FUSE TESTS AND STANDARDS

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INTRODUCTION In the last few years, there have been widespread fundamental changes to the standard tests and requirements for fuselinks, both nationally in BSI, and internationally in IEC.

National requirements changed with growth of knowledge of the relative severity of factors likely to be encountered by fuses in application, and also due to the growing need for new and more sophisticated types of fuselink, necessitated by advanced developments in technology, combined with cost-consciousness requiring very fine coordination of protection and damage characteristics.

In the first category is the growth of semiconductor technology and in the second the new technology of cable rating.

Fuselinks which had proved their worth in trouble-free operation in service over many years are able to meet new tests of greater severity where these represent some newly discovered severity in actual service, because the fuses will have been exposed to that service already in large numbers without problem. There is great temptation to economise on protection, however, which could deteriorate into inherently unsafe practice. Thus additional testing to eliminate danger in new developments, and to give data for application of well established equipment under more exacting modern requirements is needed.

National requirements of the first category arise from new technology (of semi-conductors for example) demanding new performance characteristics for the protective fuselinks, and completely new concepts had to be incorporated into standards in order to establish criteria for desirable limitation of hazards which present no problem in conventional applications.

Clearly there is a need for constant surveillance to provide for such new requirements as technology develops, and in the next generation we may yet see completely new standards for a new 'breed' of links, to meet a technology as unexpected as was semi-conductor technology a generation ago.

Changes imposed for 'International' reasons will tend to decrease in future years for the following reasons:-

1) International approach to standardisation is at a peak at present due to the universal emphasis on the spread of international trade, and the logical desire for a common set of standards of quality and performance for the same article in different countries, to enable free flow of goods between nations without impediment due to the need for time-consuming testing to prove to slight differences in conventional requirements representing the same extreme severity of duty.

2) Eventually, the philosophy of testing can become the same in all countries, except for specified special test to cover extreme applications (e.g. in tropical or arctic conditions). National Standards bodies will follow the decisions made in International meetings, merely translating

the requirements to meet local needs with as few variations in testing procedure as is possible.

Factors which tend to prolong International differences are those which would conflict with long standing practice in the individual countries, such as time/current characteristic standardisation, which related to established procedures to obtain reliable discrimination, and problems of interfacing with other equipment. The most pressing example is dimensional standardisation. If electricity were completely new, this would be standardised first, but long established different systems exist in different countries, and it will require at least a generation (making no new dimensions and selective elimination of little used sizes). There is the primary need to have the facility of ready replacement of blown fuselinks in the considerable bulk of existing installations. Dimensional realignment is thus an evolutionary rather than a revolutionary activity, and accounts for the long time taken by Working Group 8 of SC32B, which makes steady but very slow progress in this direction, in spite of considerable effort over many years.

Fuse tests and standards are merely a simulation of their application, and in this paper we will classify the various types of fuselink available and indicate how tests and standards reflect the uses to which they are put.

MAIN CLASSIFICATION OF FUSELINKS It is convenient to classify fuselinks according to the three main subcommittees of IEC technical committee TC32:

High voltage fuses	(IEC SC32A)
Low voltage fuses	(IEC SC32B)
Miniature fuses	(IEC SC32C)

Fig. 1 summarises the main categories and their separate types, advantages and disadvantages, and brings up to the date of writing the detail of the specifications, BS and IEC, which relate to these types.

For the purposes of fuse specification, "High voltage" is an arbitrary division, set at a rated voltage exceeding 1000 V. a.c. or 1500 V. d.c. "Low voltage fuses" are those fuses of breaking capacities of not less than 2kA, intended for the protection of circuits of rated voltages up to the above levels.

This definition of "High voltage" differs from the values set in safety regulations and the differing legal requirements of many countries. For example, the wiring rules of the IEE set a limit at 650V. This was not a significant problem until recently, when the growth of the use of 660V circuits for economy in energy and materials on the continent, has necessitated a re-think of the future level of these voltage limits. Strong arguments have been presented for the extensive use of industrial power supplies at approximately 700V. This is claimed to be no less safe than 415V (with appropriate precautions). There have already been proposals before IEC for standard tests for the 660V fuselinks.

