STANDARDISATION OF FUSES.

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The standardisation of electric fuses and the enforcement of more stringent regulations with regard to their design and use would contribute greatly to the increased safety of electrical installations and would put the manufacture of this class of apparatus on a more uniform and scientific basis. So long ago as 1905 an editorial in one of our electrical journals* drew attention to the importance of standardising low-tension fuses, and, whilst regretting that we lagged far behind other countries in giving this matter the attention it deserved, took comfort in the assurance that, at some future date, we should fall into line. The difficulties to be overcome before a standard system of fuses can be brought into general use are certainly numerous, but delay renders the problem more and more complex. The necessity for and advantages of standardisation do not require very much demonstration, and the only point in this connection which the author desires to emphasise is the importance of simplicity, efficiency, and reliability in every detail of the electric circuit. If we would foster the popularity of electrical applications and the prosperity of the industry we must create and maintain confidence in the safety, reliability, and convenience of electrical power by every possible means. In addition to contributing largely to the attainment of this end the standardisation of fuse design would undoubtedly conduce to economy in manufacture and result finally in a reduction of cost.

Makers of fuses now display in their catalogues so many types and so many designs of each type that it is difficult to escape the conclusion that the fuses are ornamental adjuncts to a switchboard and may be chosen in a style most suitable to, say, the scrollwork which supports the clock. Up to a certain point it is a very simple matter to determine the behaviour of a fuse when blown under working conditions, and this fact renders still more inexplicable the retention of many types which are wholly inadequate and of others which are needlessly elaborate.

In the present paper the subject is dealt with from a practical rather than academic point of view, the object being, if possible, to suggest a few lines along which certain essential questions may be

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* *Electrical Review*, vol. 56, p. 713.

tackled. The results of tests on commercial fuses will be considered in conjunction with corresponding theoretical indications, and definite deductions will be drawn as to the most suitable quantitative and structural properties for a standard line of fuses. Up to the present time the tests referred to have been confined to low-tension fuses up to a normal carrying capacity of about 60 amperes, but it is hoped to continue the experiments on fuses of much larger capacity.

The complete specification of a line of fuses will embrace :—

(*a*) A definition of the "marked" or "rated" current in terms of the "limiting" current (also called the "normal fusing" current).
(*b*) A standard range of rated-current values and voltages.
(*c*) A definition of one or more points on the "time-overload" curve of each fuse.
(*d*) Regulations as to non-interchangeability, temperature rise, freedom from deterioration, and perfect operation under all conditions.
(*e*) Specifications for the standard method of carrying out short circuit, temperature rise, and overload tests.

In framing suggestions with regard to the above points due consideration is demanded for the user, the workman, the retailer, and the manufacturer; for example, the quantitative properties of the fuses should lend themselves to simple control in the factory, the number of types should be reduced to a minimum, the price should be moderate, etc.

(*a*) THE RATED CURRENT.

As is well known, the chief characteristic of a fuse for quantitative purposes is its "time-overload" curve and the asymptotic current value of this curve to which the name "normal fusing current" has been given, but which will be referred to in this paper as the "limiting current." Fig. 1 shows the general type of a time-overload curve, of which the abscissæ represent the time intervals from the moment of switching on, and the ordinates either ampères or percentage overload above the rated current. The curve is asymptotic to the ordinate A B, and the current value corresponding to this asymptote is the "limiting current." The strict definition of the limiting current is the minimum steady current which will produce fusion after an infinite time interval, but for practical purposes we might substitute with advantage a definition referring to a definite time-interval—say 4 hours—instead of the unlimited period. The limiting current or limiting overload is the one fundamental quantity to which any definition of rated current should refer. An appropriate way of defining the rated or marked current of the fuse is as follows: A fuse which is rated at R amperes must fuse within 4 hours when carrying a times its rated current, but must be capable of carrying $a - \alpha$ times its rated current for at least 4 hours without fusing. If L amperes is the limiting current, the rated current R amperes must lie between $\frac{L}{a}$ and $\frac{L}{a - \alpha}$.

The values chosen for a and $a - \alpha$ depend on a large number of practical considerations, and should also be selected with a view to facilitating the application of the above definition in factory and test-house. Thus the difference α between the two values may be looked upon as a measure of the accuracy with which the specified conditions can be attained in manufacture.

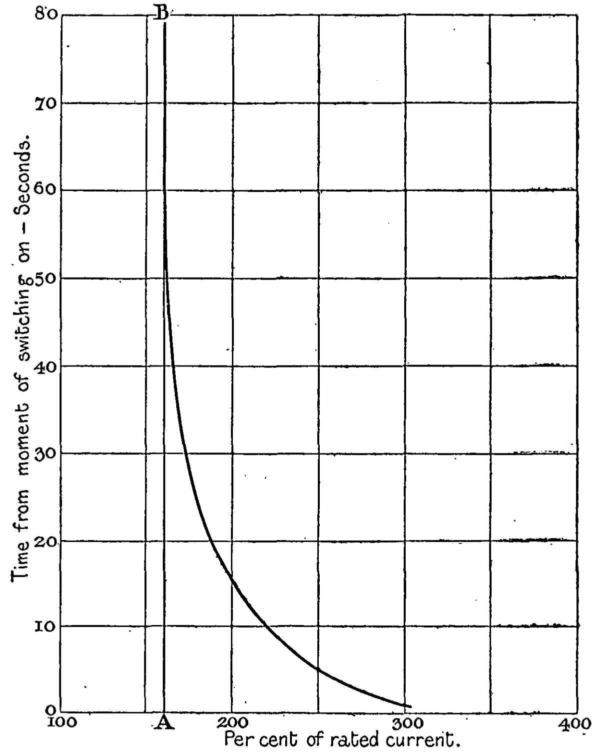


FIG. 1.—General Type of "Time-overload" Characteristic of a Fuse.

The latter point recalls the fact that the Wiring Rules of this Institution require that no fuse shall carry more than 200 per cent. overload without fusing (*i.e.*, $a = 3{\cdot}0$), whereas the rules of another recognised authority in this country restrict the permissible overload to 50 per cent. ($a = 1{\cdot}5$). The writer has recently heard of suggested modifications to the overload regulation from two independent sources, one of which was a proposal to permit an overload of 300 per cent.

($a = 4$), while the second authority was of the opinion that the permissible overload should be even less than 50 per cent. if manufacturers could work to a narrower limit. If, as may be assumed, the smaller overload is the one dictated by considerations of safety, irrespective of manufacturing limitations, whereas the higher figure is based on a compromise between what is desirable and what is present practice, these figures furnish one of the most striking arguments for the need of a system of non-interchangeability for fuses of small capacity. This point will be dealt with more fully later in the paper. The regulations for enclosed fuses by the Underwriters Association in the United States, which have been framed with the co-operation of manufacturers, fix the values of a and $a - \alpha$ at 1·25 and 1·10 respectively, but these figures were only decided upon after manufacturers had endeavoured to work to a smaller value of α than 0·15, as

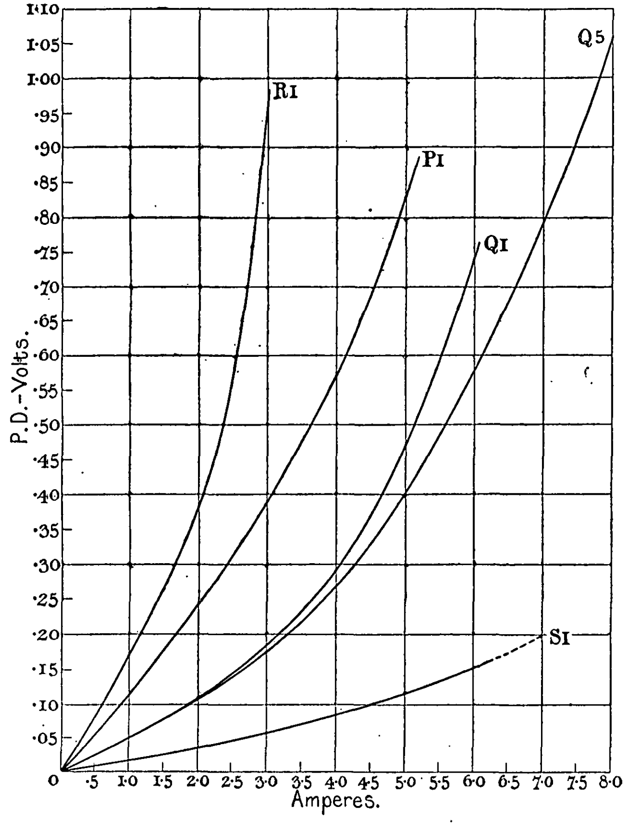


FIG. 2.—Pressure Drop across Fuses Rated at 4 Amperes.

specified above. These close limits are in marked contrast with the figures quoted above.

