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Space product assurance

Wire-wrapping of high-reliability electrical connections

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, National Space Agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work.

This Standard has been prepared by editing ESA PSS-01-730, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board.

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Introduction

This Standard defines the requirements and quality assurance provisions for the manufacture of high-reliability wire-wrapped connections made with round single-strand silver-plated wire onto appropriately designed gold-plated terminals. Equipment design requirements, such as terminal spacing and terminal mounting are not included in this Standard.

This Standard deals with the mechanical and electrical stability of wire-wrapped connections operating under high vacuum, thermal cycling and vibration conditions imposed by space flight.

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Scope

This Standard specifies the methods for preparing and assembling the parts to be joined by wire wrapping, and the selection, calibration, use and certification of the wire wrapping tools.

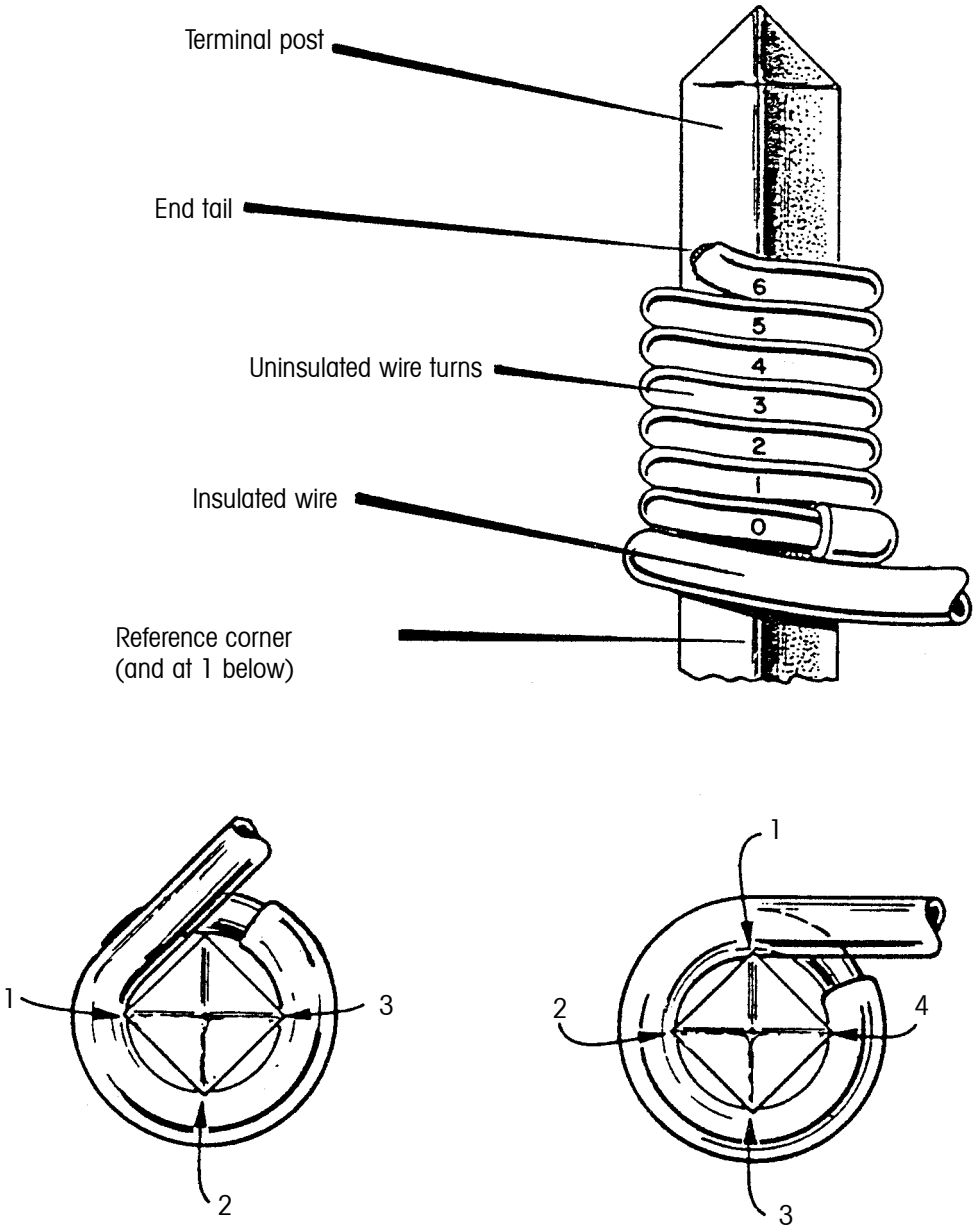
The required wire-wrapped connections are illustrated in Figure 1.

This type of connection is similar to “Class A preferred” or “modified” connection detailed in MIL-STD-1130, and NASA NHB 5300.4(3H).

Only tested and qualified wire-wrapped connections are covered by this Standard, which lists four wire sizes from 24 AWG to 30 AWG, and three terminal post sizes up to 1,78 mm maximum diagonal.

The use of heavier gauge wire and larger terminals is not absolutely prohibited, but it is considered unlikely that wire-wrapping would be chosen here, as the electrical interconnection technique. It is anticipated that wire larger than 24 AWG will be multistranded and terminated by soldering to ECSS-Q-70-08, or crimping to ECSS-Q-70-26.

Training and certification requirements for operators and inspectors are defined in subclause 9.7 and in ECSS-Q-20.



Shows either 3 or 4 corners of contact of insulation minimum ¾ turn of insulated wire

Figure 1: Single wire-wrapped connection to square terminal and reference corner

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

ECSS-P-001	Glossary of terms
ECSS-Q-20	Space product assurance - Quality assurance
ECSS-Q-20-09	Space product assurance - Nonconformance control system
ECSS-Q-70	Space product assurance - Materials, mechanical parts and processes
ECSS-Q-70-02	Space product assurance - Thermal vacuum outgassing test for the screening of space materials (to be published)
ECSS-Q-70-08	Space product assurance - Manual soldering of high-reliability electrical connections
ECSS-Q-70-26	Space product assurance - Crimping of high reliability electrical connections
ESA/SCC No. 3903	Solid wires, electrical 350V, for wire wrapping
MIL-STD-1130	Connections, electrical, solderless wrapped
NASA NHB 5300.4(3H)	Requirements for crimping and wire wrap

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Terms, definitions and abbreviated terms

3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional with respect to those contained in ECSS-P-001.

3.1.1 Wire-wrapped connection

This connection consists of a helix of continuous, solid, uninsulated wire tightly wrapped around the terminal post to produce a mechanically and electrically stable connection. The number of turns required will depend on the gauge of wire used. All completed wraps have an additional minimum of 3/4 turn of the insulated wire that is in contact with at least three corners of the terminal post (see Figure 1).

3.1.2 Terminal post

Post of square or rectangular section onto which the interconnection wire is wrapped.

3.1.3 A turn of wire

This consists of one complete single helical ring of wire wrapped 360 degrees around the terminal post, touching all four corners of the post. For the purpose of counting turns, the number of times the wrapped wire passes and intercepts the reference edge of the terminal post after the first intercept of uninsulated wire and terminal post, constitutes the number of turns of uninsulated wire in the connection.

3.1.4 Reference corner

The corner of the terminal post at which the first turn of uninsulated wire contacts, and from which the number of turns of the wrapped wire are counted.

3.1.5 End tail

An end tail is the end of the last turn of wire on the terminal post which may extend in a tangential direction instead of resting against the post.

3.1.6 Gas-tight area

The gas-tight area is that contact area between the terminal post and wire which excludes gas fumes.

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard:

AWG	American Wire Gauge
ETFE	ethylene-tetrafluorethylene
PTFE	polytetrafluorethylene
PVDF	polyvinylidene fluoride
PFA	perfluoroalkoxy
RH	relative humidity

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Preparatory conditions

4.1 Hazards, health and safety precautions

Particular attention shall be paid to health and safety precautions. A safety checklist is produced below.

a. Hazards to personnel, equipment and materials shall be controlled and reduced to a minimum.

b. Components, tools and controls shall be so located that personnel are not exposed to hazards such as electric shock, cutting edges, sharp points or toxic atmospheres.

c. Pneumatic air-powered wire-wrapping tools shall be connected to a regulated, lubricated and filtered air supply, and disconnected when not in use.

