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Splicing of SD List 1 coaxial cable on the seafloor has been demonstrated to be feasible using a grease/gel filled coaxial splice. Experimental electrical models fabricated for underwater mating have been operated successfully at 6,000 VDC and 5,000 psig ambient pressure with leakage currents less than 1 μa. Impedance mismatches of the electrical models were about 0.4%. The search for a compatible dielectric grease for use with the SD cable splice identified a gelling agent (Cab-O-Sil) which can be used to gel liquids (continued)

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to a grease-like consistency. Castor oil, available in liquid form only, has some unique properties desirable for SD cable splicing applications. These are: (1) low water absorption (about 1%), (2) little or no change in dielectric constant with about 1% water absorption, compatibility with high density polyethylene, and ability to gel using Cab-O-Sil. Electrical splice models filled with gelled castor oil have been mated several times at 5,000 psig ambient pressure in seawater at 8°C. The splice was subjected to 6,000 VDC with no high voltage breakdown and leakage currents were less than 1 μa in each case. Due to lack of internal seals, the splice failed after a 30 day duration in the pressure vessel because seawater was forced into or migrated to the cable and splice interface area. The tests do show the feasibility of the underwater splicing concept of SD coaxial cables.

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INTRODUCTION

Work reported previously, reference 1, describes several mechanical and electrical test models of the List 1 SD coaxial cable underwater splice which were fabricated and tested successfully. A split washer strength member termination was shown to offer considerable promise but required further development and refinement. Electrical models tested in air and in water showed acceptable impedance mismatches of less than 1%. These models were also subjected to sustained high voltages of 6,000 VDC in air and no breakdown or leakage occurred.

This report concentrates on the work performed during FY-78 under the Ocean Facilities Engineering Block Program. This effort consisted of dielectric grease investigations and underwater mating of electrical splice models. Gelled dielectric fluids for use as a grease are shown to be most suitable for underwater SD coaxial cable splicing applications. Electrical models fabricated for underwater mating have been operated successfully at 6,000 VDC for 30 days at 5000 psig. Impedance mismatches of the electrical test models were about 0.4%.

BACKGROUND

Figure 1 shows the SD coaxial cable underwater splice concept. The entire splice unit is prefabricated with a suitable length of replacement cable attached. A splice unit is connected to each end of a cable repair section. The length of the section depends on the extent of the damage and cable separation caused by parting the cable under tension on the seafloor (reference 2).

The splice unit is designed for mating to the prepared end of the undamaged coaxial cable on the seafloor independent of depth. All that would be required to repair a damaged SD cable is to cut out the damaged section, prepare the ends of the cable to fit into the splice units and insert the cable ends. Once the cable is inserted, the splice unit will restore approximately 75% of the original 16,000 lbs breaking strength, restore transmission characteristics, prevent seawater from leaking into the splice and provide protection of the spliced area from the environment.

Description of Splice

Figure 2 shows the internal mechanisms of the splice concept. The center strength member of the SD cable is held in place by a specially designed split-washer cable gripping mechanism which is housed inside a steel body. The steel body is gold plated to improve conductivity. A Multilam band captured by the steel body makes contact with the inner copper conductor of the prepared cable end and restores electrical continuity through the splice. An O-ring seal, also captured by the steel body, will prevent seawater from hosing back into the interface area from the previously exposed strength member. Also the O-ring prevents grease from hosing into the steel strands by preventing pressure loss in the cavity containing the split washers.

The geometric relationship of the coaxial cable inner and outer conductors for proper impedance match is provided by the specially shaped acrylic (or polyethylene) dielectric. The shape is defined by the ratio of the inner and outer conductor radii where:

$$Z_o = \frac{60}{K} \ln \frac{r_o}{r_i}$$

where K = dielectric constant of inner dielectric

r_o = outer conductor radius

r_i = inner conductor radius

Z_o = 44 ohms for SD coaxial cable

A brass or copper sleeve, which captures the interface seal and a Multilam band, fits over the acrylic dielectric body. This sleeve provides electrical continuity for the outer shield conductor through the Multilam band and on through the splice. The interface seal prevents water which hosed up the cable between the outer copper conductor and the polyethylene dielectric from entering the interface area.

