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EXECUTED BY	W. Destro									
VERIFIED BY	Alysson M.									
APPROVED BY	A. Bernardes									
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TITLE: ELECTRICAL AND/OR HYDRAULIC CABLE FOR PERMANENT DOWNHOLE INSTALLATION IN OIL AND GAS WELLS

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## 1 SCOPE

This specification presents detailed technical information and requirements for the permanent downhole electrical or hydraulic and electrical cable to be installed on the PDG system in Low Pressure (LP) and High Pressure (HP) wells.

## 2 TERMS AND DEFINITIONS

<b>PDG</b>	Permanent Downhole Gauge.
<b>LP</b>	Low Pressure.
<b>HP</b>	High Pressure.
<b>“Shall” or “Must”</b>	Indicates a mandatory requirement.
<b>“Should”</b>	Indicates a requirement for the good engineering practice.
<b>OD</b>	Outside Diameter.
<b>ETFE</b>	Ethylene-tetrafluoroethylene.

## 3 REFERENCES

<b>ASTM A312</b>	Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes.
<b>ASTM B704</b>	Standard Specification for Welded UNS N06625, UNS N06219 and UNS N08825 Alloy Tubes.

## 4 GENERAL DESCRIPTION

4.1 There are five types of permanent downhole cable for PDG installation:

4.1.1 Type 1: Permanent downhole electrical cable encased in a 1/4” metal tube, stainless steel for LP or Inconel 825 for HP, insulated by ETFE or similar or material of better quality and filled by a dielectric material, with two steel ropes (3/8”). The assembly shall be encapsulated by a polymer compound appropriated for oil industry: waterproof, chemical attack, gas transmission, rated temperature, etc., forming a 36 x 14 mm flat cable.

4.1.2 Type 2: Permanent downhole electrical cable encased in a 1/4” metal tube, stainless steel for LP or Inconel 825 for HP, insulated by ETFE or similar or material of better quality and filled by a dielectric material. The assembly shall be encapsulated by a polymer compound appropriated for oil industry: waterproof, chemical attack, gas transmission, rated temperature, etc., forming a 11 x 11 mm flat cable.

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- 4.1.3 Type 3: Permanent downhole electrical cable encased in a 1/4" metal tube, stainless steel for LP or Inconel 825 for HP, insulated by ETFE or similar or material of better quality and filled by a dielectric material, hydraulic tube 3/8" metal tube, stainless steel for LP or Inconel 825 for HP, and with two steel ropes (3/8"). The assembly shall be encapsulated by a polymer compound appropriated for oil industry: waterproof, chemical attack, gas transmission, rated temperature, etc..., forming a 44 x 14 mm flat cable.
- 4.1.4 Type 4: Permanent downhole electrical cable encased in a 1/4" metal tube, stainless steel for LP or Inconel 825 for HP, insulated by ETFE or similar or material of better quality and filled by a dielectric material, hydraulic tube 3/8" metal tube, stainless steel for LP or Inconel 825 for HP, and with one steel rope (3/8"). The assembly shall be encapsulated by a polymer compound appropriated for oil industry: waterproof, chemical attack, gas transmission, rated temperature, etc..., forming a 36 x 14 mm flat cable.
- 4.1.5 Type 5: Permanent downhole electrical cable encased in a 1/4" metal tube, stainless steel for LP or Inconel 825 for HP, insulated by ETFE or similar or material of better quality and filled by a dielectric material, two hydraulic tubes 3/8" metal tube, stainless steel for LP or Inconel 825 for HP. The assembly shall be encapsulated by a polymer compound appropriated for oil industry: waterproof, chemical attack, gas transmission, rated temperature, etc..., forming a 36 x 14 mm flat cable.
- 4.2 The cable shall have a track record of at least 30 successful installations in wells that operate at similar or higher pressure and temperature. At least one cable shall be functional for one year. The documentation must be submitted for PETROBRAS approval.
- 4.3 If the item 4.2 is not accomplished by the supplier, the cable shall be qualified in advance by the supplier. The documentation must be presented.
- 4.3.1 The supplier must provide to PETROBRAS one cable for field test. The test consists of installing the cable in a subsea well. The pass criteria is one year of operation without failure. The field test is part of the qualification.
- 4.3.1.1 The field test depends on the existence of a favorable scenario for the cable installation.
- 4.3.2 The qualification must be witnessed and certified by a third part.