4.2 Facility cleanliness

a. Unless classified as a clean room, the areas in which wire-wrapping is carried out shall be maintained in a neat orderly fashion, with no loose material (such as dirt, dust, oils or clipped wires) that can cause contamination of the wire-wrapped connection. Furniture shall be kept to a minimum in the work areas and be arranged to allow easy and thorough cleaning of the floor.

b. Working surfaces shall be covered with an easily cleaned hard top, or have a replaceable surface of clean, noncorrosive silicone-free paper.

c. Tools used in the wire-wrapping operation shall be clean. Excess lubricants shall be removed before wire-wrapping starts.

d. Before assembly, wire and terminal posts shall be visually examined for cleanliness, absence of oil films and freedom from tarnish or corrosion.

4.3 Environmental conditions

The wire-wrapping area shall have a controlled environment which limits entry of contamination. The area shall be continuously controlled as follows:

- room temperature: (22 ± 3) °C;
- relative humidity: (55 ± 10) %.

The work stations shall not be exposed to draught. Fresh air shall be supplied to the room through a filtering system so that there is a positive pressure difference with regard to adjacent rooms; the exhaust air shall be suitably restricted.

4.4 Lighting requirements

The light intensity shall be a minimum of 1080 lux on the work surface. At least 90 % of the work area shall be shadowless and without severe reflections.

4.5 Configuration of process/workpiece

In order to ensure compatibility with the customer requirements and as a means of identifying potential problems, the supplier shall perform a review of the tools, materials and techniques which he plans to use for the work. The review shall cover each separate manufacturing step and consider the dimensions and metallurgical properties of the terminal post and wire such that they are guaranteed to be suitable for the manufacture of wire-wrapped connections. Special attention shall be paid to the appropriate choice of functional tools, particularly the type of power-driven wire-wrapping tool and associated rotary wrapping bit and stationary sleeve. The quality of a wrapped connection depends largely on the maintenance and adjusting of the cutting, stripping and wrapping tools.

Work shall be managed and organized such that tool bits and sleeves cannot be interchanged.

During handling and transportation, wrapped joints and their wires shall not suffer from any constraints likely to cause deterioration.

4.6 Cleaning

The cleaning of materials where necessary, prior to wire-wrapping, shall be performed using one of the following solvents:

- Ethyl alcohol, 95,5 % or 95 % pure by volume.
- Isopropyl alcohol, best commercial grade, 99 % pure.
- Any mixture of the above.

Procedures for cleaning shall be generated before solvent cleaning is begun. Further cleaning or other treatments of the joint after wire-wrapping are not permitted.

Materials and workpieces shall be handled only with clean lint-free gloves or finger cots.

4.7 Tools and equipment

Before the first production of wire-wrapped connections, the tools shall satisfy the control requirements of this subclause.

4.7.1 Cutting tool

The cutting tool selected for use shall cut the conductor wire without causing flattening of the wire. Any tool not achieving this requirement shall be removed from the work area.

4.7.2 Insulation strippers

a. **Thermal strippers**

Thermal-type insulation strippers may be used on types of wire insulation for which they are suited. Heat of the stripper shall be controlled to prevent blistering and excessive melting of insulation. Local extraction units shall be used if thermal stripping is employed, in order to avoid part contamination or health hazards due to resultant fumes.

b. **Precision cutting-type strippers**

Automatic power-driven strippers with precision, factory-set, non-adjustable cutting and stripping dies and wire guards may be used. Precision-type hand strippers with accurately machined and factory-preset cutting heads may be

used with a caution about making certain that the die openings for wire sizes other than that being used are masked off. The conductor shall not be twisted, ringed, nicked, cut or scored by this operation.

4.7.3 Wire-wrapping tools

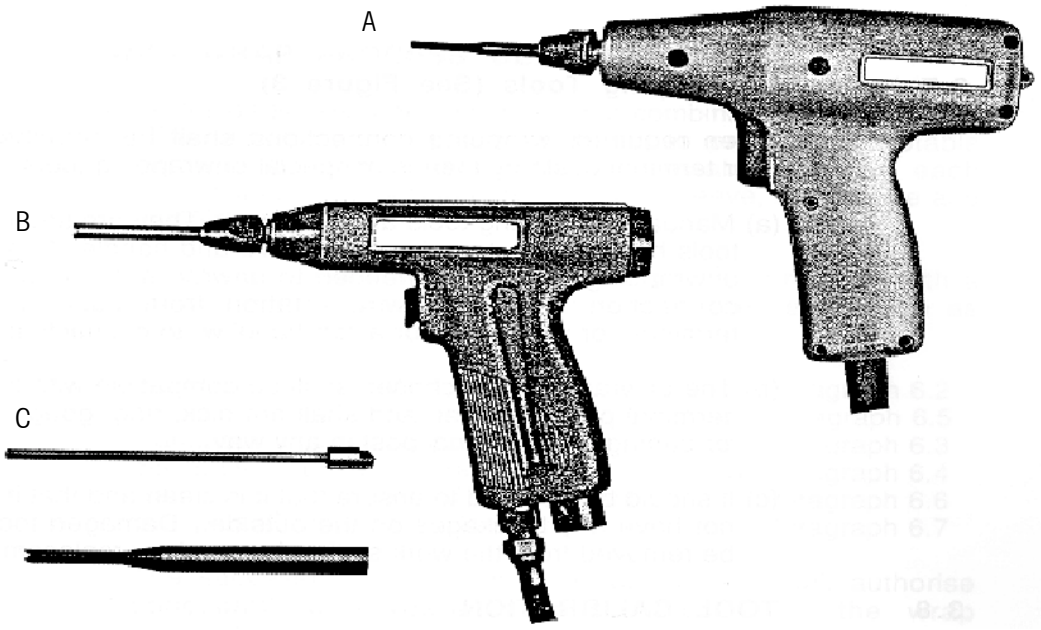
a. The wire-wrapping tools (see Figure 2 below) shall be power driven. The tool shall be either an electrical tool (mains supply), or a pneumatic tool (supplied with regulated, lubricated and filtered air). It should be fitted with a "back-force" device to prevent overwrapping defect. Hand-powered or battery-powered wrapping tools shall not be used.

b. A wrapping tool together with appropriate rotary bit and stationary sleeve will be assigned to each wire gauge and terminal combination in use, and suitably marked to show the size for which it is calibrated.

c. Refer to the tool manufacturer for appropriate selection of bit and sleeve for each wire/terminal post diagonal combination.

d. The tool and associated accessories shall be checked for cleanliness and general satisfactory condition at up to ×10 magnification. The extremity of the bit shall be perfectly clean and smooth without blockages or faults. The sleeve should not have any sharp blockage in its neck, and shall be checked manually to ensure that the bit runs perfectly in the sleeve, without any hard or rough points of contact. Any tool not meeting the above requirements shall be removed from the work station for repair or replacement.

e. The wire-wrapping tool shall not nick, ring, gouge, or scrape conductors, or damage the terminal post in any way during its operation.



Key: A - Electrical mains supply
B - Pneumatic
C - Typical design of bit and sleeve

Figure 2: Examples of approved wire-wrapping tools

4.7.4 Unwrapping tools

When required, wrapping connections shall be detached from their terminal posts by means of special unwrapping tools (see Figure 3).

a. Manual unwrapping tools are preferred. They are short tubular tools having an external spiral groove and handle. A “left-hand” unwrapping tool is required to unwrap a “right-hand” wrap connection (clockwise wire rotation from base to top of terminal), or vice versa for a “left-hand” wrap connection.

b. The unwrapping tool chosen shall be compatible with the terminal post diagonal, and shall not nick, ring, gouge, scrape or damage the terminal post in any way.

c. It shall be checked that it is clean and that it does not have any blockages on the outside. Damaged tools shall be removed from the work station for repair or replacement.

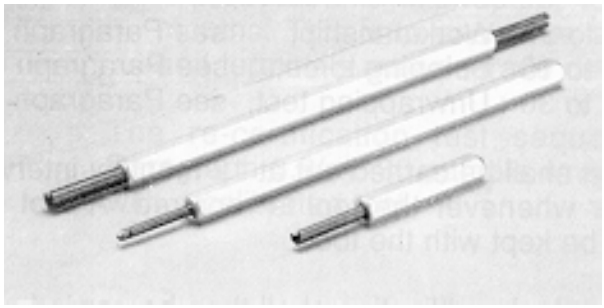


Figure 3: Hand unwrapping tools

4.8 Tool calibration

a. Initial tool calibration shall be carried out to confirm that a new or repaired tool (with appropriate bit and sleeve) is working correctly, and shall only then authorize the use of the tool.

b. First confirm that the tool meets the requirements of subclause 4.7.3. The operator shall make 30 sample wrap connections between the selected wire and terminal post referred to in subclause 5.3, appropriate to the tool.