The interface seal is fabricated from a conductive or semi-conductive material to assure proper impedance matching.

Grease channels from inside the split washer housing through the steel body (by means of a check valve to the rear of the split washers and into the rear grease reservoir allow the displaced gelled dielectric to flow freely during cable insertion. Grease channels in the interface area also allow gelled dielectric to flow freely to fill voids in these areas and also vent into the compensating grease reservoir during insertion of the cable.

Over the entire copper sleeve is a flexible rubber boot which also forms the grease reservoir and the compression seal on the ends. The entire unit is enclosed by a steel pod for protection from the environment.

The splice is completely filled with a gelled dielectric grease to keep seawater out and fill all the voids. It is fitted with wiping seals at the entry to aid in wiping the cable of seawater as it is inserted into the splice unit. The end of the steel pod is equipped with a serrated gripping mechanism to grip the polyethylene outer jacket. The gripping mechanism prevents the residual tension in the outer jacket from pulling it out of the splice. Flexural strain relief for the cable is also provided.

Operating Scenario

The operation of the splice is as follows. First, the damaged cable is located, the damaged portion is removed and the ends of the remaining good cable are prepared to fit into the splice. Next, the cable ends are inserted into the splice. As the cable is inserted, the wiping seals wipe the cable of seawater. The gelled dielectric being displaced by the insertion of the cable carries seawater out and also helps to wipe the dielectric interface. The strength member reaches the split washer strength termination and passes through easily. At the same time all the seals begin to seal onto the cable and excess gelled dielectric from the interface area and the split washer termination housing flows into the grease reservoir. The compression seal releases excess gelled dielectric to seawater and seals onto the outer jacket. Also, the Multilam bands engage with the inner and outer conductors and restore electrical continuity. After the cable is fully set into the splice, a slight withdrawal (1/8 inch maximum) of the cable will engage the split washer strength termination. Any voids formed at the interface by this movement will be automatically filled with gelled dielectric from the grease reservoir. The outer jacket gripping mechanism is actuated by a sliding cone type device which cause the serrated jaws to grip the outer jacket. The steel pod serves only to protect the splice from abrasion on the seafloor. Once the two ends of the splice are connected to the existing cable the repair is completed.

Problem Areas

Discussions with personnel knowledgeable about conventional SD cable splicing clearly point out the interface between the cable dielectric and the splice dielectric as the key problem area. The presence of sustained high voltage on the cable can cause dielectric breakdown or corona noise in this area even with existing surface splicing by injection molding techniques. The long term effects of the dielectric gel on the polyethylene dielectric used on the SD coaxial cable are not fully studied yet so this is a prime area of concern. The effects of seawater on gelled castor oil also require further study.

Since the success of an underwater repair system for SD coaxial cable depends on the reliability and performance of the splice itself, these two areas were considered first. The entire concept of the self-contained splice depends on the use of a grease to prevent seawater from entering the splice during mating with the cable on the seafloor and an interface with no corona noise or breakdown in the presence of high voltage. This investigation is discussed in the following.

APPROACH

A search for a dielectric grease compatible with high density polyethylene was conducted first. Many compatible dielectric materials come in liquid form only. However, a gelling agent was identified which can be used to gel liquids to a grease-like consistency. This agent has some unique properties when used to gel liquids which are discussed later.

After studying and then selecting dielectric greases and fluids, wet mateable high voltage test models were fabricated and tested in shallow water to determine the feasibility of the wet mating concept. After successful completion of the shallow water tests, the models were tested in the pressure vessel to simulate deep ocean applications.