## 5 CHARACTERISTICS

### 5.1 OPERATIONAL

The permanent downhole cable shall be designed to withstand 20 years in the well under nominal pressure and temperature.

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The complete cable shall withstand 300 F (150 °C) with no deformation and the mechanical penetration test shall present a maximum penetration of 0.2 mm.

**5.1.2 INTERNAL RATED PRESSURE**

The 1/4" stainless steel tube shall withstand 10,000 psi of internal pressure (nominal operational pressure).

The 3/8" stainless steel hydraulic tube shall withstand 10,000 psi of internal pressure (nominal operational pressure).

The 1/4" Inconel 825 tube shall withstand 15,000 psi of internal pressure (nominal operational pressure).

The 3/8" Inconel 825 hydraulic tube shall withstand 15,000 psi of internal pressure (nominal operational pressure).

**5.1.3 EXTERNAL RATED PRESSURE**

The 1/4" stainless steel tube, filled with the center conductor, insulation, and dielectric, shall withstand 15,000 psi of external pressure (rated pressure).

The 3/8" stainless steel hydraulic tube shall withstand 10,000 psi of external pressure (rated pressure).

The 1/4" Inconel 825 tube, filled with the center conductor, insulation, and dielectric, shall withstand 20,000 psi of external pressure (rated pressure).

The 3/8" Inconel 825 hydraulic tube shall withstand 20,000 psi of external pressure (rated pressure).

**5.2 ELECTRICAL****5.2.1 CENTER CONDUCTOR**

- a) DC resistance @ 20 °C: 23 Ω/km maximum;
- b) Capacitance, center conductor/steel tube @ 1 kHz: 94 pF/m maximum.

**5.2.2 1/4" METAL TUBE**

- a) DC resistance @ 20 °C: 180 Ω/km maximum. (Standard: 65 Ω/km for 316SS and 92 Ω/km for Inconel 825)

**5.2.3 COMPLETE CABLE**

- a) Insulation resistance @ 20 °C, 1 min: 2,000 MΩ/km minimum;
- b) Voltage rating: 1,000 Vdc.

### 5.3 MECHANICAL

#### 5.3.1 ELECTRICAL CABLE (CENTER CONDUCTOR AND METAL TUBE)

- a) Center conductor: 18 AWG, solid tinned copper;
- b) Inner insulation: ETFE or similar or material of better quality,  $2.60 \pm 0.08$  mm diameter;
- c) Outer insulation: ETFE or dielectric filler material between the inner insulation and metal tube that shall provide complete protection against movement within the metal tube.

#### 5.3.2 HYDRAULIC TUBES

For LP: ( $3/8'' \pm 0.003''$ ) 9.525 mm  $\pm$  0.08 mm diameter, type 316SS;  
Wall thickness enough to withstand 10,000 psi of internal pressure;  
Wall thickness tolerance  $\pm$  10%;  
Tensile strength: 70,000 psi (minimum);  
External operational pressure of 10,000 psi (minimum);  
Yield strength 25,000 psi (minimum).

For HP: ( $3/8'' \pm 0.003''$ ) 9.525 mm  $\pm$  0.08 mm diameter, Inconel 825;  
Wall thickness enough to withstand 15,000 psi of internal pressure;  
Wall thickness tolerance  $\pm$  10%;  
Tensile strength: 85,000 psi (minimum);  
External operational pressure of 20,000 psi (minimum);  
Yield strength 35,000 psi (minimum).

#### 5.3.3 GALVANIZED STEEL ROPES

Type 1 cable:

- a) 2 x  $3/8''$ ;
- b) Formation: 7 x 3.17 mm, 9.52 mm diameter ( $\pm$  0.1 mm).

Type 3 cable:

- a) 2 x  $3/8''$ ;
- b) Formation: 7 x 3.17 mm, 9.52 mm diameter ( $\pm$  0.1 mm).

Type 4 cable:

- c) 1 x  $3/8''$ ;
- d) Formation: 7 x 3.17 mm, 9.52 mm diameter ( $\pm$  0.1 mm).

