THE CONTROL OF VOLTAGE-DROP IN MINIATURE FUSES

J.D. Flindall

Dubilier plc, Beswick Division

ABSTRACT

Voltage-drop is an aspect of performance uniquely significant in miniature fuse design and specification. This paper endeavours to explain the reasons for this importance, and to describe the treatment of voltage-drop and the associated power dissipation in miniature fuse Standards. Techniques for satisfactory design are discussed.

INTRODUCTION

In larger fuses, the voltage-drop is usually only regarded as important in that it is an indication of power dissipation, and therefore of circuit loss, and of excess heat generation.

While these factors are also important in a miniature fuse, voltage-drop is of fundamental concern for other reasons.

When the voltage-drop at the minimum fusing current approaches the system voltage, there is danger that the fuse will fail to operate correctly. This is particularly important where circuits operate on a supply of 5V or less, and where normal currents may be of tens of milliamps.

Balanced telecommunications line applications require not only that fuse impedance be limited, but also that for a given type and rating the range of voltage-drop values be closely controlled.

International Standards have for many years recognised voltage-drop as an important factor in specification. More recently it has become of prime importance in the requirements of quality control as an indicator of possible degradation of the fuse. Specifications for power dissipation and acceptance have had to be introduced to enable safe co-ordination of fuse-link and fuse-holder.

Much can be done in design and material selection to influence voltage-drop. However, there have inevitably to be compromises in other areas of fuse performance.

USER REQUIREMENTS

Minimum Operating Voltage V_o

It is obvious that if the voltage applied to a fuse under fault conditions (nearly always the system voltage) is less than the maximum value of voltage-drop attained before operation at the fault current applied, then there is a danger of the fuse failing to operate, or operating in a much longer time than is usual. This is a danger unique to miniature fuses, which are frequently used in systems operating well below V_n.

Unfortunately, the only specification point given in International Standards or in manufacturers' literature is a maximum of voltage-drop at rated current. It has for many years been a 'rule-of-thumb' that a fuse should not be used where the system voltage is less than twice the maximum expected voltage-drop. If this (somewhat unreliable) rule is followed, then Fig. 1 shows the relationship between I_n and the minimum operating voltage for fuses with values of voltage-drop corresponding to the maxima allowed by IEC 127 : 1974, and also for representative realistic fuse types.

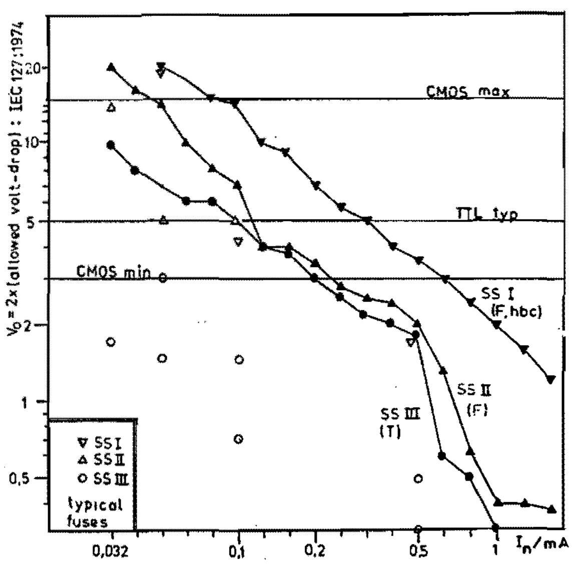


Fig. 1 I_n : Minimum operating voltage at twice IEC127 voltage-drop limits.

It can be seen that the problem is at its worst at very low values of I_n. It is unfortunate that, with the emphasis on low power consumption in all types of equipment, this is an area of immediate importance.

For reference, minimum and maximum power supply voltage values and indications of typical circuit currents for a number of recognised electronic circuit configurations are given in Fig. 2.

Industrial Standards

9V	battery operated consumer equipment
12V	military. typical RS232
15V	industrial analogue equipment
24V	DIN industrial standard

Semiconductor Families

≈1.2V	I^2L devices
2-6V	74HC logic
3-15V	4000 series CMOS
5V	nominal TTL and LSI supply
12.5V	EPROM programming.
21V	EPROM programming.
25V	EPROM programming.

Fig. 2 Typical power supply specifications.

