Woods Hole
Oceanographic
Institution

Copy 1

TECHNICAL MEMORANDUM NO. 7-75

OIL FILLED ELECTRICAL CABLES EXTERNAL
TO THE PRESSURE HULL ON DSV ALVIN

David S. Hosom

December 1975

WHOI Tech.
Memo. 7-75
c.I

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

TECHNICAL MEMORANDUM 7-75

OIL FILLED ELECTRICAL CABLES EXTERNAL
TO THE PRESSURE HULL ON DSV ALVIN

prepared by

David S. Hosom

December 1975

Contract N00 244-76-M-ME 12

Oil Filled Electrical Cables External
to the Pressure Hull on DSV ALVIN

David S. Hosom

Woods Hole Oceanographic Institution
Woods Hole, Ma. 02543

Abstract

This report provides background information on undersea cables of conventional construction and of the oil filled type. Design considerations for oil filled cable systems are presented as well as description of the ALVIN oil compensated electrical system. Descriptions of individual components used in the ALVIN system are provided as well as operating experience. This information is of use in designing oil filled electrical cables external to the pressure hull of any submersible.

Introduction

The purpose of this report is to describe the oil filled electrical cables external to the pressure hull on DSV ALVIN. Some background on the problems with other cable configurations and the advantages of oil filled cables over these designs are of interest. The initial approach to undersea cable was to use a standard cable with a waterproof jacket. In low pressure applications, this worked well. In higher pressure applications, the jacket was squeezed in around the wire causing a high stress level in the jacket material. Pressure cycling then lead to fatigue and failure of the jacket. The next step in cable design was to use pressure resistant filler materials and finally a filler that was both pressure resistant and that provided a seal so that in the event of failure water could not hose up the cable and flood connectors or equipment. These cables are stiff and it is not possible to provide a filler core that eliminates the jacket flexing completely. Oil filling of cables is an alternative design approach that was implemented on some earlier submersibles. ALVIN was designed with oil filled cables from the beginning, 1963.

An excellent source of information on cable technology for deep ocean use is the Handbook of Electric Cable Technology for Deep Ocean Applications published by Naval Ship Research and Development Laboratory in November of 1970. This reference states that; "The technology concerning cables to be used at relatively low hydrostatic pressure, such as present naval submarine service, is well established. A new technology in cable design is required to provide cables that will withstand service at maximum ocean depths". A second excellent reference is a paper, "Pressure-Compensated Electro-Connective Systems for Outboard Usage on Deep Submersibles" by Donald G. O'Brien published in IEEE '71 Engineering in the Ocean Conference Proceedings, p. 309. This paper states; "conventional electrical hull penetrators for deep submersible applications employing pressure-resistant construction become prohibitively heavy when designed for reliable operation at 20,000 feet depth. Outboard cable assemblies employing conventional helical-lay conductors with a heavy rubber jacket and attached to the back of the pressure-proof electrical connectors by rubber-molding or similar techniques have been shown to be extremely short-lived and very unreliable when subjected to a relatively small number of typical pressure cycles. A solution to both of these problems has been found in utilization of oil-filled pressure-compensation construction". The key words in this quote are pressure-resistant and pressure compensation construction. One of the unique features of the original ALVIN design was the early commitment to pressure compensation wherever possible. This point of design

philosophy has resulted in simpler, lighter and more reliable systems for ALVIN. A third excellent reference is a report published by Lockheed Missiles and Space Company, "DSSV Engineering Report - Pressure Compensated Cables" - LMSC-D 177821-8 31 August 1971. This report describes a program at Lockheed on oil-filled pressure-compensated cables. Four configurations that were designed in Lockheed and one configuration each from Bendix and Viking Industries were fabricated and tested. Each configuration included connectors, cables, junction boxes and penetrators. Only a minor component on one configuration failed during test with all other units completing the test successfully. This report also mentions trying a configuration from Cole Electric Co. but being unable to obtain parts. Since that time Viking Industries bought Cole Electric and distributes these parts.