The results of an experimental investigation of the properties of current commercial types of fuse should give a reliable and useful indication of the possible values of a and $a - \alpha$, the limits between which the ratio $\frac{\text{limiting current}}{\text{rated current}}$ must lie, and it becomes a relatively simple matter to determine whether this ratio should have the order 4 or 1·5. In drawing inferences from such tests due weight must be given to the many other properties which are closely connected with the ratio a, and observations must be made of running temperature, voltage drop, behaviour when blowing on overload and short circuit, and general reliability and safety.

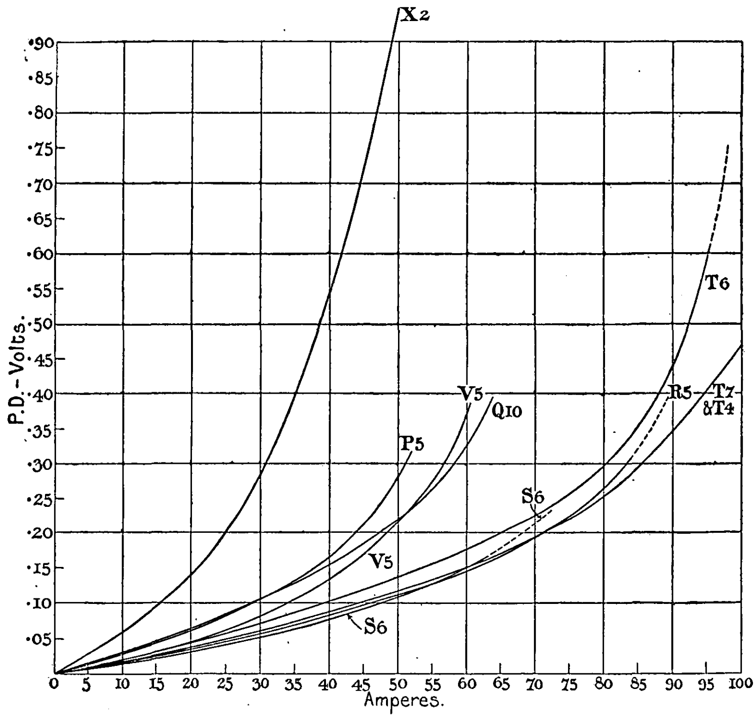


FIG. 3.—Pressure Drop across Fuses Rated at 50 Amperes.

Table I. is a summary of some of the tests carried out on a representative variety of fuses in common use; illustrations of a few of the fuses tested are shown in Plate I. A distinctive letter has been given to all fuses made or supplied by one firm and the various sizes and types are denoted by a number which follows this letter. Figs. 2 and 3

TABLE I.

Symbol of Fuse.	Rated Current.	Rated Maximum Voltage.	Ratio. $\frac{\text{Limiting Current}}{\text{Rated Current}}$		Voltage Drop at		Watts Lost at		Remarks.
			$a - a$ Minimum.	a Maximum.	Rated Current.	Rated Current $\times\, a - a$.	Rated Current.	Rated Current $\times\, a - a$.	
P_1	4	500	1·25	1·50	0·572	0·830	2·290	4·15	
P_2	10	500	1·30	1·40	0·247	0·351	2·470	4·21	
P_3	20	500	1·58	—	—	—	—	—	
P_4	30	500	0·93	1·07	0·300	0·235	9·000	6·58	
P_5	50	500	1·00	1·16	0·277	0·277	13·870	13·87	
Q_1	4	250	1·63	1·75	0·288	0·740	1·150	4·44	
Q_2	6	250	1·67	2·00	0·232	0·695	1·390	6·95	
Q_3	10	250	1·50	1·70	0·143	0·263	1·430	3·68	
Q_4	15	250	1·53	1·67	0·151	0·306	2·120	6·11	
Q_5	4	500	2·00	2·25	0·268	1·060	1·070	8·48	
Q_6	6	500	1·50	1·67	0·315	0·600	1·890	4·80	
Q_7	10	500	1·70	2·00	0·161	0·529	1·610	9·00	
Q_8	15	500	2·00	2·20	0·149	0·484	2·080	14·52	
Q_9	30	500	1·27	1·43	0·255	0·484	7·140	18·36	
Q_{10}	50	500	1·40	1·60	0·224	0·321	11·200	19·26	
R_1	4	550	0·75	1·00	—	0·958	—	2·87	Dangerous on short-circuit. Case burnt on continuous overload in all fuses. Calibration. very ununiform.
R_2	10	550	0·80	1·00	—	0·272	—	1·91	
R_3	20	550	1·38	—	—	—	—	—	
R_4	30	550	1·07	1·27	0·235	0·387	6·580	12·07	
R_5	50	550	1·60	1·70	0·111	0·265	5·560	21·21	
S_1	4	250	1·50	1·75	0·082	0·153	0·328	8·20	Case burst on all short-circuit tests of these fuses and frequently on overload tests.
S_2	10	250	1·00	1·20	0·180	0·890	1·800	10·66	
S_3	10	500	1·15	1·20	0·203	0·983	2·030	11·79	
S_4	20	500	1·98	—	—	—	—	—	
S_5	30	500	1·27	1·40	0·106	0·412	2·970	15·66	
S_6	50	500	1·40	1·60	0·109	0·151	5 450	9·06	
T_1	6	250	2·67	3·00	0·078	0·563	0·466	9·01	All these fuses behaved irregularly on overload, and a continuous arc was often formed.
T_2	10	250	2·50	3·00	0·069	0·750	0·691	22·50	
T_3	25	600	2·00	2·20	0·106	0·372	2·640	17·90	
T_4	50	600	2·00	2·20	0·114	0·464	5·680	45·95	Solder melted on overload, wire not fused; holder burnt in halves.
T_5	25	600	2·40	2·80	0·124	0·554	3·110	33·46	
T_6	50	600	2·00	2·40	0·141	0·775	7·030	75·40	
T_7	50	600	2·00	2·20	0·119	0·463	5·950	45·80	
V_1	5	500	1·00	1·40	0·647	0·647	2·590	2·59	
V_2	10	250	1·00	1·20	0·261	0·261	2·610	2·61	
V_3	25	250	1·00	1·12	0·545	0·545	13·630	13·63	
V_4	30	250	1·70	1·83	0·117	0·445	3·260	21·33	
V_5	50	250	1·40	1·56	0·220	0·367	11·000	22·04	
W_1	6	250	2·00	2·33	0·122	0·634	0·729	7·61	
W_2	6	250	2·33	2·67	0·119	0·737	0·714	10·33	
W_3	6	250	2·00	2·33	0·147	0·875	0·883	10·50	
W_4	30	250	1·43	1·60	0·323	1·048	9·040	45·00	
X	25	500	1·00	1·12	1·245	1·245	31·110	31·11	These fuses ran very hot owing to their excessive length & the small value of a.
X_2	50	500	1·00	1·20	0·948	0·948	47·380	47·38	

are typical sets of curves showing the voltage drop as a function of the current or percentage overload, while Figs. 4 and 5 show the watts losses corresponding to the voltage drops plotted in Figs. 2 and 3.

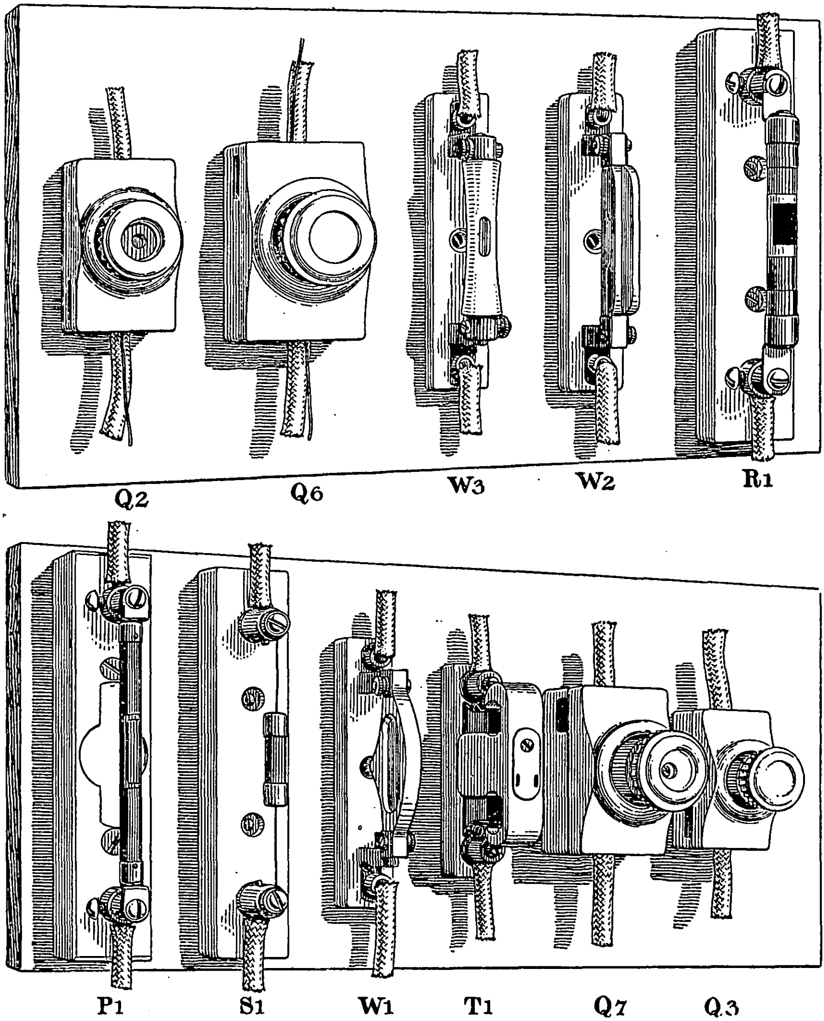


PLATE I.—Some Representative Types of the Fuses Tested.