DIELECTRIC STUDY

Several dielectric fluids were identified for use with the splice. Since many petroleum products attack the high density polyethylene dielectric of the SD coaxial cable, only non-petroleum dielectric fluids and petroleum products compatible with polyethylene were studied. Some of these fluids were mineral oil (Marcol 70), inert fluorocarbon (Fluorinert PL-77), castor oil, silicone fluids and grease, and transformer oil. The approach was to determine the best dielectric candidates in terms of cost, availability, ability to gel using a gelling agent (Cab-O-Sil),resistance to water absorption, dielectric properties, and compatibility with polyethylene.

Cab-O-Sil

Cab-O-Sil is fumed silicon dioxide (silica) manufactured by the Cabot Corporation. The lack of significant amounts of ionic impurities makes Cab-O-Sil an excellent dielectric in itself. Hence, it has been used frequently in electrical insulators. The most unique of Cab-O-Sil's characteristics is its ability when used as an additive to modify flow properties. It does this by building a three dimensional network of Cab-O-Sil aggregates in the fluid which alternately forms and breaks in response to the degree of shear force applied. Hence Cab-O-Sil's important and widespread use in liquid systems is for the control and increase of viscosity and thixotropy. A thixotropic system is one which exhibits a time dependent decreasing viscosity or shear stress at a constant shear rate. Eliminating the shearing force will allow the viscosity to return over a period of time to its original static valve. The combination of thickening and thixotropic properties of Cab-O-Sil makes it an ideal substance to use in the formation of dielectric gels for use in the splice. Refer to Appendix A for additional information on Cab-O-Sil.

Dielectric Fluid

Two dielectric fluids, castor oil and Marcol 70 mineral oil were chosen for testing because of their low water absorption characteristics and good dielectric properties. The Naval Research Laboratory performed studies on castor oil (reference 3) and found that castor oil had a very low water absorption characteristic of about 1%. More significant is the fact that the dielectric constant does not change with absorption of water.

Because of this Naval Research Laboratory study, a detailed analysis of castor oil was not performed. Rather, the gelling of castor oil by Cab-O-Sil was studied and the gelled castor oil was tested in the splice configuration. Also Marcol 70 mineral oil was gelled and tested on the splice.

Experiments determined that approximately 9.4% by weight of Cab-O-Sil added to castor oil produced a gel which had the consistency of soft grease. For Marcol 70 mineral oil 6.4% of Cab-O-Sil by weight was required to obtain a gel with the same consistency.

When the grease-like gelled castor oil and Marcol 70 were subjected to shear stresses from a mixer, the gel became less viscous such that when the container was tipped, the gel flowed like very thick oil. After the shear stress was removed, the gel returned to its original grease-like consistency.

During mating of the cable to the splice, the gelled dielectric is subjected to shear stress and becomes less viscous enabling the gel to flow more easily. Once the cable and the splice are set and movement ceases, the castor oil returns to its original static gelled state.

SPLICE TESTING

Two underwater mateable electrical models were fabricated for testing in shallow water and in the pressure vessel for deep water applications. First, a high voltage underwater mateable model was fabricated and tested. Upon successful completion of these tests a complete laboratory electrical model was fabricated and tested. After testing was completed these models were placed in pressure vessels for long term tests under sustained high voltage which will continue until failure occurs.

High Voltage Underwater Mateable Model

Figure 3 shows the high voltage underwater mateable test model in the test stand prior to pressure vessel tests. The splice model shown on the lower portion of Figure 3 was first tested in shallow seawater (about 3 feet deep). This model was designed and fabricated to test the wet mating concept and to test for high voltage breakdown or leakage currents at the interface area after being mated in seawater at 5000 psig ambient pressure. Figure 4 shows a cross-sectional sketch of the model. It consists of a brass sleeve with Multilam bands, a neoprene wiping seal, an acrylic dielectric and a check valve assembly.

The model was filled with gelled dielectric and then placed in seawater without the wiping seal. The SD cable was then inserted into the splice and 6,000 volts DC was applied. This sequence was repeated several times. The results were inconsistent in that sometimes there were no high voltage breakdowns and sometimes it failed completely.