Cable Design Considerations

The Handbook of Electric Cable Technology states that, "Cables filled with oil are more pliable than cables having similar components and a core-sealing compound and they are pressure compensated. Oil filled cables are more stable electrically than free-flooding cables and they will weigh less than core-sealed cables of the same dimensions. With oil-filled cables the selection of the oil and the cable insulating and jacketing materials must be based on compatibility among components. If stuffing tubes or unblocked terminations are employed, the fluid selected must be the same throughout a system. Preparation of oil-tight terminations and the possibility of oil leaks or seawater contamination are problem areas for this type of cabling". The problem areas mentioned in the Handbook can be minimized with good design practice and good craftsmanship in installation. Good craftsmanship and quality control procedures are critical to all aspects of submersible fabrication and operation.

The pressure difference in compensated systems is normally a few p.s.i. and by proper design the oil should be at a slightly higher pressure than ambient seawater. Any slight leaks or jacket pin holes will therefore lose negligible volumes of oil out of the system rather than take seawater into the system. All major oil filled boxes should have a saltwater leak detector located at some low place in the box to signal the operator should a leak occur. In addition, after each dive, the oil systems should have a cup of oil drained from each box to check for water and then the system should be properly filled prior to the next dive.

Oil filled cable is comprised of three basic components. These include conductor, insulator and jacket. There may also be a core-filler. This is not present on oil filled

cable. It is important to recognize the different functions of the insulator and jacket. The insulator provides a high insulation resistance around the conductor. The jacket provides a waterproof seal from seawater around the insulator and mechanical protection from abrasion. Neoprene is normally considered a jacket only since neoprene is not normally formulated to have good insulation resistance. Based on Woods Hole Oceanographic Institution experience however, neoprene used on Carroll Cable Co. welding cable and neoprene formulated by the Advance Cable and Assembly Co. or Electro Oceanics Corp. has a high insulation resistance. The neoprene from these sources also have a low water absorption rate. A listing from the Handbook of Electric Cable Technology of insulators and jackets follows: The materials used on ALVIN are marked.

Insulators

- Butyl Rubber
- Ethylene Propylene Rubber
- Teflon - FEP
- Mineral Insulation
- Natural Rubber
- Nylon
- Mylar
- Polyethylene
- Polypropylene
- Teflon PTFE
- PVC
- Styrene Butadiene Rubber
- Silicone Rubber
- Polyurethane
- Neoprene - (selected only)

Jackets

- Hypalon
- Nitrils - butadiene Rubber
- Neoprene
- Polyethylene
- Polyurethane
- Tygon - oil resistant formulation.

The Handbook lists several problems encountered with out-board cable. The experience and design approach in each area will be noted relative to ALVIN oil filled cable.

"1. Incompatibility of insulation and jacket compounds with pressure - compensating fluids".

The pressure compensating fluids used on ALVIN are Bray Oil Co. 3M-626 and Marcol 52. Bray Oil has replaced Hoover #2 but both are low viscosity hydrocarbon base oils. This oil is used in all electrical boxes and propulsion box. Marcol 52 is a high grade mineral oil and is only used in the battery boxes.

The cable insulating materials used on ALVIN include: Teflon, polyurethane, selected neoprenes and butyl rubber. All

of these, except butyl rubber, are totally compatible with the oils used. Butyl rubber is only used on small single wires with a neoprene jacket. Some swelling of butyl occurs in oil however there has been no functional problem resulting from this on ALVIN.

Cable jacket materials used on ALVIN include: Neoprene, and Tygon Tube (a modified vinyl compound) - note that only the oil compatible formulation can be used.

The oils and cable materials used on ALVIN have shown successful long term compatibility.

"2. Water penetration of cable jackets, and molded plug terminations".

The pressure balanced oil-filled system on ALVIN does not have a water penetration problem on either cables or plugs. There are few plugs used on ALVIN except for selected instruments. Cables are normally terminated in oil filled junction boxes.

"3. Cracking of cable sheath".

