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Standard Guide for Specification and Quality Assurance for the Electrical Contact Performance of Crimped Wire Terminations¹

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1. Scope

1.1 This guide contains practices for specifying and evaluating the electrical contact performance of crimped-type terminations with solid or stranded conductors.

1.2 This guide provides information relevant to the electrical contact performance of a crimped wire termination. It does not cover other aspects of selection and use of crimped terminals.

1.3 The methods discussed in this guide apply only to the wire termination, which is the electrical contact interface between the conductor(s) and the terminal. Other aspects important to terminal evaluation, such as the properties and performance of electrical insulation, the effectiveness of strain relief features, and the quality of contact between the terminal and other electrical circuit elements, are not included.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet (MSDS) for this product/material as provided by the manufacturer; to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

B539 Test Methods for Measuring Resistance of Electrical Connections (Static Contacts)

B542 Terminology Relating to Electrical Contacts and Their Use

¹ This guide is under the jurisdiction of ASTM Committee B02 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.11 on Electrical Contact Test Methods.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

B827 Practice for Conducting Mixed Flowing Gas (MFG) Environmental Tests

B845 Guide for Mixed Flowing Gas (MFG) Tests for Electrical Contacts

B868 Practice for Contact Performance Classification of Electrical Connection Systems

B913 Test Method for Evaluation of Crimped Electrical Connections to 16-Gauge and Smaller Diameter Stranded and Solid Conductors

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

2.2 Other References:³

UL 486-A Wire connectors and Soldering Lugs for Use With Copper Conductors

UL-310 Electrical Quick-Connect Terminals

3. Terminology

3.1 Many terms related to electrical contacts used in this guide are defined in Terminology **B542**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *connection resistance, n*—the electrical resistance attributable to a wire termination over and above that of an identical solid metallic structure without pressure contact interfaces. For crimped terminations that are the subject of this guide, the connection resistance results from the resistance of a multitude of contact regions having both film and constriction resistance, plus, where stranded wire is involved, an additional amount due to unequal current distribution among the wire strands at the termination.

3.2.2 *crimp, v*—to establish an electrical and mechanical attachment between the two members by mechanically deforming one contact member around another. In most cases, one member is a stranded or solid wire, or a group of wires, the other is a hollow cylinder or partial cylinder that is deformed around the wire(s).

3.2.3 *crimp barrel, crimp tab, n*—the portion of the crimp terminal that is deformed in the crimping operation.

3.2.4 *crimped termination, n*—a mechanical and electrical connection between a conductor, generally a wire, and a component, typically a terminal specifically made for the

³ Available from Underwriters Laboratories Inc. (UL), <http://www.ul.com>.

purpose. The crimped termination is made by compressing (crimping) the component (crimp barrel) or tab(s) of the component around the conductor using a tool specifically designed for the purpose.

3.2.5 *crimp terminal, n*—a metal component designed to be electrically and mechanically attached to a wire by deforming a portion of the component in a crimping operation to form an attachment to the wire. The other end of the terminal usually has a ring, fork, spade, tab, or related configuration designed to attach to another circuit element. Some crimp terminals terminate multiple wires within the same crimp barrel.

4. Significance and Use

4.1 The purpose of this guide is to provide end-product manufacturers and other users with technical information and methods recommended towards the achievement of successful application of crimped wire terminals.

4.2 For any given use, there is generally a choice of terminal types available, employing different mechanical design, materials, and installation tooling. Although terminals available to choose from may be similarly rated, typically according to wire sizes and combinations, their electrical contact performance in the end product may vary substantially. For many applications, the end-product reliability and user safety is substantially influenced by the choice of terminal and the quality of the completed termination. This guidance document contains specialized information on selection, assembly, and quality control of crimped wire terminals, covering aspects considered to be necessary to achieve reliable long-term operation in the intended application. This information is not generally found in commercial literature or textbooks. The methods discussed utilize connection resistance as the primary measure of termination quality, and change of connection resistance with time as the measure of termination deterioration. The methods are based on a foundation of modern electrical contact theory and practice.

5. Connection Resistance Considerations

5.1 The required performance of a crimped wire termination depends on the application, and it must be determined by the user or end-product manufacturer based on the effect that connection resistance may have on the reliability or safety, or both, of the end product. To satisfy the more demanding application requirements, it is necessary to establish adequate initial metallic contact at the wire-to-connector interface and maintain that contact over many decades of service without maintenance or inspections.