Analysis of the first splice model, without wiping seals, revealed that the gelled dielectric by itself was not completely wiping the cable of seawater as it was being inserted. Hence, the interface area had trapped seawater which caused the splice to fail.

To solve this problem, a wiping seal was placed over the splice entry. The seal consisted of a neoprene rubber sheet with a hole large enough to fit over the inner conductor (see Figure 5) and four additional holes to allow gelled dielectric to be expelled from the splice. As the cable is inserted into the splice the seal helps to wipe seawater from the inner dielectric interface area.

With the addition of the wiping seal shallow water mates resulted in no high voltage breakdown and essentially zero leakage current ($<1\mu A$). Several shallow water tests were conducted and the voltage was raised to 10 KV. There were no failures with gelled castor oil for 14 days, however, gelled Marcol 70 failed after 3 days under sustained 10 KVDC in seawater.

The splice was then prepared for pressure vessel tests. The splice was mated at 5000 psig and afterwards 6 KVDC was applied for 1-2 hours. A total of seven mates were performed in the pressure vessel and in each case the splice had no high voltage breakdown or leakage current. These test results were particularly significant in that they show the feasibility of the underwater mating concept.

This model was placed back in the pressure vessel for a long-term test and after 30 days at 5000 psig and 6 KVDC the splice failed. Post test analyses showed that the lack of internal seals allowed seawater to be forced or to migrate into the interface area.

Complete Electrical Laboratory Model

Based on the test results of the high voltage model, a complete laboratory electrical model was fabricated. The complete electrical model (shown in Figure 6) was designed for impedance matching, sustained high voltage, experimental internal seals, mating at pressure in seawater, and pressure compensation. The internal arrangement of the splice is very similar to that shown in Figure 2 except split washers, outer jacket gripping mechanism, inner conductor seal, check valve and repair section assembly, were not included. The differences of this model and the high voltage underwater mateable model are: (1) longer entry for more wiping action of the gelled dielectric on the cable, (2) specially shaped acrylic dielectric for an impedance match, (3) internal seals added to prevent seawater from entering interface area, (4) pressure compensation by means of a grease reservoir, and (5) two wiping seals fabricated from a perforated Neoprene diaphragm (exterior wiping seal can be seen in Figure 5).

The electrical model was packed with gelled castor oil and placed in a test fixture for mating underwater at pressure (shown in Figure 7). A total of four mates were performed, two with instrumentation for impedance matching and two for high voltage breakdown leakage current. Separate tests were necessary because the available coaxial connector through the pressure vessel head could not operate under high voltage. The pressure vessel seawater temperature was about 8^{o}C.

The first two mates at 5000 psig were instrumented with a Tektronics Model 1501 Time Domain Reflectometer (TDR). The results showed a reflection of 0.4% due to impedance mismatch. The second set of mates were to test for high voltage breakdown/leakage current using a Hi-Pot cable tester. The splice was subjected to 6 KVDC and no breakdown occurred. Leakage current was only about 2 μa and most or all of it was from leakage in the cabling and connectors through the pressure vessel head. The splice was left for 6 days at 5000 psig and a 6 KV was sustained with no breakdown or increased leakage currents. The model was removed after 6 days because of pressure vessel scheduling.

DISCUSSION/CONCLUSION

The test results of the high voltage model and the complete electrical model demonstrate that the underwater splicing concept does work. Long term effects are not known at this time and will be studied as data becomes available.

One particular problem of concern is seawater which hoses up the damaged cable and becomes trapped between the steel strength members and between the dielectric and outer conductor. The hosing can cause problems since once the cable is set inside the splice, gelled dielectric can also hose up into the cable and deplete the splice of pressure compensating gel. This problem can be overcome by the design of special seals at the critical locations.