Power Dissipation P_d

The importance of correct design of terminations to enable adequate and controlled dissipation of generated heat has long been recognised in power fuses (Wright and Newbery[1] state that up to 75% of the heat generated by a fuse-link is dissipated through the end connections, and Wilkins et al[2] point out the importance of the heat-generating contribution of fuse endcaps and connecting cables in modelling fuse performance). I^2R heat and its dissipation are of equal importance in miniature fuse design, for two reasons:

1) As Fig. 3 shows, for fuselinks of relatively high rated current, the design of termination systems has a significant effect on the low-overload performance and volt-drop. The comparison here is between fuse-links mounted in a) the test-fixture specified in IEC 127, and b) a commercial chassis-mounting fuse-clip.

Fuse-link type: 20x5mm to UL198G
Rated current: 5A
Conditions: 1.35 I_n operation

a) Using IEC 127 test-clip:

Operating time = mean: 13.8s
σ : 2.1s

b) Using commercial fuse-clip (as used in testing by UL)

Operating time = mean: 9.2s
σ : 0.9s

2) If a fuse-link is mounted in a fuse-holder of inadequate design, possibly with poor electrical and mechanical connections to the system, then it is all too possible for the total heat generated by the fuse and its connections even at rated current to cause damage to the fuse-link, the fuse-holder and the terminations. Typically, if the fuse-link to fuse-holder terminal contact is maintained by a compression spring, this may anneal and thus cause a decrease in contact pressure. The contacts and terminations inside and outside the fuse- holder may become oxidised, and the fuse-link itself, after a prolonged period of operation at, effectively, an abnormally high ambient temperature, may suffer deterioration causing a high inherent resistance, and possibly a potential failure to operate normally. The result is a thermal runaway situation, and unless the fuse eventually operates, the outcome will be a fire in combustible parts of the fuse-holder or its connections. The author knows of such a case systematically occurring in consumer equipment, which in the short term caused a number of fires in public buildings, and in the long term a large claim for damages and compensation!

Matching and tolerance of voltage-drop values.

In telecoms line applications, fuses are often required to be placed between outside line equipment and sensitive amplifying and switching circuits inside the telephone exchange. Here, in conjunction with parallel-connected over-voltage protectors they protect the exchange circuits against the effects of accidental mains connection to the telephone lines.

In this position, the fuse necessarily forms a part of the termination network of the balanced line. Therefore its impedance must be closely controlled. In circuits in current use, only the resistive component of the impedance is significant; in future systems, the inductance may also be important.

A typical interface circuit is shown in Fig. 4., and a typical specification for a matched pair of line fuses in Fig. 5. In this particular case the fuse is also required to have a nominal resistance of 1.15Ω; this is rather higher than the minimum achievable value for the fuse characteristic. The requirement that, in order to maintain line balance, the resistance of the two fuse elements must be matched to ±7.5%, after one of the elements has been subjected to 10 x 1.5kV pulses of 10/700μs waveform, is very difficult to meet on a mass-production device.

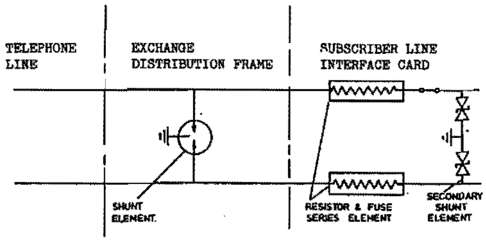
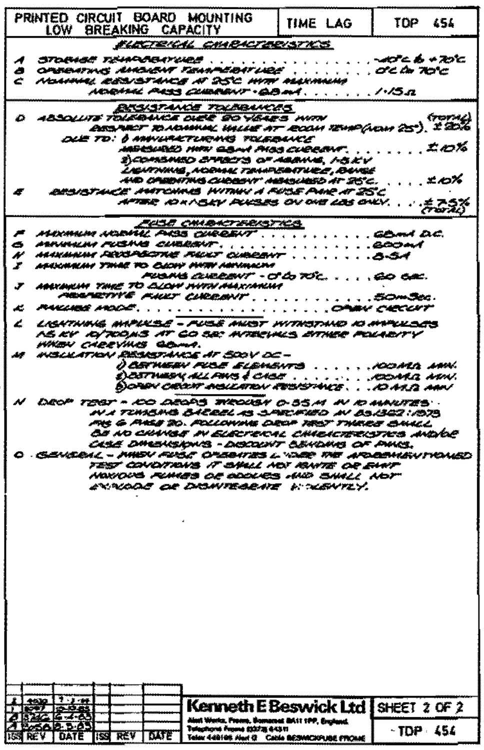


Fig 4. Typical telecoms line protection circuit.