Before proceeding to make any deductions from these results let us consider one or two points which may serve for general guidance. Taking first the case of a bare fuse wire stretched between two terminals, let us assume that a line of fuses, all of equal length, is to be designed. It will be found that the voltage drop is proportional inversely to about the square root of the limiting current: thus, for example, fuses for 5 amperes and 50 amperes limiting current, which are to be rated at 50 per cent. or at 2·5 and 25 amperes respectively, will, if of tinned copper, have diameters:—

5 amperes limiting current	... ...	0·0145 cms.
50 amperes limiting current	... ...	0·079 „

At the same percentage of their limiting currents, corresponding in this example to the same percentage overload, the two fuses will have voltage drops proportional respectively to—

$$\frac{5}{(0{\cdot}0145)^2}, \text{ or } 23{,}800 \text{ for the } 2{\cdot}5\text{-ampere fuse,}$$

and—

$$\frac{50}{(0{\cdot}079)^2}, \text{ or } 8{,}010 \text{ for the } 25\text{-ampere fuse,}$$

so that the volts drop of the smaller fuse will be roughly three times that of the larger one. With a length of 3½ in. the actual voltage drop when the fuses are run at 50 per cent. of the limiting current will be—

0·34 volt at (5 × 0·5) amperes,

and—

0·11 volt at (50 × 0·5) „

The corresponding figures for a current 90 per cent. of the limiting current are—

1·40 volt at (5 × 0·90) amperes,

and—

0·47 volt at (50 × 0·90) „

The drop of 1·40 volts is excessively high and would in most cases form a large proportion of the total fall of pressure in the circuit; the figure can be reduced either by decreasing the length of 3½ in. between the terminals or by increasing the ratio of $\frac{\text{limiting current}}{\text{rated current}}$, *i.e.*, by using a larger wire and permitting a greater overload. Hence the same value of a is not advisable for large and small fuses; it may be desirable to increase the value of a as the normal working current diminishes.

In the case of fuses of the totally enclosed type, whilst the above remarks still apply, we have also to consider the effects of the increased cooling facilities and capacity for heat of the fuse enclosure. Owing to the large radiating surface, the size of wire for a given limiting current is reduced, and the drop of volts may therefore become large if the length of the fuse is not reduced or a metal adopted which has a low melting-point. If the fuse is very short, on the other hand, conduction and dissipation of heat from the terminals will play an important part and exercise a similar influence in increasing the voltage drop and power loss. In order to reduce these two quantities to economical and safe limits, it becomes necessary to rate the smaller fuses at a lower percentage of the limiting current. Since well-designed fuses of the enclosed type may be made very much shorter than a corresponding open-type fuse for the same voltage, advantage should be taken of this possibility in order still further to reduce the losses; the alternative course of using a low melting-point metal is far inferior, and the larger volume of metal required may prove a source of danger. It may be noticed that it is open to the designer to rate the higher capacity fuses at the same low percentage of the

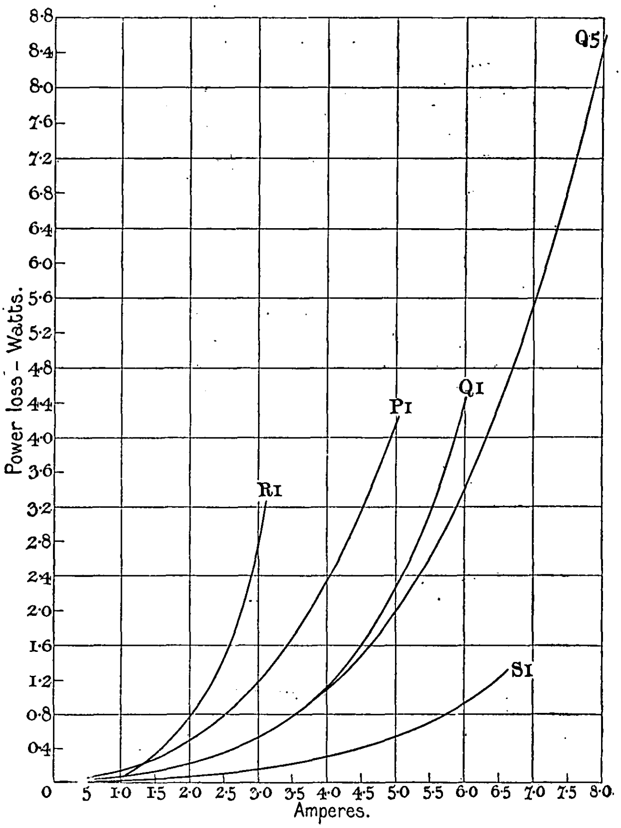


FIG. 4.—Power Lost in Fuses Rated at 4 Amperes.

limiting current as the smaller sizes, but this again involves the use of an unnecessarily large volume of metal, a proceeding to be avoided as much as possible, particularly for fuses carrying heavy currents and liable to severe short circuits.

From a purely utilitarian standpoint it is probably correct that small fuses should carry higher overloads than fuses of large capacity, and all that might be said from this point of view may be best summed up by considering a 5-ampere fuse capable of carrying 10 amperes, and a 100-ampere fuse permitting a continuous load of 200 amperes.

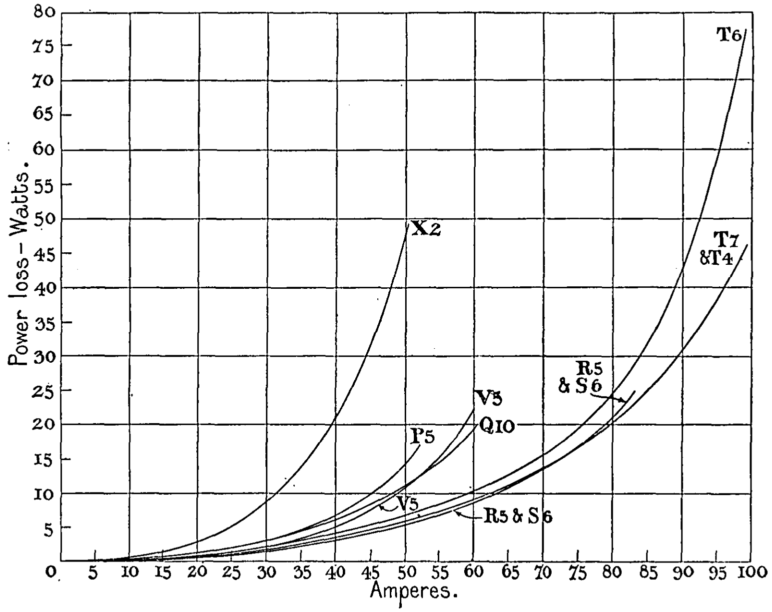


FIG. 5.—Power Lost in Fuses Rated at 50 Amperes.

The most important factor in determining a standard value or values for the ratio $a = \frac{\text{limiting current}}{\text{rated current}}$ is the maximum safe overload to which an electric circuit may, on the average, be subjected; the results arrived at from this consideration can, if necessary, be modified to meet the limitations of manufacture. The possibility of more economical utilisation of the apparatus protected is a natural consequence of adopting fuses which restrict within narrow limits the overload which may be imposed on a circuit. For fuses up to 50 amperes a maximum permissible continuous overload of 25 per cent.—as in the United States—is not wholly desirable, since most circuits and apparatus should be designed to withstand this amount of overload without injury, and further, even the best system of non-interchangeability would fail and the circuits be overfused if users and wiremen found that they could not overload circuits to more than 25 per cent. even for short periods. Fuses run normally at only 20 per cent. under the limiting current must of necessity have fusible metal of low melting-point if the running temperature is not to be unduly high ; for reasons of equal importance the use of such metals is bad.

