SAE/USCAR-21 REVISION 3

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PERFORMANCE SPECIFICATION FOR CABLE-TO-TERMINAL ELECTRICAL CRIMPS

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1. SCOPE

This specification defines test methods and requirements for validation of solderless crimped connections. The purpose of this test is to simulate in the lab the stress seen in a typical life (15 years and 150,000 miles) for a crimp connection and assure the crimp is mechanically strong and electrically stable. This specification was developed for use with stranded automotive copper wire. Only where specifically mentioned are other constructions or other core materials (aluminum, clad, steel core, etc.) applicable. This specification does not apply to wire types not mentioned.

This specification is based on accepted levels of environmental exposure for automotive applications. In any intended vehicle application, if the products covered by this specification are or may be subjected to conditions beyond those described in this document, they must pass special tests simulating the actual conditions to be encountered before they can be considered acceptable for actual vehicle application. Products certified by their supplier as having passed specific applicable portions of this specification are not to be used in applications where conditions may exceed those for which the product has been satisfactorily tested. Any deviation must be documented and included in the final test report.

Crimp applications validated to this specification are intended to supersede crimp information on the component prints. The terminal supplier has the primary responsibility for testing and selection of crimp tooling and to supply detailed crimp information or make crimp tooling available to the wiring assembly supplier actually doing the production crimping. The wiring harness supplier is responsible for validating all crimps produced per this specification.

Environmental exposures called-out in this specification include Thermal Shock and Temperature Humidity Cycling and are used to stress every production terminal and cable combination used under test to simulate field exposure. SAE/USCAR-21 has tests that will detect deficiencies in crimp tooling geometry, plating quality, strand distribution, and cable strand count. SAE/USCAR-21 must be done in addition to a connector system validation such as SAE/USCAR-2 to assure the entire allowable production crimp height range of every combination is acceptable. Testing to a connector system specification also validates what is not tested in SAE/USCAR-21 such as long-term high temperature exposure.

Procedures included within this specification are intended to cover performance testing and development of electrical terminal crimps that are part of the electrical connection systems in low voltage (0 - 48 VDC) road vehicle applications at ambient temperatures of 125 °C maximum. Higher voltages and temperatures may be tested if the OEM customer approves use of these test procedures for use at voltages and temperatures beyond these limits.

1.1 Crimping Parameters

1.1.1 The Crimped connection performance is characterized by:

- Visual conformance of crimp attributes including cross-sections.
- Mechanical performance as measured by terminal-to-conductor pull-out force.
- Electrical performance as measured by terminal-to-conductor resistance or voltage drop.

1.1.2 The geometry of a crimp is characterized by:

- Conductor crimp height (CCH)
- Conductor crimp width (CCW)
- Insulation crimp height (ICH)
- Insulation crimp width (ICW)
- Cut-off tab
- End of conductor (wire brush length and height)
- End of insulation
- Bell mouth
- Burr (anvil flash) dimension on the base of the conductor crimp
- Step between the core and insulation wings
- Information on terminal drawing

2. DOCUMENTS

2.1 Document Hierarchy

To claim conformance to this specification, the tooling and process settings used to crimp a terminal/wire application in production must be the same as what was used to make samples submitted for a USCAR-21 test that met all criteria. The tooling and process settings used to meet USCAR-21 may be developed independently and may be different than crimp specifications listed on a terminal drawing or process specification developed by the terminal maker. Note that the settings used for USCAR-21 validation supersede any documentation for crimp settings not aligned to USCAR-21 in order to claim conformance.

2.2 Test Request/Order

2.2.1 Samples, Test Type and Special Tests

The laboratory test request/order shall provide location and documentation of test samples, identify the type of test to be performed (development, validation, special purpose, etc.) and describe any special tests that are not a part of this specification. Any required revisions to or deviations from any tests in this specification must include detailed instructions for each change.

2.3 Materials and Process Specifications

Suppliers are expected to adhere to the appropriate materials and process that are referenced in this specification and any associated drawings and reference documents. Unless otherwise specified or required by law, suppliers are expected to use the most recent versions of any applicable drawings, reference documents, and standards.

2.4 Referenced Documents

- SAE/USCAR-2: Performance Specification for Automotive Electrical Connector Systems
- AIAG: Measurement Systems Analysis Reference Manual
- SAE J1128: Low Tension Primary Cable
- SAE J1127: Battery Cable
- ISO 6722 Part 1: Dimensions, test methods and requirements for copper conductor cables

3. GENERAL REQUIREMENTS

3.1 Record Retention

The supplier shall maintain a central file for the storage of laboratory reports and calibration records. Record storage must be in accordance with established (i.e. ISO or AIAG) policies and practices.

3.2 Sample Documentation

All test samples shall be identified in accordance established (i.e. ISO or AIAG) policies and practices.

3.3 Sample Size

Minimum sample sizes are given for each test in this specification. No part or device may be represented as having met this specification unless the minimum sample size has been tested and all samples of the group tested have met the applicable acceptance criteria for that test. It is never permissible to test a larger group then select the minimum sample size from among those that passed and represent that this specification has been met. It is permissible to include additional groups of crimp heights to insure at least 3 consecutive crimp heights (nominal, “+1”, and “-1” crimp height tolerance) meet the requirements.

3.4 Default Test Tolerances

Default tolerances, expressed as a percentage of the nominal value unless otherwise indicated:

A.	Temperature	± 3˚C
B.	Voltage	± 5%
C.	Current	± 5%
D.	Resistance	± 5%
E.	Length	± 5%
F.	Time	± 5%
G.	Force	± 5%
H.	Relative Humidity	± 5%

3.5 Test Default Conditions

When specific test conditions are not given either in the product design specification, the test request/order or elsewhere in this specification, the following basic conditions shall apply:

A.	Room Temperature	23 ± 5˚C
B.	Relative Humidity	Ambient
C.	Voltage (DC)	14.0 ± 0.1V

3.6 Equipment

Table 3.6 highlights specialized equipment or devices with particular accuracy requirements used for USCAR-21 testing. Neither Table 3.6 nor the list in each test section is all-inclusive; items of customary laboratory equipment and supplies will also be required. Use of equipment with a lesser range is acceptable for specific tests where the required range for that test can be met. The equipment range specified does not preclude use of equipment with a larger range, but the accuracy must remain within the specified tolerance.

TABLE 3.6 - EQUIPMENT LIST

DESCRIPTION	REQUIREMENTS
DC Power Supply (Regulated)	⇒0~20V current sized as required
Micro-Ohmmeter	⇒0-20 mV maximum open circuit voltage ⇒100 mA maximum test current ⇒0.01 mΩ resolution
Digital Multimeter (DMM)	Capable of measuring 0.001-50 Volts DC with accuracy of 0.5% of measurement
Millivolt Meter	Capable of measuring 0-100 mV DC with accuracy of 0.5 mV
Thermocouples	Type "J" or "T" as required (small size ~.08mm)
Force Tester	Capable of an accuracy of 1% of measurement
Temperature Cycling Chamber	⇒ -40 °C to 125 °C, 0% to 98% RH
Thermal Shock Chamber	⇒ -40 ± 3 to 125 °C (in 5 minutes or less)
Forced Air Oven	⇒ +85 ±3 °C
Temperature Chamber	⇒ -40 ± 3 ˚C
Temp. /Humidity Chamber	⇒ 95 to 98% RH at +65 ± 3 °C

3.7 Definitions and Glossary

Definitions for technical terms are listed in Appendix B. Abbreviations and acronyms are listed in Appendix C.

3.8 Measurement Resolution

Unless otherwise specified, meters and gages used in measurements of test samples shall be capable of measuring with a resolution one decimal place better than the specified value. For example, wire diameter specified as 0.1 mm might actually be the same as one specified as 0.10 mm, calipers capable of 0.01 mm resolution may be used to measure the first wire but a micrometer with 0.001 mm resolution is required to measure the second wire.

3.9 Test Repeatability & Calibration

All equipment used for the test sample evaluation shall be calibrated and maintained along with periodic gage R&R's in accordance with individual test facility certification requirements and applicable standards. The AIAG publication "Measurement Systems Analysis Reference Manual" can be used as a guideline. A list of instruments and equipment used for the USCAR test, date of the last calibration, and when the next calibration is due is to be included in each USCAR test report.

3.10 Conformance Determination

Table 5.1 lists the requirements to meet USCAR-21. Test conformance shall be determined by the acceptance criteria of the test being conducted. All samples must satisfy the requirements regardless of sample age, test cycles, or test temperature, except where a test to failure is specified. Additional sample groups with alternate crimp heights may be tested to help determine the nominal and min/max crimp height for a given terminal/wire combination. Three consecutive crimp height groups (nominal, high limit of tolerance, and low limit of tolerance) must meet the requirements but groups tested outside of this range need not pass.

4. TEST & ACCEPTANCE REQUIREMENTS

4.1 General Testing Requirements

The test procedures in this section were written as stand-alone tests and may be used as such. However, they are normally used in a sequential test format and common sense is required to overcome any redundancies in sample preparation or in procedures. For example, if samples have already been prepared for the preceding test in a sequence, it should be obvious that the sample preparation step for that individual test (included so that test can be used as a stand-alone test) should be skipped. (Note: The resistance measurement method for terminals crimped on >6mm^2 wire has changed from using 4.5.3 Dry Circuit resistance to 4.5.6 Voltage Drop method to get better measurement accuracy.)

4.1.1 Dimensional Characteristics

Part construction shall conform to the dimensions, shape, and detail attributes specified on the latest revision of the applicable part drawing(s).

4.1.2 Material Characteristics

All material used in each test sample shall conform to the material specifications on the latest revision of the applicable part drawing(s).

1. Any engineering development, prototype, or production part may be submitted for test.
2. The samples submitted for test shall be identified by description, part number, and revision letter.
3. For validation testing, all parts are to be in their "as furnished for vehicle assembly" condition when testing begins. This same condition must prevail for test samples.
4. Samples submitted for any test shall be prepared per Appendix E.

4.2 Visual Inspection

4.2.1 Purpose

This test is used to document the physical appearance of test samples and to assist in the evaluation of the effects of environmental conditioning on test samples using descriptions, photographs and/or videos. Examinations in most cases can be accomplished by a person under cool white fluorescent lighting.

4.2.2 Samples

1. The samples must conform to the requirements of the specified conditioning and any additional measurements that are to be performed.
2. For purposes of comparison and especially when only subtle appearance changes are anticipated, it is desirable to submit an additional sample to serve as a control.

4.2.3 Equipment:

1. Video and photographic equipment able to produce clear images.

4.2.4 Procedure

1. Visually examine each test specimen prior to testing and/or conditioning, noting in detail any manufacturing or material defects such as cracks, bending, deformation, etc. Take photographs and/or video recordings of representative samples to be tested and keep a properly labeled control sample.

2. After testing and/or conditioning, re-examine each test sample and note in detail any observable changes such as physical distortions, cracks, etc. Compare the tested and/or conditioned samples to the control samples, the videos, and/or the photographs, recording any differences in the test report. An additional sample is needed as a control sample.

3. If the terminal supplier's appearance requirements are stricter than those specified below, then the terminal supplier specifications should be applied.

4. Return test samples to requestor after all tests are completed and all data have been obtained.

4.2.5 Acceptance Criteria

1. General Appearance: Confirm the crimping operation does not affect the contact, locking, connector mating, or insertion functions of the terminal. These characteristics are verified as part of USCAR-2 testing. Refer to Figures 4.2.5-1a and 4.2.5-1b for applicable attributes.

