Underwriters Laboratories Inc. Standards for Safety for Fuses

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Summary:

This paper will explain the role of Underwriters Laboratories Inc. (UL) in fuse safety testing and certification. Emphasis is placed on the the relationship of UL's standards to the National Electrical Code (NEC[1]), and the general requirements which are common to most UL Listed power fuses.

Introduction:

For over 95 years, Underwriters Laboratories has tested and certified fuses to standards developed in cooperation with the United States fuse industry and other interested parties. Throughout this time, UL Standards have reflected the safety and performance concerns of the NEC which demand protection of distribution systems, wiring, and utilization equipment from dangerous overcurrents. A broad spectrum of tests is used by UL to verify the fuse's performance. These tests include: temperature rise, verification of fuse current rating, full-voltage overload, maximum let-through energy, verification of current-limiting threshold, maximum interrupting capacity, and limitation of let-through current and energy.

For brevity, this paper focuses on power fuses, and no attempt is made to specify every exception or unique case. The exact details of testing, ratings, and requirements are best stated in the standards themselves.

1. UL Background

1.1 UL History

Underwriters Laboratories is the world's largest independent product safety testing and certification organization. UL was founded in 1894, in response to the alarming number of fires caused by the new electric light bulb at the Chicago Columbian Exposition. Now, 97 years later, UL continues testing a wide variety of products for safety, as well as performing research testing, developing safety standards, working with local inspection authorities, and educating the public about safety.

1.2 UL's Standards and the NEC

In order to assure that all manufacturers of a similar product are treated equitably, consistent standards must be applied. UL develops such product standards through cooperation with manufacturers and other interested parties, taking into consideration the users of the product and any installation codes that apply, such as the NEC.

It is important to note the strong correlation between the NEC and UL's fuse standards. The NEC is an installation code which contains provisions necessary for practical safeguarding of persons and property from hazards arising from the use of electricity. It contains a number of specific requirements for fuses, as well as several general items which also apply. UL's standards are based on the same overall premise of safety, and are carefully written to support and complement the requirements of the NEC with specific requirements for fuses. The result of this relationship is a symbiosis which benefits both fuse users and manufacturers by enhancing the level of electrical safety.

1.3 UL Certifications

UL has three types of safety certification: UL Listing, UL Classification, and UL Component Recognition. The type which applies to power fuses is UL Listing.

Products which are Listed by UL have been found to be in compliance with UL's requirements for the category of equipment involved; they bear the Listing Mark of Underwriters Laboratories. Fuses used to protect distribution systems must be Listed, and all Listed products must meet identical requirements for the specific rating and size involved. They are also required to be suitable for installation in accordance with the NEC[2]. They are considered to be physically and electrically interchangeable with other Listed fuses of the same Class and rating.

1.4 UL Fuse Standards

UL currently has several published standards for power fuses summarized in Table 1.

UL also has published standards for the following fuses: Supplemental Fuses, UL 198G; DC Fuses for Industrial Use, UL 198L; and Mine-Duty Fuses, UL 198M. Special purpose fuses, new or innovative fuses, or novel ratings for a product can be accomodated by using related requirements from UL's present standards, or by evaluating the safety risks involved and designing a new test program to encompass these risks. A common misconception concerning UL is that products outside the scope of present standards cannot be certified. On the contrary, UL is willing to devise an appropriate investigation for any product.

2. Fuses for the Protection of Distribution Circuits

UL tests and certifies a broad range of power fuses which are intended to protect power distribution circuits, switching equipment, and wiring. These circuits are often called "branch circuits" because they begin at the utility entrance to the building and branch out to usage equipment around the facility. Several types or Classes of fuse are used to protect these circuits, including Class G, H, J, K, L, R, T, CC, and Plug fuses. The major characteristics of these fuses are summarized in Table 1. Examples of applications of these fuses would be protection of a switchboard, switch, or individual circuits supplied by a distribution panelboard.