"Miniature Fuses" are the most extensively used fuses included in this survey. They are produced in a vast range of types and ratings (from 32mA) and are used in apparatus. They are also usually replaced by persons untrained in fuse technology, and thus the requirements for the fuseholders alone are so extensive that they merit a completely separate IEC publication (IEC Publication 257 (1968)) at present under revision to take account of new problems arising from the recent extension in the current ratings of the fuselinks in the corresponding IEC Miniature Fuse specification (IEC Publication 127 (1974)).

COMMON ASPECTS OF STANDARDS Nearly all fuses contain fusible metal elements which open the circuit in which they are inserted, by fusion, when the current has exceeded a given value (the minimum fusing current) for a sufficient time. The fuse comprises all parts that form the complete switching device.

The only type of fuse considered by these committees that does not fit this description is the so-called 'thermal fuse', dealt with by IEC 32C, and briefly described later in this paper.

Consequently it is possible to use a common set of definitions for most fuse components and general terms, and the reader is referred to section 2 of any of the IEC recommendations referred to in Fig. 1, or to IEC Publication 291 (1969) Fuse Definitions.

All the types have standards which have the object of establishing the characteristics of the fuses or their parts in such a way that accurate replacement is facilitated. Characteristics are presented with reference to rated values, insulation, temperature rise in normal service, power loss, time/current characteristics, and effectiveness in clearing short circuits, in all the standards.

In the detail of the specifications however, the difference in requirements and capabilities of the various types become apparent, and this is best illustrated by considering some of the more important clauses of each specification in turn.

BREAKING CAPACITY TESTS These vary most of all between the various specifications, because differences in supply voltage and circuit severity appear across the fuse terminals only when the element has melted, the potential difference before that time being the same at all supply voltages, and equal to the product of current and fuse resistance.

As an illustration tables for the most general types are given for high voltage fuses in Table 1, and for low voltage fuses in Table 2.

There are other special breaking capacity tests for expulsion fuses, domestic fuses, miniature fuses, semi-conductor fuses etc., but the tables illustrate the general principles applied to all breaking capacity tests.

Important regions included in such tables are maximum breaking capacity (test duty 1 in Tables 1 and 2), tests at maximum arc energy (test 2) and tests at small overcurrent (test 3 in Table 1; tests 3, 4, and 5 for l.v. fuses in Table 2). In every case the maximum breaking capacity is tested at the most severe repeatable condition. This test is set at a given making angle (30° ± 5°) for miniature fuses only, because so many fuses are tested, and repeatability is impostant. For h.v. and l.v. fuses however, where fewer fuses are tested, the more difficult arcing angle is specified

TIME/CURRENT CHARACTERISTICS AND I^2T Time/current data are required for every fuse, but the degree of specification and the tests required to obtain them are different.

The h.v. fuse specification requires the manufacturer to provide them, but does not specify how they are to be obtained, the test conditions, or what the method should be.

The l.v. fuse specifications require 'time/current zones' to be verified, where the lowest curve is the minimum pre-arcing time (i.e. the minimum time/current characteristic in normal parlance). The upper limiting curve is the total operating characteristic (i.e. includes the arcing period). Detailed specifications do not exist for the test methods for obtaining these curves (i.e. circuit conditions, voltage, etc.) except a vague statement that they can be verified from the breaking tests. Study of Table 2 shows that this would not define a full time/current curve.

Test rigs also produce somewhat different shapes of characteristic, compared with the variety of fuseholders.

The sensitivity of semi-conductor fuses to point-on-wave requires a symmetrical closing angle.

The miniature fuses specification is much more clearly defined. The test points are pre-arcing values only, and are to be determined with d.c. at constant current. Actual pre-arcing times on a.c. may be considerably different from those checked in the standard test. This is due to low thermal inertia of the element, and Peltier and similar effects.

CONVENTIONAL TESTS Tests in standards are conventional tests, i.e. tests made in a repeatable manner, which simulate practical conditions. Other tests (notably the many different temperature rise tests) could be quoted as examples of the danger of reading too much precision into conventional test results.