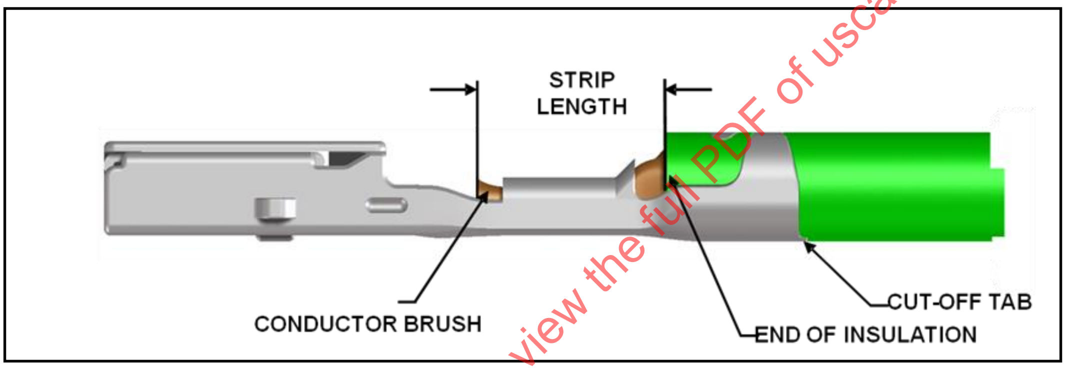


FIGURE 4.2.5-1A - PARTS OF A CRIMP (SIDE VIEW)

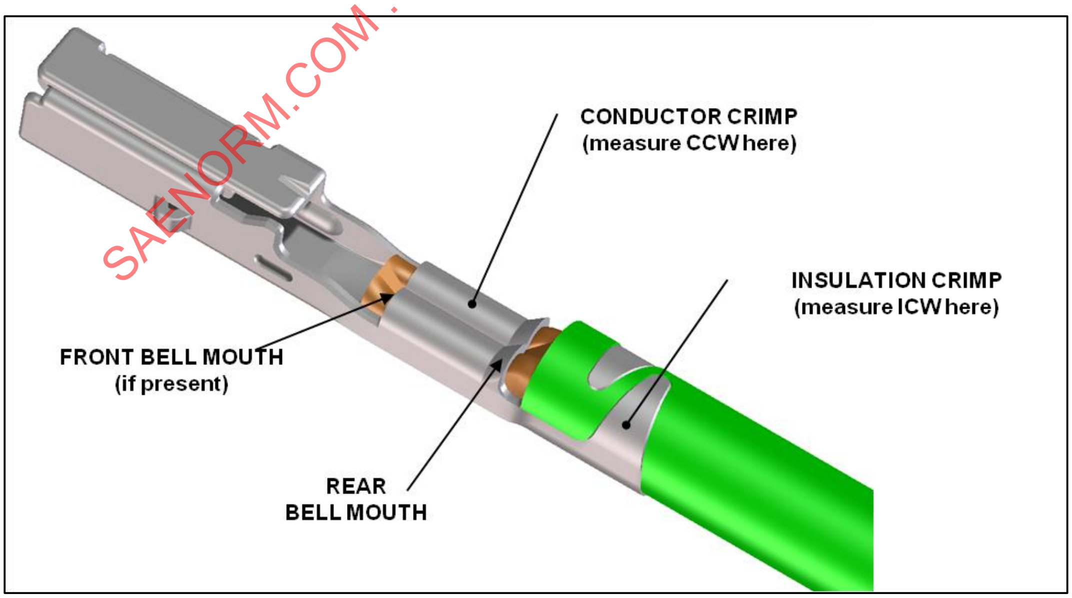


FIGURE 4.2.5-1B - PARTS OF A CRIMP (ISOMETRIC VIEW)

2. End of Conductor

The end of conductor must extend beyond the front edge of the conductor crimp. The insertion and locking functions of the terminal must not be affected by the projecting end of the conductor. Mat seals must not be damaged by the core and may require control of the wire core in front of the core wing. Refer to 4.2.5-6 (in this section - Conductor Crimp) for details.

3. End of Insulation

The end of the insulation must be visible in the window between the conductor crimp wings and the insulation crimp wings such that conductor is visible and should be centralized as much as possible. In no case may insulation be crimped in the conductor crimp wings.

4. Cut-off tab

a. The cut-off tab length shall not exceed 0.5 mm or ½ terminal stock thickness, whichever is greater, unless otherwise specified on the component print.

b. The burr on the cut-off tab must not exceed 0.3 mm on terminal stock thickness ≤0.8 mm unless otherwise specified on the component drawing. The burr must not exceed 0.6 mm on >0.8 mm stock thickness unless otherwise specified on the component drawing. Refer to Figure 4.2.5c.

c. The cut-off and burr must not affect the insertion function of the terminal into the connector.

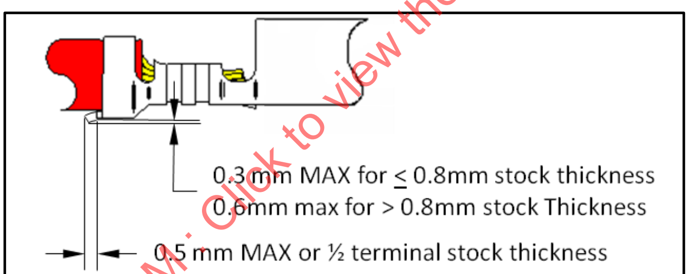


FIGURE 4.2.5C - BURR CRITERIA FOR CUT-OFF TAB

5. Bell mouth

The conductor crimp shall produce a bell mouth on the side of the crimp nearest the insulation crimp. A front bell mouth is not required, but the conductor crimp may have a bell mouth on the front edge of the conductor crimp, nearest the terminal body. Figures 4.2.5d and 4.2.5e illustrate the max. allowed bell mouth and min. allowed bell mouth. USCAR does not control these dimensions. Applicable values may be provided by the terminal manufacturer or customer.

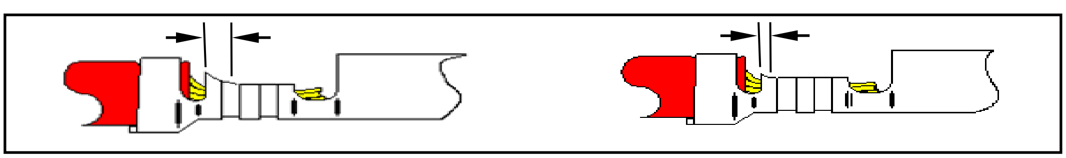


FIGURE 4.2.5D AND 4.2.5E - BELL MOUTH ACCEPTANCE CRITERIA (MAX. AND MIN.)

6. Conductor Crimp

All strands must be enclosed within the crimp; no strands outside the crimp or broken-off before the crimp are allowed. For wires <= 3mm^2, the wire brush length (ℓ in Figure 4.2.5f) shall not exceed 0.5mm (beyond the core wings) unless verified as acceptable by the connector manufacturer for a specific connector design or terminal maker for eyelet designs. The wire brush must not interfere with any downstream assembly process (for heat shrink, TPA, etc.)

7. Conductor Crimp when in a mat seal

If the crimp is used in a connector with a mat seal, the validation shall comply with the connector supplier's USCAR-2 correlated directions for wire brush length and height. If no connector supplier recommendations are available, the wire brush length shall not exceed 0.5mm (beyond the core wings) and the strands shall be even with or below the level of the core crimp ("t' in Figure 4.2.5f must be ≤0) at all allowable CCH. A front bell mouth (on the brush side of the crimp) shall not be used on a terminal to be loaded through a mat seal. (The top of the bell mouth can be sharp and damage a mat seal during plugging.)

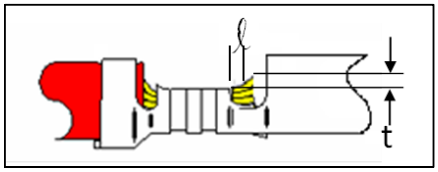


FIGURE 4.2.5F - WIRE BRUSH PROTRUDING STRAND HEIGHT ABOVE CORE CRIMP (t) AND LENGTH (l)

8. Insulation Crimp

The purpose of an insulation crimp is to add strain relief to the crimped conductor. This moves stress between the crimped and uncrimped wire strands into the un-crimped portion of the wire core. The test lab must determine the acceptable ICH range and tooling requirements to meet these requirements and be followed in production. Criteria are:

a) The insulation crimp must contact the surface of the insulated cable in at least 3 locations.
b) The insulation crimp must not interfere with any subsequent operations.
c) The insulation crimp must not push insulation compound under the wire strands (CUS).
d) The insulation crimp must not interfere with seating of a terminal into its plastic connector cavity.
e) The insulation crimp must not split or damage the cable. Use Figures 4.3.5-3 a, b, and c as criteria.
f) The bell mouth on the insulation crimp (if used) shall not exceed the insulation crimp tolerances.

9. Cable Conductor Appearance Prior to Crimping
   a. Strands in stripped wire shall not be cut, missing, excessively nicked (significant strand reduction), or elongated.
   b. Insulation shall not be stuck or embedded in strands.
   c. Length as described in Figure 4.2.5g shall meet applicable instructions (not controlled by USCAR-21).

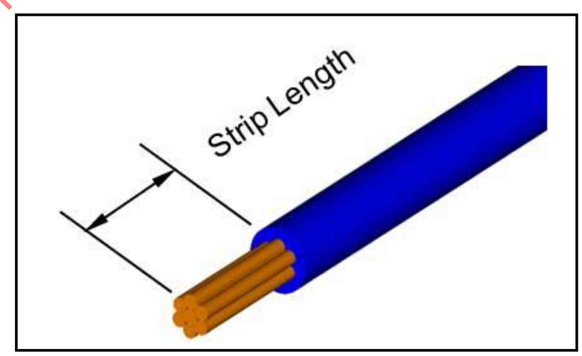


FIGURE 4.2.5G - STRIPPED WIRE LENGTH

10. Individual Cable Seal Crimp

   a. Seal location must meet terminal maker's product specification for lengthwise seal position, if specified. (In addition to achieving the proper position, the seal retention test per Section 4.6 must pass to assure it's secure.)

   b. The seal ribs must have no damage. Reference Figure 4.2.5h for what area is called a rib.

c. The end of the seal neck must be visible in the area between the insulation and the conductor crimps. It is expected that some cable seal designs with no hub at the end of the neck will not be able to pass the retention requirements of Section 4.6. In those cases, a redesigned seal is needed.

d. The cable insulation must be visible under the seal. Refer to Figure 4.2.5h as an example of correct position.

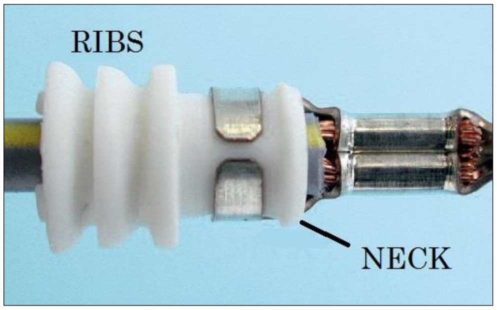


FIGURE 4.2.5H - INDIVIDUAL CABLE SEAL DETAIL

4.3 Cross-Section Analysis

4.3.1 Purpose

Cross-sectional analysis is used as an aid in determining why a crimp passes or fails a portion of this test. Failure to pass an electrical test may be due to uneven strand dispersion, inadequate wing closure, voids, wings bottoming out, etc.

4.3.2 Sample Size

At least one specimen for each crimp height shall be evaluated. Data shall be obtained and recorded for minimum, maximum and nominal production crimp heights.