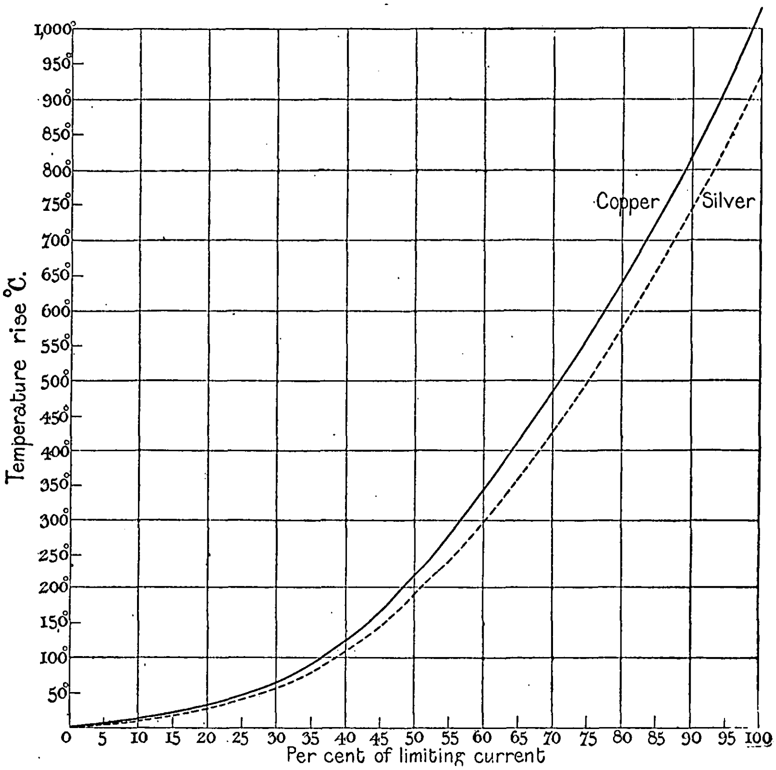


FIG. 6.—Approximate Temperature Rise of Copper and Silver Fuses in Relation to the Percentage of the Limiting Current.

Nearly all the metals used for fuses suffer oxidation if run at temperatures much above that corresponding to 50 per cent. of their limiting current, although if silver be employed the rated current may certainly be as much as 65 to 70 per cent. of the limiting current without the occurrence of any deterioration. The permissible overloads corresponding to a rating 50 per cent. and 70 per cent. of the limiting current are 100 per cent. and 43 per cent. respectively, and the large difference in these overload capacities is of interest as showing the superiority of a non-oxidising metal like silver if it is desired to reduce to a minimum the possible overload. Assuming, as will be afterwards shown, that copper and silver are the only metals suitable for standardised fuses, we can take as a rational basis—

$$\textit{Copper.}\text{—Minimum value of } \frac{\text{limiting current}}{\text{rated current}} = 2{\cdot}00$$

$$\textit{Silver.}\text{—Minimum value of } \frac{\text{limiting current}}{\text{rated current}} = 1{\cdot}43.$$

Returning for a few moments to the Table I., classes T, V, W, and X include fuses of tinned copper wire, and for all these the ratio *a* varies between about 1·12 and 3·0. The fuses whose symbol is X are rated at between 88 per cent. and 100 per cent. of the limiting current, and therefore the whole fuse-fitting became unbearably hot, with a current much below the rated value, whilst at the rated current of 25 amperes the fuse wire was red-hot and oxidising rapidly. On the other hand, the fuses T_5, which are rated at between 36 per cent. and 42 per cent. of their limiting current, contained about 2·9 times as much copper as the X_1 fuses, and are consequently far more dangerous on a high-voltage overload or severe short circuit.

Definite recommendations with regard to this part of the subject are reserved until other important questions have been discussed. Before passing on, however, attention may be drawn to Fig. 6, which shows the approximate variation of temperature of a bare copper fuse wire with increasing currents up to the melting-point and limiting current. The dotted curve is for silver fuse wire. The rapid rate at which the temperature rises after about 50 per cent. of the limiting current has been passed is noteworthy, and has an immediate bearing on the subject of rating.

(*b*) STANDARD RATED CURRENT VALUES AND VOLTAGES.

For the limits of capacity now under consideration the standard voltages of 250 and 500 volts are certainly sufficient for all requirements at the present time. Whether two standard voltages are necessary is very doubtful, and the average performance of many types of fuse on 500 volts is such as to suggest that they might act better on a considerably lower voltage. An excellent plan seems to be the adoption of a standard voltage of 500 for all sizes, and the addition of a range of small capacity fuses for 250 volts for use on lighting circuits where small size and cheapness are important and very severe short-circuit conditions do not often occur.

In proposing a standard range of rated currents the important point is to reduce the number of sizes to a minimum while providing for all current values with a reasonable margin of overload capacity. It is necessary to take into account the values of the $\frac{\text{limiting current}}{\text{rated current}}$ ratio discussed above, but provided the standard current values now commonly used are compatible with the adopted values of this ratio, there is little reason to do anything further than eliminate any redundant steps and put forward for general use the range settled upon. With bare wire, of course, any size will be used, finally the size which will not blow; but so far as the use of this type of fuse is allowed, any regulations or standards are useless.

A convenient subdivision is with steps differing by multiples of 5 amperes, giving, say, 5-, 10-, 15-, 20-, 30-, 40-, and 50-ampere sizes. At least one smaller capacity than 5 amperes is required, and since 4 and 6 amperes are standard values with a large number of manufacturers, a satisfactory completion of the range will be to adopt multiples of 2 amperes up to a value of 6 amperes, the complete standard line becoming:—

2, 4, 6, 10, 15, 20, 30, 40, 50 amperes.

(*c*) DEFINITION OF ONE OR MORE POINTS ON THE "TIME-CURRENT" CURVE OF EACH FUSE.

The main object in defining further points on the "time-current" curve of Fig. 1, in addition to the limiting current, is to ensure that the fuse will give adequate protection against very heavy overloads or short circuits, and to restrict within limits its sluggishness of action or "time element." From a practical point of view a regulation of this kind is useful because compliance with it can be readily checked, and it may be so framed as to eliminate the use of too large a mass of fusible metal and other faults of design. In order to be of real value such a regulation should require that a fuse shall melt within a fixed time—say 1 minute—when loaded with a certain multiple of its limiting current —say double that value. The actual time interval between the moment of switching on this overload and the blowing of the fuse would at the same time be taken as a practical measure of the "time element," although for this purpose a current less in excess of the limiting current would give a longer time interval capable of more exact observation. It will be convenient to return to this clause of our standard specification when finally deciding upon the question of rating.

(*d*) GENERAL REGULATIONS FOR CONSTRUCTION AND OPERATION.

While it is not desirable to specify too rigidly the constructional details to be embodied in standard fuses, yet it appears imperative that a few general principles should be laid down for the guidance of manufacturers, and one or two essential features should be demanded.

The extreme necessity of directing attention to some fundamental principles before fuse standardisation can be accomplished, is illustrated by two examples taken from samples tested by the author. A fuse (T_5 and T_6) made in several sizes for rated currents of over 20 amperes is of the protected or tubular type and of thoroughly substantial design,

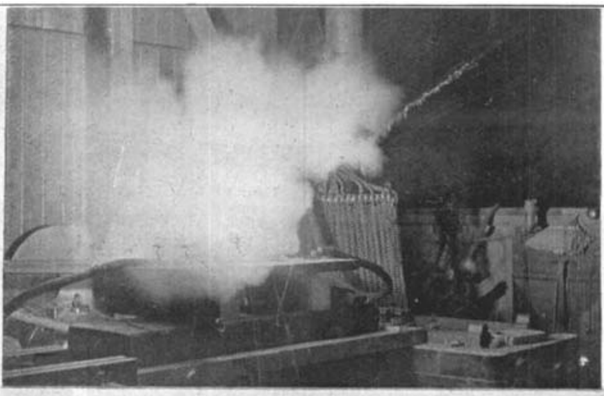


Fig. A. Fuse class R4.

Fig. B. Fuse class T7.

PLATE II. (A and B).—Operation of Fuses on Short Circuit.

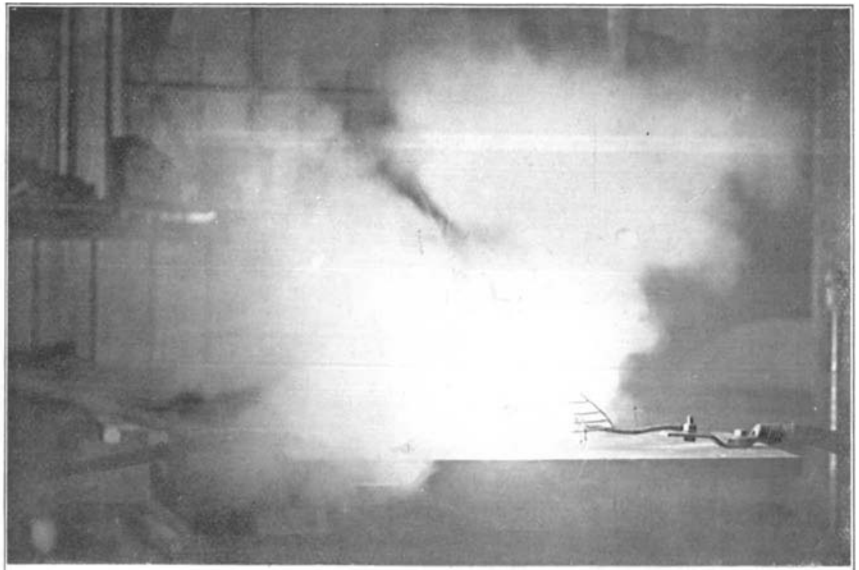


Fig. C. Fuse class S5.