The calibration test sequence shall be as follows:

Sample 1 to 30	Workmanship	(see subclause 7.2)
Sample 1 to 15	Stripping force	(see subclause 7.3)
Sample 16 to 30	Unwrapping test	(see subclause 7.4)

c. Recalibration shall be carried out at 12 monthly intervals thereafter or whenever the tool is repaired. A tool-calibration record shall be kept with the tool.

d. Tool/wire/terminal certification shall then be carried out using the calibrated tool (see subclause 4.9).

4.9 Wire-wrap process certification

a. **Initial certification of each wire-wrap combination**

The capability of the wire-wrap tool to produce acceptable wire-wrap connections shall be established for each combination of tool with correct bit and sleeve, wire gauge and terminal post.

30 sample wrap connections shall be prepared with a calibrated tool. The certification test sequence shall be as follows:

Samples 1 to 30	Workmanship	(see subclause 7.2)
Samples 1 to 30	Connection resistance	(see subclause 7.5)
Samples 1 to 10	Stripping force	(see subclause 7.3)

Samples 11 to 20	Unwrapping test	(see subclause 7.4)
Samples 21 to 26	Gas-tightness test	(see subclause 7.6)
Samples 27 to 30	Metallography	(see subclause 7.7)

The successful completion of all above tests will authorize spacecraft wire wrapping to commence for the wrap combination.

b. **Re-certification of each wire-wrap combination** shall be carried out after the following occurrences:

1. When production wraps fail to meet the requirements of the daily process-control tests specified in subclause 9.8.2.
2. At every 10000 wire-wrap connections in a continuous programme.
3. If production is interrupted for a period in excess of 12 months. This shall ensure reliability of the joint, as the wire and terminals may degrade during storage.

The re-certification test sequence shall be a repeat of subclause 4.9.a., 30 sample wrap connections being prepared with a calibrated tool.

4.10 Test monitoring equipment

a. For performance tests the following test equipment is required:

Connection resistance:	0 A - 10 A ammeter with current source 0 mV - 20 mV voltmeter
Stripping force:	Tensile testing machine 0 N - 100 N, accurate to ± 0,2 N
Visual inspection:	Binocular microscope, magnification ×7 minimum, with suitable light source
Microsectioning:	Metallurgical microscope, magnification up to ×400.

b. Suitable measuring equipment to fulfil the monitoring requirements of the process area, which are:

Temperature:	15 °C to 30 °C, accurate to ± 1 °C
Humidity:	RH 40 % to 70 %, accurate to ± 1 % RH

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Materials selection

5.1 Wire

5.1.1 General

Wire used for wrapped connections shall conform to ESA/SCC No. 3903 or other approved national wire specification intended for wire-wrapping. The insulation type and wire finish shall be approved by the customer.

5.1.2 Conductor

a. The wire shall be a single solid round conductor. Stranded conductors shall not be used. Excessive bending, stretching, or other cold working of the wire shall be avoided.

b. The conductor diameter shall be within the range 0,25 mm to 0,51 mm nominal (30 AWG to 24 AWG), and shall be either:

   1. soft-annealed, high-conductivity copper having an elongation at fracture of not less than 15 %, for wire gauges 24 AWG and 26 AWG, or
   2. high-strength, high-conductivity copper alloy with less than 2 % strengthening elements, having an elongation at fracture of not less than 7 %, for wire gauges 28 AWG and 30 AWG.

   These materials are suitable for use within the temperature range -55 °C to +100 °C, but annealed copper shall not be continually operated for long periods above 90 °C, owing to the likelihood that excessive wire stress relaxation affects the reliability of the wrap connection.

c. The conductor shall be finished with silver plating, which shall be smooth and uniform. The preferred average thickness of silver plating is 0,002 mm. At the time of making the connection, the silver finish shall be free of tarnish.

5.1.3 Wire insulation

a. The insulation shall consist of flexible polymer materials suitable for use in a space environment with low outgassing properties, conforming to ECSS-Q-70-02. Recommended insulation materials include ETFE (Tefzel), PFA (Perfluoroalkoxy), PVDF (Kynar), and Kapton polyimide over extruded PTFE.

b. The insulation shall not be bonded to the conductor, and shall be capable of being readily stripped from the conductor without change to the physical characteristics of the wire.

c. The insulation shall be removed just prior to wrapping, or, if pre-cut and stripped, protected prior to use, i.e. under dry nitrogen. There shall be no exposure of the conductor base material after insulation stripping.

d. The conductor and its insulation shall be concentric such that the minimum insulation wall thickness is not less than 70 % of the maximum wall thickness.

e. The insulation shall have sufficient wall thickness, which is generally in excess of 35 % of the conductor diameter. Insulation wall thickness varies between wire manufacturers. Hence, the compatibility between the outer diameter of the insulated wire and the tool bit shall be established.

f. Care shall be taken to ensure that the wire strip length is accurately controlled to give the correct number of turns of bare wire onto the terminal post (these are specified in Table 2).

5.2 Terminal post

a. Materials: suitable grades of copper or nickel alloys, such as copper-zinc, phosphor bronze, copper-nickel-zinc, beryllium-copper, nickel-copper (Monel) and nickel-clad copper (Kulgrid) shall be chosen. The alloy hardness shall be within the range 150 Vickers to 220 Vickers hardness.

b. Terminal posts shall be finished with 0,001 mm to 0,003 mm thickness of gold plating over 0,001 mm minimum average thickness of copper or nickel underplating. Silver underplating shall not be used. The surface finish shall be smooth and uniform.

c. The length of terminal post projecting from the mounting fixture shall be sufficient to accommodate the required number of wrapped connections, which shall not exceed three per terminal. The minimum wrapping length for each wire gauge for one, two and three wrapped connections on each terminal is shown in Figure 4.

d. Terminal posts shall have a solid cross-section. Geometry and dimensions for each approved terminal size are shown in Figure 5. Terminal posts with a square cross-section are preferred. The rectangular (0,76 mm $\times$ 1,52 mm) post is included to achieve better terminal packing density if required for 24 AWG and 26 AWG wire, where the more robust terminal is necessary.

   Referring to Figure 5, note that the tolerance on diagonal C is more important than on A and B dimensions, as posts are accommodated by round holes in the tool bit.

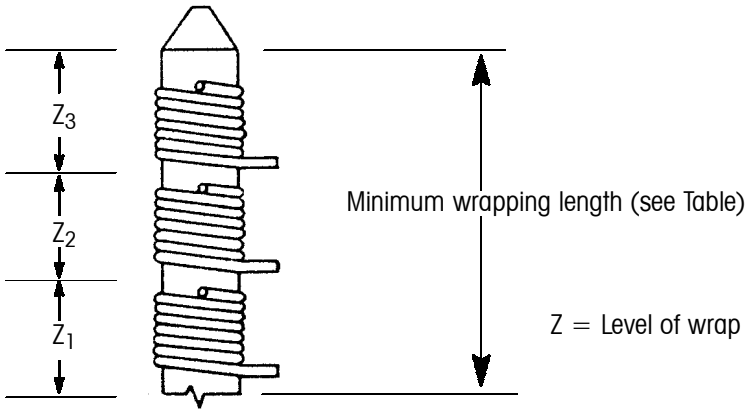
e. The terminal posts shall be straight and free from bends and bows which might restrict the free entry of the post into the hole of the tool bit. Bent terminals shall be rejected.

f. Tip configuration: the tip of the terminal post shall terminate in a radius or bevel to facilitate insertion into the wrapping tool. If the tip of the post terminates in a bevel, then the apex of the bevel shall be flat. No side of the flat shall exceed 0,38 mm on the 0,64 mm square post geometry, or 0,50 mm on the 1,14 mm square post and 0,76 mm $\times$ 1,52 mm rectangular posts.

g. Terminal posts shall be sufficiently durable to withstand being unwrapped and re-wrapped, as detailed in subclause 6.3.5, and still meet the test requirements of this Standard detailed in clause 7.

