THE TECHNOLOGICAL DEVELOPMENT OF THE H.R.C. FUSE

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The activities of Technical Committee No.32 of the International Electro-Technical Commission on both high voltage and low voltage fuses has resulted in the issue of a number of specifications for both types of fuse. On low voltage, IEC.269 Part 1 provides the general requirements and Parts 2, 3 and 4 cover supplementary requirements for industrial, domestic and semi-conductor fuses respectively. On high voltage IEC.282-1 covers H.V. current limiting fuses.

These are the result of a number of years of detailed discussions on the various problems of breaking capacity, Time-current characteristics, thermal requirements etc and reflect the good measure of agreement which has been reached. There are however further recent developments which extend beyond these agreements. This further activity on fuse standards is worthy of mention at this Conference because it highlights the area where future discussions will take place and it is opportune to review them at this time.

LOW VOLTAGE FUSES The requirements for breaking capacity now contained in IEC269 Part 1 are more onerous than in any previous national standard and it is not likely that further discussions will take place on this subject for some time. Certainly not until countries have some experience arising from the application of the IEC test parameters.

The area in which the future activity is likely to be centred is that covering time-current zones, power loss and power acceptance. Time-current zones were introduced into IEC 269 Part 2, for industrial fuses, and Part 3, for domestic fuses, primarily to ensure that adequate discrimination is obtained if fuselinks of different makes but complying with Part 2 or Part 3 respectively are interchanged. The zones were also influenced to some extent by the desire to achieve international harmonisation but this has only been partly successful. For example in IEC 269 Part 2 the GII (British) and the GI (German) time-current zones above 100 amps are identical for all practical purposes but for 100 amps and below they are distinctly different.

It is unfortunate that according to the IEC Recommendation a manufacturer can utilise the complete zones for a given current rating whereas there are many designs which can comply to a mean characteristic within a tolerance of +10%. This fact has led to much criticism of these very wide zones and it is obvious that further attention will have to be devoted

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to them if a fuse is to be used to its best advantage to produce an economic protective scheme. The majority of British fuses have always complied with the tolerance +10% and it is for this reason that this further requirement has been retained in the recently issued revision of BS.88 covering L.V. fuses.

If the IEC time-current zones are used for co-ordination purposes with other protective devices (motor starters) arrangements can be produced which are less economic than that utilising the narrower characteristics of an individual manufacturer. This point has not been lost on some motor control gear manufacturers and there is already a tendency to continue to refer to the characteristics of the individual manufacturer. The other, and perhaps the most important criticism of the time-current zones is that they do not accurately reflect the ability of the H.R.C. fuse to provide adequate overload protection to P.V.C. insulated cables and it is for this reason that the revised British Standard retains the reference to fusing factor (the 4 hour operating current of the fuse) although no such test is included in the IEC Recommendation.

It is probable that this or a similar requirement will be included in the IEC Recommendations on international wiring rules in order to properly determine the over-current protection being afforded to P.V.C. insulated cables. This subject is being actively discussed in the I.E.C. Committee TC64 whose task is to produce recommendations for the electrical installations of buildings. One of the factors on which international agreement on overcurrent protection depends is the 'no damage' characteristic of cables, particularly P.V.C. insulated types, which pose the most difficult protection problems. Information on these characteristics is now emerging and based on this the desirable long time operating characteristic for all protective devices is being studied. A factor which has to be taken into account is the practical time-current characteristic of a fuse at long times rather than the conventional characteristic at the conventional time which is used at present. In all of the discussions on cable protection the worst possible conditions are envisaged for the cable i.e. subjection to a 4 hour overload after carrying rated current continuously and reaching a conductor temperature of 70°C. This is being compared with the operating characteristic of a fuse starting from cold. Furthermore in the case of GII fuses the time-current characteristic is at present established on a fuselink mounted in a conventional test rig. Although the work of TC64 on this subject is not yet complete, it is probable that the agreement reached will be similar to that which has been accepted in U.K. for many years. This means that fuses with a fusing factor of 1.5 or less in accordance with British Standard BS.88 can provide complete protection to P.V.C. insulated cables when the current rating of the fuse is equal to or less than the current rating of the cable, thus simplifying fuse selection. This statement is supported by at least 15 years satisfactory practical experience.

A further problem which is being investigated by Committee TC64 is the protection to be afforded to persons against electric shock in the event of a fault. Various types of installation conditions have been considered together with the desirable characteristics of the various protective devices. The rule regarding the application of fuses in this context is, however, fairly simple. It has been agreed that for fixed installations on TN systems (low impedance earthed system such as is used in U.K) adequate protection against shock is provided if the earth loop impedance is low enough to cause the fuse to operate within 5 seconds when a phase-to-earth fault is applied. A review of typical installations in U.K. has already shown that this requirement for ensuring shock protection by the use of fuses is already met in the vast majority of cases without the need for supplementary earth bonding. Although it is the responsibility of the installer to select the necessary protection in accordance with these rules, these requirements do impinge upon the desirable time-current characteristic for a fuse as well as for other protective devices.