PLATE II. (C).—Operation of Fuses on Short Circuit.

the fuse wire, however, consisting of stranded tinned copper wire, is *soldered* at each end into a small terminal plate. The distribution of the masses of metal is such that all the fuses of this type which were tested opened the circuit by melting the soldered connection; had the full rated pressure of over 500 volts been maintained, the arc consequent on the separation of the wire from its terminal plate would have spread speedily and consumed the entire fuse fitting and terminals until the circuit was broken elsewhere. In a second line of fuses (R) of the totally enclosed or cartridge type, also rated for over 500 volts maximum pressure, a solid single link of soft fusible metal is used, containing a volume of metal nearly fifteen times as great as that contained in another make of cartridge fuse of the same rating. This protective device is completed as an explosive of a most dangerous kind by the provision of a number of vent holes in the metal cap at each end. Every principle of the design of enclosed fuses is ruthlessly violated, and, needless to say, the behaviour of these fuses on short circuit was of a violent description. A photograph of one of these fuses in operation on short circuit is included in Plate II.

If any efforts to increase the efficiency and serviceableness of fuses are to be successful it is inevitable that bare wire fuses should be abandoned, and the logical consequence of the standardisation of small capacity fuses is the introduction of a simple method by means of which the control of the fuse capacity on any circuit is placed in the hands of competent persons only. This requirement of non-interchangeability is far-reaching in its effect on fuse design since it involves the abolition of all fuse fittings having two exposed terminals, and in so doing leads half-way to the requirement dictated by safety, namely, that no terminals whatever should be exposed on fuse-fittings intended for use in private houses or public situations. Attention was drawn on page 622 to the fact that if an overload of 200 per cent. is permitted before the fuse comes into action, non-interchangeability becomes of the highest importance, since for small currents up to 10 amperes we may assume that fuse wire of "the next larger size" will increase the possible overload by some multiple of 200 per cent., rendering the circuit liable to overloads up to 400 per cent. or 600 per cent.

If the permissible overload is reduced to a much lower figure, for example, 50 per cent., less risk is indeed incurred by inserting the next size larger fuse, but if the circuit is faulty this process will be repeated several times until the size is arrived at which does not blow. An ideal system for safeguarding a circuit against overfusing should consist of some small separate part or adjustment which can be suitably set by an electrician either to restrict the capacity of the fitting to the present current or so as to allow a definite margin for increasing the size of fuse consistent with the dimensions of the wiring or apparatus. It is difficult to see how the requirement of non-interchangeability can be met to an adequate degree by any form of exposed wire fuse when we consider that enclosure of the terminals must not prevent the non-technical user replacing a blown fuse by one of the correct size. Athough it is admitted that no non-interchangeable system will do away with the deliberate overfusing of the circuits, yet sufficient will have been attained if accidental overfusing is made impossible and an obstacle is placed in the way of using hairpins and similar well-known substitutes for the legitimate article. In their own interests, insurance companies should require the use of some system for preventing overfusing and should strictly forbid the use of any other conductor than the proper one intended for the fitting installed. A requirement of this kind would lead to the general use of the standard types which would become generally stocked and easily obtainable; the idea that the ubiquity of metal wire in some form or other justifies its indiscriminate use to nullify the purpose of a protective device would be gradually dispelled.

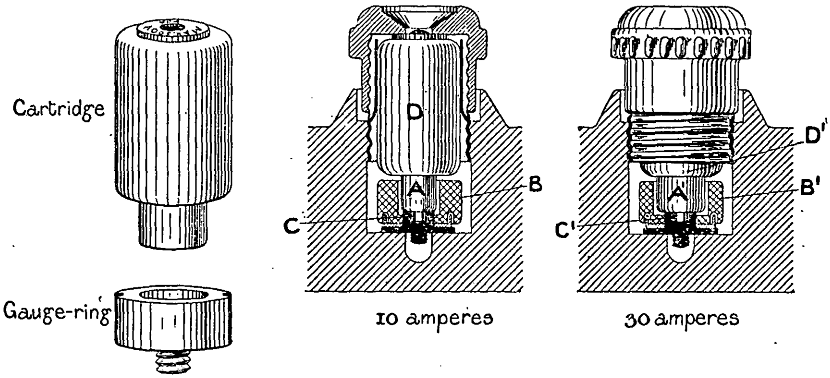


FIG. 7.—Example of Non-interchangeable Fuse System.

In order that the idea of non-interchangeability may be fully grasped, reference may be made in detail to what is, so far as the author knows, the only type of foolproof fuse on the market. Many varieties of non-interchangeable device have been employed in Edison plug fuses and allied types, but the design illustrated in Fig. 7 is a part of a fuse system which almost completely meets the requirements outlined in this paper. The loose pieces or "gauge-rings" B, B_1 consist of a steatite ring of constant external diameter, but having the diameter of the hole varying with the rated current. One of the terminals with which the cartridges D, D_1 make contact is situated at the bottom of the cylindrical hole in the steatite ring, and unless the stud A, A_1 is of equal diameter or smaller than this cylindrical hole, contact cannot be made. Thus B and D are gauge-ring and cartridge for 10 amperes, whilst B_1 and D_1 are the corresponding parts for 30 amperes rated current. The rings B for all capacities screw interchangeably into the same terminal block, but it is evident that a cartridge D_1 for

30 amperes will not make contact through its stud A_1 with the terminal C which lies at the bottom of a ring B for 10 amperes. It is, in fact, impossible to insert D_1 in a fuse fitting containing a gauge-ring B of smaller capacity. Needless to say, each rated current has its own special diameter of stud and gauge-ring orifice.

Bare wire fuses, or rather fuse fittings, in which a conductor can be easily inserted by the user, are incompatible with protection against overloading. Two other objections of equal weight against exposed fuse wire are:—

1. Their liability to scatter molten or hot metal.
2. The rapidity of corrosion unless certain non-active metals are used.

The first objection holds good of all metals, but more particularly of low melting-point metals, of which a larger volume is required than if copper or silver were employed. The second objection is especially applicable to copper, which in many other respects is an excellent fusible metal.

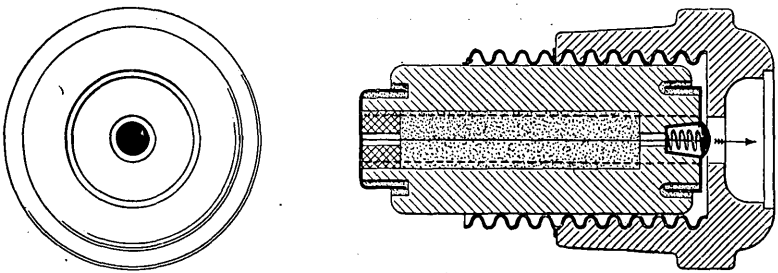
If, on the other hand, we examine the case for fuses of the totally enclosed type, we have the following outstanding advantages:—

1. The fuse wire is less liable to corrode or become injured, and therefore enclosed fuses lend themselves to exact calibration.
2. Tampering with the fuse wire is difficult, and a system of non-interchangeability is greatly facilitated.
3. If properly designed no molten or hot matter can be thrown about.
4. Perfect operation can be obtained on heavy overloads at full voltage.
5. Less metal is required, and the weight and size of the complete fuse fitting is reduced.

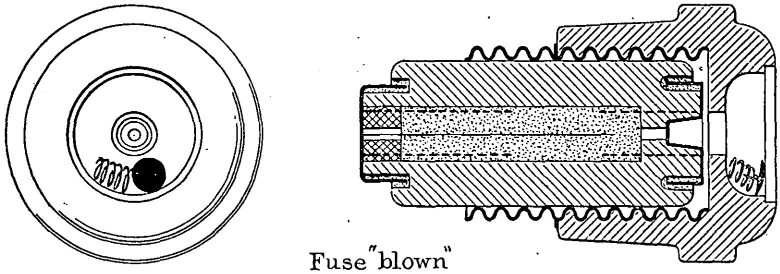
The principal objections raised against enclosed fuses are mainly questions of cost, the impossibility of inspecting the fuse wire, and the difficulty of ascertaining with certainty when the fuse has blown. The first-named objection appears to be almost wholly fictitious if account is taken of the frequency with which not only the fuse wire of an open fuse is melted, but the holder itself is either cracked or so fused as to be useless. Engineers do not seem fully to recognise how much more severe in many cases is the effect of fusion produced by a heavy gradual overload at full voltage as compared with the effect of a severe sudden short circuit. Fuses of the china holder type are often reduced to a useless condition by an overload, whereas they may withstand repeated short circuits of a severe character without great damage.