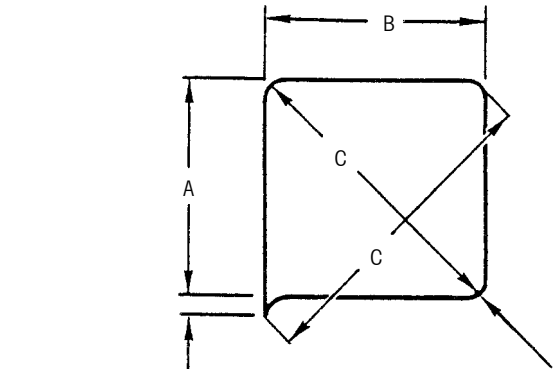
h. Terminal posts shall be securely mounted and shall not rotate during the wrapping operation.

i. Take great care when handling boards or connectors with terminal posts for wrapping, to avoid damaging the sharp corners (see subclause 6.2.b.).



Number of wrapped connections	Minimum wrapping length (mm)			
	30 AWG	28 AWG	26 AWG	24 AWG
1	4,7	5,6	5,8	6,6
2	8,2	9,9	10,2	11,9
3	11,6	14,2	14,7	17,2

Figure 4: Minimum wrapping length on terminal post for each wire gauge



Dimension (mm)			Parallelism (mm/mm)
A	B	C	
0,64 nominal 0,56 minimum	0,64 nominal 0,56 minimum	0,90 nominal 0,83 minimum	0,005
1,14 nominal 1,07 minimum	1,14 nominal 1,07 minimum	1,68 nominal 1,50 minimum	0,005
0,76 nominal 0,69 minimum	1,52 nominal 1,45 minimum	1,78 nominal 1,60 minimum	0,005

Figure 5: Terminal post dimensions over minimum wrapping length for each terminal size

5.3 Wire to terminal post combinations

Table 1 gives the allowed combinations of wire size to terminal post size.

Table 1: Wire size to terminal post combinations

Terminal post size (nominal)	Wire size AWG			
	30	**28**	**26**	**24**
0,64 mm × 0,64 mm	yes	yes	yes	no
1,14 mm × 1,14 mm	no	no	yes	yes
0,76 mm × 1,52 mm	no	no	yes	yes

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Wire-wrap operation

6.1 Preparation for wire-wrapping

a. Insulation shall be removed by the approved tools referred to in subclause 4.7.2. Stripping shall not expose conductor base metal.

b. After insulation removal, the remaining conductor insulation shall not exhibit any damage such as nicks, cuts, crushing or charring. Conductors with damaged insulation shall not be used. Slight discoloration from thermal stripping is acceptable.

c. The stripped conductor shall not be nicked, cut, scraped or otherwise damaged. Burnishing of the wire is allowed, provided the conductor base metal is not exposed. Conductors which have been reduced in cross-sectional area shall not be used. Damaged wires shall not be used.

6.2 Process

Wire-wrapped connections shall be made with an approved tool type detailed in subclause 4.7.3.

The sequence of operations for making the connection shall be as follows (see Figure 6).

a. Verify that the tool is in calibration, and that tool/wire/terminal certification has been successfully carried out, as detailed in subclause 4.9.

b. Confirm that the terminal post alignment or orientation is to the engineering drawing requirement, and that the external condition of the post is satisfactory. A practical means of preventing damage to terminal corners prior to wrapping is to cover each terminal with PTFE sleeving, which is removed just before wrapping.

c. Position the insulated wire radially so that subsequent routing of the non-wrapped portion of the wire does not unwrap the connection.

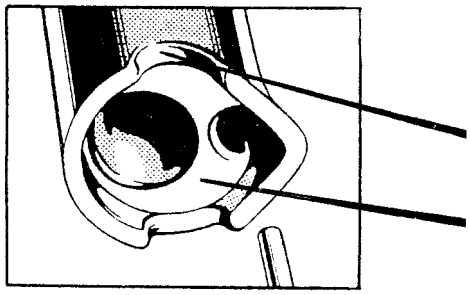
d. Insert the stripped wire end completely into the tool tip feed slot.

e. Bend the insulated wire into the notch in the tool, to anchor in position.

f. Carefully place the large hole in the tool tip over the terminal post, and adjust tool height to correct position for wrapping at levels Z_1, Z_2 or Z_3.

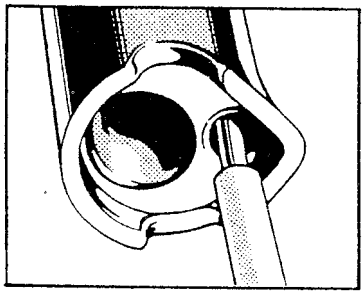
g. Operate wrap tool to rotate tool bit around terminal post to form the connection. Let the tool do the work, do not press too hard.

h. After wrapping is complete, remove tool. Inspect connection for workmanship prior to further wrapping onto the same terminal post.

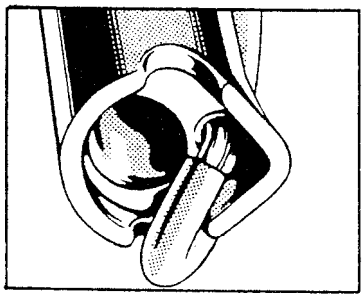


STEP 1: Tool tip
Wire anchoring notch

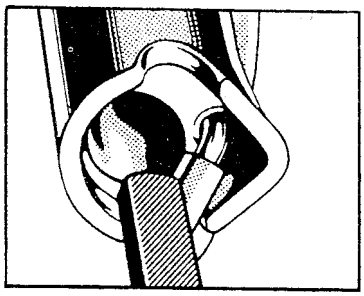
Rotating bit with wire and terminal post slots



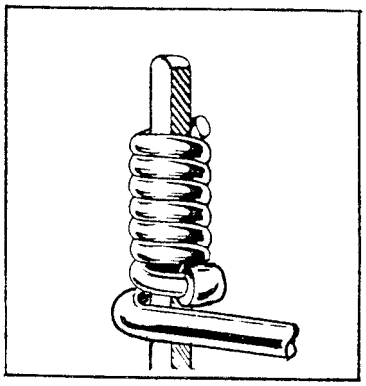
STEP 2: Wire insertion into wire feed slot



STEP 3: Wire anchored



STEP 4: Terminal post insertion



STEP 5: Finished wire wrap

Figure 6: Wire-wrap connection process

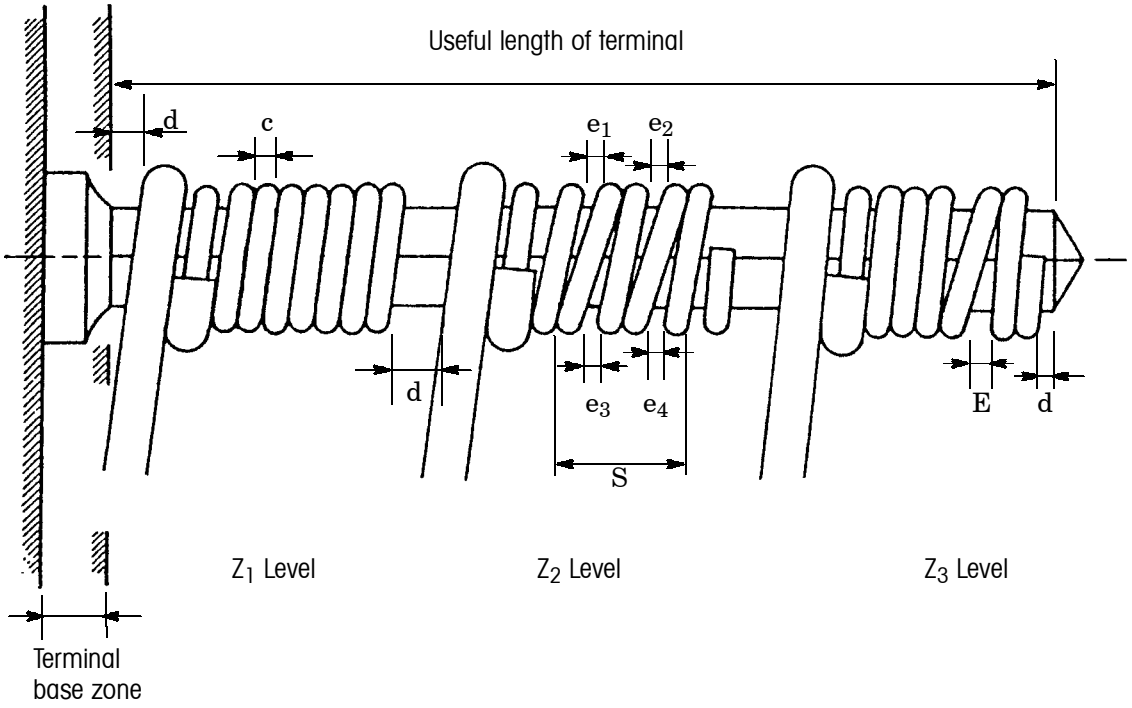
6.3 Wire-wrap criteria

6.3.1 Usage of wrap levels

a. Terminal post length is designed to receive a maximum of three levels of wrap joint. The distribution of the wraps on the same post shall depend on the level of wiring.