#### 5.3.4 COMPLETE CABLE

- a) Type 1 nominal external measurements: ( $36 \pm 1.0$ ) mm x ( $14 \pm 0.5$ ) mm;
- b) Type 2 nominal external measurements: ( $11 \pm 0.5$ ) mm x ( $11 \pm 0.5$ ) mm;
- c) Type 3 nominal external measurements: ( $44 \pm 1.0$ ) mm x ( $14 \pm 0.5$ ) mm;
- d) Type 4 nominal external measurements: ( $36 \pm 1.0$ ) mm x ( $14 \pm 0.5$ ) mm;
- e) Type 5 nominal external measurements: ( $36 \pm 1.0$ ) mm x ( $14 \pm 0.5$ ) mm.

The cable drawings may be seen in section 11.

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## 6 TESTS AND INSPECTIONS

### 6.1 MANUFACTURER TEST

The supplier shall carry out the following tests/inspections and it shall provide work test/inspection records for the PETROBRAS representative before the beginning of the FAT (Factory Acceptance Test):

- 6.1.1 The OD of the inner conductor insulation shall be monitored continuously during extrusion and one measure shall be printed, at least, every 10 m of wire.
- 6.1.2 Tube heat analysis shall be carried out, when applicable, to show the percentage of the components: (C, Mn, P, S, Si, Cr, Ni, Mo, Ti, Cu, Al, Fe, N, Co, V, W, Ta).
- 6.1.3 Non-destructive test eddy current on 100 % of the tube or Helium leak test under water (in that case, the coils shall be checked at 1000 psi (minimum) internal pressure for at least one hour with Helium under water) shall be carried out.
- 6.1.4 The tensile strength and yield strength of the tubes shall be informed.
- 6.1.5 High-voltage test shall be carried out. A voltage of 3,000 Vdc shall be applied between the center conductor and metal tube for five minutes. This test shall be carried out after the tube has been formed around the electrical core and on the complete cable assembly.
- 6.1.6 DC resistance measurement of the center conductor @ 20°C shall be informed.
- 6.1.7 DC resistance measurement of the metal tube @ 20°C shall be informed.
- 6.1.8 Capacitance measurement between the center conductor and metal tube @1 kHz shall be informed.
- 6.1.9 Insulation resistance between the center conductor and metal tube @ 500 Vdc, measured after 1 min, shall be informed.

### 6.2 FACTORY ACCEPTANCE TEST (FAT)

A FAT shall be carried out on the complete cable assembly (100% of manufactured order). These tests shall include, at least:

- 6.2.1 Checking of data and compliance with specifications.
- 6.2.2 Reports of the tests and inspections listed above (items 6.1.1 to 6.1.9).

### 6.2.3 MECHANICAL TESTS

The mechanical tests described below shall be carried out.

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A crush resistance test shall be carried out on a 0.5 m long sample cable. The sample shall be placed in a hydraulic press having a calibrated pressure gauge and a sufficient range of force. The crushing plates shall be 6" square. Short circuit and electrical continuity shall be monitored during the test. The crushing force shall be steadily increased to 20,000 pounds (9.072 kg) without electric failure. This test shall be carried out on one sample from the lot to be delivered, at least.

**6.2.3.2 WIRE RELATIVE MOVEMENT TEST**

The outer insulation shall fit tightly within the metal tube in order to prevent any relative movement when the cable is lifted vertically. This requirement shall be demonstrated by the following test.

A one foot (300 mm) sample of completed cable shall have 2 inches (50 mm) of the metal tube removed from one end. The sample shall be straight, and the ends of the tube shall be free from burrs or other discontinuities that would avoid axial movement of the insulated conductor. The conductor shall be attached to one grip of a tensile tester, and the other end of the sample shall be attached to the other grip in such a way that there is no force tending to prevent movement of the insulated conductor within the metal tube. The jaws of the tensile tester shall be separated at a rate of 5 inches (127 mm) per minute. The force required to break the bond between the outer insulation and the metal tube shall be recorded. This force shall exceed the weight of the conductor plus inner and outer insulation layers for the sample length.