PLANS

Additional studies will be conducted on gelled castor oil. These studies will concentrate on long-term effects of sustained high voltage, pressure, temperature, contact with seawater, and contact with other slice materials. Long-term effects of seawater, pressure, and high voltage on the electrical models will be analyzed. In a parallel effort, seals will be designed and tested for use in the splice. Based on the results of these tests and analyses, a complete electrical prototype model with seals, will be fabricated and tested.

Design and testing of the split washer strength termination will also be conducted in parallel with the material and seal studies. Analyses of cable and fault location methods will be conducted as well as studies of alternate damaged cable replacement sections. The concept analysis for a cable end preparation machine will also begin.

ACKNOWLEDGEMENTS

The assistance of Mr. J.V. Wilson and Mr. T. Roe, Jr. was invaluable in development of the splice concept and analyzing the test data.

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1. Civil Engineering Laboratory. Technical Memorandum 43-77-21: Underwater Splicing of SD Coaxial Cable, by A.T. Inouye, Port Hueneme, CA, September 1977.

2. Civil Engineering Laboratory. Technical Memorandum 43-78-14: Movement of Seafloor Cable When Parted Under Tension, by J.V. Wilson and R.L. Brackett, Port Hueneme, CA, November 1978.

3. Naval Research Laboratory Problem 82 S02-43, Sonar Transducer Reliability Improvement Program, quarterly reports for FY-78 by Dr. R.W. Timme.