PRINTED CIRCUIT BOARD MOUNTING LOW BREAKING CAPACITY	TIME LAG	TDP 454

ELECTRICAL CHARACTERISTICS

A STORAGE TEMPERATURE .... -40°C to +70°C
B OPERATING AMBIENT TEMPERATURE .... 0°C to 70°C
C NOMINAL RESISTANCE AT 25°C WITH MAXIMUM NORMAL PASS CURRENT - 68mA .... 1·15Ω

RESISTANCE TOLERANCES

D ABSOLUTE TOLERANCE OVER 20 YEARS WITH RESPECT TO NOMINAL VALUE AT ROOM TEMP (NOM 25°). ±20% (TOTAL)
DUE TO: i) MANUFACTURING TOLERANCE MEASURED WITH 68mA PASS CURRENT .... ±10%
ii) COMBINED EFFECTS OF AGEING, 1·5KV LIGHTNING, NORMAL TEMPERATURE RANGE AND OPERATING CURRENT MEASURED AT 25°C ..... ±10%
E RESISTANCE MATCHING WITHIN A FUSE PAIR AT 25°C AFTER 10 x 1·5KV PULSES ON ONE LEG ONLY ... ±7·5% (TOTAL)

FUSE CHARACTERISTICS

F MAXIMUM NORMAL PASS CURRENT .... 68mA D.C.
G MINIMUM FUSING CURRENT 600mA
H MAXIMUM PROSPECTIVE FAULT CURRENT .... 8·5A
I MAXIMUM TIME TO BLOW WITH MINIMUM FUSING CURRENT - 0° to 70°C ..... 60 SEC.
J MAXIMUM TIME TO BLOW WITH MAXIMUM PROSPECTIVE FAULT CURRENT .... 50mSec.
K FAILURE MODE .... OPEN CIRCUIT
L LIGHTNING IMPULSE - FUSE MUST WITHSTAND 10 IMPULSES 1·5 KV 10/700μS AT 60 SEC INTERVALS EITHER POLARITY WHEN CARRYING 68mA.
M INSULATION RESISTANCE AT 500V DC -
i) BETWEEN FUSE ELEMENTS .... 100MΩ MIN.
ii) BETWEEN ALL PINS & CASE .... 100MΩ MIN.
iii) OPEN CIRCUIT INSULATION RESISTANCE ... 10 MΩ MIN
N DROP TEST - 100 DROPS THROUGH 0·55 M IN 10 MINUTES IN A TUMBLING BARREL AS SPECIFIED IN BS1362:1973 FIG 6 PAGE 20. FOLLOWING DROP TEST THERE SHALL BE NO CHANGE IN ELECTRICAL CHARACTERISTICS AND/OR CASE DIMENSIONS - DISCOUNT BENDING OF PINS.
O GENERAL - WHEN FUSE OPERATES UNDER THE AFOREMENTIONED TEST CONDITIONS IT SHALL NOT IGNITE OR EMIT NOXIOUS FUMES OR BODIES AND SHALL NOT EXPLODE OR DISINTEGRATE VIOLENTLY.

ISS REV DATE ISS REV DATE | Kenneth E Beswick Ltd | SHEET 2 OF 2 | TDP 454

Fig. 5. Specification for telecoms line fuses: balanced pair.

INTERNATIONAL STANDARDS REQUIREMENTS

1. IEC Standards have until recently not specified (or even defined) power dissipation for fuse-links. Since 1980, IEC 257[4] has required manufacturers to provide in their catalogues the accepted power (P_a) of their fuse-holders; this figure is verified by a temperature rise test using a 5Ω power resistor in place of the fuse-link, at a current of, typically, 900mA. In fact, the requirement to publish P_a has been rarely been obeyed.

Furthermore there has been no definition or test for the power dissipation of fuse-links in IEC 127[5]; nor has a temperature-rise test been specified. The only relevant parameter specified has been the maximum allowed voltage-drop.

More recently, the Working Groups of IEC Technical Sub-committee SC 32C have prepared specifications for the power acceptance of fuse-holders and for the maximum sustained dissipation of fuse-links (tabulated against I_n), together with test requirements. These parameters are both arranged in preferred values of 1.6, 2.5 and 4 watts to enable users easily to specify safe combinations of fuse-links and -holders. These requirements will be incorporated in the forthcoming complete revision of IEC 127, which will become a multi-part document covering a comprehensive range of miniature fuse-links types.