5.2 A crimped wire termination is intended to be a permanent electrical contact. Current passes through a multitude of contact interfaces among the wire strands and from some of the strands to the connector body.

5.3 In many applications, substantial connection deterioration can be tolerated because there are no harmful consequences of increasing connection resistance. Crimp termination failures in other applications have potentially severe consequences, however, which may be avoided by use of stringent acceptance criteria and quality control methods that assure high quality connections.

5.4 A crimp termination is conceptually visualized as compressed into a virtually solid mass of metal, with wire and terminal in intimate contact at the interfaces. Because of an effect generally called “spring-back,” this is often incorrect. Spring-back is the elastic recovery of the distorted metal back towards its original shape. While the crimping dies are closed on the terminal, the surfaces are in contact. Spring-back then occurs when the crimping die is removed.

5.5 If the outer terminal springs back more than the wire strands, then the normal force and the real area of contact at the contact interfaces within the termination are substantially reduced. When this occurs, there may be little or no residual compressive force at the contact interfaces within the termination. This degrades the mechanical integrity of the termination and also makes it more susceptible to corrosive deterioration. Spring-back causes open spaces to develop where intimate surface-to-surface contact is expected, allowing ingress of moisture and atmospheric contaminants, thereby accelerating oxidation and corrosion related deterioration.

5.6 The selection and setup of the correct die set for the particular terminal are critical factors. For a given terminal and wire fill, there is a narrow range of compression within which satisfactory results will be obtained. Inadequate crimping generally results in shortened service life. Over-crimping may also be harmful, due to crack formation in the crimp barrel, severing of wire strands, or excessive deformation of the wire.

5.7 The typical connection resistance of crimped wire terminations when initially made will be low, about the same order of magnitude as the bulk resistance of the terminal. A newly-made termination of #16 AWG stranded copper wire, for example, is expected to have a connection resistance of less than $10^{-4}\Omega$ (0.1 milliohm). Deterioration at the metallic contact interfaces within the crimped termination may occur after initial installation, causing increasing connection resistance with time in service. Termination deterioration may be due to oxidation, corrosion, mechanical and/or thermal effects, any of which may occur within the normal and expected conditions of use in a particular application.

5.8 Increasing connection resistance of terminations in a particular end-product may influence reliability or safety, or both, depending on the particular function and current for each crimped termination in the circuit. Within a given product, there may be crimp terminations having substantially different reliability and safety requirements.

5.8.1 An example is a portable heater intended for retail sale and residential use. There are eight crimped wire terminations in the unit’s internal wiring that are in series with the heating element, which draws 12 A. There are also seven crimped wire terminations associated with neon indicator lights (less than 0.01 A), and another four in the heater’s blower motor circuit (1.2 A). (Note: there may be more than one subcircuit terminated within a single crimp fitting.) The influence of connection resistance on reliability and safety for each of the crimped termination types in this example heater is outlined in **Table 1**. Adverse consequences of connection resistance increase are generally more severe with higher circuit current.

5.8.2 A second example is a temperature sensitive control or safety device, on which the effective operating set point may be

TABLE 1 Example—Crimp Terminations within a Portable Electric Heater

Circuit Application within Heater Assembly	Maximum Current, Amps	No. of Terminals/ No. of Different Types	Maximum Allowable Connection Resistance, Ohms	Consequence(s) of Exceeding Maximum Allowable Resistance
Main power	13.2	2/1	0.005	damage to wire insulation
Heater element power, general	12	4/2	0.005	damage to wire insulation
Temperature limit switch (heater element power)	12	2/1	0.001	offset of trip point, product malfunction
Blower Motor	1.2	2/1	2.0	motor may fail to start
Indicator Lights	nil	7/3	>10 000	indicator light malfunction

substantially offset due to self heating (I^2R) at its wire terminals. For instance, a manually-reset thermal safety device may erroneously trip due to connection heating, causing malfunction of the product or system in which it is installed.

5.9 Factors Influencing Connection Resistance:

5.9.1 Acceptably low initial resistance of crimp terminations is very easily achieved. To assure that it will remain acceptably low in the intended application is the greater challenge, since the rate of deterioration (resistance increase) in service is sensitive to many variables of the terminal/wire/tooling system.