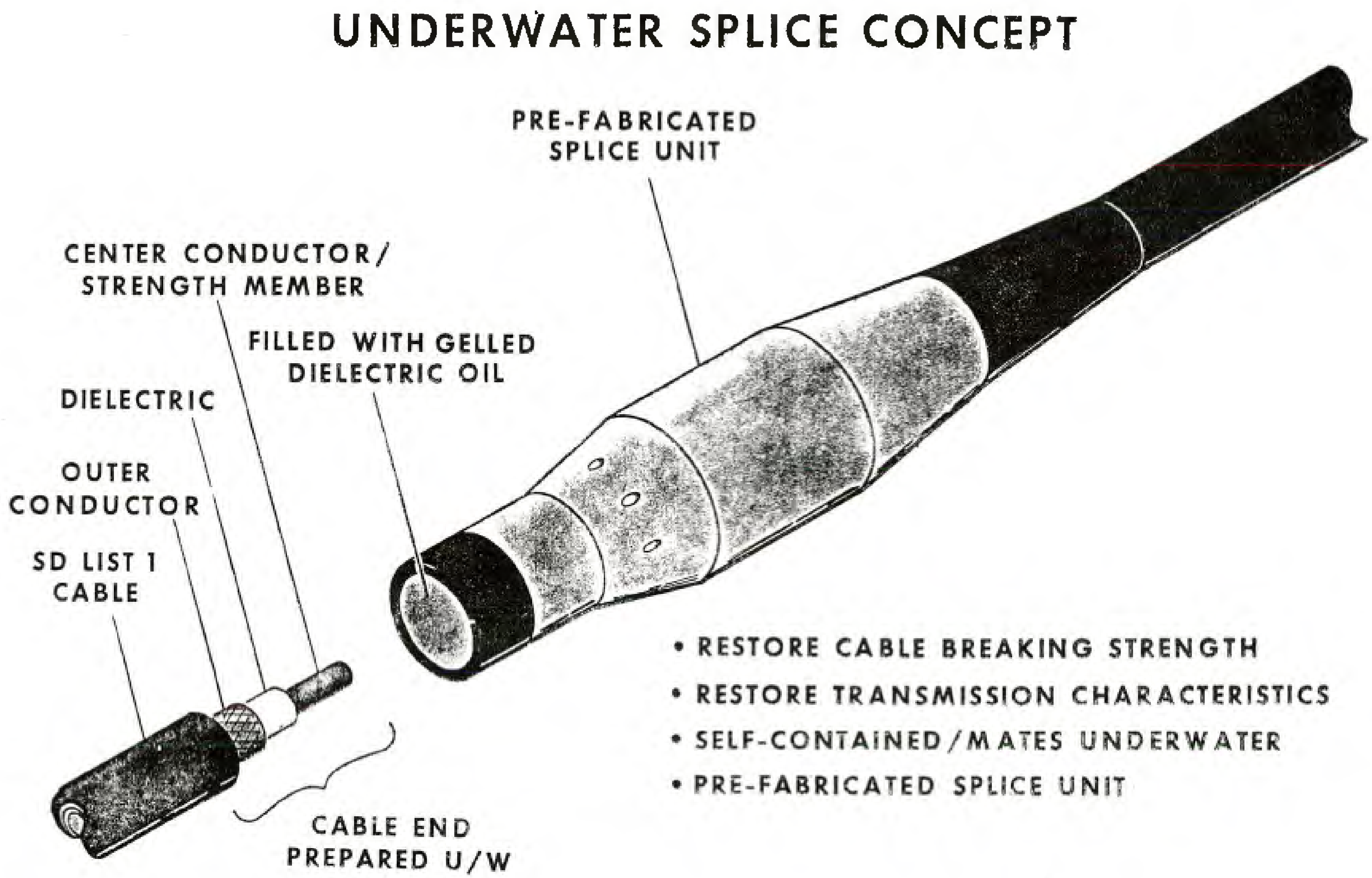


Figure 1. Underwater Splice Concept.