However, such conventional test conditions are essential, in order that tests in different test stations are comparable, and that like products can be compared with each other, for standardisation purposes.

Knowing the effect of location of the fuse and circuit severity on the direction of deviation, the user can make his own allowances for special conditions of his installation.

HIGH VOLTAGE FUSES Tests and standards are now separately specified for the two main types. These are non-current limiting fuses and current-limiting fuses.

The non-current limiting fuse, or 'expulsion fuse', behaves differently during its arcing operation to most of the other types. There is more than one version of this type of fuse, widely used internationally. The least expensive is an easily rewired version, popular in remote districts, where economy is needed, and covered by BS 2692, 1956. A more sophisticated version is available in the USA in a number of types. This second type is more closely covered by IEC Publication 282 - 2. During the operation of these fuses the extinction of the arc is within a tube of gas-evolving material, and there is often a display of flame and noise, which would usually only be acceptable outdoors. In IEC 282 - 2, Class I has better insulation level or dielectric properties than Class II, a higher breaking capacity and higher maximum rated currents. Class II has replaceable fuse-links. Class I is recommended for the protection of large transformer banks, voltage transformers and important power factor correction banks, whereas Class II is applicable to protection of small transformers, smaller power factor correction banks, or for sectionnalising the circuit on outdoor open wire power distribution systems.

These differences are reflected in two different sets of complicated breaking capacity tests.

The current-limiting fuse is covered by IEC 282 - 1 (1974), which is very closely parallelled by BS 2692 (1975).

There are three levels of breaking capacity, identified above, and shown in Table I. With a powder filled fuse it is more reliable to predict a region of maximum arc energy at reduced prospective current where the instantaneous current at the instant of arcing is between 0.85 to 1.06 times the rms value of the test current. (Making at an angle of 0° -20° after voltage zero).

The most controversial feature of the breaking capacity tests of IEC 282 - 1 is the specification of a test voltage below rated voltage for breaking capacity tests 1 and 2. The test voltage is reduced to 87% of rated voltage, on the argument, that in three-phase systems they will not be subjected to the highest line-to-line voltage, because two fuses in series would share this voltage. This is a principle that is still strongly challenged from several quarters.

On single-phase use, fuselinks with a voltage rating equal to 115% of the highest single-phase circuit voltage have to be employed.

The problem of a double earth fault on a three-phase unearthed system with a fault on the supply side of the fuse simultaneously with a fault on the load side, is clearly not covered.

Test duty three is expensive and time consuming, but is necessary, because many h.v. fuselink designs are back-up fuses. This helps the user to ensure that the circuit protected by the fuse is interrupted by some other associated device at currents between rated current and minimum breaking current. This test must be performed at full rated voltage, and a fuse is not considered to be 'general purpose' unless the time, corresponding to minimum breaking current is at least one hour.

As with low voltage fuses, attempts are still being made, to standardise dimensions. The same problems exist as in the l.v. case, and the solution emerging is similar.

Time/current characteristic standardisation is also proceeding, but with some difficulty. Unlike low voltage fuses, where common standards for time/current characteristics are now established world-wide for fuselinks of rated currents above 100A, it has been found necessary for h.v. fuses to have different characteristics, particularly in the centre of the time/current range.

For motor protection, where the 'take-over' of other switching devices is involved, a vertical (almost constant current) time/current characteristic is preferred.

For transformer protection a 45° slope is needed (i.e. practically constant I^2t).

<u>Low Voltage Fuses</u> One general type cannot be used for all applications because of the conflicting requirements of protection in different realms

of application - e.g. industrial, domestic and similar purposes, semi-conductor protection. This is recognised in IEC 269 by the existance of 4 separate publications, IEC 269 - 1 which sets out the general tests and requirements necessary for all low voltage fuses, and IEC 269 - 2, 269 - 3, and 269 - 4 which are specialist parts dealing respectively with Industrial fuses, domestic fuses and semi-conductor protection fuses.

Some countries combine Industrial fuselinks of the equivalent to the British BS 88 type with domestic fuselinks for the protection of conductors at the supply point. This clearly has difficulties of compromise, which are evident in the break in the continuity of the shape of the fuselinks in GI characteristics of IEC 269 - 2 at 100A.