It is obvious from the foregoing that when further consideration is given to the time-current characteristics of low voltage fuses it will be necessary to consider a more practical representation of service conditions than those upon which the present characteristics are based.

DIMENSIONS A supplement to IEC269 Part 2 in Report form will soon be issued containing the dimensions of British industrial fuses at present contained in BS.88 and the German NH type fuses at present contained in DIN43620. It has been agreed that these two sets of dimensions are in such widespread use that they reflect the best compromise to international standardisation for the present and possibly for the foreseeable future. It is recommended that uncommitted countries choose one or the other of these sets of dimensions. Dimensional standardisation of domestic fuses is in a much more fluid position and it is further complicated by the uncertainty of the time-current characteristics which may ultimately be required arising from the deliberations of IEC TC64. At the recent IEC Meeting in The Hague it was decided to collect, as a first step, sets of standard dimensions of domestic fuses in popular use and it is possible that arising from this a Report will be issued as a supplement to IEC 269 Part 3 containing such dimensions. Until this position is reached, it has been decided in U.K. to retain British Standards BS.1361 and BS.1362. Fuses to these two British Standards comply with the technical requirements of Part 3 and therefore there is no immediate necessity to review these Documents until the international situation is clarified.

This dimensional problem has occupied many hours of discussion at I.E.C. Fuse Meetings and little progress has been made towards unified dimensions. This is not surprising when agreement has not yet been reached on one set of desirable and practical time-current characteristics.

It is more important that this target is achieved first of all. It is also questionable whether any useful purpose will be served by further debating unified dimensions for fuses in a Technical Committee. User preference is a more likely solution. It certainly gives more scope for technical progress.

<u>POWER LOSS AND POWER ACCEPTANCE</u> In IEC269 Part 2 and 3 maximum power loss values have been agreed for fuselinks of standardised dimensions, but it must be realised that they have been obtained from existing designs of fuselinks. They are also established, of necessity, in a conventional manner and in free air. Although this is a reasonable first step it should be viewed with caution. The natural next step is to consider power acceptance of associated devices (fuse-holders, fuse-switches etc). There is a body of opinion which suggests that such equipment must accept these maximum power loss values but this tends to ignore important and practical considerations, some of which are:-

1. The power loss of a fuselink will increase when it is enclosed.

2. No attempt has been made to restrict the power loss values of fuselinks.

3. Conversely there are designs of fuse switches appearing on the market which take advantage of the fact that there is as yet no temperature limit specified for fuse terminals in enclosed fuse switches.

4. The thermal limitations of associated equipment should not be based on test at rated current alone.

5. In the majority of instances there is a load or diversity factor to consider which has a beneficial affect on the combination and should not be ignored.

There is a need for further consideration of this problem in I.E.C.so that a solution is reached which more accurately reflects practical considerations. This was obvious from comments made in various low voltage product committees at the recent I.E.C. Meeting in The Hague and at least one Working Group has been charged with giving further consideration to this problem.

The problems confronting I.E.C. on time-current characteristics and power loss are concerned with practical considerations and the fuse committee cannot solve them in isolation. There is a need for a collaborative effort from the various low voltage product committees to produce the best solution and it is in this way that further progress will undoubtedly be made in the I.E.C. deliberations of low voltage fuses.

H.V. FUSES There have in the last few years been noticeable technological advances in high voltage fuses, the most interesting being the H.V. motor circuit fuse. The reason for the rapidly increasing popularity of this fuse is a) its improved time-current characteristics and repetitive withstand capability and b) the introduction of vacuum contactors and motor switching devices (MSD) as an acceptable technical alternative to circuit breakers, with obvious economic advantages. The motor circuit fuse was first mentioned in I.E.E. Paper No. 6353P October 1970 but there have been rapid advances in design since that time. Some indication of this effort can be appreciated from the information presented in Figure 1. This gives recommendations for fuse selection for various repetitive starting duties and has been based on a series of pulsing tests on various sizes of fuses conducted over a long period of time (in excess of two years) followed by a detailed physical examination, including metallurgical examination of the fuse elements. Figure 2 compares old and new elements showing the different form of the new element and the stress relief feature achieved by bending it at specific points along its length in a precise manner. There is a marked improvement in the ability of a given fuse element to withstand repetitive current pulses when stress relieving is introduced. Figure 3 compares the performance of straight and stress-relieved elements when subjected to a given duty cycle. This information ensures the proper selection of fuses for high voltage motor circuits and eliminates premature operation which occurred in previous designs because of their inability to cope with an onerous repetitive starting duty. Fuses are now available in current ratings up to 630 amps at voltages up to 11kV and 1000 MVA.