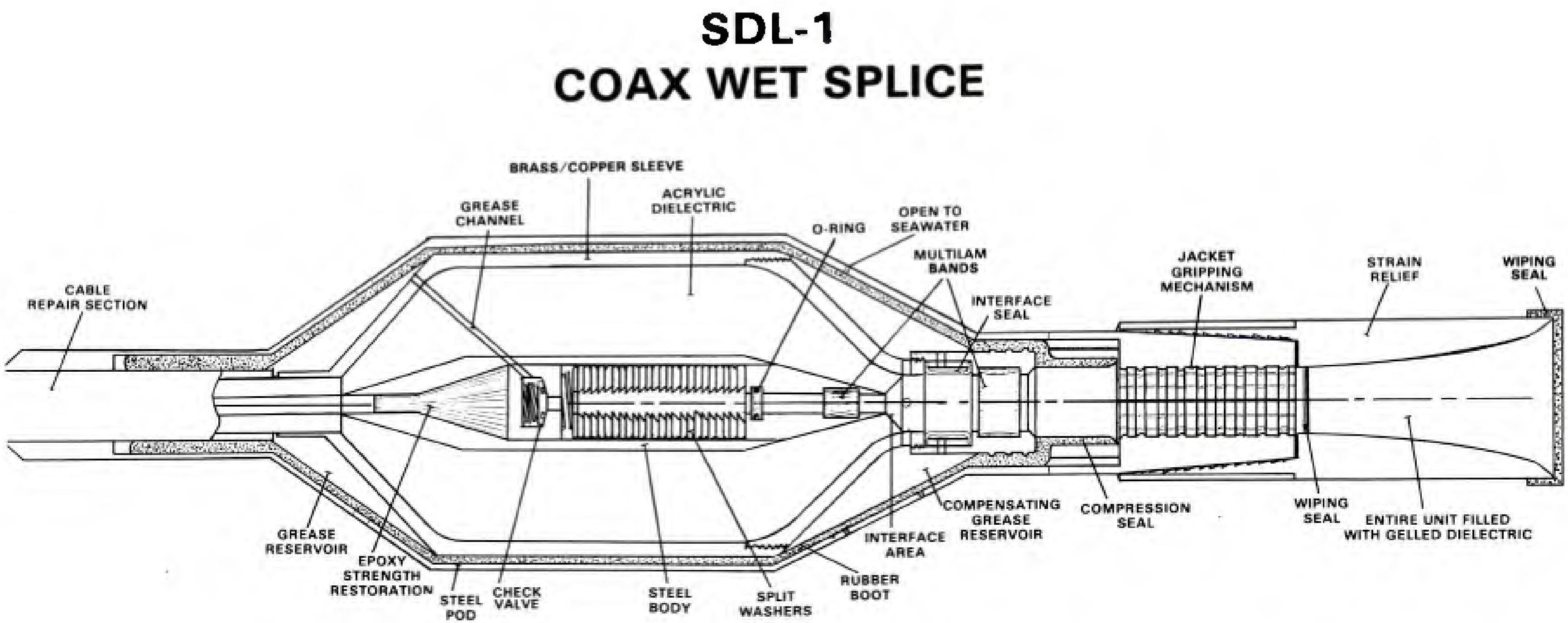


Figure 2. Cross-section Splice Concept.