4.3.3 Equipment

Various specialized equipment exists for cross-sectioning samples. The choice of equipment is up to the supplier, but should be capable of sectioning the crimp with minimal disturbance to the terminal and cable stranding.

4.3.4 Procedure

1. Cross-section and photograph each specimen for analysis.

2. Cross-section analysis shall be performed on all conductor crimp applications at each crimp height setting (nominal, min., and max. tolerance).

3. Cross-sections shall be in the area marked in Figure 4.3.4-3, as close to the center as possible. The core section must be made between serrations in the core crimp. Both core and insulation sections are required.

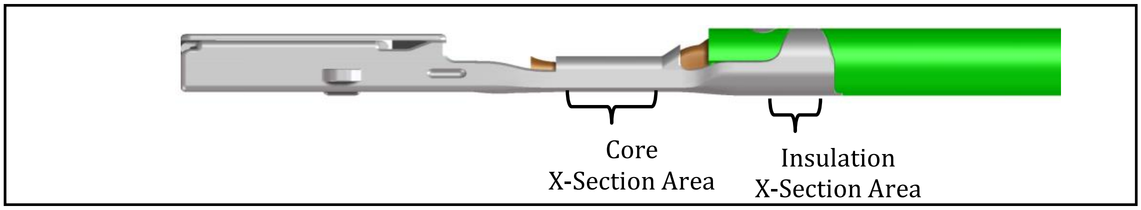


FIGURE 4.3.4-3 - CRIMP CROSS-SECTION LOCATIONS

4.3.5 Acceptance Criteria

Cross-section views of conductor crimps must comply with Figure 4.3.5-1.

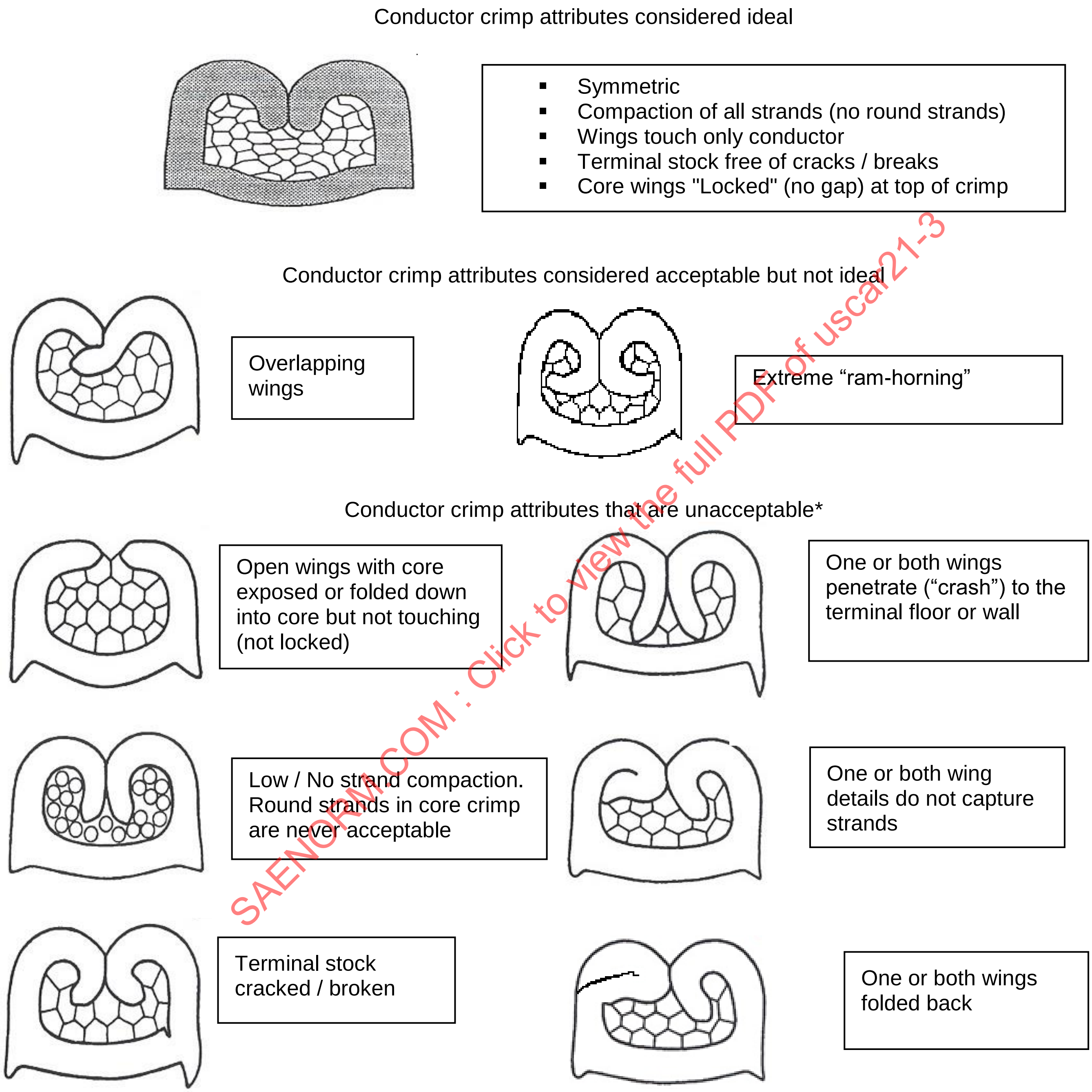


FIGURE 4.3.5-1 - CONDUCTOR CRIMP CROSS-SECTION CRITERIA

***NOTE**: With OEM customer approval, unacceptable attributes may be deemed acceptable for that customer if it is shown that all other requirements of this specification are met. Each customer needs to approve variances separately since one customer cannot approve a variance for a different customer. OEM is expected to only approve with technical understanding of the cause and severity of the condition. Refer to Section 5.2 for customer approval process.

2. The width of the burr on the base of a crimp must not exceed 0.1mm for ≤0.8mm thick terminal stock or 15% of stock thickness for >0.8mm stock. (For accurate crimp height measurement, it is recommended that the burr height not exceed the lowest position of the crimp.) The burr must not cause damage to any subsequent operation. Special care must be taken when using mat seals that can be cut by a burr. Seals are validated per USCAR-2 for each connector design.

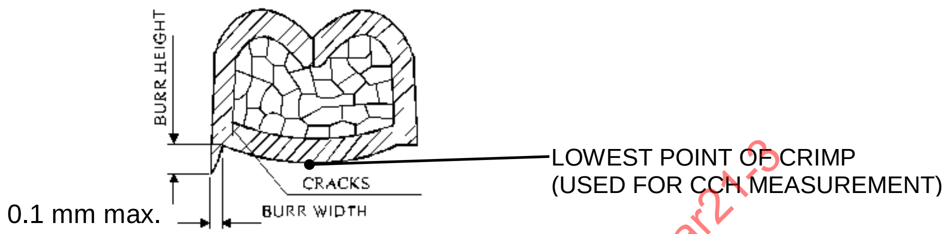
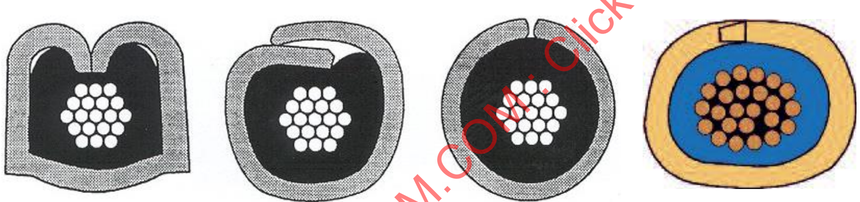


FIGURE 4.3.5-2 - CONDUCTOR CRIMP BURR DETAIL

3. Insulation cross-section (with no cable seal) must meet ideal views shown in Figure 4.3.5-3a or acceptable views in Figure 4.3.5.3b. No unacceptable cross-section views as shown in Figure 4.3.5-4c are allowed. For acceptance criteria on non-standard insulation crimp designs, refer to the terminal manufacturer's recommendations; some insulation crimps serve as a functional part of the terminal/cavity retention system and functional failures will result from non-compliance.



IDEAL INSULATION CRIMPS HAVE:
- Symmetric crimp
- No insulation penetration
- Wings embracing insulation

FIGURE 4.3.5-3A - IDEAL INSULATION CRIMP CROSS-SECTIONS FOR DIFFERENT STYLE DESIGNS

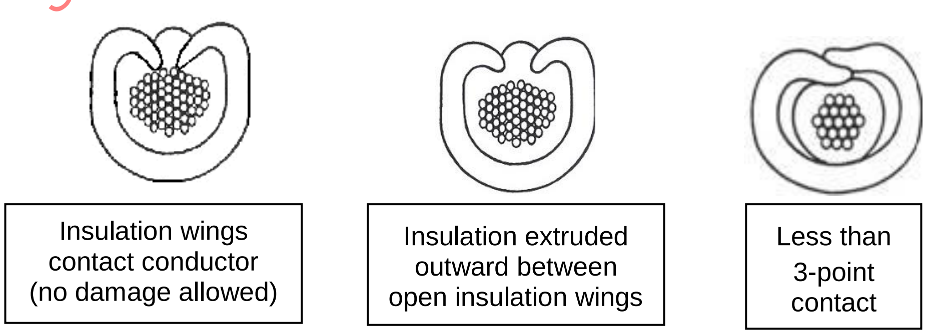


FIGURE 4.3.5-3B - ACCEPTABLE BUT NOT IDEAL INSULATION CRIMPS

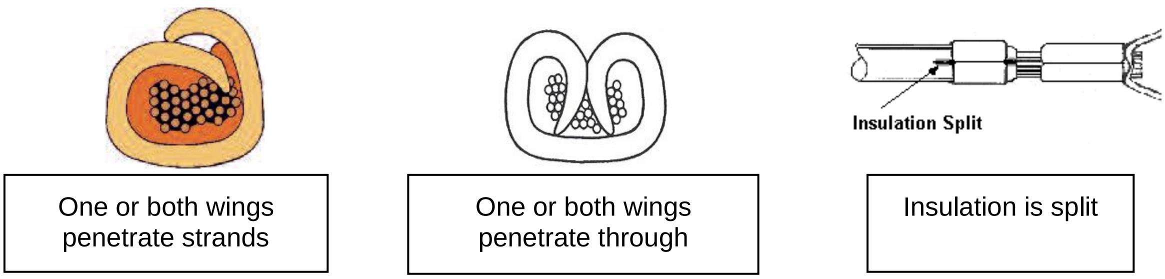


FIGURE 4.3.5-3C - UNACCEPTABLE INSULATION CRIMPS

4. Cable seals must have no nicks or cuts in the sealing ribs. Minimal nicks or cuts are allowed in the seal neck if functional seal retention requirements are met. Insulation crimp wings are not permitted to penetrate into the seal neck. See Figure 4.3.5-4a for a cross-sectional illustration of a cable seal and Figure 4.3.5-4b for a mat seal.

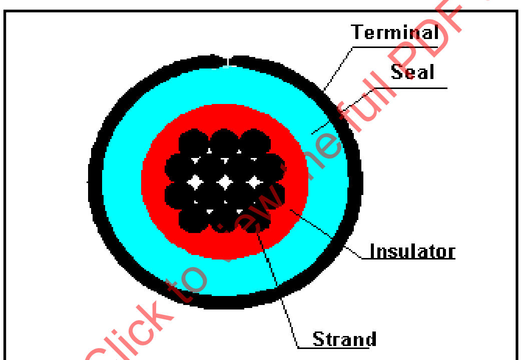


FIGURE 4.3.5-4A - CABLE SEAL CROSS-SECTION (INCLUDING TERMINAL AND WIRE)

5. Crimped terminal and wire must be designed to avoid damage (such as nicks and cuts) to the sealing ribs when inserting terminated leads through mat seals. Refer to Figure 4.3.5-4b for a sample cross-section view. Functional sealing performance is determined in USCAR-2 testing.