Comparatively, the GII (British type) characteristic has a smooth transition, largely because of the existance of the specialised industrial fuselinks to BS 88 and the separate tests in BS 1361 to meet special 'domestic' requirements.

IEC 269 - 3 also covers the tests for the type of fuselink used in plugs in the UK, (the BS 1362 fuselink). The significant difference in the tests for this fuselink is the absence of the low power factor in the Test duty 2 test, since such a highly inductive low level of short circuit is not met in domestic situations when connected by a flexible lead in a plug or spur box.

Mention has been made elsewhere of the difficulties of dimensional standardisation, and to reduce the proliferation, a supplement to 269 - 3, 269 - 3A (1974), has been issued which requests all countries to keep to existing nationally standardised systems until it becomes possible in the distant future to introduce a world wide acceptable unified system.

Low voltage back-up fuses of the type aM are included in IEC 269 - 2 for industrial use. These should not be confused with the general purpose fuse element in a small size barrel used for a similar type of purpose in the UK and referred to as a 'motor-rated' fuselink.

MINIATURE FUSES These are covered by IEC publication 127 (1974) and BS 4265 in fuse holders to IEC publication 257 (1968). Since these fuselinks are well down the chain of protection backed up by low voltage fuses, and mcb's at the end of the flexible cable connection, the prospective short circuit current is quite low. Maximum breaking capacity tested is set by IEC to be 2 kA at 250V a.c. (although some designs are capable of much higher breaking capacities - power factor minimum 0.7).

International standardisation is needed for these fuses more than for other types, because equipment fitted with miniature fuselinks crosses frontiers in multi-million quantities annually, and such equipment needs replacement fuselinks locally in its new home.

The fuselinks are also available in glass (transparent) barrels unfilled, and the maximum breaking capacity then tested is 35A or $10I_n$ (whichever is the greater), at unity power factor and 250V a.c.

The latter fuselinks should not be placed in circuit locations where the prospective current is greater. This has caused some controversy in recent years when the current ratings exceeding 2A were introduced in the 5mm x 20mm size.

Since only two sets of dimensions are specified, the marking clauses of these fuses are important, for all types in a given barrel size are physically interchangeable but electrically non inter-changeable. These fuselinks are tested in greater numbers than any other type of fuselink, and the manufacturer is required to supply 48 fuselinks of every rating when submitting samples for type testing (4 extra are required for time delay fuselinks which additionally are tested for one hour at 70°C carrying a multiple of the rated current).

Time/Current Characteristics of Miniature Fuses A way out of this problem is at present being considered by a special working group (WG4) of IEC 32C.

This working group is seeking to divide the operating range into up to 5 bands of time/current and to classify fuses as FF (very quick acting) F (quick acting) M (medium time lag) T (time lag) and TT (long time lag) according to which of these bands they 'fit'.

With small fuse ratings the element is often scarcely visible to the naked eye, and precision, particularly in a complicated construction, is not necessarily as great as that attainable with elements of much bigger dimensions.

In addition there are considerable differences in the philosophy of rating etc. in different countries, with an identical fuselink being assigned a higher current rating in USA, for example, than in Europe.

When agreement is reached on this fundamental issue, there will be a considerable step forward in the value of the fuselinks tested to these standards, world wide.

Thermal Fuses These devices are not fuses in the strict sense of the IEC definition, because they are not designed to be fused by the action of the current passing through them (although they may do so in exceptional overload conditions) but operate when they reach a critical temperature, due to fusion of some component of the thermal fuse by the surrounding heat. They can consist of tiny switches held close by a pellet of low fusing material, conductors of low fusing metal or other such constructions. In IEC these are being considered by a special working group (No. 2) for a specification for tests of thermal fuses for use in applications where temperatures of a dangerous or hazardous value have been caused by some defect within apparatus.

Capacitor Protection This is not a great problem with h.v. fuses, but problems of application do arise with h.v. fuses, and a special working group of SC32A (WG4) has evolved special tests for this purpose which are nearing the issue of standard recommendations.