**6.2.3.3 BENDING TEST**

A bending test shall be carried out on a sample of completed cable. One end of the sample shall be attached to a mandrel having a diameter of 500 mm, and the other end shall be bended 180° around the mandrel. The process shall be repeated by turning the cable over, and bending it in the reverse direction. After bending, the sample shall be tested electrically to demonstrate that there is no short circuit or loss of continuity. There shall be no damage to the external encapsulation, and there shall be no relative movement between the internal components.

**6.2.3.4 TORSION RESISTANCE TEST**

A torsion resistance test shall be carried out on a 10 foot (3 m) sample length of completed cable. One end of the sample shall be adequately secured to a device to prevent radial movement from occurring. The opposite end shall be fixed to a fixture which will provide the necessary force to rotate that end of the sample 180°. Conductor continuity shall be verified before the cable has been rotated and after the cable has been rotated 180° and returned to its original position. This test shall demonstrate the ability of the sample under test to not short circuit nor lose continuity when 180° radial torsion is applied.



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### 6.2.3.5 PENETRATION TEST

To ensure that the encapsulation material will not soften and deform at 150 °C, a sample of completed cable shall be subjected to the following test. A Randal and Stickney micrometer with a 500 gm load resting on a knife edge shall be conditioned for 1 hour in an oven at a temperature of 150°C. A sample of completed cable shall also be conditioned for 1 hour at 150°C, and shall then be placed under the knife edge, with 500 gm applied, and the thickness measured. The sample shall remain under the knife edge with 500 gm load for a further hour at 150°C, and the thickness measured again. It shall not be more than 0.2 mm less than the initial measurement.

## 7 SPLICE KIT

Splice Kit shall comply with the following requirements:

- 7.1 It shall be compatible with the manufactured cable.
- 7.2 The primary seal shall be metal to metal.
- 7.3 It shall be capable of being field assembled and tested (the first barrier must be field pressure tested).
- 7.4 The electrical connections shall be protected by two mechanical barriers against fluid ingress.
- 7.5 The second barrier shall be designed considering the use of a rubber boot sleeve. The use of tape will not be accepted.
- 7.6 The splice kit shall have a metallic housing to protect the splice itself and to hold/splice the steel ropes tightly.
- 7.7 A splice kit drawing shall be sent with the proposal during any future BID phase.
- 7.8 An itemized price list of spare parts and necessary tools for assembling the splice kit shall also be sent with the proposal during any future BID phase.

## 8 MANUFACTURE DATA BOOK

- 8.1 One copy of a manufacture data book that shall include all the documentations referring to the manufacturing process shall be provided together with the package of cable ordered and also in digital media. It must contain at least, but not limited to:
  - a) Material certificate;
  - b) Tests and inspections carried out (including procedures);
  - c) Tests reports;
  - d) Statement of inspection release.

8.2 The datasheet of the cable must be provided in digital version. It must contain at least, but not limited to:

- a) Electrical characteristics: center conductor DC resistance @ 20°C, 1/4" tube resistance @ 20°C, capacitance curve against frequency varying from 50 to 2,000 Hz, voltage rating, and propagation velocity of an electromagnetic wave in the cable.
- b) Mechanical characteristics: tubing diameter and wall thickness, center conductor diameter, materials of each part of the cable (tubes, dielectric, filler, conductor, and encapsulation), yield stress and ultimate stress of materials, cable weight per 100 meters, maximum axial strength necessary to break up the cable, internal pressure rating, external pressure rating, tubing burst pressure, tubing collapse pressure, temperature rating, minimum deployment bend radius, and minimum static bend radius. All dimensions must be presented with their respective tolerances.

## 9 REFERENCES AND PROTOTYPES

- 9.1 The supplier must attach a list of recent supplies of similar cable, with emphasis on the ones used in similar applications.
- 9.2 The supplier shall inform any prototypes and/or equipment without previous application as well as its actual experience in other subsea installations. PETROBRAS reserves the right to refuse, at any time, non-informed prototypes.

