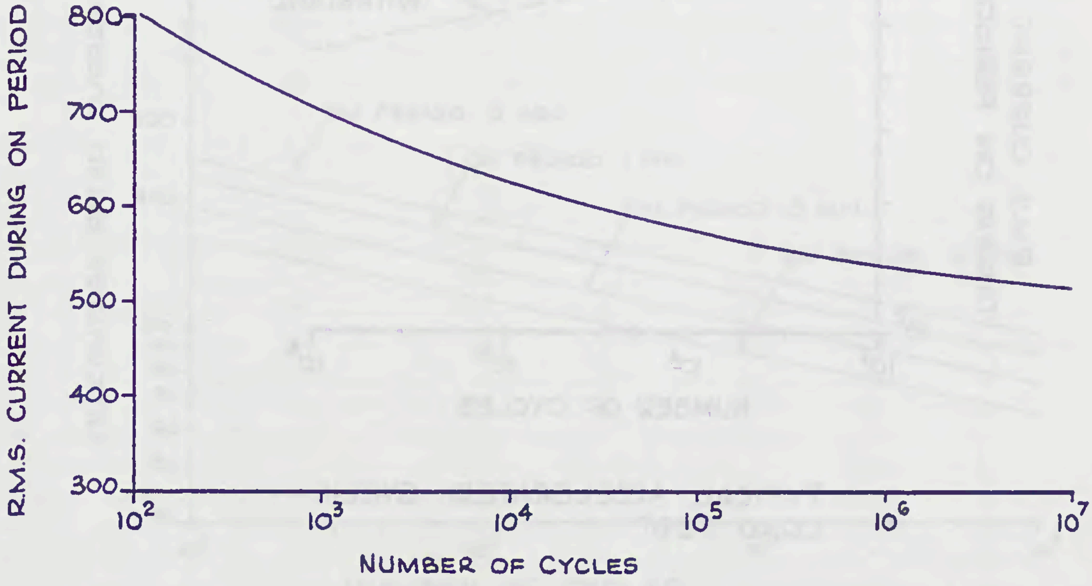
REFERENCES

"The Technological Development of the H.R.C. Fuse" J. Feenan - Liverpool Polytechnic, International Conference on Electric Fuses and their Applications. April 1976.



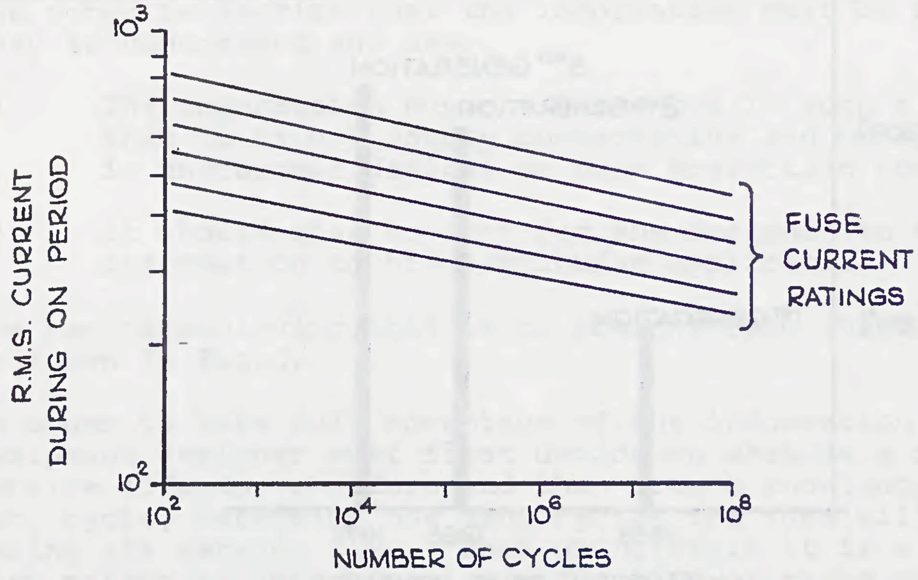
HISTORICAL DEVELOPMENT OF HIGH SPEED FUSES