5.9.1.1 Terminal variables include the physical configuration, the materials of construction (including plating) and their properties, and the surface finish.

5.9.1.2 Conductor variables include the material, hardness, plating material and thickness, stranding, and surface cleanliness. If wire strands are to be pre-tinned, it is especially important to specify and control the thickness, since most tinning materials are self-annealing at room temperature. If the tinning is too thick, loss of contact force due to self-annealing (or creep/stress relaxation) may result in premature failure.

5.9.1.3 Tooling variables include selection of the tooling (dies and associated crimping tool or machine), its setup, its operation, and its wear and maintenance.

5.10 The rate of deterioration is also influenced by the environmental and mechanical conditions of the application.

5.10.1 Deterioration due to corrosion and oxidation can occur in ordinary environment, and is generally accelerated by high temperature and high humidity. Corrosive agents are present in the normal atmosphere as well as in special industrial and household situations.

5.10.2 Temperature variations in service may cause deterioration due to differential thermal expansion effects (causing fretting and thermal ratcheting), while extreme high temperature can result in metallurgical changes (dezincification of brass, annealing) and loss of contact force (creep, stress relaxation). The specific operating conditions in many common applications impose harsh thermal conditions, such as in the engine wiring harness of an automobile, or at the terminal of a heating element.

5.10.3 Deterioration may also occur due to mechanical vibrations (causing fretting) and due to mechanical motions and stresses that cause conductor strand breakage.

6. Specification of Required Crimp Termination Performance

6.1 The sensitivity of each particular circuit to connection resistance of its crimp terminations must be assessed, and a maximum allowable connection resistance must be specified.

Connection resistance is a series resistance, and, in a newly-made wire termination, is generally negligible, of the order of less than 0.001Ω . With time in service, however, or if poorly made, connection resistance may exceed 1Ω .

6.1.1 Relatively high series resistance of one or more crimp terminations in a circuit may have an adverse effect on the circuit's functionality. For example, some battery chargers will malfunction (improperly regulate the charging cycle) if a series resistance of the order of 0.1Ω or more is introduced in the output circuit.

6.1.2 Resistive heating (I^2R) at a high resistance termination may have an adverse effect on both the functionality and also on the safety of the product.

6.1.2.1 An example of thermally-induced malfunction due to excessive crimp termination resistance is at a manually reset over-temperature cutout device in a portable electric heater. Normally, with connection resistance of the order of 0.0001Ω , at 12 amps, the I^2R heating from the two crimp terminations on the device (0.03 W) results in a negligible temperature increase at its temperature sensing element. If the connection resistance increases to 0.01Ω at one of the terminations, the resulting heat generation (1.4 W) causes sufficient temperature rise at the over-temperature device to activate it, incorrectly shutting off the heater.

6.1.2.2 A safety problem arises if self-heating at a termination causes damage to the electrical insulation or is extreme enough to pose a direct fire hazard. For example, if the connection resistance of a crimp termination carrying 12 A increases to 0.1Ω , (14 W heat generation), the temperature on the wire would become high enough to destroy the insulation on the adjacent section of wire and present a fire ignition hazard if any combustible materials are in contact with it.

6.2 The minimum life requirement must be determined and specified. This is the time that must pass before a termination can deteriorate to its allowable maximum connection resistance.

6.2.1 When there is no safety consequence of failure, the specified crimp termination minimum life may be set as low as the expected (or guaranteed) life of the system of which it is a part.

6.2.2 When there may be safety consequences of failure, it is recommended that the required life be considered as indefinite. In terms of connection resistance, that requires that there be no reasonable possibility that the resistance will increase to its allowable maximum no matter how long it remains in service. This is achievable, in that crimp terminations can be reliably manufactured that will demonstrate essentially zero resistance increase under most service conditions. If it cannot

be done with a crimp termination, due to the specific challenges of the particular application, then it is recommended that a more suitable termination type should be utilized.

7. Crimp Termination Evaluation for Initial Selection

7.1 Potential suitability for the application, for commercially-available terminals, may be determined by the manufacturer's information together with listing or certification by a recognized testing laboratory based on an existing standard (UL 486-A, for example). It must be understood that listing or certification by a testing laboratory does not guarantee or imply suitability for any particular application. For non-critical (no safety risk on failure) and non-demanding (large tolerance for connection resistance increase) applications, however, this level of assurance of performance may suffice.