This is undoubtedly a success story for the British H.V. fuse industry and it is interesting to note that U.K. are now formulating proposals for inclusion in I.E.C. to cover such fuses for both time-current characteristics and repetitive pulse withstand requirements.

SEMI-CONDUCTOR FUSES Since their inception in the 1950's the demand for such fuses has steadily increased at an appreciable rate and with it the demand for higher current and voltage ratings together with the requirement for faster characteristics. These fuses are now recognised internationally in the recently published IEC269 Part 4 "Supplementary Requirements for Fuselinks for the Protection of Semi-conductor Devices" which incidentally covers both

H.V. and L.V. fuselinks

The increase in knowledge of the design limits of semi-conductor devices has led to a simpler method of fuse selection for standard applications and a desire to explore the ultimate limits of utilisation of such fuselinks, particularly the very fast acting types, in order to achieve maximum economy from solid state equipment.

One of the greatest problems is the apparently infinite variety of applications which exist. Furthermore the methods of assessing no-damage limits of semi-conductor devices and determining the protection afforded by semi-conductor fuses are not yet fully aligned although considerable progress has been made. I.E.C. 269 Part 4 specifies for the first time an internationally accepted method for determining and presenting fuse performance based upon A.C. tests. This will be of great assistance to the user because there had been a tendency in different countries to use a different test basis for the determination of such data as I^2t values, arc voltage characteristics etc.

The application problem will, it is hoped, be further eased with the publication of an Application Guide still under discussion in I.E.C. and further consideration will be given to formulating D.C. tests on an internationally agreed basis to augment the A.C. tests already specified.

There is, however, one problem on which progress is difficult. This concerns the highly repetitive duty cycle to which some applications are subjected. An example of this is a rolling mill drive commonly used in steel production. Such applications also require very fast acting fuses and the combination of these two opposing requirements has led to intensive investigations into obtaining the best solution. One of the most interesting discoveries has been the considerable improvement in pulse withstand capabilities of fast acting fuses by the inclusion of stress relieving configurations such as those described earlier on H.V. fuses. Here again the length of the fuse element is a factor in deciding when to introduce such a feature but because the 'necks' of semi-conductor fuse elements run at much higher temperatures than more conventional fuses it is obviously more critical in such fuses.

The element material and basic design philosophy used also have an appreciable influence on the ability to withstand repetitive over-loads and investigations are not complete at the present time. Nevertheless a part of the Application Guide has been devoted to this problem and manufacturers are issuing more precise guidance than previously.

The dimensions of semi-conductor fuselinks in the U.K. are virtually standardised for voltage ratings up to 600V AC and current ratings up to 600 amps. These dimensions, which ensure non-interchangeability with industrial and domestic fuses, will appear in the British Standard version of IEC 269 Part 4 namely BS.88 Part 4. Above this range of current and voltage ratings, however, the constantly changing demand for fast acting fuses of different current and voltage ratings has led to novel arrangements in an attempt to satisfy this demand on an economic basis. One such method is shown in Figs. 4 & 5. It is possible, by utilising standard modules to produce a wide range of fuselinks of different configurations. Fast operation is ensured because the maximum cooling surface is presented to the surrounding air. It is possible, with this form of construction, for the equipment designer to design his own fuse. Figure 6 presents per-module data on I^2t together with the appropriate factor for the desired multiple arrangement. (Factor A = (Number of Modules)^2).

The precise configuration is not critical because the resistance of a single module swamps that of the contact resistance in the end terminations and the constant given in the published data provides an adequate safety margin to counter the slight effect of current inbalance in the different dispositions of modules in any grouping.

The use of high volume standard modules makes this an attractive proposition for both manufacturer and user by avoiding the delay and relatively high cost resulting from the production of special bodies, end caps, etc., necessary for special fuses.

<u>CONCLUSIONS</u> It is reasonable to claim that, within the range of voltage and current ratings at which the majority of cartridge fuses are used, technology is sufficiently advanced to enable the achievement of the primary function of fault interruption without much difficulty. Present design efforts are concentrated more on the achievement of high volume production at economic unit price coupled with more consistent and sophisticated characteristics to suit particular requirements. These two objectives tend to oppose each other and can only be achieved by the use of precision components and a high degree of quality control. The degree to which these objectives are being achieved is evident from the wide ranging protection within precise limits provided by the modern H.R.C. fuse at a cost which makes it the most economic and effective fault protective device available today.