FIG. 1



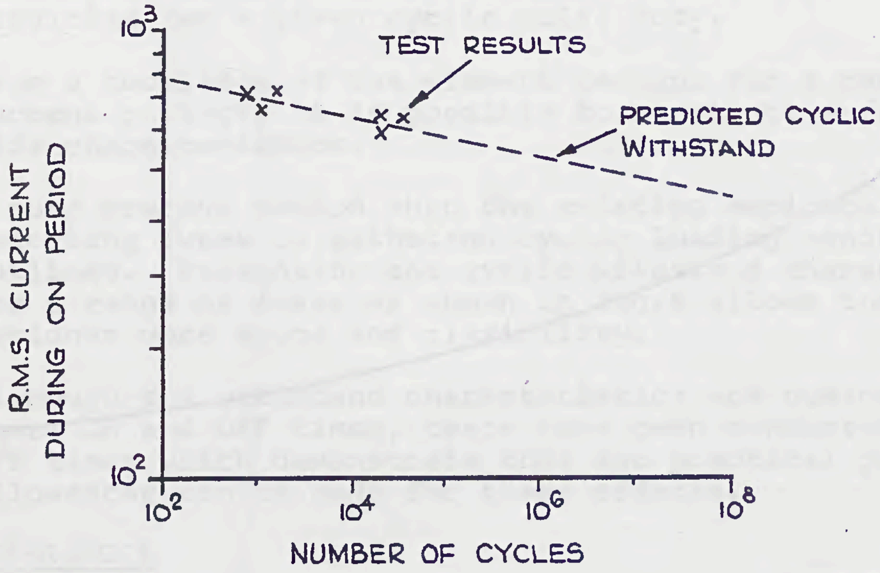
TYPICAL CYCLIC WITHSTAND CHARACTERISTIC FOR A HIGH SPEED FUSE

FIG. 2



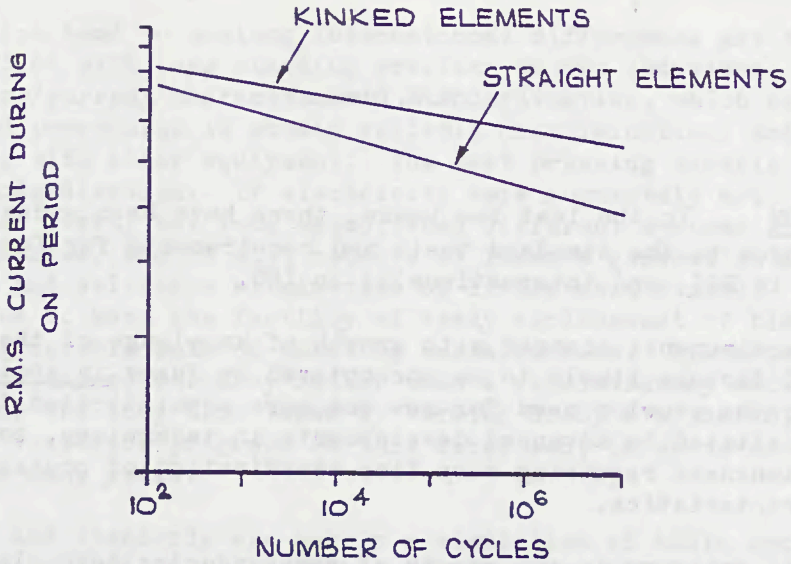
TYPICAL CYCLIC WITHSTAND CHARACTERISTIC
FOR A RANGE OF ULTRA FAST ACTING FUSES

FIG. 3



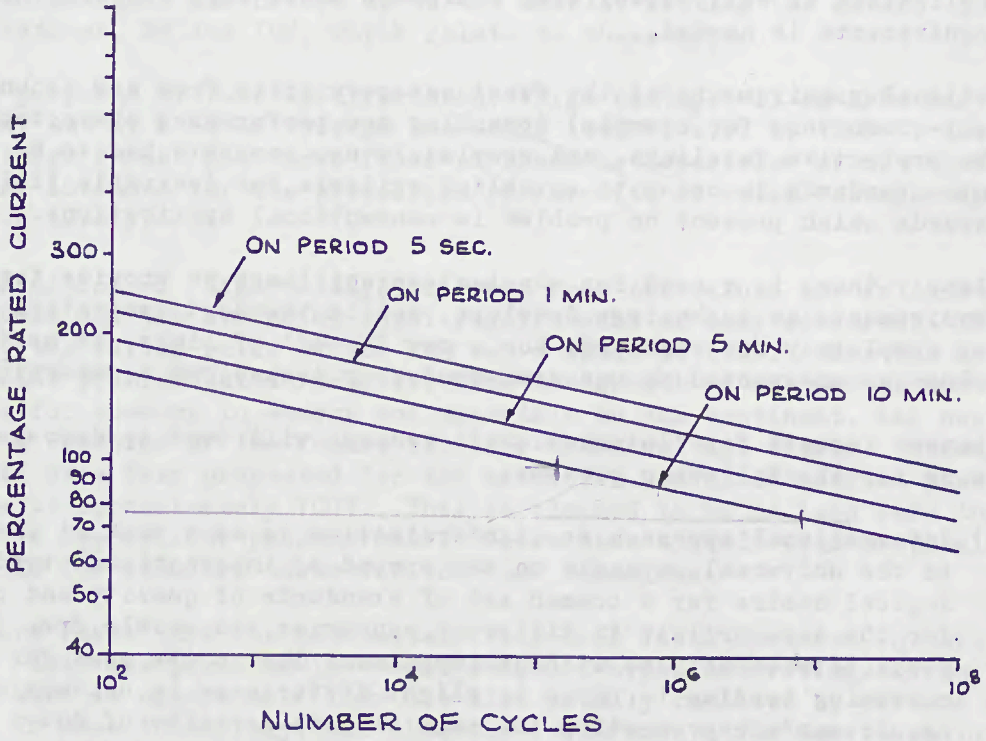
TYPICAL ACCELERATED CYCLIC
LOAD TEST

FIG. 4



COMPARISON BETWEEN KINKED AND STRAIGHT ELEMENTS IN A GIVEN FUSE.

FIG. 5



PRESENTATION OF CYCLIC WITHSTAND CHARACTERISTICS

FIG. 6