2.1 Voltages Common in The United States

Several low voltage (600 V ac and less) distribution systems are used in the U.S., depending on the local utility and the needs of the user; voltages of 120, 208, 240, 277, 480, and 600 V are available. These systems are protected by Class G, H, J, K, L, R, T, CC, and Plug fuses with corresponding voltage ratings. A 600 V fuse can be used on any of these circuits, but lower voltage rated fuses are generally smaller, and thus using the closest sized voltage rating will allow the switching equipment to be downsized as well.

2.2 Current Ratings

The UL system of fuse classes divides each fuse class into several distinct sizes based on the current range in that size, as shown in Table 1. Intermediate ratings which are between the case size breaks have the same overall dimensions as the next larger case size. For example, ratings of 31-60 A are all sized the same.

2.3 Interchangeability

The UL standards for fuses include detailed requirements for the physical dimensions of the fuse. These requirements result in Listed fuses of the same Class, voltage, and current rating being consistant in size so that a cleared fuse can be easily replaced. However, the differences between designs of the fuse Classes and case sizes is such that no fuse is interchangeable with one of a higher voltage rating, lower current rating, lower interrupting rating, or different Class. This is a requirement of the NEC[3], and an essential aspect of UL Listed fuses; they can be used with confidence that improper replacement is unlikely. This also means that safety is not diminished by allowing replacement by untrained personnel. For example, a Class H fuse rated 100 A and 250 V has a 10 kA interrupting rating and will only fit in a fuseholder specifically designed for these ratings. A Class R, 100 A, 250 V fuse (with a 200 kA interrupting rating) is the same size and will fit into the same fuseholder. The reverse substitution cannot be made because a Class R fuseholder has a rejection feature which allows only Class R fuses to be installed. Thus the lower interrupting rating Class H fuse cannot be installed in a Class R fuseholder where a short circuit current above its rating might be available.

2.4 High Interrupting Capability

The design of utility power systems in the United States is such that many industrial and commercial installations have very high available short circuit currents at the

Table 1

Fuse Class	UL Standard	Voltage Ratings	Current Ratings	Interrupting Rating, A rms	Sub-Classes	Size Breaks are at the following Ampere ratings:
G	UL 198 C	300	0-60	100,000	-	15, 20, 30, and 60
H	UL 198 B	250 or 600	0-600	10,000	Renewable and Nonrenewable	30, 60, 100, 200, 400, and 600
J	UL 198 C	600	0-600	200,000	-	30, 60, 100, 200, 400, and 600
K	UL 198 D	250 or 600	0-600	50,000, or 100,000, or 200,000	K1 and K5	30, 60, 100, 200, 400, and 600
L	UL 198 C	600	601-6000	200,000	-	800, 1600, 2000, 2500, 3000, 4000, 5000, and 6000
R	UL 198 E	250 or 600	0-600	200,000	RK1 and RK5	30, 60, 100, 200, 400, and 600
T	UL 198 H	300 or 600	0-1200	200,000	-	30, 60, 100, 200, 400, 600, 800, and 1200
CC	UL 198 C	600	0-30	200,000	-	30
Plug	UL 198 F	125	0-30	10,000	"Edison Base" and Type S	30 15, 20, and 30

Notes: RK1 and K1 fuses have a high level of current limitation
RK5 and K5 fuses have a moderate level of current limitation

power entrance to their building. Calculated available currents of over 100,000 A rms are common, and for this reason, the industry and UL have selected 200,000 A as the necessary interrupting capability for Class R, L, J, T, and CC fuses. Equipment which uses fuses (Class G, H, and Plug) that have a lower interrupting rating can have interrupting ratings only up to that of the fuse. Class K fuses, because they are interchangable with Class H fuses, are considered as having a 10 kA interrupting rating for the purpose of fuseholders and usage equipment.

The UL requirements for interrupting testing and ratings are based on Section 110-9 of the NEC. This Section requires equipment which is intended to break current at fault levels to have an interrupting rating sufficient for the system voltage and maximum available short-circuit current.