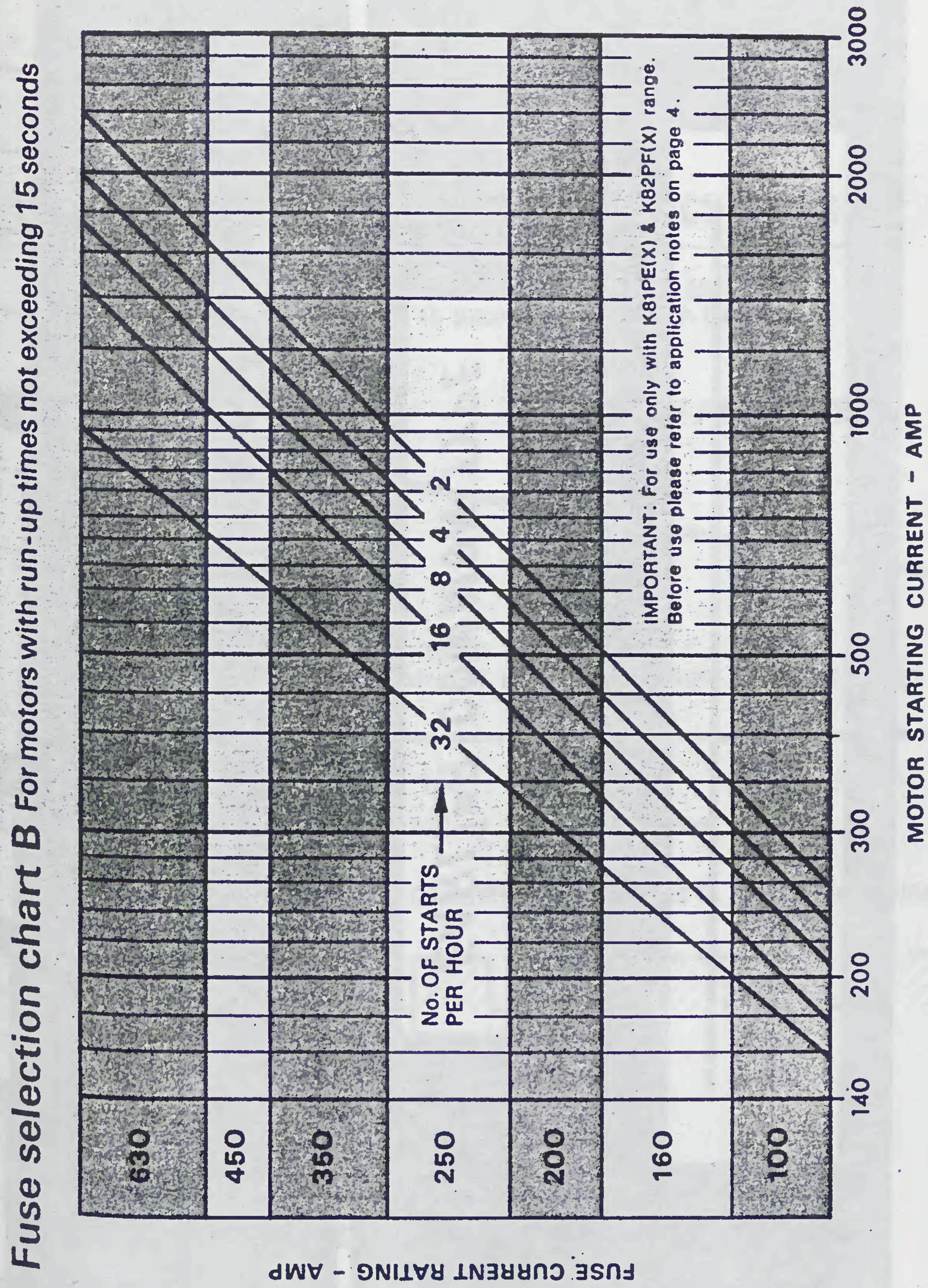
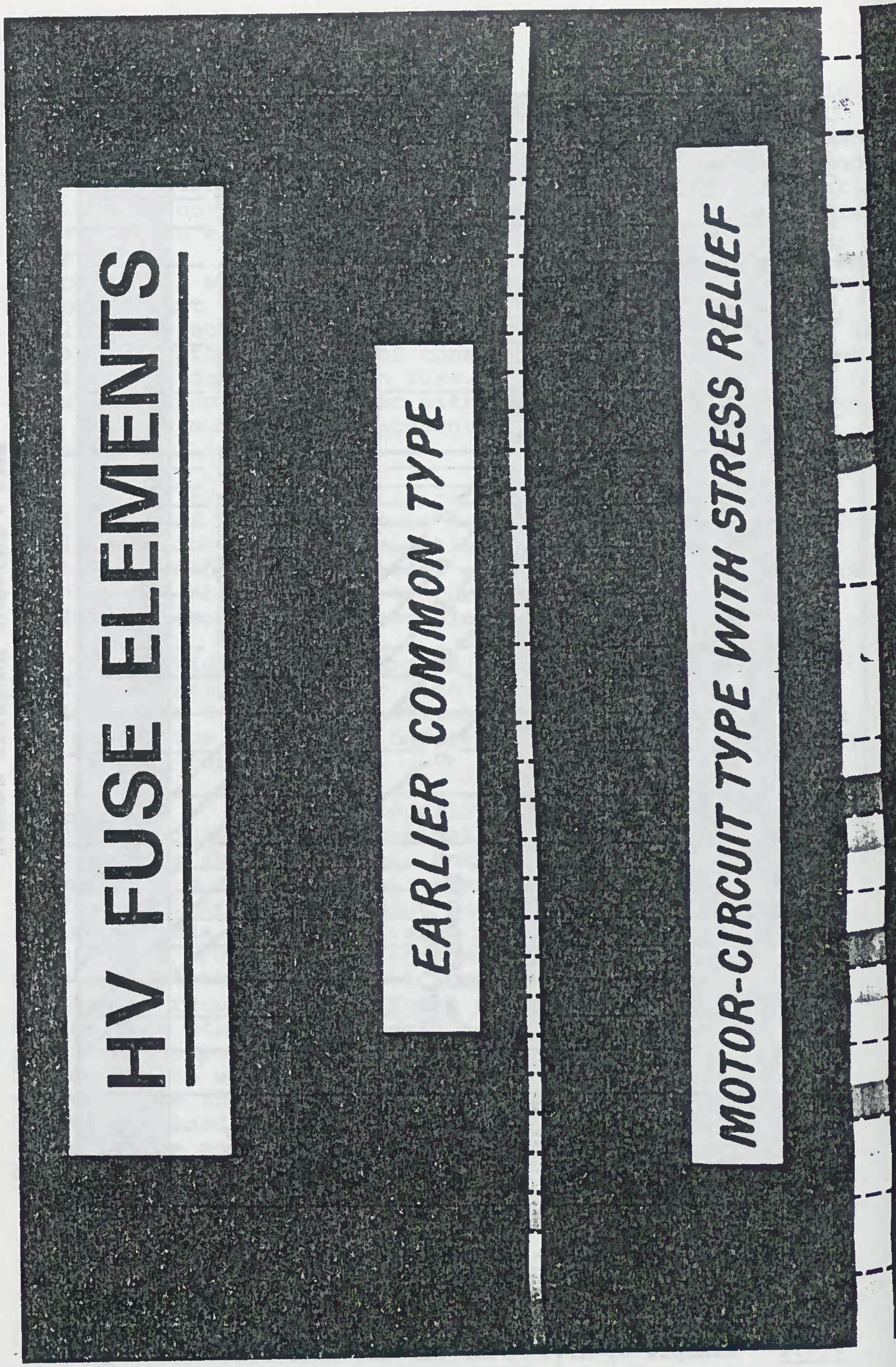