This is attributable partly to the fact that when fusion occurs on an overload the fuse wire melts at the centre and an arc is drawn out and partly to the fact that the voltage is maintained on an overload, but a short circuit usually causes a main circuit breaker or another fuse to operate simultaneously, so that the circuit is broken in several places. The fact that a gradually increasing overload heats up the fuse fitting and diminishes its power of cooling the arc and vapours is also influential.

Plate III. shows a number of fuses which have been blown by gradually increasing overload on the normal rated voltage for which the respective fittings are sold. It will be observed that the majority of the damaged fittings illustrated are rated at 500 volts or over, and this draws attention to the almost total absence of any type of open-wire fuse, which is reliable for use on high-voltage circuits. The asbestos protection now largely used, although fairly efficient when new, soon loses its efficacy after repeated blowing of the fuse, and is, moreover, frequently discarded altogether.



Fuse intact



Fuse "blown"

FIG. 8.—Example of Cartridge Fuse with "Self-testing" Indicator.

With regard to the deficiency of enclosed-type fuses in not permitting inspection of the fuse wire or giving reliable indication of fusion, the latter is a mechanical detail, which can be quite satisfactorily solved, as is shown by the arrangement adopted in a new type of enclosed fuse recently put on the market. Fig. 8 shows the design of indicator referred to. The diagrams are self-explanatory, and show that this device possesses the important advantage of being self-testing.

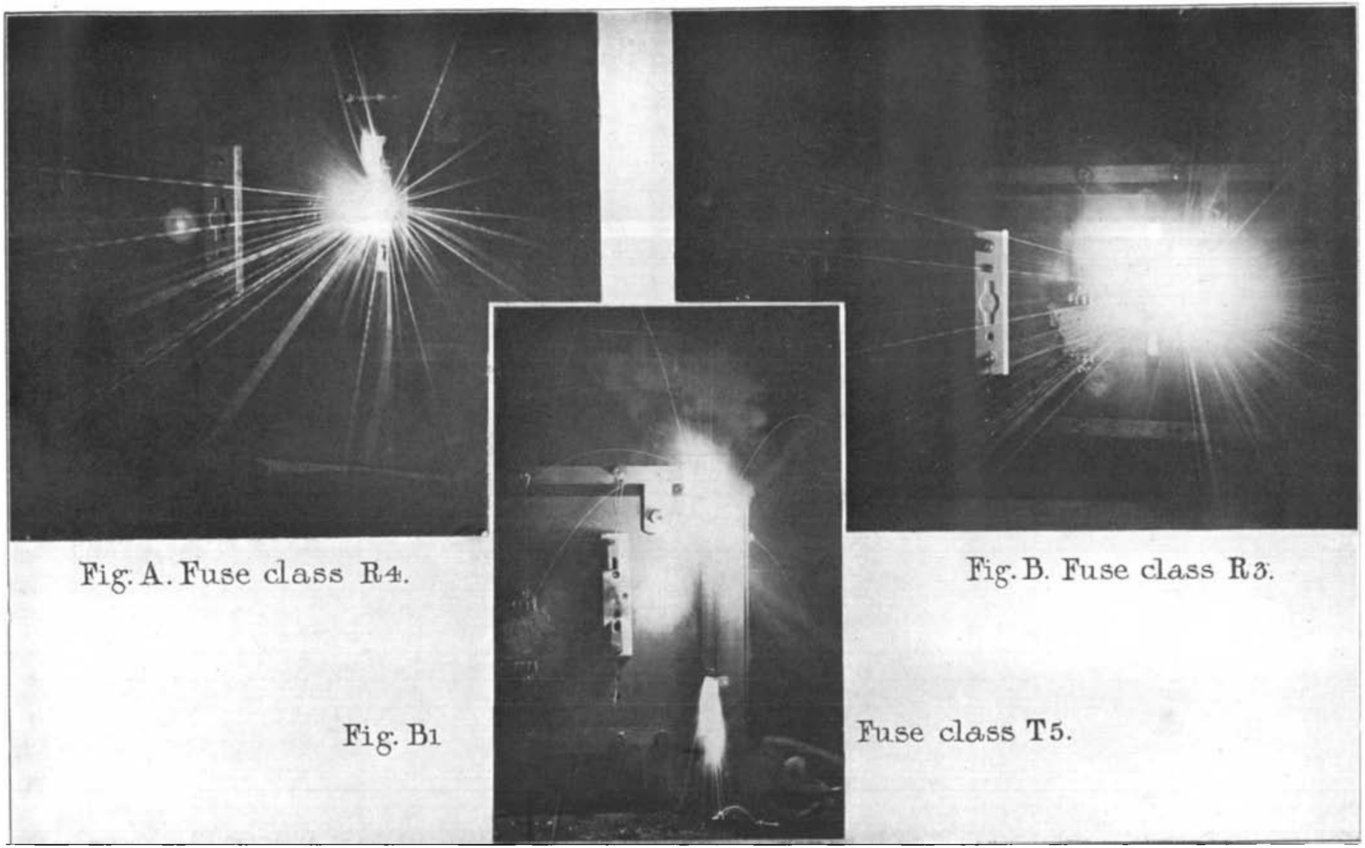


Fig. A. Fuse class R4.

Fig. B. Fuse class R3.

Fig. B1 Fuse class T5.

PLATE III. (A).—Operation of Fuses on Overload.

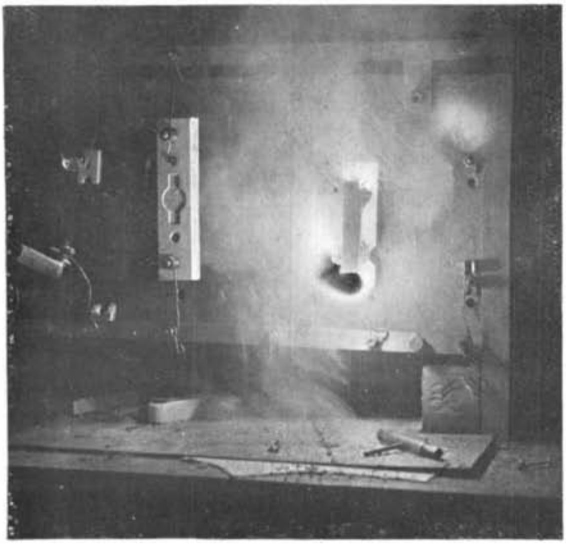


Fig. C. Fuse class V4.

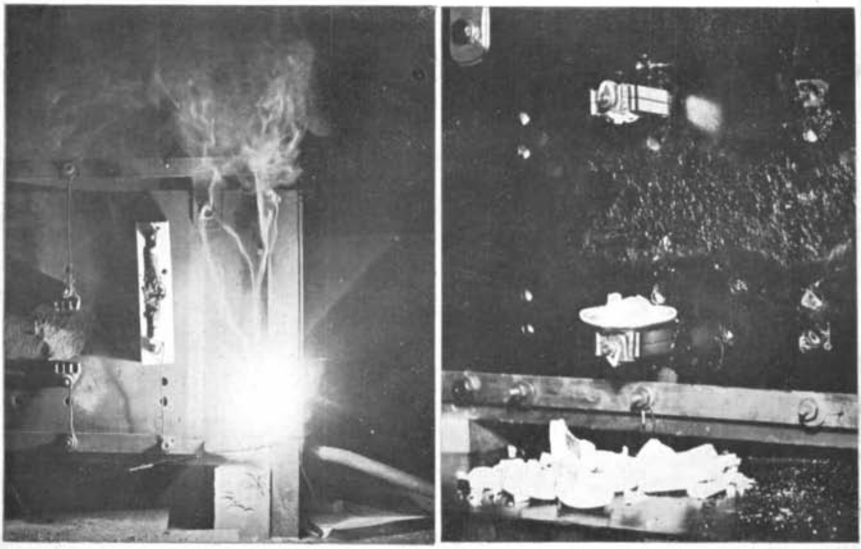


Fig. D. Fuse class S5. Fig. E. Fuse class X1.

PLATE III. (B).—Operation of Fuses on Overload.

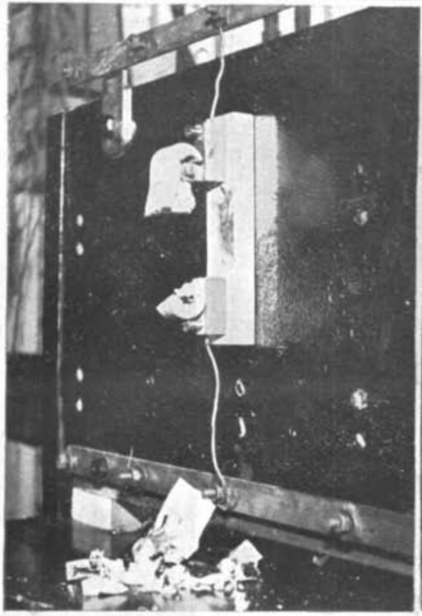


Fig. F. Fuse class T4.