Again, the pressure balanced, oil-filled design is not subject to cracking.

"4. Potting problem of plug molding compounds to cable jackets and metal shell of plugs".

This is not a problem with the manufacturers that supply ALVIN. Present manufacturing techniques result in high quality bonds. Both molded neoprene and molded polyurethane cable terminations are used on ALVIN.

"5. Conductor breakage at molded plug terminations".

Conventional cables that are terminated at molded plugs are subjected to uneven stress concentrations. It is speculated that there is a 'piston' force that pushes the wires into the plug with increasing pressure and allows them to relax with decreasing pressure. Since the plug end is fixed and the sides are somewhat pressure protected the wire tends to form into a "z" shape and then ultimately opens. There is speculation on the mechanism but no conclusive evidence about the actual process.

This classical "z" bend failure at a termination has never occurred on ALVIN. The most likely place for this to occur would be the penetrator cable. Since the oil-filled cable eliminates the "piston" forces on each wire, this problem has not occurred. The qualification penetrator was subjected to 500

cycles and after disassembly there was no evidence of "z" bends or broken wires.

- "6. Instability of electrical characteristics with change in hydrostatic pressure or with long-time immersion".

Oil-filled cable is not subject to instability of electrical characteristics with change in pressure or with immersion. One case requires a note of caution. Welding cable purchased from Carroll Cable Co. has been used for many years on ALVIN, is very flexible and has provided excellent service. At some later time, standard welding cable was purchased for an installation. This cable was satisfactory at the start of the diving season but began to have lower and lower ground readings during the season. At overhaul time this cable was inspected with a meggar and found to have very poor insulation resistance. Standard welding cable does not have a good insulation resistance. The welding cable from Carroll Cable Co. has good insulation resistance properties, is still used on ALVIN and provides good service.

- "7. Breakage of braided shields with repeated cable flexing".

The oil filled cable has not exhibited this problem.

- "8. Mechanical damage during vehicle servicing".

Placement of cable during installation and protection of cable during vehicle servicing must be given design consideration. Good craftsmanship is required in the service and maintenance operations as well as during fabrication. While isolated cables have been damaged on ALVIN due to human error, damage is not incurred during routine servicing.

The cable runs on ALVIN are laced in place with clear nylon cable lace material. Where possible, PVC tubes or channels are provided for wire protection.

ALVIN Oil Compensated Systems

Oil-filled cables are one part of the total oil compensated system on ALVIN. Figure 1 shows the present system on ALVIN. The compensation fluid used in all parts except the battery box is Bray Oil Co. 3M-626. The battery boxes use Marcol 52. closer inspection of Figure 1 shows that there are several independent compensated systems. Each part has a drain/fill line, a vent line and a compensation volume. The fill and vent points should be at the lowest and highest places in the system.

Vertical separation between the system high point and low point should be reviewed carefully. In air, the oil in the system causes a hydrostatic head on the bottom of the system. In water the lighter oil results in a hydrostatic head at the top of the system. A sufficient volume of oil must be guaranteed under both conditions. In the ALVIN operation, the oil is filled just prior to launch to minimize excessive heads and loss of oil. In several cases, the neoprene front cover of a box acts as the compensation bellows. The major volumes are provided by separate bladder compensators. Every effort is made to insure that the cable is oil-hosing. The large, multiconductor cable used on the penetrators, and interbox control wire between the control center and the sphere disconnects was designed especially for oil hosing service. This cable is manufactured to a Woods Hole Oceanographic Institution drawing. Other wire is standard unblocked, neoprene jacketed commercially available cable.

In ALVIN, a considerable effort has been expended on simplifying and shortening wire and cable runs. The vehicle wiring harness has been completely redesigned and rebuilt several times as simplification could be effected.

Components

A listing of components used in ALVIN includes the cable as well as the related equipment such as stuffing tubes, penetrators, disconnects and oil filled boxes.