FIG.1 Example of H.V. Motor Circuit Fuse selection chart for various repetitive start conditions.



<u>FIG.2</u> Comparison of old and new H.V. fuse elements for motor circuit protection.

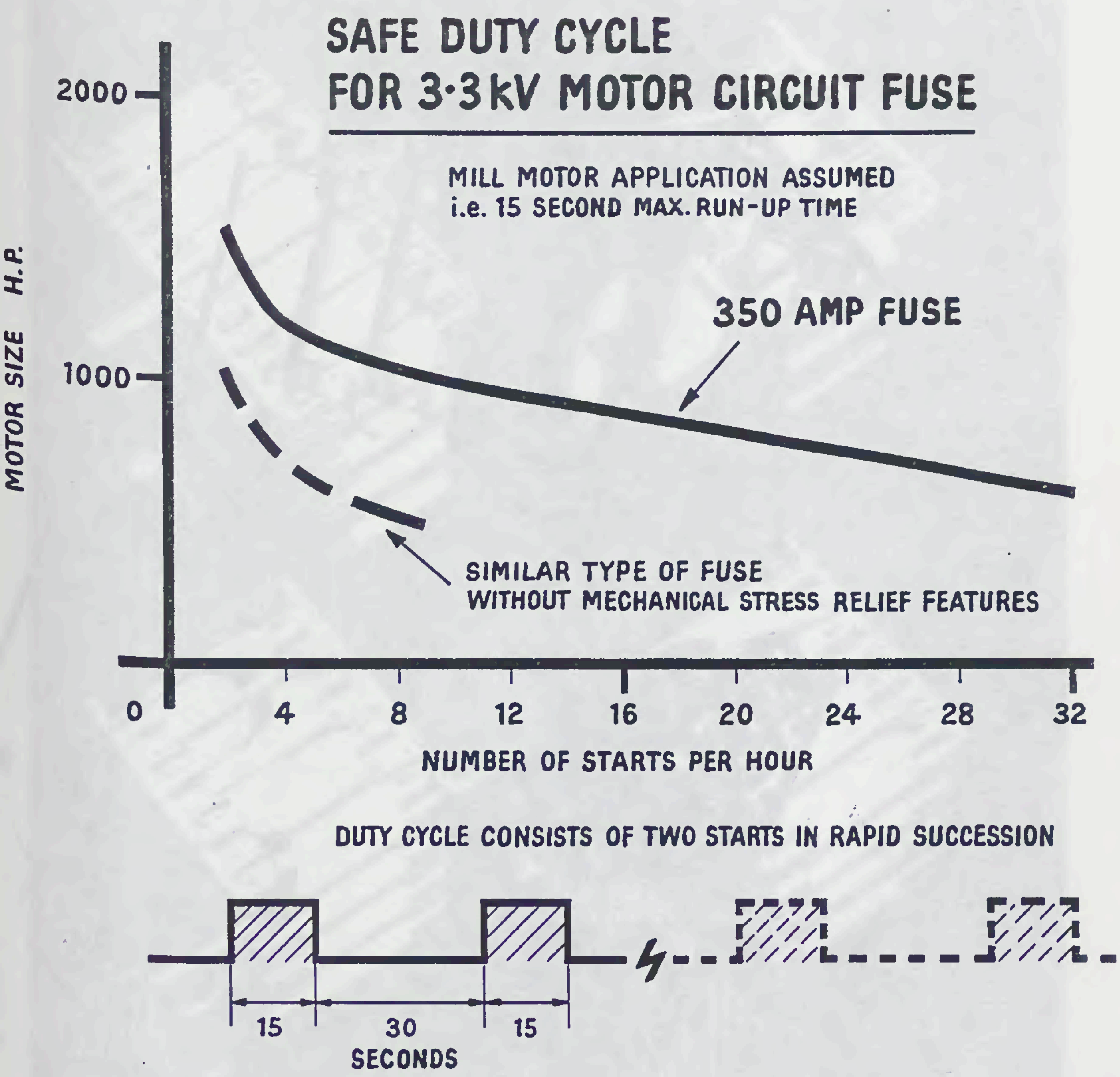


FIG.3 Improvement in repetitive pulse withstand ability of fuse elements by inclusion of stress relief features.