## 10 IDENTIFICATION AND PACKAGING

10.1 The completed cable shall be printed along its length, on the flat side, in order to show its identification, including the label and sequential footage specified in meters, as follows:

“PETROBRAS S.A. - PDG ELECTRIC CABLE TYPE “X” LP or HP, S/N – xxxx m”  
X: 1, 2, 3, 4 or 5  
S/N: Manufactured serial number,  
xxxx: Sequential footage in meters

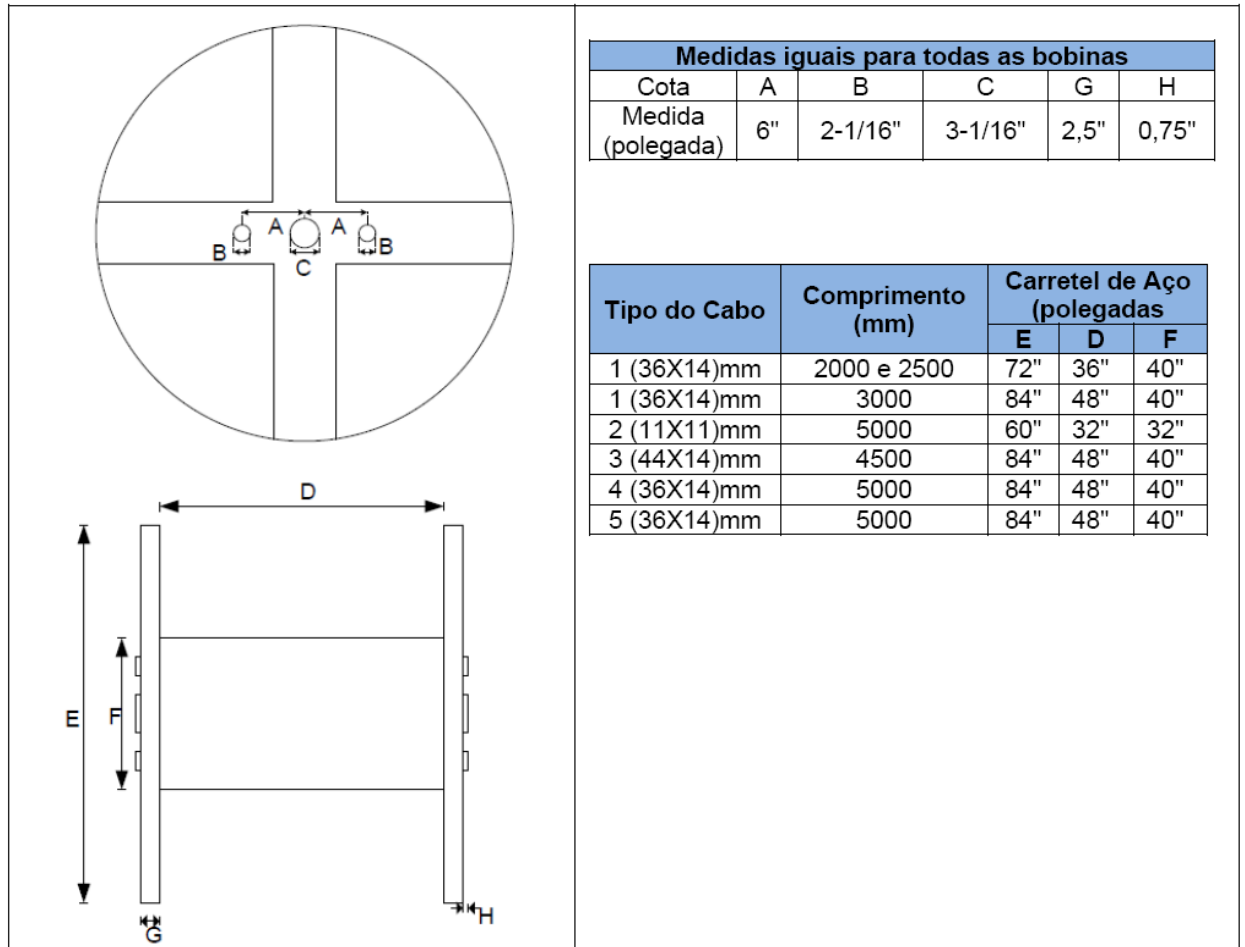
10.2 The completed cable must be contained on a steel reel that shall have an identification plate with, at least, the following information:

- a) Length of cable.
- b) Cable weight per meter.
- c) Total weight.
- d) Reel number.
- e) Serial number of cable.

10.3 The steel reel shall follow the specifications of **Table 10.1**. It will not be accepted reels with other dimensions.

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Table 10.1 – Reel Dimension.