1. Cable

Several cable and single conductor wires are in use on ALVIN. These include:

(a) 24 Conductor Cable - The cable used on the penetrators as well as primary control wire runs is called '24 conductor cable'. It consists of 18 single #16 AWG wires and 2 #18 AWG shielded pairs per MIL-W-16878. Both the single wire and shielded pair have a teflon insulation. Early cable had some cracked teflon due to a manufacturing defect however this problem has been corrected and has not recurred. The teflon provides good service in oil and is preferred to a softer material. The outer jacket is neoprene with a minimum wall thickness of 0.125" per MIL-R-6855 cl II, grade 60. There are two shielded pairs and four single conductors in the center with a cotton twine wrap. The remaining single conductor are then placed around the core with a mylar wrap around the second layer, under the neoprene jacket. The cable has a nominal 10:1 lay ratio which provides a high flexibility. The manufacturer of this wire is Advance Cable and Assembly Co.

(b) Shielded Pair - The same shielded pair used in the 24 conductor cable is used alone with a neoprene jacket. The manufacturer of this wire is Advance Cable and Assembly Co.

(c) #4 Single Wire - can be either of two types. The first type uses a polyurethane insulator and a neoprene jacket. This type has a 1038 strand copper conductor for good flexibility. The manufacturer of this wire is Advance Cable and Assembly Co. The second type is a welding cable from Carroll Cable Co. that has a high insulation resistance.

(d) #10 Single Wire - The #10 single wire is a 10/1 cable manufactured by Vector Cable Co.

(e) #18 Single Wire - The #18 single wire is a general purpose oceanographic wire manufactured by Vector Cable Co.

(f) Tygon Tube - A new t.v. camera uses an oil filled tygon tube with a special connector from D. G. O'Brien. The connector mates to the t.v. camera and the other end goes through a stuffing tube into an oil filled junction box. A special bleed screw is part of the connector for venting air on installation. The tygon tube is of the oil resistant formulation. If an oil resistant formulation is not used, the oil causes the tygon to become brittle and crack.

2. Stuffing Tubes

All stuffing tubes are nylon units called "Dancos" that are distributed by the Penn El Service, Co. Refer to Figure 2 for a cross section view of a Danco. The body is installed from inside the box and an 'O'-ring and lock nut tightened on the outside. This provides a good low pressure seal to the box. The cap and washers compress the bushing around the cable to provide a seal to the cable. A large variety of standard bushings are available from Penn El Service, Co. and special bushings are available from Advance Cable and Assembly Co. These special bushings include 19 single #18 AWG wires in a No 4 T Danco, 5 single #4 AWG wires in a No 6 Danco and 10 single #10 AWG wires in a No 6 Danco, as typical configurations. Refer to Figure 3 for a typical bushing.

3. Penetrators

The titanium penetrators for the 12,000 foot TITANES hull were obtained by the Woods Hole Oceanographic Institution as part of the TITANES Program. The design guidelines for the penetrator include, (1) simplicity, (2) minimum number of penetrator parts, (3) two water pressure barriers, (4) all titanium parts, (5) no connectors, (6) cable suitable for oil hosing, (7) standard taper body, and (8) records suitable for Navy

certification. The final design satisfied all of these requirements. A cutaway view of the penetrator is shown in Figure 4. ALVIN has had good operational experience with this penetrator.

Refer to Figure 4 and note that both the inner and outer pressure barrier has a neoprene puck molded on the face of the pressure header. This neoprene is standard Navy-approved-for-salt-water-service-formulation. In one case, there has been evidence of neoprene degradation resulting in grounding conductors. As penetrators are rebuilt, this puck will be made of polyurethane to obtain higher insulation resistance and stability.

ALVIN has at the present time only one penetrator configuration. The original ALVIN design had four different penetrator configurations. This was reduced to three and finally two configurations on the steel hull ALVIN. The opportunity to reduce the number of types of penetrators to one was quickly utilized when the TITANES hull was built.