Semi Enclosed Fuses These rewirable fuses for l.v. are still very extensively utilised in the UK, and appear to be quite adequate for any circuit where the prospective short circuit current is low and the power factor not too low. They are cheap and easy to renew and do not appear to be unsatisfactory except when misused e.g. by over-wiring or placing in locations where the short circuit level exceeds this breaking capacity comparatively speaking, they are relative to the high breaking capacity low voltage fuse, as the expulsion fuse is relative to the h.v. current limiting fuse, and equally well can expect application in the UK for some considerable time yet, although specifically excluded from IEC 249 - 1 and

BS 88 (1975). However, a British Standard BS exists which gives a comprehensive series of tests for these fuses, and strict adherence to its requirements ensures that the above remarks on adequacy remain true in modern applications.

It should be remembered, as with expulsion fuses, that these are a coarser and more variable form of protection than the sand filled cartridge fuse and suitable allowance made in their use.

Concluding Remarks   The tests required in the standards of testing become more and more complicated and extensive with time, largely because of the final control required for close economical protection demanded increasingly today on the one hand, and the demands made by technology on the other. The lesson can be learned from the use of some standards however that if the testing becomes too expensive, the standard could drop out of use with disadvantage to user and manufacturer alike, and thus the standards engineer must set tests which are both searching, well matched to the application, and inexpensive to perform. Although it is impossible to meet all these contradicting criteria, an optimum choice between them has to be made.