b. Levels Z_1 and Z_2 (see Figures 4 and 7) should be used for point-to-point interconnection. Level Z_3 should be reserved for e.g. modification, doubling of wire gauge between two points. The first connection onto the terminal shall be at level Z_1.

c. Wraps that extend above level Z_3 (onto the bevelled apex portion of the post) shall be removed and replaced. Lower wraps may extend into the Z_3 level if it is open and not reserved for future wiring. Wire-wrap level and wire routing shall be identified on the engineering drawing.



E = Maximum single spacing within one wrap; E ≤ c/2

S = Sum of the spaces within one wrap; S ≤ c

$S = e_1 + e_2 + e_3 + e_4$

c = Conductor diameter

d = Distance for positioning the wrap within the useful length of the terminal post; d ≥ 0 (or, no overlap allowed):

- between base of post and the conductor insulation,
- between two adjacent wrap connections,
- relative to the limits of the terminal, not including the tip region.

e = Space between adjacent turns - exclusive of gaps on the first and last half turns.

Figure 7: Position and regularity of wrap connection

6.3.2 Number of turns on terminal post

a. The number of turns of uninsulated conductor is counted from the reference corner. This will be the first corner of contact if the insulation stops before the central axis of the post; or the second corner if the insulation crosses the central axis of the post (see Figure 1).

b. Table 2 specifies the minimum number of turns of uninsulated conductor and insulated wire to be wrapped for each wire gauge. This ensures that the gas-tight area of the connection results in a larger cross-section than that of the wire used.

c. There shall be no overlap of turns to the last locked point (last terminal post corner), within the minimum number of turns specified. However, the end tail shall not extend away from the outside diameter of the conductor on the post by more than the diameter of the conductor.

Table 2: Minimum number of wire turns on terminal post

Wire size		Minimum number of turns (conductor + insulated wire)
AWG	Nominal diameter (mm)	
30	0,25	7 + 3/4
28	0,32	7 + 3/4
26	0,40	6 + 3/4
24	0,51	5 + 3/4

6.3.3 Positioning and regularity of wrap connection

The requirements relating to spacing between adjacent turns, the sum of all spaces within one wrap, and the distances for positioning wraps on the terminal post are detailed in Figure 7. This also gives the dimension limits for the minimum number of turns required.

6.3.4 Wire routing

a. Wire routing around and between terminal posts shall be such that wires do not press against the corners of posts with sufficient force to cut the insulation. Wire with insulation which has been cut shall be removed and replaced.

b. Wires may be re-routed to correct a tight wire condition or relieve a wire density problem, provided the wrap connection is not disturbed. Disturbed joints shall be rejected and replaced.

c. Wire routing above the terminal posts is prohibited.

d. Long lengths of interconnect wire shall be bonded or tied down to the module at 50 mm to 75 mm intervals to reduce resonance in the wire during vibration.

6.3.5 Rework

a. A wire-wrapped joint is not intended to be a “removable” joint, but it can be easily reprocessed. Reprocessing, or unwrapping followed by re-wrapping is termed “rework” in this instance.

b. To disconnect a wrapped connection, the wrapped wire shall be carefully uncoiled using an approved hand tool (see subclause 4.7.4), to preserve the corners of the terminal post.

c. Cut off the part of the wire which had been previously wrapped on the terminal post, and if possible, prepare the wire end for re-wrapping.

d. After inspection to confirm that the external condition of the post is satisfactory, the new length of stripped conductor, or a completely new interconnection wire length may then be wrapped onto the previously wrapped terminal post, provided that the post and connection are capable of meeting the requirements of this specification.

e. The wire and terminal post materials and conditions have been selected to enable joints to be reworked, with new wire each time:
   - up to 3 times, using copper alloy wire, or
   - up to 5 times, using soft copper wire.

f. When replacement connections are made, the wire routing shall follow the original route as closely as possible.

g. If only two levels of wrap on the terminal post are occupied, then consideration shall be given to using the Z3 level as an alternative to reworking the lower level wrap joints.

h. A wire-wrap rework log shall be established and maintained for each flight assembly, stating the positions of the reworked wraps and the number of reworks on every terminal post, which shall accompany the assembly during manufacture and test.

6.3.6 Wire-wrap and solder connections onto the same terminal post

Under no circumstances shall solder connections be added to terminal posts supporting wire-wrap connections.

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7

Test methods

7.1 General

The following test methods shall be used to verify the quality of wire-wrap connections. The number of wire-wraps to be tested, together with the appropriate test methods, are detailed in the following subclauses.

- Tool calibration: see subclause 4.8.
- Wire-wrap process certification: see subclause 4.9.
- Process control: see subclause 9.8.2.

7.2 Workmanship

a. Visual inspection of terminal posts, wire, the form and position of the wrap connection, and the routing of wire shall be carried out with the aid of a binocular microscope having an initial magnification of $\times 7$. Further examination of suspect defects should be made at higher magnifications up to $\times 30$. Great care shall be taken not to probe with any object or to physically disturb the wire-wrap connection.

b. Visual inspection shall ensure compliance with the requirements of this specification, and acceptance criteria detailed in subclause 8.1.

7.3 Stripping force

a. The stripping force test determines adequate tightness of the wire around the terminal post. A completed wire-wrap connection with the minimum number of turns listed in Table 2, shall be capable of meeting the minimum stripping force specified in Table 3.

   The minimum stripping force shall be the measurement recorded immediately after the force has been applied and before the wrapped conductor has been moved one wire diameter from its original position. Each result shall be greater than the acceptable minimum stripping force.

b. The samples shall be tested using the test fixture illustrated in Figure 8. There shall be no binding or wedging between the jaws and the terminal post, and the clearance shall not exceed 70 % of the conductor diameter. The jaws shall engage at 90° to the axis of the terminal post, creating a flat surface contact with the wire at the base of the wrap connection. When testing wraps onto the rectangular (0,76 mm $\times$ 1,52 mm) terminal post, the jaws of the hook shall engage along the 1,52 mm edge dimension.

The test fixture shall be placed in a tensile testing machine whose calibration is accurate to ± 0,2 N, and the axial load applied at a cross-head speed of 1 mm/min to 50 mm/min.

Table 3: Minimum stripping force

Wire size		Minimum stripping force (Newton)	
AWG	**Nominal diameter (mm)**	**0,64 mm square terminal post**	**1,14 mm square and 0,76 mm × 1,52 mm terminal posts**
30	0,25	20,0	-
28	0,32	25,0	-
26	0,40	25,0	35,0
24	0,51	-	40,0