Discussions of future design improvements include elimination of the molded cable. A transition adapter would be fastened to the outer body of the penetrator to allow attachment of a tygon tube cable. The major difference between this configuration and the D. G. O'Brien 20,000 foot design is that there would be no connector. There would be a vent for bleeding all air from the cable at the penetrator. This configuration would allow replacement of wires in the field should that be required. Some "pull-strings" could be installed with the wires to help in this. All of this only indicates preferences and not an ongoing program at the present time.

4. Disconnects

There are two types of break-away disconnects on ALVIN. Both utilize the Cole Electric Co. ball and spring socket design contacts, developed for high reliability aerospace applications. Figure 5 is a cross section of this contact. The battery disconnect has 6 #4 AWG contacts around a vent tube. Figure 6 is a photograph of the top of a battery box with the disconnect installed. The main sphere disconnects are shown in Figure 7. These disconnects provide connection from forebody to afterbody and have 144 wires each. Should the sphere be released the disconnect will break away with minimum force. The sphere disconnects are installed in oil filled disconnect boxes that are pressure compensated. Oil flows easily from top to bottom box, and along the 24 conductor cables that enter the boxes via Danco stuffing tubes.

5. Junction Boxes

At convenient places around the submersible, oil filled junction boxes satisfy the requirement for easily accessible wire terminations. Standard terminal strips mounted in these boxes provide complete flexibility of wire interconnection. Figure 8 is a photograph of an open junction box with the fill and vent lines in position for servicing.

6. Basket Disconnects

ALVIN must be prepared to install and remove a variety of scientific instruments from the basket that is mounted in front of ALVIN. These instruments are built by the scientist making the dives, and may need to be changed each day. Anything connected to the basket must be capable of being released in the event of entanglement. These requirements are met by the basket disconnects shown in Figure 9. PVC end plugs with Danco's installed in them at the end of a radiator hose filled with oil provides an economic and satisfactory solution. An amphenol connector with the locking sleeve removed connects the wire inside of the hose. The radiator hose provides for pressure compensation as well as the disconnect housing. If the wire is pulled, the PVC plug pulls out of the hose, the amphenol disconnects and the basket falls free with minimum force.

7. Control Center/Propulsion Box

Figure 10 shows the control center with cables, Dancos, contactors, fuses and relays that comprise the power distribution center of ALVIN. The front cover of this box is a rubber sheet with a fiberglass outer cover for holding the oil column in air. The fiberglass is open to allow seawater to pressure equalize the oil in the box. This construction is the same for the propulsion box, lift prop box and all other externally mounted equipment.

NOTE: --- HOSING WIRES
 --- OIL HOSES

Figure 1

Figure 2

Figure 3

PENETRATOR-TITANES HULL

Figure 4

TYPICAL CONTACT INSTALLATION

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

References:

1. Robert J. Forbes, Michael A. DeLucia and Samuel H. Behr, Handbook of Electric Cable Technology for Deep Ocean Applications, published by the Naval Ship Research and Development Laboratory, Annapolis, Md. (Nov. 1970)
2. Donald G. O'Brien, Pressure-Compensated Electro-Connective Systems for Outboard Usage on Deep Submersibles, p. 309 of the IEEE '71 Engineering in the Ocean Environment Conference Proceedings.
3. DSSV Cable Report, Pressure Compensated Cables LMSC-D 177821-8 31 Aug. 1971, by Lockheed Missiles and Space Company.

List of Manufacturers

1. Advance Cable and Assembly Co.
10841 Laurel Avenue
Santa Fe Springs, Calif. 90670
(213) 944-9937
2. D. G. O'Brien
Rt. 30/ Exit 13 of Mass Pike
Framingham, Ma. 01706
(617) 872-6596
3. Penn El Service Co.
357 West 5th Avenue
Conshohocken, Pa. 19428
(215) 825-1622
4. Vector Cable Company
555 Industrial Road
Sugar Land, Texas 77478
(713) 494-9196
5. Viking Industries (Cole Electric Components)
21001 Northoff Street
Chatsworth, Ca. 91311
(213) 341-4330

*Season's
Greetings
from Acodac*