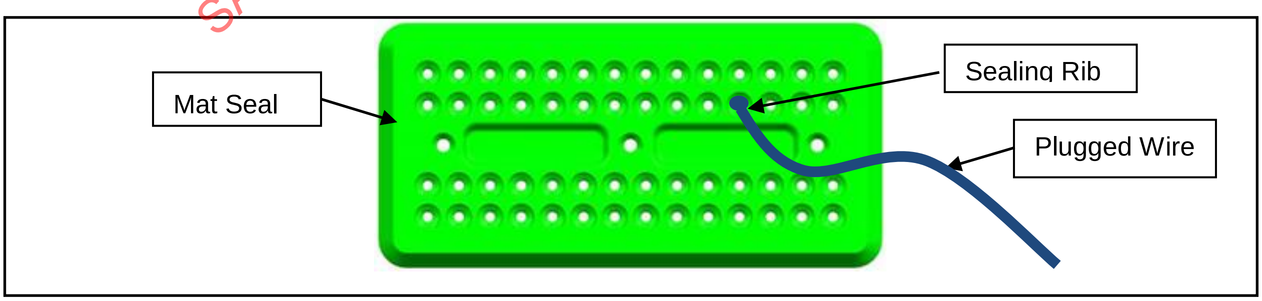


FIGURE 4.3.5-4B - MAT SEAL APPLICATION

4.4 Conductor Crimp Pull-Out Force Test

4.4.1 Purpose

This procedure details a method to measure the retention capability of crimped connections. The pull-out force test is not be used to determine overall performance of the crimp application. It is intended to be used for mechanical crimp evaluation only. It will only be used to determine the mechanical limits of the application for handling purposes. Applications may require additional protection to assure the crimped circuit survives the harness handling and vehicle assembly process.

4.4.2 Equipment

1. Measuring device capable of measuring crimp heights and widths
2. De-crimping tool or other suitable means of opening insulation crimp wings without damaging the cable conductor (Note: It is acceptable to make the samples with the insulation wings not crimped to avoid this step.)
3. Force tester
4. Cable strippers, long-nose pliers and/or side cutters

4.4.3 Samples

1. A minimum of 20 samples is required to be tested for each tested crimp height (3 crimp heights minimum, 5 are often used to give a wider range of tested crimp heights). Additional samples may be required for crimps with multiple wires of various sizes (See 4.4.4, steps 7 and 8).

4.4.4 Procedure

1. Pull-out force test shall be performed on leads with the insulation crimp wings open (not crimped).
2. Pull-out force test shall be performed on taut leads (i.e., remove slack in cable before performing pull-out test to prevent incorrect test results due to “jerking”).
3. Measure and record the conductor crimp height and width in millimeters for each sample. Refer to Appendix E, 6-8.
4. If the insulation crimp is not already open, open it with a de-crimper or other suitable tool so that the pull-out force will reflect only the conductor crimp connection.
5. Visually inspect the de-crimped area to ensure that none of the conductor strands have been damaged. Do not use any samples that have damaged conductor strands.
6. Measure and record pull-out forces in Newtons for each sample.
7. Apply axial motion at a rate between 50 and 250 mm/minute (100 mm/min. is recommended).
8. For double, triple, or multiple wire crimp setups with conductor sizes within one step, pull the smallest conductor. (e.g. for a 0.35/0.50 double, pull the 0.35 mm^2 wire).

   For double, triple, or multiple wire crimp with conductor sizes more than one size apart, one of the smallest and one of the largest gage size cables must be tested. (e.g. for a 0.50/1.0 double, pull both wires individually, for a 0.50/1.0/2.0 triple, pull the 0.50 mm^2 and the 2.0 mm^2 wires, for a 0.50/0.50/2.0 triple, pull one of the 0.50 mm^2 and the 2.0mm^2 wires.) In this case, 20 samples per wire size tested are required. A new specimen is required for each pull.

9. Calculate the mean and standard deviation using the following formulas (using Excel or other suitable spreadsheet to calculate the mean and standard deviation of the tensile result obtained in steps 6~9). Report minimum, maximum, mean ($\overline{X}$), standard deviation (s), and the mean minus three standard deviations ($\overline{X}$ -3s) for each crimp height set.

$$\text{Mean}(\overline{X}) = \frac{\sum_{i=1}^{n} X_i}{n}$$

$$\text{Standard Deviation (s)} = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 - n\overline{X}^2}{n-1}}$$

Where X_i = individual pull-out force; n= number of samples.

EQUATION 4.4.4-9A AND 4.4.4-9B - MEAN AND STANDARD DEVIATION FOR PULL CRITERIA

10. Report any observations from visual examination.

4.4.5 Acceptance Criteria:

The ($\overline{X}$ -3s) value calculated using Equations 4.4.4-9 a and b must meet or exceed the value specified in Table 4.4.5. Forces for unlisted wires can be calculated by linear interpolation of values in Table 4.4.5.

NOTE: Tensile strength is intended to be an indicator of crimp quality. When the test fails due to the tensile strength of the wire (unrelated to crimp) not meeting the listed values, an engineering change to a stronger wire is required.

TABLE 4.4.5 - PULL-OUT FORCE REQUIREMENT (IN MM AND GAUGE SIZES)

ISO[a] (mm^2)	$\bar{X}$-3s Pull-out Force (N)
0.13[b]	50
0.22	50
0.35	50
0.50	75
0.75	90
1	120
1.5	150
2	180
2.5	210
3	240
4	265
5	290
6	320
8	350
10	450
>10	600[c]

Wire Gauge	SAE[a] (mm^2)	$\bar{X}$-3s Pull-out Force (N)
26[b]	0.13	50
24	0.22	50
22	0.35	50
20	0.50	75
18	0.80	90
16	1	120
14	2	180
12	3	240
10	5	290
8	8	350
	>10	600[c]

[a] ISO standard sizes based on ISO-6722-1. SAE is based on SAE J1127 and J1128.
[b] 0.13mm^2 (26 AWG) and smaller require special handling and controls not covered in this document.
[c] The requirement on > 10mm^2 is for minimum value only. No pull-to-failure or $\bar{X}$-3s calculation is required.

4.5 Electrical Performance Tests

4.5.1 Electric Current Cycling Test (ECC)

4.5.1.1 Purpose

Current cycling is an accelerated aging test that emphasizes the effect of expansion and contraction of terminal interfaces and conductor crimps as a result of thermal cycling. This test is optional when run in addition to ENV. With the approval of the customer, it may be used in lieu of ENV (See Table 5.1) but must be noted as such on the drawing and requires customer approval. Typically, the Accelerated Environmental Test (Paragraph 4.5.2) is done and not ECC.

4.5.1.2 Samples

1. Any engineering development, prototype, or production terminal – particularly those intended for high current or "Power" applications – may be submitted for test.
2. Test data will be collected on 10 samples of each crimp height. Data shall be obtained and recorded for minimum, maximum and nominal production crimp heights.
3. Where mating terminals are available, apply them to the opposite ends of the test samples. These shall be 150mm min. The terminal crimps on the mating terminals shall be soldered. Connect to form a continuous series circuit.
4. Test sample terminals that have no mating terminals should be applied to one end only of the test cable (a minimum cut length of 150 mm). The opposite stripped ends of the samples are then soldered to box or blade of the next sample to form a continuous series circuit.
5. Double terminations should be terminated with the test terminal on one end only. A mating terminal may be applied (with the crimp soldered) to the other end of the largest size cable.

4.5.1.3 Equipment

1. Power supply – AC or DC current regulated capable of supplying the test current.
2. Cycle timer.
3. Ammeter or current shunt/voltmeter.
4. Voltmeter.
5. Voltage sense lead – solid conductor 0.22 mm or smaller diameter (tinned or non-tinned).
6. Welder – Tweezer Weld TW-3 or similar device.
7. Terminal test board.
8. Samples (3) with solder added to the conductor crimp for deduct calculation.

4.5.1.4 Procedure

1. Perform a visual inspection of components per paragraph 4.5.2.
2. Attach voltage sense leads per figure 4.5.1.4. The same location must be used for all samples. The V+ test lead may be connected to back of insulation wing if wing does not touch the core.

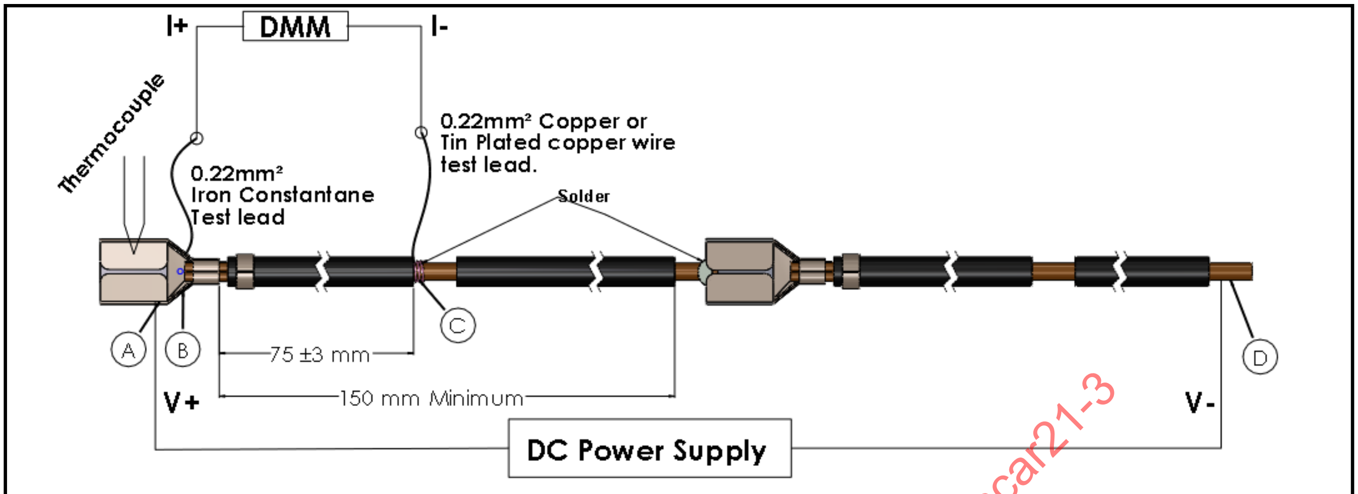


FIGURE 4.5.1.4 - TEST LEAD ATTACHMENT.

3. Attach sense leads to the test cable at a point 75 ± 3 mm from the rear edge of the conductor crimp.
4. Connect in a series circuit.
5. Loosely attach the samples to a test board with a minimum of 35mm between single terminals.
6. Connect the series test circuit to the ammeter (current shunt) and a timer-controlled power supply. Include the soldered test samples (4.5.1.3-8) in the circuit. The test duration shall be 200 ± 8 hours with the test current cycling on for 45 minutes ± 2 minutes and off for 15 ± 2 minutes.
7. Use test currents listed in table 4.5.1.4. The test currents for conductors sizes not listed above can be defined by linear interpolation (i.e. read out from plotted values). Perform step 8 if wire is equal to or larger than 8mm².