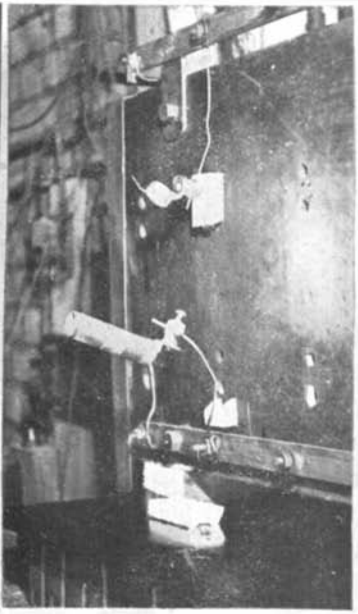


Fig. G. Fuse class S5.

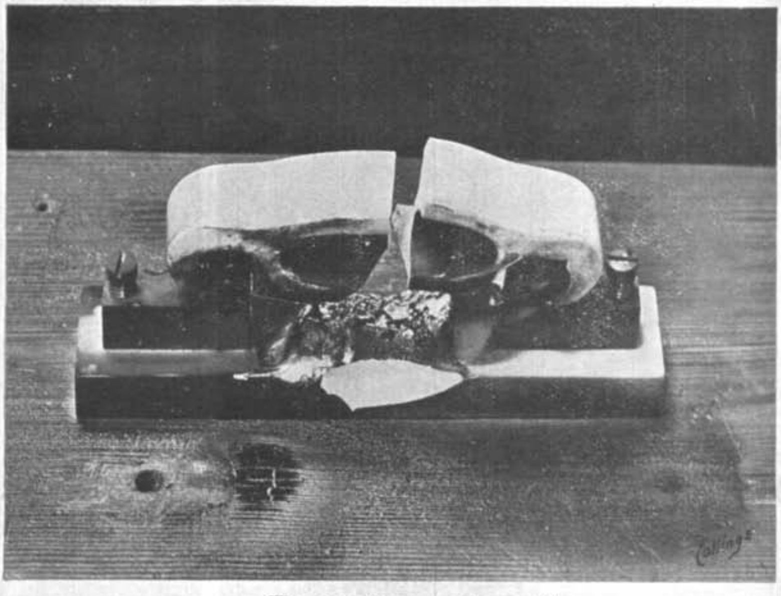


Fig. H. Fuse class T3.

PLATE III. (C).—Operation of Fuses on Overload.

The demand for exposure of the fuse wire has arisen from the custom of inspecting a fuse, say of copper, either for the purpose of seeing what progress oxidation has made or to determine by its red glow or otherwise whether it was being unduly overloaded. The oxidation of a fuse is, as we have seen, harmful and unnecessary, and the rating and design of standard fuses should be directed towards minimising its occurrence; similarly a well-considered and consistent rating will in time enable the user to become familiar with the overload capabilities of a fuse of certain capacity.

For fuses of the capacity under discussion a completely enclosed design is the only one which enables any set of standards to be followed or enforced with reasonable success. In discussing the subject of the standardisation of fuses for the National Association of Underwriters, Lacount* states of a well-known type of enclosed cartridge fuse, which is widely used in the United States, that the "rarity of its misuse" is due to: (1) The Underwriters and Inspector's rules; (2) the readiness with which the cartridges can be secured in any location; (3) their reasonably low price; (4) the ease of replacement; (5) the difficulty in replacing the fusible wire.

Stress may be laid on four points essential to the satisfactory operation of any fuse whether of the open-wire, tubular, or totally enclosed type; these are :—

1. The volume of fusible metal should be reduced to the minimum compatible with correct rating and moderate temperature rise.
2. The fusible metal should be subdivided so that the ratio of exposed surface to cross-section does not fall below a figure depending on the design.
3. The provision of cooling arrangements adequate to extinguish the arc formed on overload.
4. In exposed wire fuses the provision of sufficiently free expansion space to prevent explosion when a short circuit occurs. In enclosed fuses the same end must be attained by precisely opposite means, and no opening or weakness of any kind is permissible in the enclosing case.

Fig. 9 shows four different makes of fuses, all for a rated current of 50 amperes, 500 volts, and all to the same scale. The black square at the side of each fuse represents by its area the volume of fusible metal in the respective casing.

While the fuse (No. 4) containing the least volume of metal operated perfectly under all overload and short-circuit conditions, and the fuse shown at the top (No. 1) which contains the next smallest volume of metal, and has a proportionately large casing also behaved satisfactorily, the two remaining samples consistently exploded or burnt often under the mildest circumstances. The great difference in the length of the

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* *Transactions of the American Institute of Electrical Engineers*, vol. 24, p. 893, 1905.

four fuses is very marked, and the standard of excellence attained by each shows quite conclusively that attention to the four points enumerated above is necessary and sufficient for the production of a satisfactory article.

It is interesting to notice how the fulfilment of requirement (2) naturally leads to the cartridge design of fuse, since only in this design can the proper subdivision of the fuse wire be guaranteed. The effect of neglecting proper subdivision as well as the use of too much metal is shown in Plate IV., Figs. A. and B. It is unfortunate that instead of attacking the problem of an enclosed fuse in an appropriate manner, some designers have considered that the simple enclosure of an open-type fuse would produce the desired end. Provided that subdivision is properly carried out and efficient means of cooling the arc are employed, a fuse of the smallest size shown in Fig. 9 is far safer and more efficient than a much larger or longer fuse containing a considerable volume of metal, all of which may be vaporised on a short circuit. From this same point of view, the use of soft metals such as tin, lead, or zinc is to be deprecated, although with very careful design successful use may be made of the non-arcing property of the last-named metal.

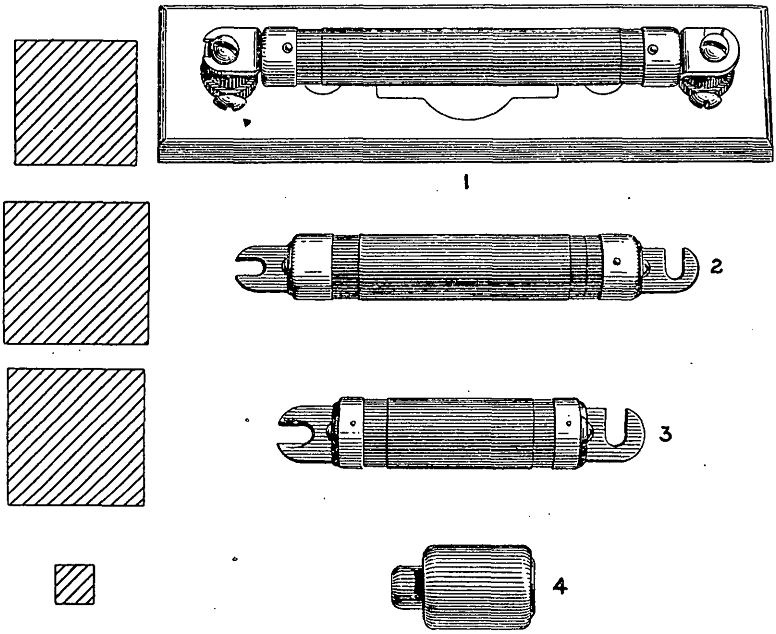

FIG. 9.—Comparison between Four Enclosed Fuses Rated at 50 Amperes, 500 Volts.

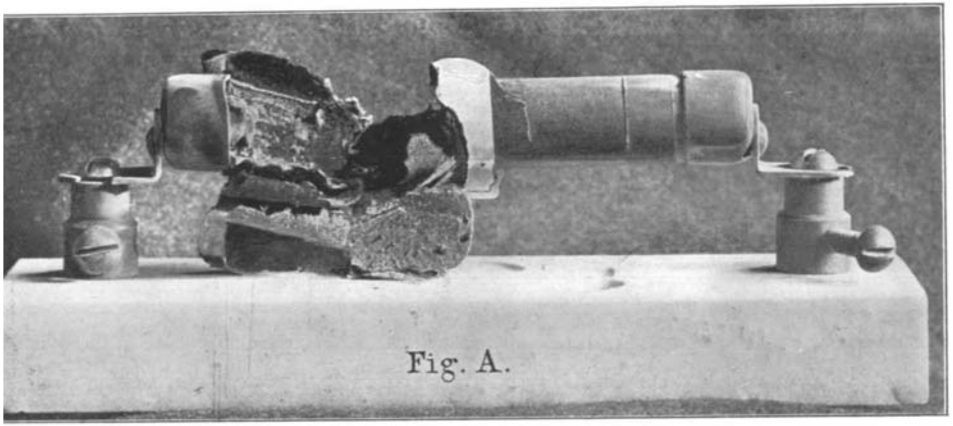

Plate IV. (A).—View of Cartridge Fuse after Short-circuit Test.