The ability to simply withstand high fault currents is not enough for many design engineers; in order to determine whether downstream equipment is being suitably protected, they need information on how much current and energy the fuse will allow to pass under short circuit conditions. This need is met by UL Standards which require fuses to meet certain maximum let-through limits when tested at high fault currents. Two specific let-through limits are applied to each fuse size, the peak let-through current, I_p, and the let-through I^2t. I_p is simply the maximum instantaneous current which the fuse lets through during clearing, and is a general indication of the magnetic forces which will be imposed on the equipment. I^2t is the integral sum of the square of the current during the fuse clearing; it represents the heat energy let through during clearing. Use of let-through information allows system designers to choose fault protection devices which will coordinate to isolate a particular fault without shutting down other circuits. This coordination is required by the NEC[4].

3. Verification of Fuse Characteristics

In order to verify the suitable performance of fuses, samples are tested on several different circuits intended to cover the complete range of possible field situations. Levels of test current range from 110% of the fuse rating (where the fuse shall not clear), through low overloads, to high short-circuit available currents up to 200,000 A.

The maximum ampere rating in each distinct size of fuse is tested (See Column 7 of Table 1) and represents the range of ampere ratings in that size (eg. 31-60, 61-100 etc.). Any major construction change within a size is also tested; this is common in the 30 A case-size where testing may be needed on a few design breaks in order to properly represent the entire range of ampere ratings.

3.1 Verification of Ampere Rating

Several tests are used to verify the ampere rating assigned to a fuse. These tests are not voltage sensitive and thus are performed at a convenient low voltage. The normal test program includes the following tests:

3.1.1 110% Current-Carrying Capacity: Fuses are placed in properly sized fuseholders and 110% of their rating is passed through them until they show thermal stability. This test shows the current-carrying ability of the fuse under open-air conditions, which is considered equivalent to the normal maximum load of 80% in an enclosure mandated by the NEC[5]. Temperatures are monitored during the test and must be within set limits. These limitations control the maximum temperatures so the thermal limits of fuse and fuseholder materials and conductor insulation are not exceeded.

3.1.2 Verification of Clearing-Time: The time required for the fuse to clear while carrying 135% and 200% of its current rating must be within the limits specified in the appropriate standard. These tests ensure that low overloads are cleared before circuit conductors and equipment are damaged by overheating.

135% Limits		200% Limits			
Fuse Rating	Max. Clearing Time	Fuse Rating	Max. Clearing Time	Fuse Rating	Max. Clearing Time
0-60	1 h	0-30	2 m	101-200	8 m
61-600	2 h	31-60	4 m	201-400	10 m
		61-100	6 m	401-600	12 m

Fuses rated above 600 A (Class L and some Class T) are not tested at the above levels, but are required to clear in less than 4h at 150% of current rating.

Fuses specified as "Time-Delay" (discussed below) are allowed longer times to clear at 200%.

3.1.3 500% Time-Delay: Fuses which are designed to not clear during short-term overcurrents, such as motor startup, may be designated "time-delay". To obtain this designation, the fuse must not clear within 10s while carrying 500% of rated current. Thus, loads which have fairly high inrush currents of short duration will not cause nuisance clearing of the fuse.

3.2 Overload at Full Voltage

In order to evaluate the fuse's ability to clear an overload under full voltage conditions, the fuse is tested at 200% of its rating at rated voltage, with a power factor of 0.8 or less. This test confirms the fuse's ability to operate under overload conditions encountered in everyday use. This is also a test of the materials and construction of the fuse, since this overload will create high temperatures in the fuse, and the fuse must extinguish a full-voltage arc in its overload section.