TABLE 4.5.1.4 - TEST CURRENT FOR CURRENT CYCLING.

ISO Wire Size (mm²)	Wire Gauge	Test Current (A)
0.13	26	4
0.35	22	10
0.50	20	14
0.75	18	18
1	16	22
1.5	-	26
2	14	30
2.5	-	35
3	12	40
4	-	52
5	10	65
6	-	80
≥ 8	≤ 8	Use step 8

8. If wire is larger than 8mm^2, determine test current using this method (an acceptable alternative to steps a, b, and c is to perform the “Maximum Test Current Capability” test identified in SAE/USCAR-2).

   a. Attach thermocouples to samples at a point on the underside and just in front of the conductor crimp. Welding or epoxy is permissible.
   b. Apply 75% of the estimated current to the circuit at room temperature.
   c. Allow the circuit to come to steady state temperature. The temperature is stable when the crimp on the sample under test changes less than 2 °C in 5 minutes.
   d. Measure the temperature, and calculate the temperature rise.
      If the temperature rise is less than the maximum temperature rise recommended by the terminal supplier or 55 °C, whichever is lower, then increase the current in 0.5A steps until that temperature is reached.

9. The current at which the maximum temperature rise recommended by the terminal manufacturer or 55 °C, whichever is lower, is reached is the test current.

10. Measure voltage drop after 2 ±1 hours from the start of test and at the completion of the test (200 ±8 hours). The samples should be energized for a minimum of 30 minutes to allow for temperature stabilization. Measurements are taken between points B & C of Figure 4.5.1.4.

11. Measure the voltage drop across the three Deduct soldered samples and average the measured values.

12. Calculate conductor crimp-to-wire voltage drop per the following: mVD=Voltage drop recorded in step 10 less the average voltage drop of the deduct samples measured in step 11.

13. Record:
   a. All voltage drop measurements and all calculated resistance values.
   b. Average, low, and high resistance values for each data set.
   c. Description of samples.
   d. Conditions of test.
   e. Instruments used, the date of last calibration, and when the next calibration is due.
   f. Soldered sample resistance value if applicable.
   g. Temperature rise on at least one part in the nominal CCH group.
   h. Observations.

4.5.1.5 Acceptance Criteria

Using the calculated resistance values from item 13a, follow the criteria in Table 4.5.2.5.

4.5.2 Accelerated Environmental Exposure Test (ENV)

4.5.2.1 Purpose

This procedure describes testing based on subjecting the parts to a sequence of environmental exposures.

4.5.2.2 Samples

A minimum of 10 terminal samples of each crimp height shall be tested. Data shall be obtained and recorded for minimum, maximum and nominal production crimp heights. Minimum cable length for samples is 75 mm.

4.5.2.3 Equipment

1. Integrated or separate temperature/humidity cycling chamber(s).

4.5.2.4 Procedure

1. Perform a visual inspection of components per paragraph 4.2.
2. Perform initial resistance measurement (either dry circuit resistance per section 4.5.3 for wire size ≤ 6mm^2 or Voltage drop per section 4.5.6 for wire size > 6mm^2).
3. Perform Thermal Shock per section 4.5.5 (72 Cycles / 3 Days. at +125 °C to -40 ± 3 °C).
4. (optional) Take midpoint resistance reading (either dry circuit resistance per section 4.5.3 for wire size ≤ 6mm^2 or Voltage drop per section 4.5.6 for wire size > 6mm^2).
5. Perform temperature humidity test per section 4.5.4 (4 Cycles / 4 Days).
6. Perform visual inspection per section 4.2.
7. Perform final resistance measurement (either dry circuit resistance per section 4.5.3 for wire size ≤ 6mm^2 or Voltage drop per section 4.5.6 for wire size > 6mm^2).

4.5.2.5 Acceptance Criteria

1. The initial resistance measurement taken in step 2 for all samples within 3 consecutive conductor crimp heights (CCH) representing the lower, nominal, and upper limits must satisfy column A in Table 4.5.2.5.
2. All samples within 3 consecutive conductor crimp heights (CCH) representing the lower, nominal, and upper limits measured after conditioning per 4.5.2.4 must have resistance measurements from Step 7 satisfy either column A or column B in Table 4.5.2.5.

TABLE 4.5.2.5 - ACCEPTANCE CRITERIA FOR ELECTRICAL RESISTANCE.

	A		B	
	Maximum Allowable **Total** Resistance		Maximum Allowable Resistance **Change**	
Wire Size	ISO Wires	SAE Wires	ISO Wires	SAE Wires
≤ 6.0 mm^2 / 10 AWG	Use Table 4.5.2.5-1a	Use Table 4.5.2.5-1b	Use Table 4.5.2.5-2a	Use Table 4.5.2.5-2b
> 6.0 mm^2	Use Table 4.5.2.5-3 (Maximum Total mV/A Column)		Use Table 4.5.2.5-3 (Maximum mV/A Change Column)	

NOTE: The referenced tables, 4.5.2.5-1a, -1b, -2a, and -2b list the maximum allowable resistance (in milliohms) for various wire sizes and terminal materials before and after completion of Electrical Current Cycling (ECC, Section 4.5.1) test or Accelerated Environmental (ENV, Section 4.2) test. If the needed resistance value is not available for the wire and terminal conductivity being evaluated, use the table value for the next more conductive material and/or next larger size.

Alternately, the value can be calculated using the formulas below. Note that the tables have limits, or "capped" values of 0.55mΩ total resistance and 0.33 mΩ resistance change. The formulas below do not include the limits.

Calculation-based criteria for Table 5.4.2.5-1a, 2a and c:

$$\mathbf{R_{max} = 0.011 \times (\rho_1+\rho_2)/(2d)}$$

Calculation-based criteria for Table 5.4.2.5-1b and 2b:

$$\mathbf{R_{change} = 0.0099 \times (\rho_1+\rho_2)/(2d)}$$

Where: R_{max} = The allowed resistivity in mOhms and R_{change} is the allowed resistivity change in mOhms.
ρ_1 = The resistivity of the conductor in µOhm-mm²/mm (For Cu, ρ_1 = 17.2 per IACS)
ρ_2 = The resistivity of the base terminal material in µΩ-mm²/mm (top plating is not a factor)
d = The diameter of a circle with the same area as the total cross-sectional area of the conductor in mm

EQUATION 4.5.2.5-1A AND 4.5.2.5-1B - CALCULATION-BASED METHOD FOR CRITERIA DETERMINATION

NOTE: The equation is typically used for non-copper wires, unusual alloy materials, or non-standard wire sizes. Use of the tables is preferred for standard configurations since an opportunity for error in calculation is eliminated. See Appendix D for notes on the derivation of this formula.

TABLE 4.5.2.5-1A - DRY CIRCUIT CRITERIA FOR TOTAL RESISTANCE (FOR ISO WIRES 0.13 TO 6MM^2)

Alloy / CDA Number (Reference)			**151**	**18080 197**	**186**	**194**	**210**	**195**	**19002 17510 220**	**19025 226**	**230 411 422**	**240**	**260 425**	**511 544 170 172 688**	**510 521**	**638 725**	**654 706 762**	**715 752 770**
Terminal Material % Conductivity			90	80	70	60	56	50	45	40	37	32	27	19	14	11	8	5
Terminal Material Resistivity (micro-ohm-mm²/mm)			19.1	21.5	24.6	28.7	30.7	34.4	38.2	43.0	46.5	53.8	63.7	90.5	122.9	156.4	215.0	344.0
Wire Size: ISO (mm^2)	Actual Cond Area (mm^2)	Dia. (Solid) (mm)	Allowable Resistance (mΩ)															
6	5.59	2.667	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.74**
5	4.35	2.354	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.84**
4	3.70	2.170	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.59**	**0.92**
3	2.79	1.884	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.68**	**1.05**
2.5	2.28	1.704	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.56**	**0.75**	**1.17**
2	1.85	1.534	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.62**	**0.83**	**1.29**
1.5	1.37	1.321	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.58**	**0.72**	**0.97**	**1.50**
1	0.94	1.094	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.70**	**0.87**	**1.17**	**1.82**
0.75	0.70	0.946	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.63**	**0.81**	**1.01**	**1.35**	**2.10**
0.50	0.47	0.772	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.58**	**0.77**	**1.00**	**1.24**	**1.66**	**2.57**
0.35	0.33	0.651	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.60**	**0.68**	**0.91**	**1.18**	**1.47**	**1.96**	**3.05**
0.22	0.20	0.508	0.55	0.55	0.55	0.55	0.55	**0.56**	**0.60**	**0.65**	**0.69**	**0.77**	**0.88**	**1.17**	**1.52**	**1.88**	**2.51**	**3.91**
0.13	0.13	0.402	0.55	0.55	**0.57**	**0.63**	**0.66**	**0.71**	**0.76**	**0.82**	**0.87**	**0.97**	**1.11**	**1.47**	**1.92**	**2.37**	**3.18**	**4.94**

TABLE 4.5.2.5-1B - DRY CIRCUIT CRITERIA FOR TOTAL RESISTANCE (FOR SAE WIRES 26 TO 10GA.)

Alloy / CDA Number (Reference)				**151**	**18080 197**	**186**	**194**	**210**	**195**	**19002 17510 220**	**19025 226**	**230 411 422**	**240**	**260 425**	**511 544 170 172 688**	**510 521**	**638 725**	**654 706 762**	**715 752 770**
Terminal Material % Conductivity				90	80	70	60	56	50	45	40	37	32	27	19	14	11	8	5
Terminal Material Resistivity (micro-ohm-mm²/mm)				19.1	21.5	24.6	28.7	30.7	34.4	38.2	43.0	46.5	53.8	63.7	90.5	122.9	156.4	215.0	344.0
Wire Size AWG	Wire Size: SAE Metric (mm^2)	Actual Cond. Area (mm^2)	Dia. (Solid) (mm)	Allowable Resistance (mΩ)															
10	5	4.65	2.433	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.82**
12	3	2.91	1.925	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.66**	**1.03**
14	2	1.85	1.535	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.62**	**0.83**	**1.29**
16	1	1.12	1.194	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.65**	**0.80**	**1.07**	**1.66**
18	0.8	0.76	0.984	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.60**	**0.78**	**0.97**	**1.30**	**2.02**
20	0.5	0.508	0.804	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.74**	**0.96**	**1.19**	**1.59**	**2.47**
22	0.35	0.32	0.638	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	**0.61**	**0.70**	**0.93**	**1.21**	**1.50**	**2.00**	**3.11**
24	0.22	0.211	0.518	0.55	0.55	0.55	0.55	0.55	0.55	**0.59**	**0.64**	**0.68**	**0.75**	**0.86**	**1.14**	**1.49**	**1.84**	**2.46**	**3.83**
26	0.13	0.127	0.402	0.55	0.55	**0.57**	**0.63**	**0.66**	**0.71**	**0.76**	**0.82**	**0.87**	**0.97**	**1.11**	**1.47**	**1.92**	**2.37**	**3.18**	**4.94**

TABLE 4.5.2.5-2A - DRY CIRCUIT CRITERIA FOR CHANGE IN RESISTANCE (FOR ISO WIRES TO 6MM²)