7.2 For resistance-sensitive or critical applications, available life test data pertinent to the intended application should be reviewed. Life test results may be available from the terminal manufacturer, from the listing or certifying laboratory, or from present or past users of the particular terminal(s) being considered. The information should be reviewed for relevance of the applied conditions to those of the intended application, for data quantifying the change of resistance resulting from the applied test conditions, and for statistical significance (sample size, see Practice E122).

7.3 When considering a specific candidate terminal for a resistance-sensitive or critical application, if the available test data does not provide a suitable basis on which to assure satisfactory performance in the intended application to a sufficient level of confidence, then additional testing is required. (See Section 10.) If additional testing cannot be undertaken, by either the supplier or potential user, then consideration of an alternate terminal (manufacturer or model) or alternate terminating means is recommended.

7.4 It is recommended that, for resistance-sensitive or critical applications, the final step in the selection process should include verification testing using the actual termination system (terminal, wire, tooling, and manufacturing procedure) that will be used in product manufacturing. Once the performance of this combination is confirmed by test results, no part of the system can be changed without risk of adversely changing the rate of deterioration in service.

8. Manufacturing Considerations

8.1 For non-critical applications, follow the terminal manufacturer's general recommendations.

8.2 For resistance-sensitive or critical applications, it is generally required to establish tight control of materials and manufacturing beyond the terminal manufacturer's general recommendations.

8.2.1 Assure that all materials, tooling, and procedures are specified and held constant. Seemingly harmless changes, such as wire stranding and hardness, cannot be made without risk of impact on service life.

8.2.2 Effective procedures for crimp tooling set up, maintenance, and verification must be established and adhered to.

8.2.3 Equipment operators must be trained and qualified for the specific operation.

8.2.3.1 Operators should be capable of identifying misoperation, such as incorrect insertion of the wire into the terminal or misaligned crimping, and taking appropriate corrective action. (Stop production, correct problem.)

8.2.3.2 Operators should be empowered and motivated to assure that, when crimp defects do occur, defective crimp terminations are not passed through for assembly into the final product.

9. Quality Control Considerations

9.1 Visual Inspection:

9.1.1 Visual inspection is necessary to determine the general quality of the termination, including the following factors:

9.1.1.1 Whether the crimp compression or indent is at the correct position on the terminal.

9.1.1.2 Whether all of the strands of the conductor are properly contained within the crimped portion of the terminal.

9.1.1.3 Whether the correct length of bare conductor is properly inserted into the terminal.

9.1.1.4 Whether any strain relief features are correctly positioned and applied.

9.1.1.5 Whether there is any insulation material or other foreign matter in the wire termination portion of the terminal assembly.

9.1.1.6 Whether there is any corrosion or abnormal coloration evident on the electrical contact surfaces of the conductor or terminal. The metal parts should appear bright and clean, without abnormal coloration.

9.1.2 Some crimp terminals are pre-insulated. It may be necessary to remove the terminal's insulation to perform an adequate visual inspection.

9.2 Crimp Dimension and Pull Test:

9.2.1 Periodic dimensional measurements and pull testing are generally specified by the crimp terminal manufacturer for setup and quality control purposes. These recommendations should be followed.

9.2.2 The dimension and pull test are primarily useful to check tooling operation, setup and wear.

9.2.3 For applications that are not critical or resistance sensitive, periodic dimensional and pull test measurements may be the only tests necessary, provided that the components (wire, terminal, and tooling) have not been changed.

9.2.4 For proper evaluation of the crimp termination, pull testing must be performed with any wire strain relief feature disabled (opened or removed).

9.3 For resistance-sensitive or critical applications, in addition to visual inspection, dimensional measurement, and pull testing, the following aspects should be incorporated into the quality control procedures.

9.3.1 Assure that all materials, tooling, and procedures are as specified. Changes, such as wire stranding and hardness, cannot be made without risk of adverse impact on the projected service life.

9.3.2 Connection Resistance:

9.3.2.1 Initial Connection Resistance (as manufactured) should be monitored for resistance-sensitive applications.