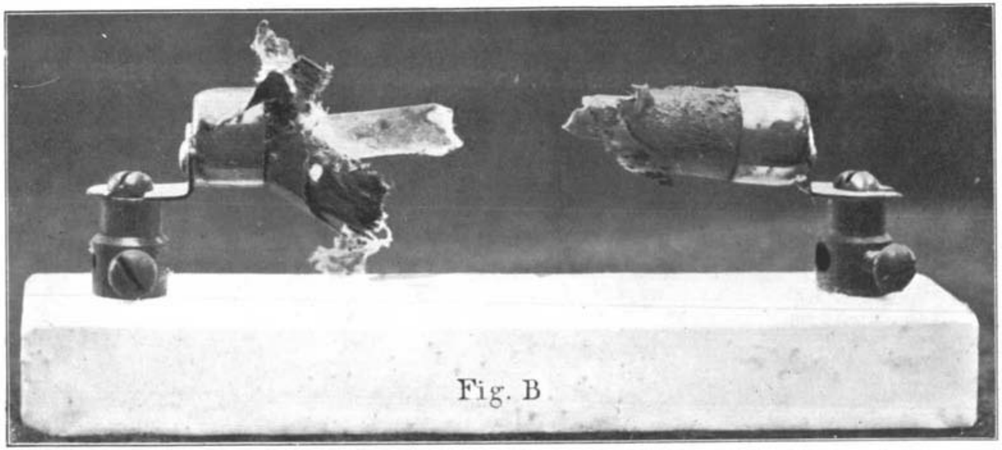

PLATE IV. (B).—View of Cartridge Fuse after Short-circuit Test, showing Effect of Excessive Volume of Metal.

The means at disposal for cooling an arc and condensing the vapours are three in number: by mechanical draught, by the surface condensation and cooling action of masses of porcelain, metal, or asbestos, and by the analogous use of an absorptive condenser in the form of filling powder. When the last method is adopted it is important that the fuse wire and filling should be free from any mutual chemical action even when subjected for a long time to alternate heating and cooling.

Fillings containing a capsule of liquid, or any hygroscopic or moist substance are bad in principle, and may be the cause of violent explosion or of chemical corrosion of the fuse wire. Tests carried out on a very large number of filling materials lead to the conclusion that the most suitable for use in enclosed fuses are thoroughly dry uniform powders of completely inert substance.

(*e*) TESTS OF FUSES.

The reliability and merits of a fuse are essentially matters to be submitted to the verdict of practical tests, which can be arranged to reproduce the exact conditions to be dealt with. The most important tests which a fuse must pass successfully in order to demonstrate its reliability are three in number :—

1. An insulation or pressure test (*a*) between all live metal parts and earthed metal parts, (*b*) between the two opposite poles of the fitting when no fuse is in place and when a blown fuse is inserted.
2. Tests for operation with gradually increasing current at normal voltage until fusion occurs.
3. Short-circuit tests at normal voltage.

In addition to the above tests measurements should be made of the temperature rise of accessible parts of the fitting and of the voltage drop. From the fire risk point of view the temperature rise of a fuse fitting should be taken as the maximum rise of temperature of any part of the fuse or fitting which is accessible when the fuse fitting is complete with its fittings and covers, etc., as in normal use.

Compliance with test 1 can be satisfactorily secured, and having been once demonstrated with a particular type or design, good insulation depends upon the maintenance of quality of the insulating materials and manufacture. A pressure test of at least 1,000 volts above the working pressure should be withstood without breakdown. Experience shows that under certain circumstances a risk of dangerous shock may be created by the use of hygroscopic materials like fibre, asbestos, or strawboard between the terminals ; leakage may occur sufficient to give a severe shock when it is thought that the operation of the fuse has rendered one terminal "dead."

Test 2 is of extreme value as an indication of the behaviour of the fuse under the conditions which in practice most frequently lead up to fusion. The fuse under test should be connected in circuit with an adjustable resistance and a battery or generator giving the maximum normal voltage for which the fuse is designed. The current is increased gradually so that the fuse has time to attain approximately its steady temperature for each value of the current. This procedure is followed in three or four steps until the fuse blows. The circuit should not be opened by other means until all arcing or glowing has ceased. This test is a most useful one, and has great commercial importance since it represents the ordinary blowing of a fuse due to continued or slowly increasing overload. The whole of the fuse attains a high temperature favourable to the production and existence of metallic and other vapours, and the relative slowness with which the fuse wire heats, becomes molten, and is dispersed in vapour, is also, as compared with the rapid severance of the circuit produced by a sudden heavy overload, favourable to the continuance of an arc across the terminals. The formation of a continuous arc after fusion must be considered as a property even more dangerous than faulty performance under short-circuit conditions, the latter consisting generally of a violent explosion and scattering of the fuse fitting without necessarily giving rise to the great fire risk which always attends imperfect operation under gradually increasing overload. It is surprising how large a percentage of sample fuses utterly fail under this test.

The carrying out of the overload test calls for no special precautions; the voltage of the generator and the current should be observed throughout the test, and the current at which the fuse blows noted, as well as the duration of any arc which may occur, and the point at which it originates. For practical purposes this test furnishes a means of obtaining an approximate value of the limiting current.

Test 3. The value of a short-circuit test as a criterion of the goodness of a fuse depends to a large degree upon the manner in which the term "short circuit" is interpreted. The difference in the severity of the test is obvious, for example, between the case of a 10-ampere fuse short-circuited across a wall plug in a house installation and a fuse of the same size connected directly across the terminals of a 500-k.w. generator or battery. The latter test is very much more severe owing to the lower impedance of the circuit, which is responsible for a momentary short-circuit current of great magnitude, while the voltage across the fuse terminals is maintained at a high value.

A fuse of the smallest size may be inserted in an auxiliary circuit on the switchboard of a central station, in the closest proximity to the busbars transmitting thousands of kilowatts, and the safety of the whole plant may be imperilled by the failure of the fuse to sever a faulty circuit cleanly and promptly. Perfect operation on short circuit is a matter of careful design, and entails neither increased cost nor elaboration.

Since fuses of all capacities from the lowest to the highest are liable to be subjected to short-circuit conditions of the same severity, it is not advisable in specifying the method of carrying out short-circuit tests to differentiate between fuses for various rated currents. Thus the "standard short-circuit" should not be defined as a maximum possible short-circuit current twenty or thirty times the rated current of the fuse under test, but all fuses for the same rated voltage should be tested in exactly the same circuit. An adequate but not too severe short-circuit test for fuses up to 50 amperes rating is provided by the following rules, which have been followed in all tests carried out by the author:—

1. The source of current should be a battery having an open-circuit potential difference 10 per cent. higher than the rated maximum voltage of the fuse under test, and capable of giving 500 amperes without the terminal voltage dropping by more than 5 per cent.
2. The total resistance of the test circuit including the fuse should be adjusted to correspond to a steady current of 1,500 amperes produced by an E.M.F. equal to the rated maximum voltage of the fuse.
3. On closing the main switch the fuse should blow without a continuous arc being formed or any explosive violence.

The following suggestions are put forward as a basis for the discussion of a specification for standard fuses:—

1. (*a*) *Material for Fuse Wire.*—The fuse wire must not corrode or permanently change its conductivity or physical structure.

(*b*) *Non-interchangeability.*—Fuses up to 50 amperes rated current should be provided with a simple arrangement by means of which the capacity of the fuse which can be inserted by a non-technical user is restricted within definite limits.

(*c*) *Type of Fuse Recommended.*—To facilitate compliance with (*a*) and (*b*) above and generally to render standardisation practicable and useful an enclosed cartridge type of fuse is recommended.

(*d*) *Indication of Fusion.*—All fuses must be provided with a simple means for detecting fusion simply by inspection of the fitting.

2. (*e*) *Rating.*—The rated current marked on the fuse shall bear a definite relation to the limiting current or least current which will produce fusion within 4 hours. The minimum value of the ratio $a = \frac{\text{limiting current}}{\text{rated current}}$ shall be 1·54 and the maximum value shall not be higher than 30 per cent. above the minimum. In a correctly proportioned line of fuses a should decrease from the maximum to the minimum values specified, as the size of the fuse increases from the lowest to the highest capacity. This regulation is based on the assumption that silver is the best metal for fusible links, taking into consideration its permanent character, the small volume required, and its "clean" action when breaking the circuit.

(*f*) *Sluggishness of Action and Time Element.*—Standard fuses shall be so rated and constructed that when loaded with 50 per cent. above the limiting current they will fuse within 1 minute. The actual time