Also included will be a warning note on the subject of minimum operating voltage: this is to be published first as an Amendment to the existing document. It will probably be necessary to include tabulated limits of minimum operating voltage for some sub-miniature fuses in the new Standard.

2. The UL Standard on miniature fuses, UL198G[6], contains no requirements on voltage-drop. There is, however, a limit of temperature rise, tested at 1.1 I_n (or for some types 1 I_n).

UL[3] require a fuse-holder to be tested for temperature-rise at its rated current (ie the maximum rated current of a fuse-link with which it is intended to be used), using a copper slug of negligible resistance in place of the fuse-link; this test can only determine the current-carrying capacity of the fuse-holder and fuse-link contact system, and not the susceptibility of the fuse-holder to heat input from the fuse-link.

IEC[4], on the other hand, have since 1980 required equivalent tests to be carried out using a power resistor of similar dissipation to a typical fuse-link, but at a small fraction of the rated current, thus testing the heat withstand of the fuse-holder but not the current-carrying capacity of the contacts. This clearly gives rise to a potential situation of dangerous misapplication; this is one of the areas of conflict between the two standards systems which the IEC Committees have been trying for many years to resolve (but so far, without success).

MATERIALS AND DESIGN

Choice of materials

In many cases element materials of the lowest possible resistivity may be used (i.e. silver or copper), and in the shortest practicable length (i.e., essentially the length between the terminations. Two constraints may cause the designer to choose another material:

1. The practical requirements of handling make it impossible to use these materials in sizes smaller than, e.g. 40 micron diameter unless physically supported. Such materials as nichrome can be handled unsupported down to about 6 micron; by special techniques, for example platinum is used in sub-micron sizes.

2. Long experience, and recent analytical work, show that the time-delay characteristic of a simple fuse element is strongly dependent upon its length and the resistivity of its material. Increasing the length of a miniature fuse element by forming the conductor as a helix is common practice, as is the use of metals or alloys of relatively high resistance such as silver/copper, brass, zinc or tin/zinc. Unfortunately such designs tend to increase the voltage-drop and dissipation of the fuse. Also, when a filler is used to increase breaking capacity it may be necessary to use another material to compensate for the change in characteristic caused by the cooling effect of the filler.

Design considerations

The following are among the techniques in design which have yielded improvements in voltage-drop:

1. Reducing element length.

This also gives a faster-operating fuse, which may be undesirable, and will adversely affect breaking-capacity. It has been achieved by, for example:

-Using a helical element[7], which is then dipped in solder to leave a short, central, operating area.

-Using a fine wire element supported on a paper former, which is then coated with conducting material[8], leaving a central operating section.

-Using a design of fuse for printed wiring board mounting, with parallel connecting pins. The element length is defined by the pitch of these pins, and provided the spacing is sufficient for the working voltage when the p.w.b. is assembled, the user can choose a fuse with the combined benefits of minimum size and minimum voltage-drop.

-Using a compound element of the spring and blob type. To achieve a reduction in voltage-drop it is necessary to shunt the spring with a flexible conductor: this may not be possible at low values of I_n where the heat generated in the spring is important to ensure operation at low overloads.

2. Use of 'Metcalfe Effect'.

This is usually considered as a technique for lowering the minimum fusing current, and thereby giving a time-delay characteristic. However, it has also been used as an expedient allowing a significant increase in element wire diameter, and thereby reducing voltage-drop and dissipation. In one particular case it was found possible to meet a UL temperature-rise specification for a non-time-delay fuse only by this method; rather than the 'M-blob", a continuous tin coating was used, giving a further slight reduction in voltage-drop.

3. Use of insulating filler.

In a paper presented at this Conference, R. Brown[9] describes the use of microporous insulation to decrease the radial heat loss from the fuse element, decreasing the minimum fusing current and thereby increasing the delay of the fuse. This also has the advantage of enabling a larger element cross-section to be used for a given rated current, thus reducing the voltage-drop and dissipation.

CONCLUSIONS

Although voltage-drop, matching and dissipation have always been important parameters in specifications agreed between suppliers and users of miniature fuses, it is only recently that this importance has been reflected in the drafting and co-ordination of International Standards.

There are useful techniques available for the minimisation or control of voltage-drop, although these invariably have effects on other aspects of performance. There remains much to be done in exploring the limits of performance of miniature fuses, and voltage-drop will be an important prime parameter in this development.

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Session VIII

APPLICATION ASPECTS

Chairman: Mr. B. Noordhuis