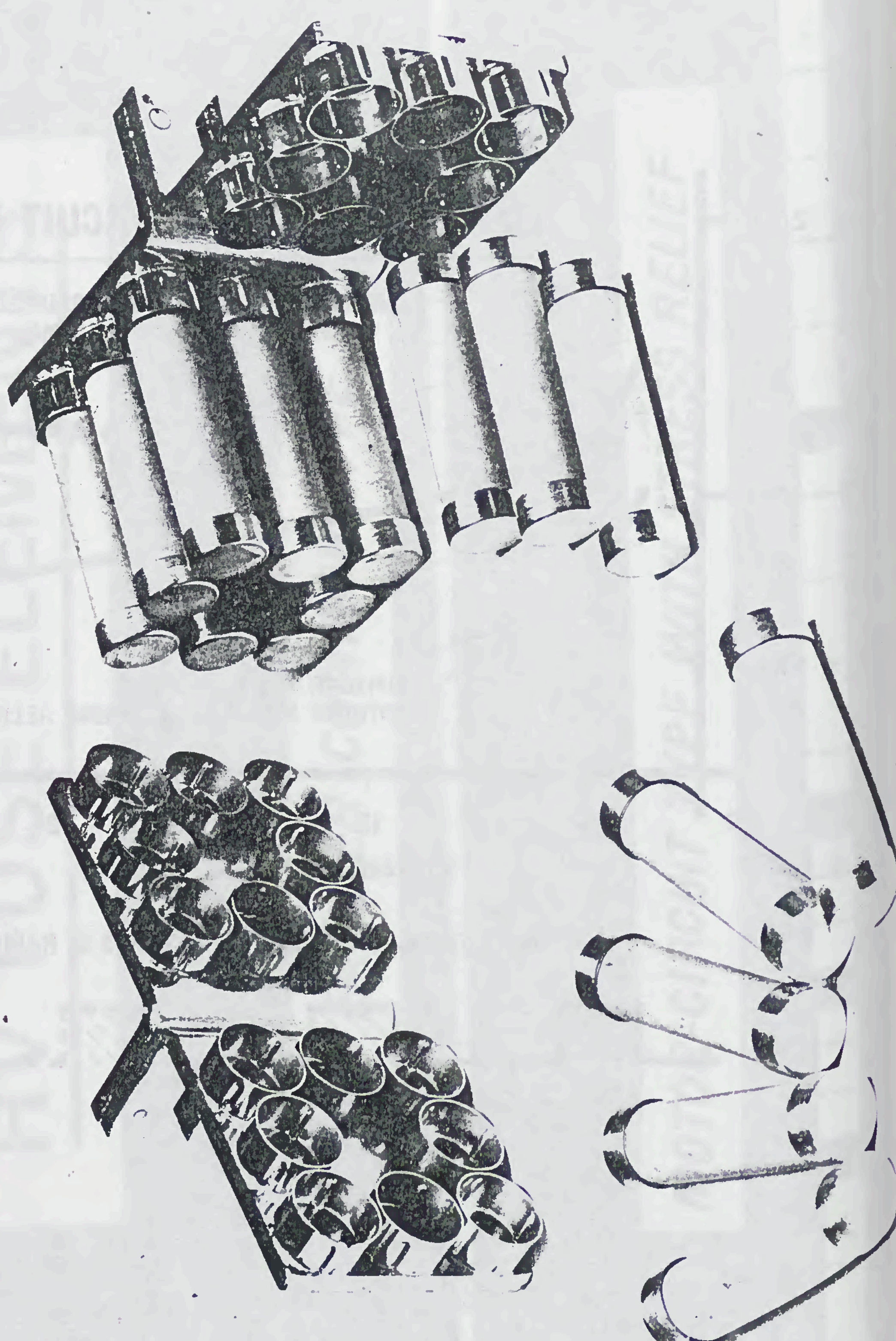


FIG.4 Modular construction of "GSH" multibody fuselinks.