Alloy / CDA Number (Reference)			151	18080 197	186	194	210	195	19002 17510 220	19025 226	230 411 422	240	260 425	511 544 170 172 688	510 521	638 725	654 706 762	715 752 770
Terminal Material % Conductivity			90	80	70	60	56	50	45	40	37	32	27	19	14	11	8	5
Terminal Material Resistivity (micro-ohm-mm²/mm)			19.1	21.5	24.6	28.7	30.7	34.4	38.2	43.0	46.5	53.8	63.7	90.5	122.9	156.4	215.0	344.0
Wire Size: ISO (mm^2)	Actual Cond Area (mm^2)	Dia. (Solid) (mm)	Allowable Resistance Change (mΩ)															
6	5.59	2.667	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.43**	**0.67**
5	4.35	2.354	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.36**	**0.49**	**0.76**
4	3.70	2.170	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.40**	**0.53**	**0.82**
3	2.79	1.884	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.37**	**0.46**	**0.61**	**0.95**
2.5	2.28	1.704	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.41**	**0.50**	**0.67**	**1.05**
2	1.85	1.534	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.35**	**0.45**	**0.56**	**0.75**	**1.17**
1.5	1.37	1.321	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.40**	**0.52**	**0.65**	**0.87**	**1.35**
1.25	1.15	1.212	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.33**	**0.44**	**0.57**	**0.71**	**0.95**	**1.48**
1	0.94	1.094	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.37**	**0.49**	**0.63**	**0.79**	**1.05**	**1.63**
0.75	0.70	0.946	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.33**	**0.37**	**0.42**	**0.56**	**0.73**	**0.91**	**1.22**	**1.89**
0.50	0.47	0.772	0.33	0.33	0.33	0.33	0.33	**0.33**	**0.36**	**0.39**	**0.41**	**0.46**	**0.52**	**0.69**	**0.90**	**1.11**	**1.49**	**2.32**
0.35	0.33	0.651	0.33	0.33	0.33	**0.35**	**0.36**	**0.39**	**0.42**	**0.46**	**0.48**	**0.54**	**0.62**	**0.82**	**1.07**	**1.32**	**1.77**	**2.75**
0.22	0.20	0.508	**0.35**	**0.38**	**0.41**	**0.45**	**0.47**	**0.50**	**0.54**	**0.59**	**0.62**	**0.69**	**0.79**	**1.05**	**1.36**	**1.69**	**2.26**	**3.52**
0.13	0.13	0.402	**0.45**	**0.48**	**0.51**	**0.56**	**0.59**	**0.64**	**0.68**	**0.74**	**0.78**	**0.87**	**1.00**	**1.33**	**1.72**	**2.14**	**2.86**	**4.45**

TABLE 4.5.2.5-2B - DRY CIRCUIT CRITERIA FOR CHANGE IN RESISTANCE (FOR SAE WIRES TO 10GA.)

Alloy / CDA Number (Reference)				151	18080 197	186	194	210	195	19002 17510 220	19025 226	230 411 422	240	260 425	511 544 170 172 688	510 521	638 725	654 706 762	715 752 770
Terminal Material % Conductivity				90	80	70	60	56	50	45	40	37	32	27	19	14	11	8	5
Terminal Material Resistivity (micro-ohm-mm²/mm)				19.1	21.5	24.6	28.7	30.7	34.4	38.2	43.0	46.5	53.8	63.7	90.5	122.9	156.4	215.0	344.0
Wire Size AWG	Wire Size: SAE Metric (mm^2)	Actual Cond. Area (mm^2)	Dia. (Solid) (mm)	Allowable Resistance Change (mΩ)															
10	5	4.65	2.433	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.35**	**0.47**	**0.73**
12	3	2.91	1.925	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.36**	**0.45**	**0.60**	**0.93**
14	2	1.85	1.535	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.35**	**0.45**	**0.56**	**0.75**	**1.16**
16	1	1.12	1.194	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.34**	**0.45**	**0.58**	**0.72**	**0.96**	**1.50**
18	0.8	0.76	0.984	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	**0.36**	**0.41**	**0.54**	**0.70**	**0.87**	**1.17**	**1.82**
20	0.5	0.508	0.804	0.33	0.33	0.33	0.33	0.33	0.33	**0.34**	**0.37**	**0.39**	**0.44**	**0.50**	**0.66**	**0.86**	**1.07**	**1.43**	**2.22**
22	0.35	0.32	0.638	0.33	0.33	0.33	**0.36**	**0.37**	**0.40**	**0.43**	**0.47**	**0.49**	**0.55**	**0.63**	**0.84**	**1.09**	**1.35**	**1.80**	**2.80**
24	0.22	0.211	0.518	**0.35**	**0.37**	**0.40**	**0.44**	**0.46**	**0.49**	**0.53**	**0.57**	**0.61**	**0.68**	**0.77**	**1.03**	**1.34**	**1.66**	**2.22**	**3.45**
26	0.13	0.127	0.402	**0.45**	**0.48**	**0.51**	**0.56**	**0.59**	**0.64**	**0.68**	**0.74**	**0.78**	**0.87**	**1.00**	**1.33**	**1.72**	**2.14**	**2.86**	**4.45**

TABLE 4.5.2.5-3 - ACCEPTANCE CRITERIA FOR WIRES LARGER THAN 6MM²

Wire Size (mm^2)	Maximum Total R (mV/A [mΩ])	Maximum Change in R (mV/A [mΩ])
>6 and <12	0.15	0.09
≥12 and <20	0.11	0.07
≥20 and <30	0.08	0.05
≥30 and <40	0.06	0.04
≥40 and <50	0.05	0.03
≥50 and <60	0.04	0.02
≥60 and ≤120	0.03	0.02

4.5.3 Measurement Method for Dry Circuit Termination Resistance of Static Contacts

4.5.3.1 Purpose

This procedure describes how to measure the termination resistance of static contacts under dry circuit conditions, which will not alter that resistance by breakdown of insulating films or softening of contact asperities. Dry circuit conditions require that the voltage across the test sample be ≤20 mV and maximum current through the sample be ≤100 mA. Performance at these levels is indicative of interface performance at any lower level of excitation. For evaluation on crimps containing multiple wires, perform the resistance measurement on the smallest wire.

4.5.3.2 Samples:

1. Prepare a minimum of 13 samples: A minimum of 10 samples of each crimp height shall be submitted for test plus three (3) additional soldered samples to be used as "deduct" samples in 4.5.3.4-4.

2. A sample length of 150 mm is recommended. However, any sample length ≥75 mm is acceptable as long as there is no effect on the crimped wings during processing and handling of samples. The same length shall be used for all samples under test and for the deduct samples.

3. Prepare resistance measurement points on the cable 75 ± 3 mm from the rear edge of the terminal conductor crimp.

4. Apply solder to measuring point C, Figure 4.5.3.4 (stripped end of wire) to obtain consistent readings.

4.5.3.3 Equipment: Micro-Ohmmeter

4.5.3.4 Procedure

1. Perform a visual inspection of components per paragraph 4.2.

2. Assure measurements are made on thoroughly dry samples without cleaning or rinsing of corrosion products.

3. Assure relative movement of samples is minimized to reduce effects of movement on measured values.

4. Measure and record the resistance of the three samples with soldered crimps and average the values. The measurement is made at a point 75±3 mm from the rear edge of the terminal conductor crimp.

5. Measure and record the resistance between the cable measuring point B and point C on the terminal just in front of the conductor crimp (Figure 4.5.3.4). The V+ lead may be on the insulation wing if it does not touch the core.
   Note: A 4-wire measurement as shown is required. "Kelvin clips" are allowed for this, but the solder method shown is a better lab practice since Kelvin clips may give false failures if good contact is not reached with the clip.

6. Calculate and record the crimp resistance. The crimp resistance is equal to the overall resistance measured in step 5, less the average "deduct" sample resistance measured in step 4.

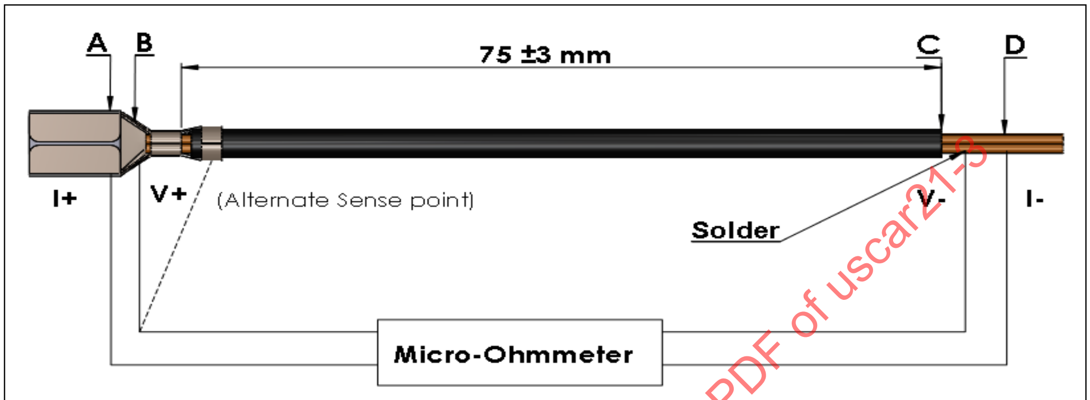


FIGURE 4.5.3.4 - DRY CIRCUIT MEASUREMENT POINTS

4.5.3.5 Acceptance Criteria

This is a measurement procedure only so there are no acceptance criteria.

4.5.4 Accelerated Temperature / Humidity Cycle Conditioning – 24 hour cycle test procedure

4.5.4.1 Purpose

1. This procedure defines an accelerated version of temperature/humidity cycle conditioning.

2. Accelerated temperature/humidity cycling conditioning is used to determine the effect of sequential exposure to high humidity and high and low temperature environments on electrical and electronic components.

3. High and low temperature and high humidity environments may promote corrosion of metals, degrade properties of other materials, and establish electrical bridging between circuits.

4.5.4.2 Samples

Prepare samples per paragraph 4.5.3.2. Note: The same sets of samples shall be consecutively exposed to the Thermal Shock (T/S) and Temperature/Humidity (T/H) conditioning and be measured by either the dry circuit or voltage drop procedures described in this specification.

4.5.4.3 Equipment

1. Humidity chamber.
2. Forced air oven.
3. Temperature chamber.
4. Automatic temperature/humidity cycling chamber. This equipment may be used as an alternative to that listed in paragraphs 1, 2, and 3 above.

4.5.4.4 Procedure

Expose test samples to four (4) cycles of the environmental exposure sequence described below:

a. 16 hours @ +65 ± 3 °C 95-98% RH
b. 2 hours @ -40 ± 3 °C Humidity not controlled
c. 2 hours @ +85 ± 3 °C Humidity not controlled
d. 4 hours @ +23 ± 3 °C Humidity not controlled

The maximum transfer / transition time of samples from one environment to the next during the defined temperature/ humidity cycle is 1 hour. The cycle timing starts when the chamber reaches the target temperature. All time periods listed in the defined cycle have a tolerance of ± 5 minutes.

4.5.4.5 Acceptance Criteria

This is a conditioning procedure only. There are no acceptance criteria.

4.5.5 Thermal Shock Conditioning Procedure

4.5.5.1 Purpose

This test specification details the procedure for testing the functional reliability of electrical and electronic components when subjected to alternating high and low temperature environments. Rapid transfer between the two environments tests the component's ability to withstand drastic temperature changes.

4.5.5.2 Samples

1. Make certain that the cable insulation can withstand the rigors of the test conditions.

2. Prepare samples per paragraph. 4.5.3.2. The same set of samples shall be consecutively exposed to the T/S and T/H conditioning and be measured by either the dry circuit or voltage drop procedures described in this specification.