10.4 The reel must be supplied on a metallic base, specified for 10 years of life cycle, and it shall be resistant to exposure to rain, dust, humidity, water, etc.

10.4.1 There must be a mechanical mechanism to lock the reel to the metallic base, in such a manner that the set is proper to be transported and lifted without relative movement between the reel and the base.

10.4.2 While the reel is on base, the set must be proper to be lifted with a forklift.

10.4.3 The metallic base must be painted yellow, with reflective green vertices.

10.4.4 As a reference of metallic base for the reel, the supplier may consult the attached drawing DE-3501.02-1516-619-PEK-217 rev. D.

## 11 DRAWINGS AND SPECIFICATIONS

### 11.1 Type 1 cable (36x14 mm electric)

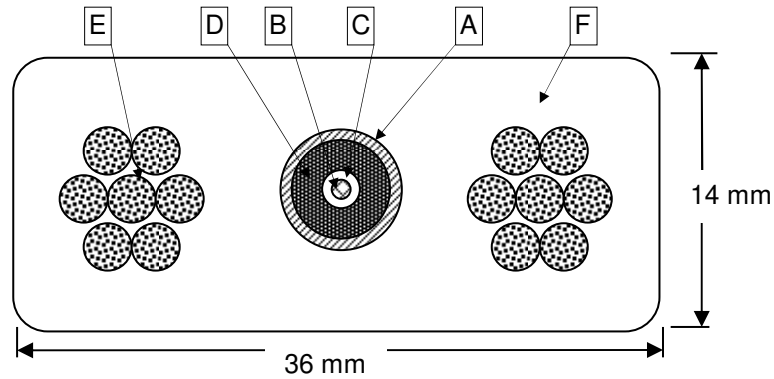


Figure 1 - Type 1 cable (not in scale).

- A. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 6.35 mm (1/4")
- B. Wire 18 AWG, solid tinned copper.
- C. ETFE insulation or similar or material of better quality,  $2.60 \pm 0.08$  mm diameter.
- D. Dielectric filler.
- E. 2 x 3/8", 7 x 3.17 mm, 9.52 mm diameter, standard galvanized steel ropes.
- F. Polymer compound encapsulation 36x14 mm.

### 11.2 Type 2 cable (11x11 mm electric)

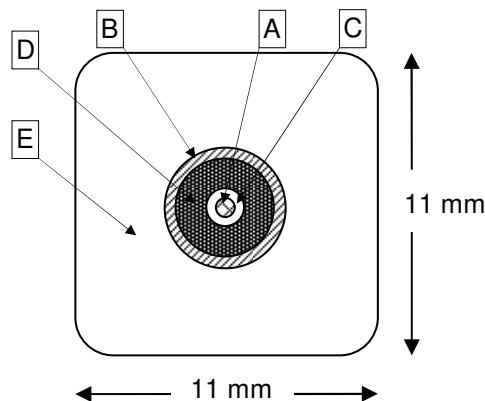


Figure 2 - Type 2 cable (not in scale).

- A. Wire 18 AWG, solid tinned copper.
- B. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 6.35 mm (1/4")
- C. ETFE insulation or similar or material of better quality, 2.60 ± 0.08 mm diameter.
- D. Dielectric filler.
- E. Polymer compound encapsulation 11x11 mm.

### 11.3 Type 3 cable (44x14 mm hydraulic & electric)

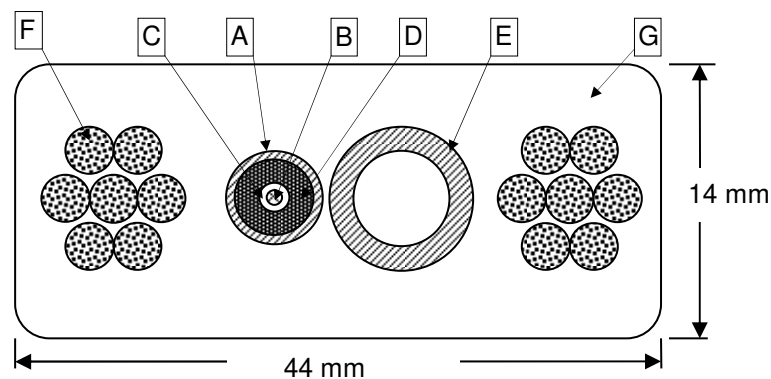


Figure 3 - Type 3 cable (not in scale).