3.3 Verification of Current Limiting Theshold

The term "current-limiting" is associated with Class G, J, L, R, T, and CC fuses. These fuses have a certain threshhold above which they limit the instantaneous peak current, I_p, to a value less than what is available from the circuit, and they will clear in less than 1/2 cycle. This threshold is confirmed by the Maximum Threshold Ratio Test as follows: The available current of the test circuit must be equal to or less than the product of the current rating of the fuse multiplied by the defined threshold ratio for the Class of fuse. The circuit closing is controlled at approximately 90° on the voltage wave and the fuse must clear in less than 1/2 cycle. As an example, a 60 A, Class T fuse has a threshold ratio of 30, and thus must be tested on a 1800 A or less circuit. The circuit is closed at 90° on the voltage wave and the fuse clears at 190°, for a total of 100° to clear. This conforms to the requirements of the standard because the fuse cleared in less than 1/2 cycle (180°).

3.4 Verification of Short-Circuit Interrupting Ability

Each short-circuit test is performed at full rated voltage and with a relatively low power factor (0.5 or less for 10 kA circuits, 0.2 or less for circuits above 10 kA). Circuits above 10 kA use controlled closing of the test circuit so the fuse element begins to arc at a point 60° to 90° after voltage zero, typically the most difficult arcing point.

Class H and Plug fuses are not tested above 10 kA since this is their interrupting rating.

3.4.1 Maximum Energy Test

The objective of the maximum energy test is to confirm that each fuse can interrupt a test circuit where the fuse permits a let-through current of 70-100% of the peak available current in the circuit. This criterion subjects the fuse to test at a point where the maximum energy must be absorbed by the fuse.

3.4.2 Interrupting Ability Test

This test verifies the capability of a fuse to safely clear a circuit with an available short-circuit current equal to its interrupting rating (See Table 1 for Interrupting Ratings). For example, Class J, L, R, T, and CC fuses have an interrupting rating of 200 kA and are tested on a circuit calibrated to deliver a minimum of 200,000 rms symmetrical amperes.

3.4.3 Verification of Conformance to Let-Through Limits

As discussed in paragraph 2.4, UL's standards require high interrupting capacity fuses to meet certain let-through limits for I_p and I^2t when tested at high fault levels. This assures users of fused equipment that excessive let-through current or energy will not be allowed by a replacement fuse.

The limits for fuse let-throughs correlate with fused equipment testing which requires the use of special test fuses which exceed these limits. Thus, any UL Listed fuse of the correct type is suitable for the equipment. The equipment will be marked with the proper fuse Class.

4. Follow-Up Testing

In addition to the above testing which verifies the performance of new fuses, the NEC[6] also requires that all product Listings include provisions for periodic inspection of products during production. This requirement arises because new products carefully prepared for certification do not always represent those manufactured for sale to users. As a result, UL has a program for regular inspections of each manufacturer's ongoing production. UL Field Representatives make frequent, unannounced visits to factories to review production controls and conduct detailed inspections. In addition to these follow-up inspections, fuses require follow-up testing since they are complicated combinations of materials which make a simple visual inspection incomplete and since they are so vital to the safety of the electrical system. UL performs regular follow-up testing on fuses which is very similar to the original testing.

5. Conclusion

The combination of several elements in UL's approach to fuse certification produces a line of fuses which provides closely sized overcurrent protection to an enormous range of fuse applications. Non-interchangeability, broad test requirements, let-through limitation, and follow-up inspection and tests are all imperative to UL's process. The genesis of these requirements is the National Electrical Code, providing the safety foundation upon which UL's fuse standards rest. By specifying construction and test requirements, Underwriters Laboratories' standards for fuses make a vital contribution to the overall level of safety in the use of electricity.

Footnotes:

[1] National Electrical Code, NFPA 70 - 1990. National Fire Protection Association, Quincy, MA. All references to the National Electrical Code are to the 1990 edition.
[2] Ibid, Section 110-3.a(1).
[3] Ibid, Section 240-60.b.
[4] Ibid, Section 240-12.
[5] Ibid, Section 384-16.c.
[6] Ibid, Article 100 - Definition of Listed.

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