4.5.5.3 Equipment: Thermal shock chamber or separate hot and cold chambers.

4.5.5.4 Procedure

1. Perform visual examination per paragraph 4.2.
2. Perform dry circuit resistance per paragraph 4.5.3.
3. Set controls to the necessary temperatures, dwell times, and number of cycles.
4. Allow the chambers sufficient time to achieve the programmed temperature.
5. Place the samples in the transfer basket. Insure that the test samples cannot jam the transport mechanism.
6. Start the test program per Figure 4.5.5.4.

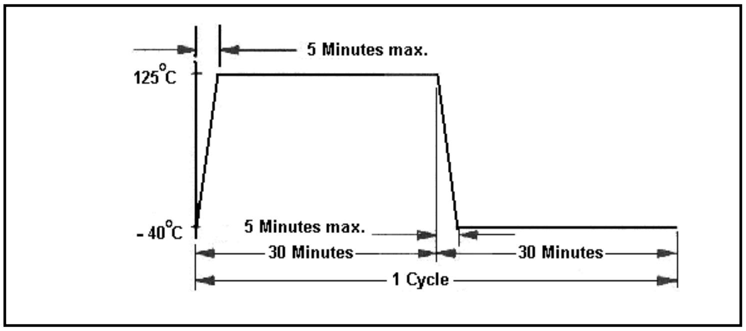


FIGURE 4.5.5.4 - THERMAL SHOCK CYCLE

7. When test program is complete, shut off the thermal shock chamber and remove samples.
8. Perform visual examination per paragraph 4.2.
9. Report operating temperatures, dwell times, number of cycles and evaluation tests, if performed.

4.5.5.5 Acceptance Criteria

This is a conditioning procedure only. There are no acceptance criteria.

4.5.6 Voltage Drop Measurement Procedure

This test is intended to be used for terminals crimped on >6mm^2 wire size.

4.5.6.1 Purpose

1. This procedure defines measuring the termination voltage drop of static crimped contacts under high energy conditions. It is to be used to validate terminal/wire combinations where the wire core cross-section is >6mm^2.

2. Current is applied to the sample under test so voltage drop of the termination can be measured. Power supply voltage will be allowed to float during this test.

4.5.6.2 Samples:

1. A minimum of 10 samples of each crimp height under test shall be submitted for test. Data shall be obtained and recorded for no less than 3 consecutive (minimum, maximum and nominal) production crimp heights. Additional crimp heights may be included in the test to assure there will be at least 3 consecutive crimp heights that meet the voltage drop requirements. These samples may also be used for the pull test samples after the accelerated environmental exposure and voltage drop measurements are made.

2. Prepare 3 additional samples to be used to determine the deduct voltage drop as required in 4.5.6.4 – Step 6. Solder the crimps on these "Deduct" samples. (The voltage drop will be measured in the same manner as the samples under test. These "Deduct" samples will be identical in length, wire type and terminal type to the other samples under test except the terminal crimp will be soldered. Use the average voltage drop measured on these 3 "Deduct" samples as the deduct value for this test.

NOTE: A sample length of 150 mm is recommended however any sample length >150 mm is acceptable as long as there is no effect on the crimp during processing and handling of samples. Longer wire length may be necessary if the samples are powered in series for this test. Use the same length for the deduct samples as for the TUT.

3. Prepare the voltage drop measurement points on the test samples at a point on the cable 75 ± 3 mm from the rear edge of the terminal conductor crimp.

4. Apply solder to measuring point C of Figure 4.5.6.2 using center strip or stripped end of wire (to obtain consistent readings). The V+ test lead may be connected to the insulation wing if the wing does not touch the wire conductor core.

NOTE: The same set of samples shall be consecutively exposed to the T/S and T/H exposure and be measured using the voltage drop procedures described in this specification.

For multiple wire crimps, high current evaluation, perform the mVD measurement on the smallest wire. Test current level will be based on the wire selected for the mVD measurement.

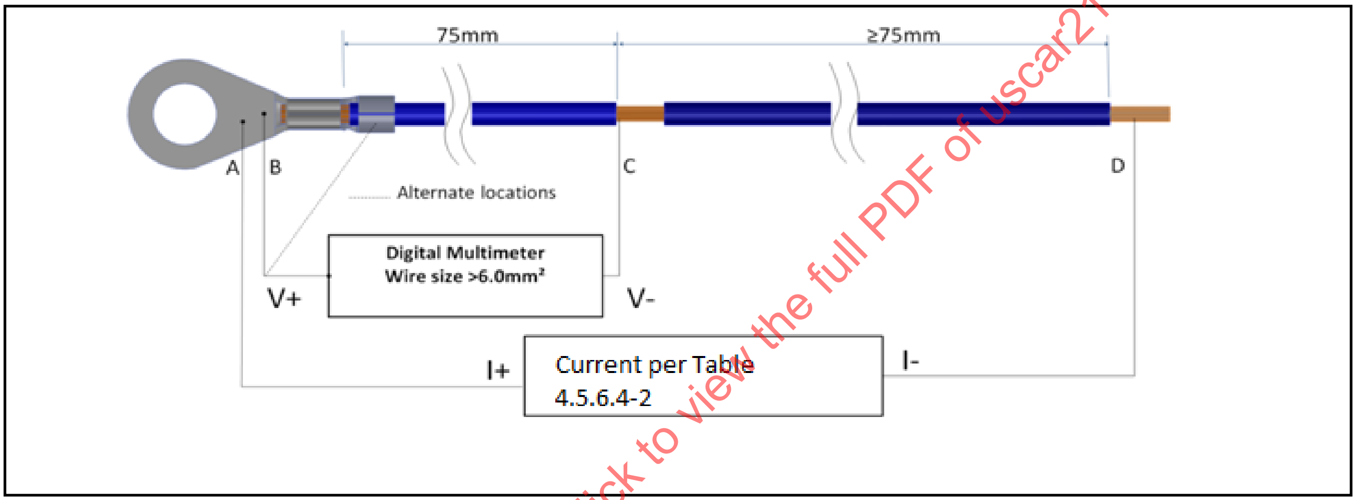


FIGURE 4.5.6.2 - POWER HOOK-UP AND MEASUREMENT POINTS FOR VOLTAGE DROP MEASUREMENT

4.5.6.3 Equipment

1. DC Power supply 0~20 V with current as required (0~20V, 100A min)

2. Digital Voltmeter

3. Test bench. Note: Relative movement of samples should be minimized to reduce effects on measured values. This is an open air bench test. In an effort to maintain repeatability, care should be taken to avoid drafts from HVAC, open windows, etc.

4.5.6.4 Procedure

1. Perform a visual inspection of components per paragraph 4.2.

2. Apply current based on wire size per table 4.5.6.4-2 at points A and D of Figure 4.5.6.2.

TABLE 4.5.6.4-2 – VOLTAGE DROP TEST CURRENT

Wire Size (mm^2)	Current (A)
>6 and <12	50
≥12 and <20	75
≥20 and <30	100
≥30 and <40	100
≥40 and <50	100
≥50 and <60	100
≥60 and ≤120	100

3. Allow the temperature of samples to stabilize with current applied.

4. Measure and record the voltage drop of the 3 Deduct samples with soldered crimps. The measurement is made at a point 75±3 mm from the rear edge of the terminal conductor crimp. The average voltage drop value of these 3 samples will be used in step 6. (If the samples are connected in series, include the soldered samples with the samples under test.)
5. Measure and record the voltage drop on each sample between the cable measuring point B and point C on the terminal, just in front of the conductor crimp. (See Figure 4.5.6.2).

6. Calculate and record the crimp-to-wire voltage drop: The crimp voltage drop is equal to the overall sample voltage drop measured in step 5, minus the average voltage drop of the 3 "Deduct" crimp samples measured in step 4.

NOTE: Samples may be connected in series and powered up all together as long as the "B" and "C" measurement points are accessible and do not interfere with measurement points on any other samples wired in this series. Split bolts or terminals crimped to both ends of the sample under test are acceptable methods for applying current in series to 2 or more terminals for the purpose of using voltage drop to validate the crimping process on >6 mm^2 cable. Applying the test current in series to all samples at once will reduce set-up, measurement and environmental errors or differences.

4.5.6.5 Acceptance Criteria

This is a measurement procedure only so there are no acceptance criteria.

4.6 Applied Cable Seal Retention

4.6.1 Purpose

This procedure provides the method to measure the ability of an insulation crimp to hold an applied cable seal in the correct position during insertion into a terminal cavity. This section applies to terminals with a cable seal applied at the crimping operation. When the insulation crimp wings retain the seal correctly, it assures full insertion of the sealing ribs into the applicable terminal cavity.

NOTE: This is a new requirement in SAE/USCAR-21 REVISION 3. Validations done to previous versions must pass this test to be compliant to this level.

NOTE: Any details governing cable seal retention and the proper positioning of the seal that are found in the terminal and/or connector suppliers' product specification or handling manual can be used to supersede these requirements but the variance to this section must be documented on the test report and in the statement of compliance to USCAR-21.

4.6.2 Equipment

1. Force tester.

2. Measuring device capable of measuring insulation crimp height.

3. Test fixture designed to fit between the insulation crimp of the terminal and the first rib of the cable seal. The test fixture must be designed in a way that provides adequate surface area to constrain the sealing ribs, while preventing excessive pressure against the neck area of the seal. An example of a test fixture / set-up is shown in Figure 4.6.2.

Note that the fixture must be sized specifically to the seal being tested. The fixture must be large enough to keep the ribs from passing through but loose enough to not tear the neck area.

FIGURE 4.6.2 – FIXTURE EXAMPLE FOR APPLIED CABLE SEAL RETENTION TEST

4.6.3 Samples

A minimum of 10 samples are required to be tested. Crimp the samples to the maximum intended ICH for the subject terminal / seal / wire combination. Care should be taken to assure the cable seal is positioned properly per Section 4.2.5.

4.6.4 Procedure

1. Measure and record the insulation crimp height for each sample.

2. Insert a test sample into a holding fixture as shown in Figure 4.6.2. The fixture must hold the applied cable seal in place while the terminal is pulled off the cable seal neck area. Excessive pressure against the neck area of the seal must be avoided as this can cause inaccurate results.

3. Record fixturing method. Include a photo of test set-up in the test report if new fixture is used for this test.

4. Measure and record the force (N) to pull the terminal off the neck area of the cable seal for each sample. The force must be applied in the axial direction at a rate of 50 ± 5mm /minute.

5. Report any observations from visual examination.

4.6.5 Acceptance Criteria

The force required to pull the terminal off the seal neck must meet the force shown in Table 4.6.5. Note: Samples that fail per Table 4.6.5 but are shown to have a higher retention force than the corresponding insertion force of the seal into its mating connector cavity meets the intent of this section and it is expected that the requesting OEM customer will accept the lesser value. USCAR-21 conformance requires the table value to be met, however.

TABLE 4.6.5 - APPLIED CABLE SEAL RETENTION

Wire Size (mm^2)	Seal Retention (Minimum.)
0.13 to 0.50	8N
0.75 to 3.0	10N
≥ 4.0	12N

5. VALIDATION REQUIREMENTS FOR CRIMPED TERMINALS

5.1 Validation Test Requirements

5.1.1 The validation requirements listed in Table 5.1 shall be conducted and meet the Acceptance Criteria to demonstrate compliance to USCAR-21.