#### 11.3.1 Electric Tube

- A. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 6.35 mm (1/4")
- B. Wire 18 AWG, solid tinned copper.
- C. ETFE insulation or similar or material of better quality, 2.60 ± 0.08 mm diameter.
- D. Dielectric filler.

#### 11.3.2 Hydraulic Tube

- E. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 9.52 mm (3/8")

#### 11.3.3 Galvanized Steel Hopes and encapsulation

- F. 2 x 3/8", 7 x 3.17 mm, 9.52 mm diameter, standard galvanized steel ropes.
- G. Polymer compound encapsulation 44 x 14 mm.

11.4 Type 4 cable (36x14 mm hydraulic & electric)

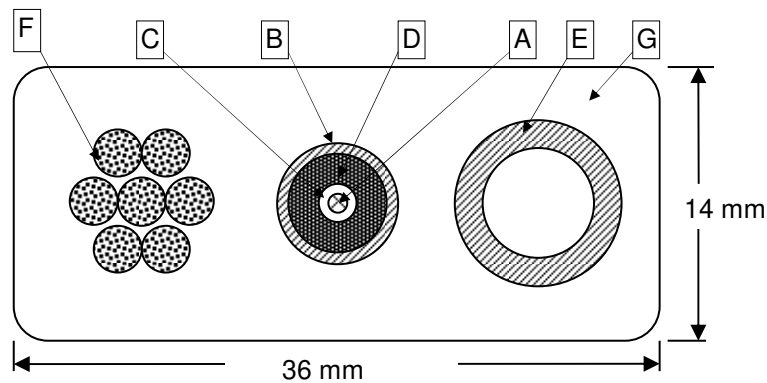


Figure 4 - Type 4 cable (not in scale).

11.4.1 Electric Tube

- A. Wire 18 AWG, solid tinned copper.
- B. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 6.35 mm (1/4")
- C. ETFE insulation or similar or material of better quality,  $2.60 \pm 0.08$  mm diameter.
- D. Dielectric filler.

11.4.2 Hydraulic Tube 3/8"

- E. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 9.52 mm (3/8")

11.4.3 Galvanized Steel Hopes and encapsulation

- F. 1 x 3/8", 7 x 3.17 mm, 9.52 mm diameter, standard galvanized steel ropes.
- G. Polymer compound encapsulation 36 x 14 mm.

11.5 Type 5 cable (36x14 mm hydraulic & electric)

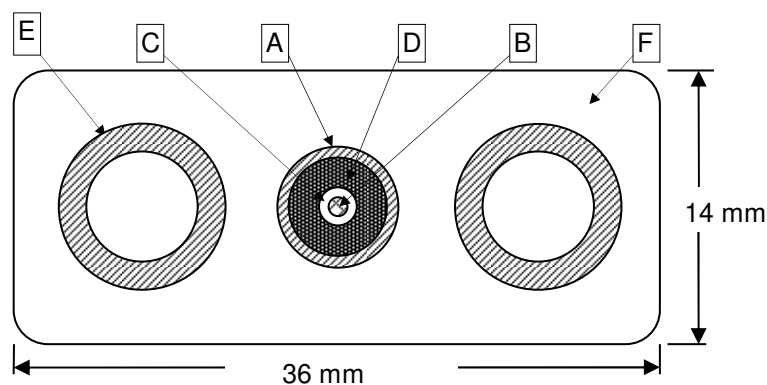



Figure 5 - Type 5 cable (not in scale).

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11.5.1 Electric Tube

- A. Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 6.35 mm (1/4")
- B. Wire 18 AWG, solid tinned copper.
- C. ETFE insulation or similar or material of better quality, 2.60 ± 0.08 mm diameter.
- D. Dielectric filler.

11.5.2 Hydraulic Tube 3/8"

- E. 2 x Type 316SS (LP) or Inconel 825 (HP), wall thickness enough to stand 10,000 psi (LP) or 15,000 psi (HP) of internal pressure, OD = 9.52 mm (3/8")

11.5.3 Encapsulation

- F. Polymer compound encapsulation 36 x 14 mm.