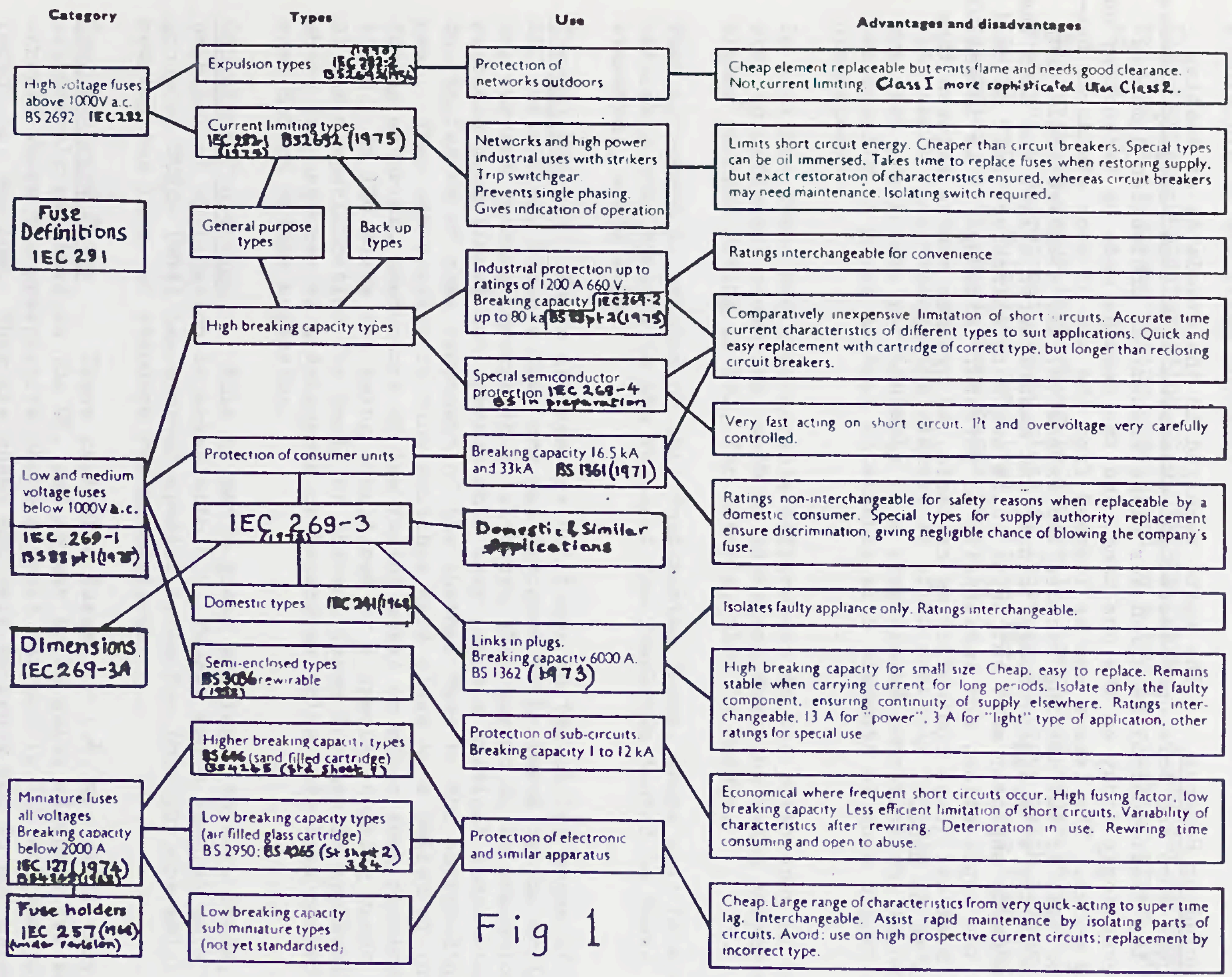
Category
Types
Use
Advantages and disadvantages
High voltage fuses above 1000V a.c. BS 2692 IEC282
Fuse Definitions IEC 291
Low and medium voltage fuses below 1000V a.c. IEC 269-1 BS88 pt1(1975)
Dimensions IEC269-3A
Miniature fuses all voltages Breaking capacity below 2000 A IEC 127(1974)
Fuse holders IEC 257(1968) (under revision)
Expulsion types
Current limiting types BS2692 (1975)
General purpose types
Back up types
High breaking capacity types
Protection of consumer units
IEC 269-3
Domestic types
Semi-enclosed types rewirable
Higher breaking capacity types (sand filled cartridge)
Low breaking capacity types (air filled glass cartridge) BS 2950:
Low breaking capacity sub miniature types (not yet standardised)
Protection of networks outdoors
Networks and high power industrial uses with strikers Trip switchgear. Prevents single phasing. Gives indication of operation
Industrial protection up to ratings of 1200 A 660 V. Breaking capacity up to 80 kA
Special semiconductor protection IEC 269-4 BS in preparation
Breaking capacity 16.5 kA and 33kA BS 1361(1971)
Domestic & Similar Applications
Links in plugs. Breaking capacity 6000 A. BS 1362 (1973)
Protection of sub-circuits. Breaking capacity 1 to 12 kA
Protection of electronic and similar apparatus
Cheap element replaceable but emits flame and needs good clearance. Not current limiting. Class I more sophisticated than Class 2.
Limits short circuit energy. Cheaper than circuit breakers. Special types can be oil immersed. Takes time to replace fuses when restoring supply, but exact restoration of characteristics ensured, whereas circuit breakers may need maintenance. Isolating switch required.
Ratings interchangeable for convenience
Comparatively inexpensive limitation of short circuits. Accurate time current characteristics of different types to suit applications. Quick and easy replacement with cartridge of correct type, but longer than reclosing circuit breakers.
Very fast acting on short circuit. I²t and overvoltage very carefully controlled.
Ratings non-interchangeable for safety reasons when replaceable by a domestic consumer. Special types for supply authority replacement ensure discrimination, giving negligible chance of blowing the company's fuse.
Isolates faulty appliance only. Ratings interchangeable.
High breaking capacity for small size. Cheap, easy to replace. Remains stable when carrying current for long periods. Isolate only the faulty component, ensuring continuity of supply elsewhere. Ratings interchangeable, 13 A for "power", 3 A for "light" type of application, other ratings for special use
Economical where frequent short circuits occur. High fusing factor, low breaking capacity. Less efficient limitation of short circuits. Variability of characteristics after rewiring. Deterioration in use. Rewiring time consuming and open to abuse.
Cheap. Large range of characteristics from very quick-acting to super time lag. Interchangeable. Assist rapid maintenance by isolating parts of circuits. Avoid: use on high prospective current circuits; replacement by incorrect type.