TABLE 5.1 - TESTS REQUIRED FOR VALIDATION

Test	Requirement Section	Lab Validation (Yes/No)	Minimum Conformance to Tolerance
Compaction (Verified in production by terminal, cable, and crimp tool - Crimp dimensions traceable to validation testing)	Appendix E, 1-2	Y	100%
Appearance - end of conductor - end of insulation - cut off - bellmouth - conductor crimp - insulation crimp - individual cable seal - terminal bend and twist due to crimping	 4.2.5-2 4.2.5-3 4.2.5-4 4.2.5-5 4.2.5-6 4.2.5-8 4.2.5-10 Appendix E #5	 Y Y Y Y Y Y Y N	 100% 100% 100% 100% 100% 100% 100% 100%
Crimp geometry - Conductor and insulation crimp height and width (CCH, CCW, ICH, ICW) constructed per provided method - cross-section requirements	Appendix E #6-8 4.3	Y Y	100% 100%
Mechanical performance - Pull out force - Applied Cable Seal Retention (if applicable)	4.4 4.6	Y Y	$(\bar{X})$ -3s > Limit 100%
Electrical performance Accelerated Environmental (ENV) (Low Impedance applications requiring tinned wire must be tested using bare copper wire (to optimize crimp parameters)	4.5.2	Y	100%
Current Cycling (ECC) – ECC is an alternate electrical test allowed for validation of Power applications only where wire is ≤ 6mm^2. This approval method requires end-customer (OEM) approval. ECC is also used as an optional test in addition to ENV testing per customer request.	4.5.1	Y	100% (When used as alternate test)

NOTE: Per standard automotive PPAP procedures, cable, terminal and crimp tooling combination used for manufacturing validation to this spec may not be varied without revalidation.

5.2 Customer Approval

Customers are advised to have an assessment and approval process for crimps that do not meet all sections of USCAR-21 but are believed to be acceptable based on engineering studies or field experience. These approvals are between a specific customer and supplier so an approval by one customer does not mean USCAR-21 was met. Any variances from the requirements of this specification must have documentation showing which sections of USCAR-21 were not met. The most common circumstance for this condition is when the electrical and pull values are met but the cross-section is marginally deficient per Section 4.3.5.

5.3 Reference Validations

5.3.1 Purpose:

The Reference [REF] method can be used to claim USCAR-21 compliance on an identical part/condition to what has already been validated. Two circumstances typically apply:

1. A crimper wants to follow the USCAR-21-validated specifications of the terminal maker rather than validating the crimp independently.

2. A crimper identifies a case where the proposed terminal, cable, tooling, and process specifications are the same and can demonstrate the existing testing is representative.

5.3.2 Allowable use of a "same as" validation

If a REF validation is requested based on the application being the "same as" another application already validated to USCAR-21, then the attributes of Section 5.3.2 must ALL be confirmed to be the same.

"Same as" is defined as having the following attributes identical:

- Terminal stock thickness.
- Material (alloy and temper).
- Terminal plating.
- Terminal conductor wing dimensions and features [serrations, etc.].
- Insulation outside diameter.
- Conductor stranding, material, compression and cross-sectional area. Exception: cables with more than 80 strands can deviate ±3% in the strand count and be considered the same. Note: "Same as" does not allow 7 and 19 strand construction for a given wire size to be called the same; they are different wires and users have found different test results. SAE, ISO, and JIS wire types with the same size designation have different conductor core cross-sectional area and must also be validated as separate wire sizes.

5.3.3 Reference Validation for similar cable core but not insulation

Cables with the same conductor core construction, but differences in the insulation may be considered the "same" for the conductor crimp validation. However, the insulation crimp must be validated per the applicable cross-section requirements for validation (cross section per 4.3.5-3 and the applied seal retention per 4.6).

5.3.4 (Deleted)

NOTE: In previous versions, 5.3.4 allowed for approvals using a "Previous Electrical Validation (PEV)" method in specific cases for high power terminals. This was a very specific exclusion and it was useful only in the early years of this spec. It is no longer allowed. As of this revision, no previous validations can be used. Any supplier requesting a variance should contact and get approval from their OEM customer.

APPENDIX A - TERMINAL CRIMP WING DESIGN RECOMMENDATIONS

A. Cable Loading: There is no preferred way to group wires so they can share a common terminal design. Any grouping strategy (cable loading schedule) is acceptable. USCAR-12 has crimp design requirements that terminals must follow that will help determine a preferred cable loading for a specific terminal.

B. Terminal Crimp Wing Engineering Guidelines

The following guidelines are intended only to assist in passing the requirements of this specification. They are based on previous experience from terminal suppliers:

1. The terminal supplier determines double application terminals.

2. Core wings that have features to break oxides and minimize cable strand movement will give better electrical results. Sharp-cornered serrations are preferred.

3. Tin or silver plating is the optimum design for a typical vehicle life (15 year/150K). EWCAP-001 specifies platings that are recommended by USCAR (http://uscar.org/guest/teams/10/Electrical-Wiring-Component-Applications-Partnership and click on terminal blades). Use caution when specifying nickel, stainless steel or gold in core wings since use of these materials have been shown to result in high crimp resistance. Nickel plated high temperature wire also may not pass this electrical testing and may require specific changes in acceptance criteria based upon circuit application sensitivity (i.e. O_2 sensor circuits).

4. Optimum 15 year/150K mile life is obtained with similar alloys, tempers used for spring members and contact arms. This maintains crimp wing normal force with time and temperature. It also provides strength to resist crimp wing relaxation due to movement and stresses applied during vehicle life.

5. Wing blank width should be designed to provide for uniform strand dispersion for the gauge size recommended. This is necessary for optimum electrical strand contact, pulls, and nuisance free use of crimp force process monitors.

6. Crimp electrical performance should be done separately from connector testing. This is done so that a low and stable milli-Ohm acceptance criteria can detect the loss of strand contacts in the crimp. Crimps that meet this criteria must then be able to pass USCAR tests in connectors.

7. Pull testing must only be used to determine mechanical strength and not used as a proxy for good electrical performance. Usually the best electrical performance is on the tight side of the pull vs. crimp height curve (ref. Figure A-1). Both over and under compaction can result in poor electrical and or mechanical performance.

8. The preferred insulation crimp geometry is the traditional “F” or “B” crimp. Overlapping, diagonal cut bypassing wings, or butting wings may be used, but may be sensitive to crimp processing conditions. It is usually best to design specific crimp wings for heavy-wall, regular-wall, thin-wall and/or extra thin-wall insulations.

9. Where possible, crimp wings should be designed for European, US, and/or Asian cable constructions.
Note: Not all cable with the same size callout has the same cross-sectional area. SAE, ISO, JIS, DIN, etc. wire types may have the same size designation but each will have its own core cross-sectional area. A crimp developed and validated to a terminal/wire combination with one wire specification cannot be used to approve the same terminal with a different wire specification. Example: validated crimp dimensions for a XXX terminal crimped on a 0.5 mm^2 SAE wire cannot be used to validate a crimp on the same XXX terminal with a 0.5 mm^2 JIS or 0.5 ISO wire. Moving from a wire constructed to one wire specification to a wire constructed to a different specification will require crimp re-validation even when they both have the same size designation. Example: SAE 0.5 mm^2 (0.508 mm^2 min) wire does not have the same cross-sectional area as ISO 0.5 mm^2 wire (0.4647 mm^2 min calculated from maximum resistance requirement).

10. A typical mechanical/electrical performance vs. crimp height curve is shown in Figure A-1.

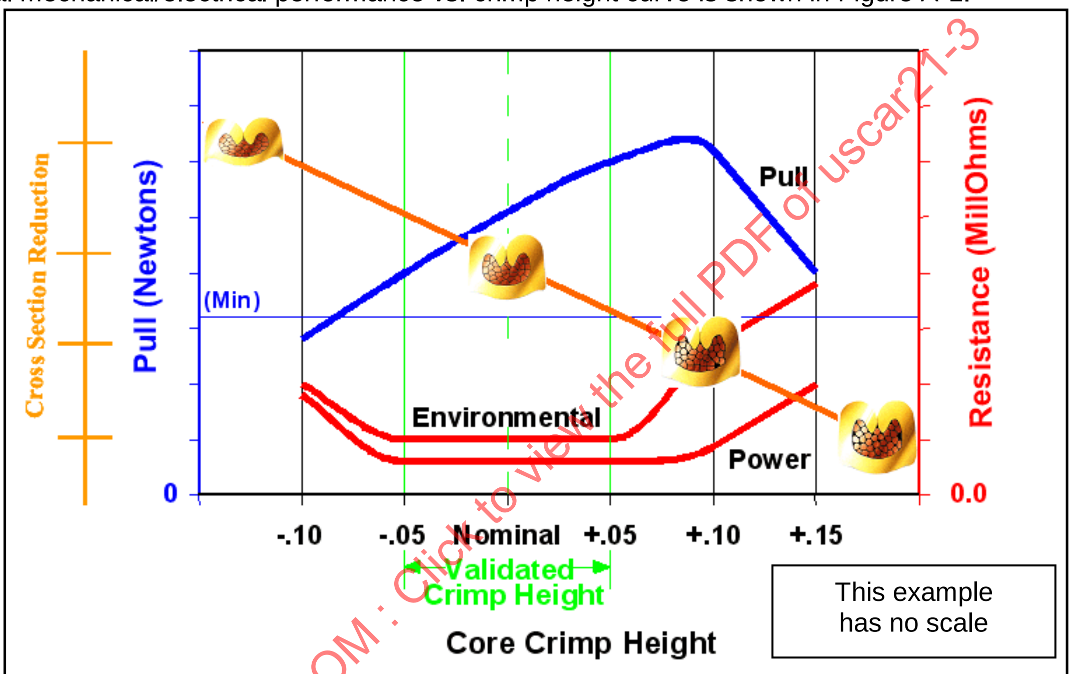


FIGURE A-1 - TYPICAL MECHANICAL/ELECTRICAL PERFORMANCE VS. CRIMP HEIGHT

APPENDIX B - DEFINITIONS

Authorized Person:
Person responsible as the final authority for releasing a given part for production and/or for testing that part.

Cable:
An assembly made up of several strands of wire (the conductor) and its insulating covering manufactured to a specific cable specification.

Compaction:
The reduction in cross-sectional area of the combination of the terminal and cable conductor caused by crimping the terminal onto the conductor.

Conductor (Core):
A part of a cable which has the specific function of carrying electrical current.

Conductor (Core) Crimp Features:
Shapes in the conductor crimp wings, such as serrations or knurls, meant to improve the electrical connection between the terminal and the conductor.

Core Cross-sectional area:
Strand count X the cross-sectional area of each strand.

Crimp:
(noun) The connection between a terminal and a cable made by deforming the wings, wrapping them around the cable in a manner that creates a permanent electrical and/or mechanical contact.
(verb) The process of joining a wire to a terminal by bending the terminal crimp wings around the wire core and/or wire insulation using applicator tooling.

Crimping:
The joining of a wire to a terminal by bending the terminal crimp wings around the wire core and/or wire insulation using applicator tooling.

Crimping Force:
The force applied by the press through the crimping tools for the re-shaping of the terminal wings around the stripped conductor during the crimping process.

Crimp Only:
An application in which the only method used to connect a terminal to a cable is the terminal crimp. No other solder, welding or termination technologies are used.

Deduct:
An additional terminal-and-wire sample that has the crimp soldered. The resistance of the Deduct sample is subtracted from test parts to remove the bulk resistance of the terminal and wire from the measured resistance.

Design Validation:
Tests that are conducted to demonstrate that the design intent is met. Manufacturing must be aware of the crimp design parameters and maintain them in production.

Grip:
Used in previous versions to mean crimp as a noun. Term is not used in this version.

Insulation:
That part of a cable that electrically separates the conductor from the external environment. The purpose of the insulation wings is to provide proper strain relief to limit/eliminate wire movement to the conductor crimp.