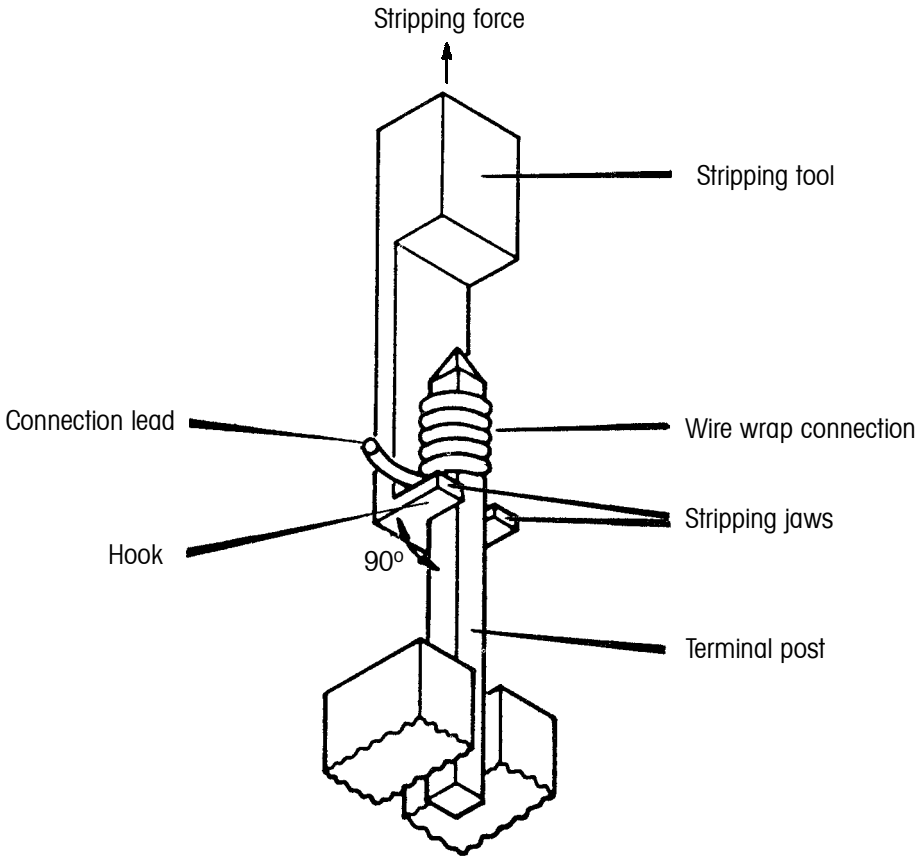


Figure 8: Stripping force test fixture

7.4 Unwrapping test

a. This is a complementary test to the stripping-force test to assess the cold working behaviour of the wrapped wire, together with the penetration of the terminal post corners into the wire. The test ensures against an overtight wrap. The wire on the terminal post shall be capable of being unwrapped without conductor breakage. The unwrapped wire will not be straight; waves and permanent deformation are permitted.

b. It is recommended that the test be carried out under a low power binocular microscope, to permit continuous monitoring of the wire as it is unwrapped, and detection of any problems as they occur. Perform the test as follows, using the appropriate unwrapping tool (subclause 4.7.4):

1. Place the tool on the end of the terminal post, ensuring that the end of the wire to be unwrapped enters the helical groove correctly. Slowly rotate the tool until all the wire has been transferred onto the tool. To ensure that no damage occurs in the lower turn, slight tension may be applied to the wire whilst the tool is being rotated.
2. When all the wire is unwrapped, carefully remove the tool with the loose helical coil of wire from the terminal post.
3. Holding the insulated portion of the wire firmly, with the tool perpendicular to the wire, unroll the wire by rotating the tool, whilst exerting slight tension along the wire.

7.5 Connection resistance

a. The connection resistance of a single wrap joint shall be determined as illustrated in Figure 9, at the current specified in Table 4. The connection resistance shall not exceed 2 mΩ, calculated from:

$$\text{connection resistance } (\text{m}\Omega) = \frac{\text{voltage drop (mV)}}{\text{test current (A)}}$$

b. The voltage drop shall be measured between the first turn of uninsulated conductor, and the terminal post, by using suitable probe contacts. The probe to the terminal post shall make contact as close as possible to the end of the wrap joint without touching the wire.

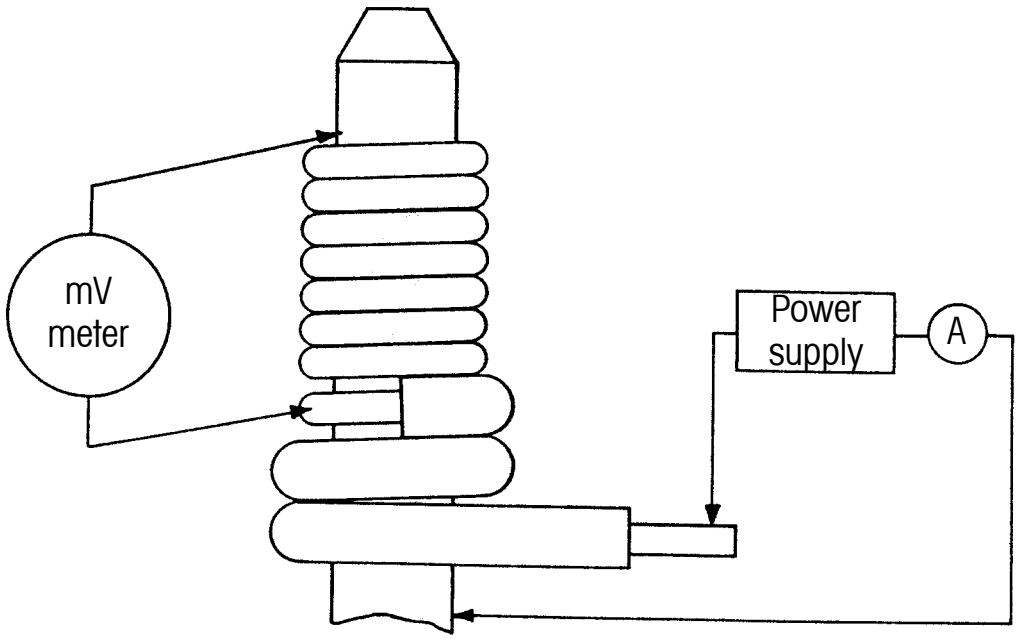


Figure 9: Connection resistance test

Table 4: Test current for connection resistance

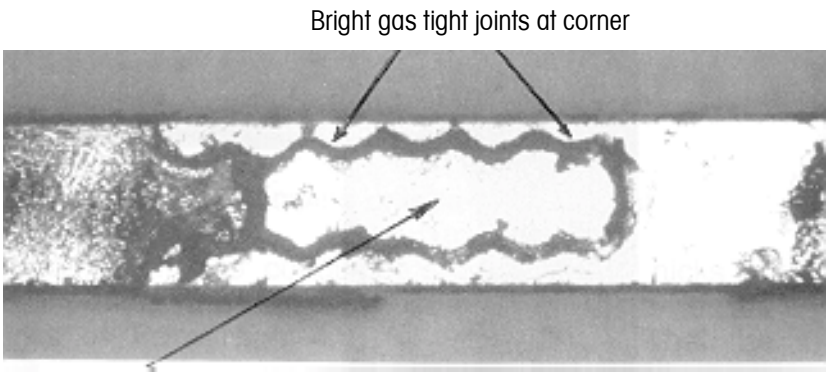
Wire size		Test current to be used to determine connection resistance (A)
AWG	Nominal Diameter (mm)	
30	0,25	1,0
28	0,32	2,0
26	0,40	2,4
24	0,51	2,4

7.6 Gas-tightness test

a. This test demonstrates the integrity of the wire-wrap connection confirming the mechanical "gas-tight" interconnection between conductor and terminal post corners. The wrapped connection shall show evidence on every turn, except the first and last, of a gas-tight surface equal to or greater than 75 % of the corners of the terminal post in contact with the bare conductor. Thus, either 3 or 4 terminal post corners per turn of bare conductor shall be gas-tight.

b. Carry out the gas-tight test as follows:

1. Suspend the test samples inside a glass vessel with a stopper containing 5 ml of aqua regia (1:1 concentrated hydrochloric acid and nitric acid), without contact with the acid. Expose the wire-wrap samples to the aqua regia fumes for a duration of 10 minutes.
2. Immediately transfer and suspend the chemically attacked test samples to a second glass vessel containing 5 ml of concentrated ammonium sulphide solution, without contact with the liquid. Expose for several minutes to this atmosphere, necessary to obtain complete blackening of the surfaces of the samples.
3. Allow to dry, and carefully unwrap the wire from the blackened connection. The gas-tight areas appear bright in sharp contrast to the blackened exposed areas on the terminal post. Figure 10 illustrates a typical satisfactory test result, where the central region of the face of the terminal pin beneath the wire-wrap has suffered attack and blackening.



Central region on the terminal post beneath the wrap may only be slightly darkened, due to build up of the corrosion product beneath the conductor, preventing blackening by the sulphide fumes.