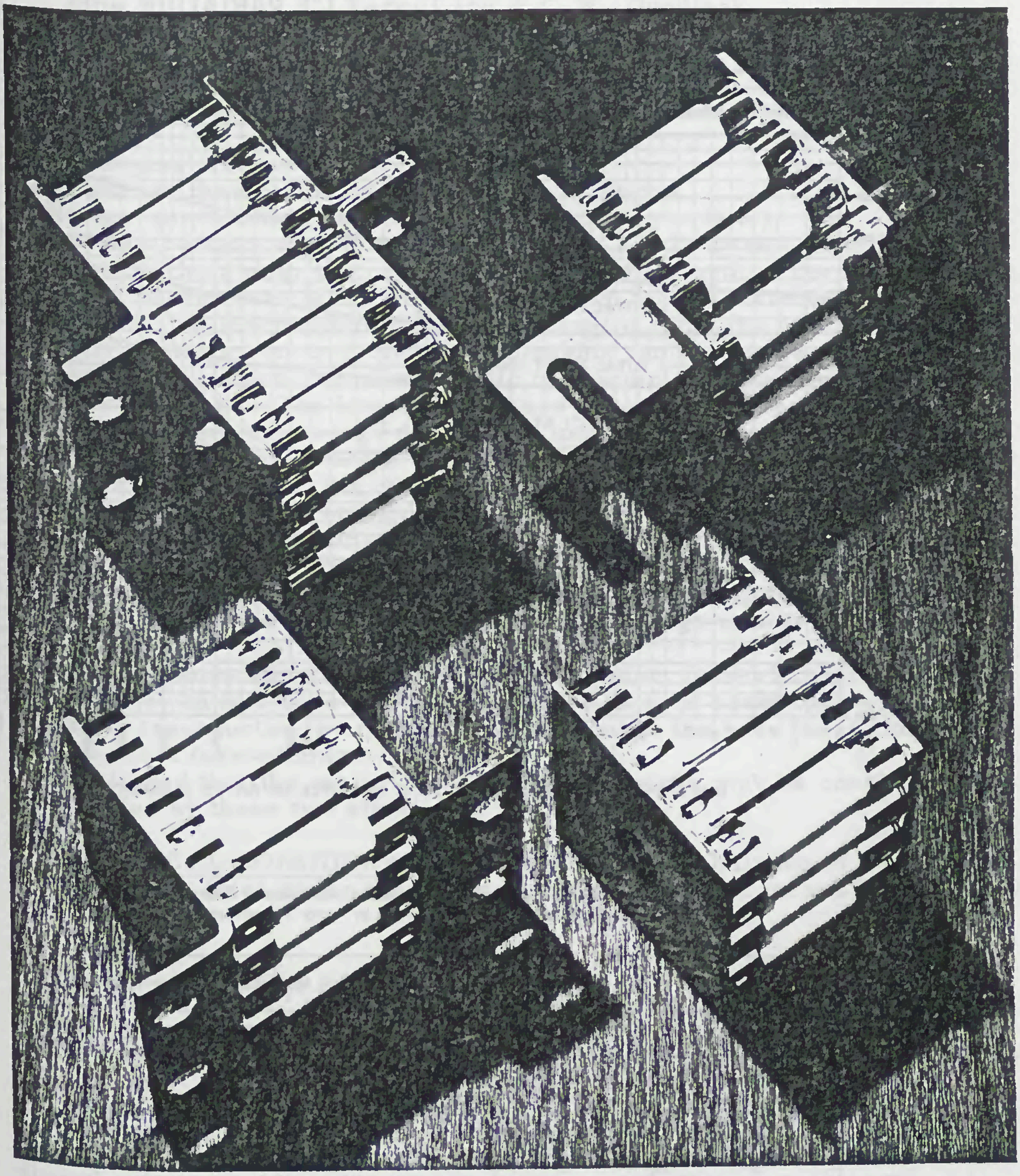
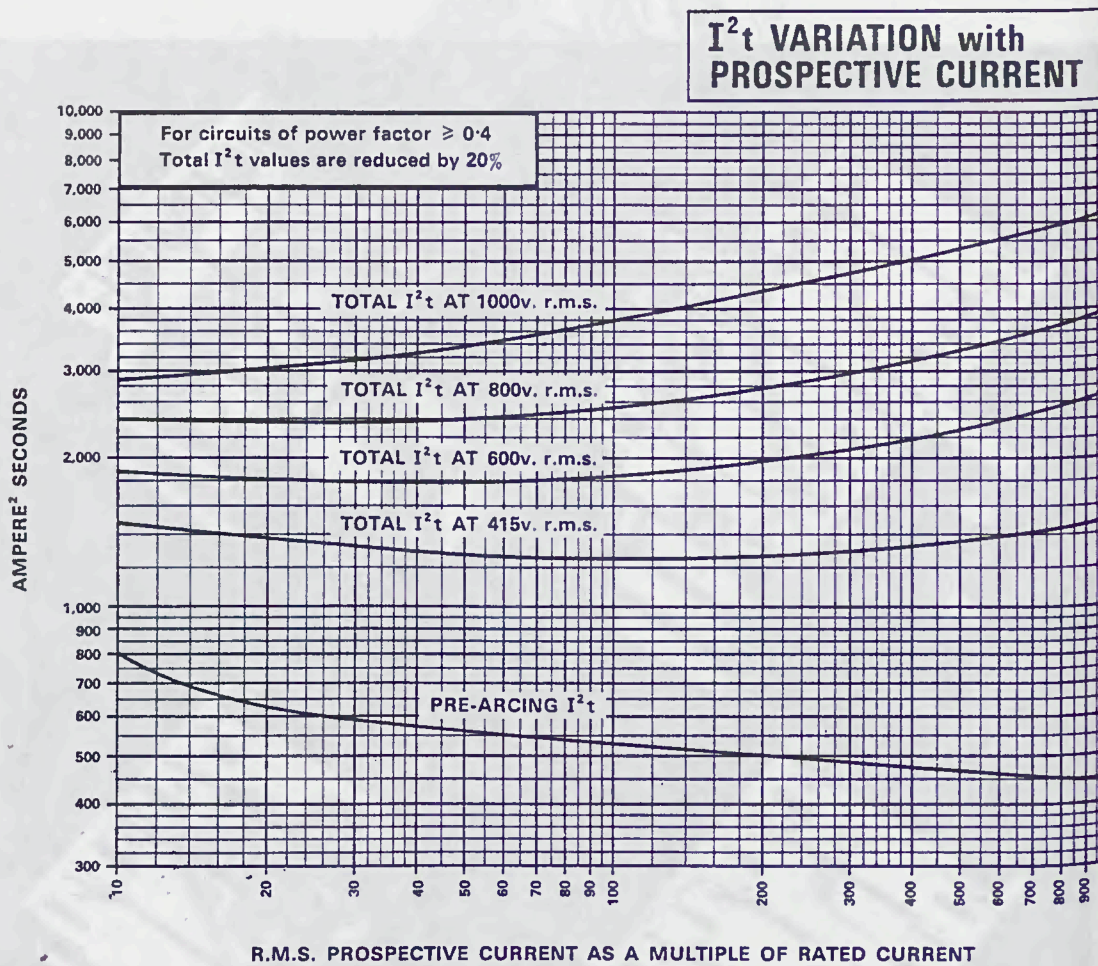


FIG.5 Arrangement of "GSMJ" fuselinks up to 800A, 800V RMS A.C. showing versatility of multibody principle.



Pre-arcing I^2t or Total I^2t of given fuse rating is obtained by reading off value on appropriate curve and multiplying by Factor 'A' from Table below.

Fuse Rating Amp.	63	120	180	240	300	350	400	460	520	580	630	680	800	1000	1200
Factor 'A'	1	4	9	16	25	36	49	64	81	100	121	144	256	400	576

FIG.6 Per-module I^2t data for "GSMK" fuselinks for voltages up to 1000V A.C.