Fig 1

TABLE I

Parameters	Test duties		
	1	2	3
Power-frequency recovery voltage	(0.87 × rated voltage) $^{+5}_{0}$ %		Rated voltage $^{+5}_{0}$ %
Prospective TRV characteristics	See Sub-clause 13.1.2		Not specified
Power factor	Not higher than 0.15 See 1 below		0.4 to 0.6
Prospective current (r.m.s. value of the a.c. component)	I_1 $^{+5}_{0}$ %	I_2	I_3 $^{0}_{-10}$ % See 2 below
Instantaneous current at initiation of arcing	Not applicable	From 0.85 I_2 to 1.06 I_2	Not applicable
Making angle	Not before voltage zero	From 0° to 20° after voltage zero	Random timing
Initiation of arcing after voltage zero	*For one test:* From 40° to 65° *For two tests:* From 65° to 90° See 3 below	Not applicable	Not applicable
Maintained voltage after breaking (See 4 and 5 below)	Not less than 15 s	Not less than 60 s	
Number of tests	3	3	2

1. To answer this specification, the circuit should not be adjusted with resistors to obtain any specified value within the tolerance.
2. When testing station limitations prevent the maintenance of constant current, the tolerance on the current can be exceeded in either direction during not more than 20% of the total melting time, provided that the current at the initiation of arcing is within the tolerance specified for test duty 3.
3. Since the operating conditions can produce a wide variety of stresses on the fuse and as the breaking tests are intended in principle to produce the most severe conditions mainly as regards the arc energy and the thermal and mechanical stresses for this value of current, it is recognized that these conditions will be practically obtained at least once, when making the three tests indicated.
4. For fuses which are subject in service to the recovery voltage for a time less than 1 s, the maintained voltage period after operation will be 1 s.
5. The initial value of the power-frequency recovery voltage shall be equal to the specified value, but when testing limitations prevent the maintenance of constant voltage, the maintained voltage may drop to 15% below the specified value.

TABLE II

Values for breaking capacity tests for a.c.

		Test according to Sub-clause 8.5.5.1				
		No. 1	No. 2	No. 3	No. 4	No. 5
Power-frequency recovery voltage		110% of the rated voltage $^{+5\%}_{-0\%}$ *				
Prospective test current	For general purpose fuse-links	I_1	I_2	$I_3 = 3.2\ I_f$	$I_4 = 2.0\ I_f$	$I_5 = 1.25\ I_f$
	For back-up fuse-links			$I_3 = 2.5\ k_2\ I_n$	$I_4 = 1.6\ k_2\ I_n$	$I_5 = k_2\ I_n$
Tolerance on current		$+10\%$ -0%	Not applicable	$\pm 20\%$	$+20\%$ -0%	
Power factor		0.2 - 0.3 for prospective test currents up to 20 kA 0.1 - 0.2 for prospective test currents above 20 kA	Same value as for test No. 1	0.3 - 0.5		
Making angle after voltage zero		Not applicable	$0\ ^{+20°}_{-0°}$	Not specified		
Initiation of arcing after voltage zero		For one test: 40°- 65° For two tests: 65°- 90°	Not applicable	Not applicable		

* This tolerance may be exceeded with the manufacturer's consent.

I_1: current which is used in the designation of the rated breaking capacity (see Sub-clause 5.7).

I_2: current which shall be chosen in such a manner that the test is made under conditions which approximate those giving maximum arc energy.

Note. — This condition may be deemed to be satisfied if the current at the beginning of arcing (instantaneous value) has reached a value between 0.60 $\sqrt{2}$ and 0.75 $\sqrt{2}$ times the prospective current (r.m.s. value of the a.c. component).

As a guide for practical application, the value of current I_2 may be found between three and four times the current which corresponds to a pre-arcing time of 0.01 s on the time/current characteristic.

I_3, I_4, I_5: the tests made with these test currents are deemed to verify that the fuse is able to operate satisfactorily in the range of small over-currents.

I_f: conventional fusing current (see Sub-clause 5.6.2) for the conventional time indicated in Sub-clause 8.4.3.3, Table VII.

k_2: see Figure 1, page 72.