Figure 10: Gas-tightness test result

7.7 Metallography

a. Metallography, which is carried out during process certification, may also be used during preliminary evaluation of the conductor/terminal post interface. The microsection shall be carefully prepared to reveal:

1. Confirmation of plating thickness, uniformity and adhesion onto wire and terminal post, and their materials.
2. Any damage to corner of terminal post due to the wire-wrap.
3. Extent of the gas-tight mechanical joint, and indentation of the wire, which, if excessive would lead to failure of the unwrapping test. Terminal post corner indentation into pure copper wire is greater than into copper alloy wire.

A typical satisfactory wrap cross-section is illustrated in Figure 11, for copper alloy wire wrapped onto a 0,64 mm square terminal post.

b. The joint to be sectioned shall be mounted in a low exotherm resin without the application of external pressure. The wrap joint shall be so oriented that the terminal post is perpendicular to the polishing surface. Grind the specimen using appropriate grades of silicon carbide papers to expose the centre wrap turns. Polish this section using diamond paste down to 1 μm grade. To aid microscopic examination, lightly etch the polished surface with an appropriate chemical reagent specific to the composition of the wrap materials.

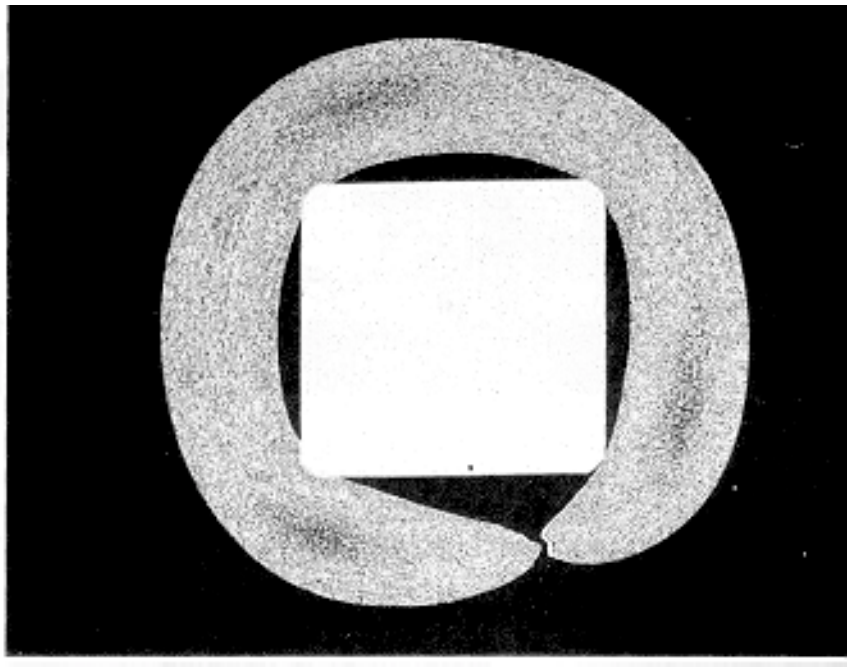


Figure 11: Typical cross-section of wire-wrap (×64)

7.8 Records of tests

Records shall be maintained of all test results identified with individual test samples. If any individual test sample fails the minimum applicable test requirement, it shall be cause for rejection of all wraps made after the last successful test sequence. The wire-wrap combination shall then be submitted to process certification tests, detailed in subclause 4.9, to determine cause of process failure.

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8

Acceptance criteria

8.1 Visual inspection

During visual inspection, the following criteria shall be met.

a. The silver plating on the conductor shall have no nicks or scratches exposing the base material (refer also to the requirements of subclause 5.1). Defective wire shall be replaced.

b. The terminal posts shall meet the requirements of subclause 5.2. Defective posts shall be replaced.

c. Wire-wrap connections shall be clean and free of foreign material.

d. There shall be no evidence that the connection has been disturbed after manufacture.

e. The wire insulation shall make captive contact with at least three corners of the terminal. Connections with insufficient insulation in contact with the terminal post shall be reworked according to subclause 6.3.5; see Figure 12A.

f. There shall be no overlapping between two adjacent connections on the same terminal post (see Figure 7 and Figure 12B). Rework the top connection. Rework both connections if the top connection overlaps more than one turn of the lower connection.

g. Uniformity and correct positioning of the wrap on the terminal post shall conform to the requirements of subclause 6.3.3 and Figure 7. Wire wrapped too high on the terminal post shall be reworked (see Figure 12C).

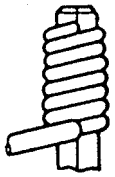
h. The number of turns of conductor shall conform to the requirements of subclause 6.3.2, and Table 2. Wraps with insufficient conductor turns shall be reworked, (see Figure 12D).

i. The end tail shall conform to the requirements of subclause 6.3.2.c. (see Figure 12E).

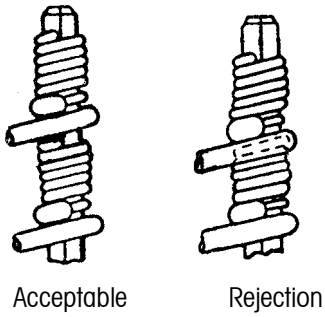
j. No overlapping turns shall be present within the wrap joint, (see Figure 12F).

k. The conductor shall be tightly wrapped onto the terminal post. The maximum spacing between adjacent turns shall not exceed 1/2 the diameter of the uninsulated conductor, and, excluding first and last turns, the sum of all gaps shall not exceed the conductor diameter, (see Figure 7). “Spiral” and “Open” wrap conditions, illustrated in Figures 12G and 12H respectively, shall be reworked.

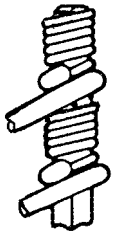
l. The insulated wire shall be routed in a manner which does not tend to unwrap the wire on the terminal post, (see subclause 6.3.4).



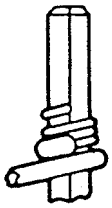
A. Insufficient insulation



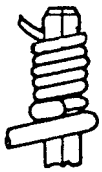
B. Overlap criteria



C. Improper positioning

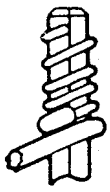


D. Insufficient turns



E. End tail

F. Overwrap



G. Spiral wrap

H. Open wrap

Figure 12: Wire-wrap rejection criteria which require reworking of the connection

8.2 Performance tests

8.2.1 General

Wire-wrap samples shall be submitted to the tests prescribed in clause 7. If any sample fails to meet the acceptance criteria listed above, then all production wraps produced by the operator concerned subsequent to his last performance sampling shall be rejected.

8.2.2 Stripping force test

The measured stripping force shall exceed the minimum values listed in Table 3.

8.2.3 Unwrapping test

The unwrapped conductor shall not be broken. Indents, waves and permanent deformation along the length of the unwrapped conductor are permitted.

8.2.4 Connection resistance test

The connection resistance of a single wrap joint shall not exceed 2 mΩ.

8.2.5 Gas-tightness test

Unattacked bright gas-tight areas shall occupy 75 % or greater of the corners of the terminal post in contact with the bare conductor (except for the first and last turns).

8.2.6 Metallography

Microsections shall be examined in the lightly etched condition to reveal the extent of the gas-tight joint between conductor and terminal post, and for confirmation of the quality and materials of conductor and terminal post.

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9

Quality assurance

9.1 General

The quality assurance requirements are defined in ECSS-Q-20. See also Figure 13 “Guide to quality assurance during wire wrapping”.

9.2 Data

The quality records (e.g. logbooks) shall be retained for at least ten years or in accordance with project contract requirements, and contain as a minimum the following:

- The as-built and test configuration list (waiver and deviation summary).
- Nonconformance reports and corrective actions.
- Copy of the visual inspection and performance test results with reference to the relevant procedure, personnel and tools utilized.
- Records of the training, testing and certification status of wire-wrapping operators (see subclause 9.7).

9.3 Nonconformance

Any nonconformance which is observed in respect of the process shall be dispositioned in accordance with the quality assurance requirements, see ECSS-Q-20-09. Furthermore, failure of a wire wrapping tool to pass any requirements specified in subclauses 4.7 to 4.9, and 9.8 shall require rejection of all wraps made by that tool since it was last tested successfully for acceptance.

9.4 Calibration

Wire-wrapping tools and test-monitoring equipment shall be periodically calibrated as detailed in subclauses 4.8 and 4.10 respectively, and calibration records shall be kept. Any suspected or actual equipment failures shall be recorded as a project nonconformance report so that previous results may be examined to ascertain whether or not re-inspection and retesting is required. The customer shall be notified of the nonconformance details.

9.5 Traceability

Traceability shall be maintained throughout the process from incoming inspection to final test, including details of test equipment, tools and personnel employed in performing the task.

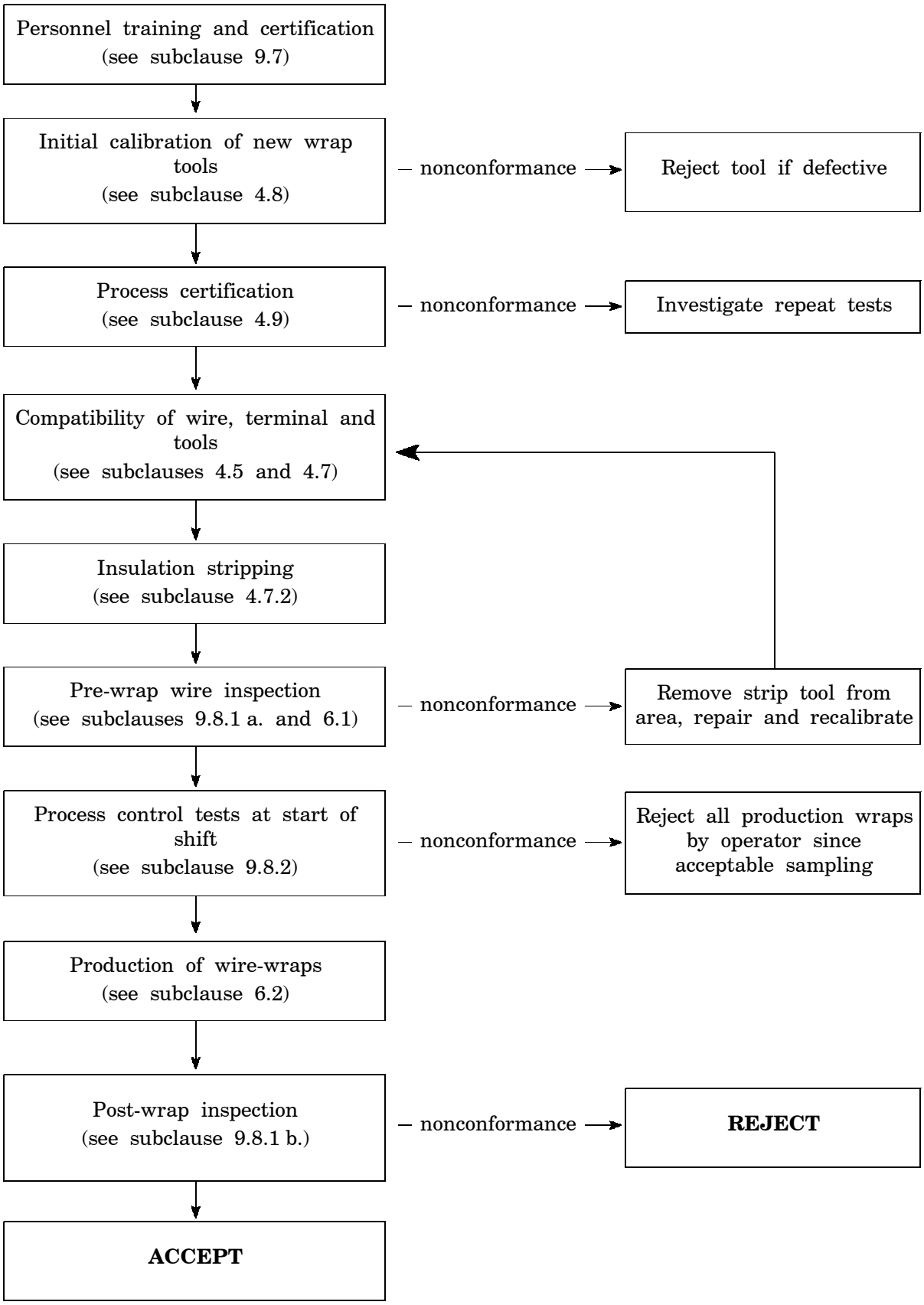

Figure 13: Guide to quality assurance during wire wrapping

9.6 Workmanship standards

Visual standards consisting of satisfactory work samples or visual aids which clearly illustrate the quality characteristics of wire-wrap connections shall be prepared and available to each operator and inspector. The illustrations presented in Figures 7 and 12, supplemented as necessary, shall be included as examples.

9.7 Operator and inspector training and certification

Trained and competent personnel shall be employed for wire-wrapping operations. A training programme shall be developed, maintained and implemented to provide for excellence of workmanship and personnel skill, careful and safe operations, and improvement of the quality of wrapped joints.

Trained personnel shall be certified. The certification of personnel shall be based upon objective evidence of wire wrap quality, resulting from test and inspection of the wrap joints. Recertification of personnel shall apply in cases of repeatedly unacceptable quality levels and changes in wire-wrapping techniques, parameters or required skills.

Records shall be maintained of the training and certification status of operators and inspection personnel.

All training and certification shall only be performed at a school authorized by the final customer.

9.8 Inspections

9.8.1 Visual inspection

a. **Pre-wrap inspection**

Before the stripped wire is inserted into the wrap tool wire feed slot, the stripped conductor and wire insulation shall be examined. The acceptance criteria are described in subclause 6.1. Inspection shall verify that wire size and type and the terminal posts are as specified on the drawing or control document.

b. **Post-wrap inspection**

The inspection shall be carried out with the aid of a binocular microscope in accordance with subclause 7.2. The acceptance criteria are described in subclause 8.1.

9.8.2 Process control

At the beginning of a production shift, for each wire-wrap combination, each operator shall prepare the following sample connections for performance testing, according to the quantity of production wraps planned, as follows:

a. six joints at the beginning, followed by a further six joints at the end of the shift (twelve joints total), when fifty or more wrap joints are planned per shift. Wrap joint samples to be identified “beginning” or “end” of shift; or

b. six joints only at the beginning of the shift, when less than fifty wrap joints are planned per shift.

In both cases, all samples shall be first visually inspected (subclause 7.2). From each set of six samples, three shall then undergo the stripping force test (subclause 7.3), and three remaining samples shall undergo the unwrapping test (subclause 7.4). The acceptance criteria appear in clause 8.

For each wire-wrap combination, all the results shall be recorded in a “Daily process control sheet” (see annex A) in order to determine performance drift.

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10

Verification

10.1 General

Verification tests shall be conducted to establish confidence in the reliability of wire-wrap combinations not detailed in Table 1. The combination is considered verified following successful completion of process certification tests in accordance with subclause 4.9, on 30 sample wraps before, and a further 30 sample wraps after temperature cycling and vibration testing detailed below.

10.2 Temperature cycling

The test samples shall undergo 200 temperature cycles in a suitable chamber from room temperature to –55 °C to +100 °C and back to room temperature (22 ± 3) °C at a rate not exceeding 10 °C per minute. Soak time at each temperature extreme should be 15 minutes. The duration of each cycle should average one hour.

These conditions may be modified by the customer to conform with the particular environmental qualification conditions for the assembly being verified.

10.3 Vibration

After completion of the temperature cycling, the test samples shall be subjected to vibration. The customer shall prescribe test levels, frequencies and durations.

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Annex A (informative)

Daily process control sheet for test samples

Daily process control sheet for test samples

Project:		**Model:**		**Date:**	
Wire-wrap tool:		**Terminal post:**		**Wire:**	
Quantity of manufactured connections	Visual result	Stripping force result (Newton)	Unwrap test result	Conclusion	Name and date

ECSS Document Improvement Proposal

1. Document I.D.	2. Document date	3. Document title
ECSS-Q-70-30A	4 October 1999	Wire-wrapping of high-reliability electrical connections

4. Recommended improvement (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)

5. Reason for recommendation

6. Originator of recommendation

Name:	Organization:	
Address:	Phone: Fax: E-Mail:	**7. Date of submission:**

8. Send to ECSS Secretariat

Name:	Address:	Phone: +31-71-565-3952
W. Kriedte ESA TOS-QR	ESTEC, P.O. Box 299 2200 AG Noordwijk The Netherlands	Fax: +31-71-565-6839 E-Mail: wkriedte@estec.esa.nl

Note: The originator of the submission should complete items 4, 5, 6 and 7.

This form is available as a Word and Wordperfect-Template on internet under
http://www.estec.esa.nl/ecss/improve/

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