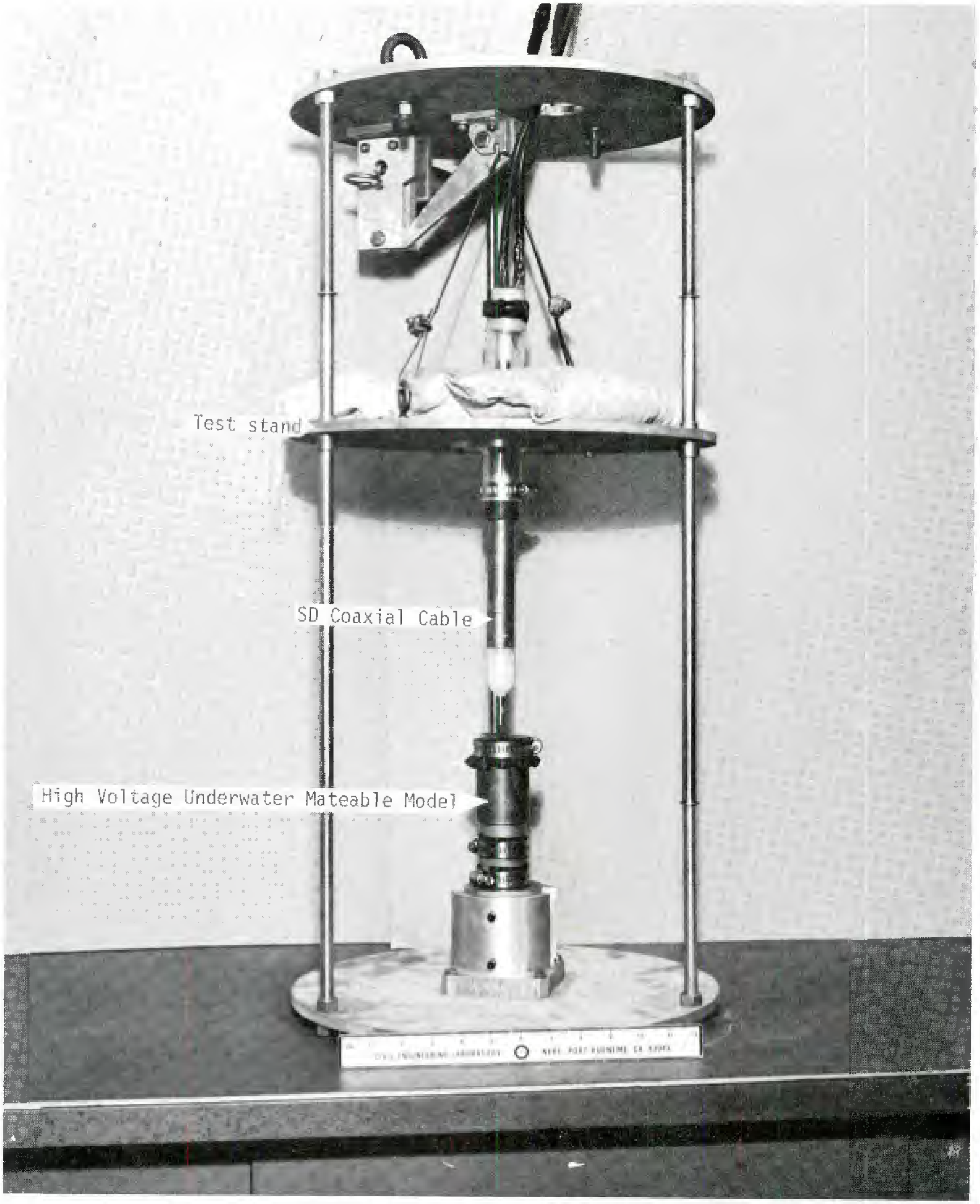
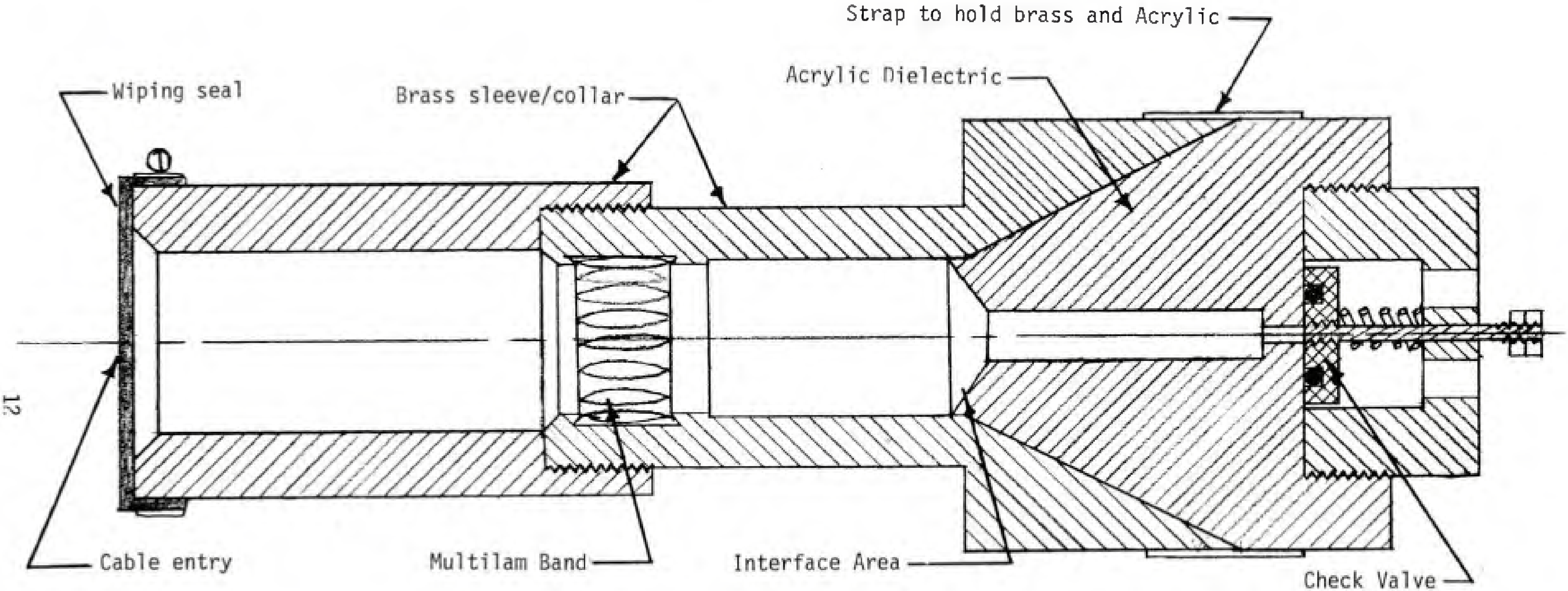


Figure 3. Wet mateable high voltage model in test stand (unmated position).



Not Designed for Impedance Matching

Figure 4. Cross-section - wet mateable high voltage model.

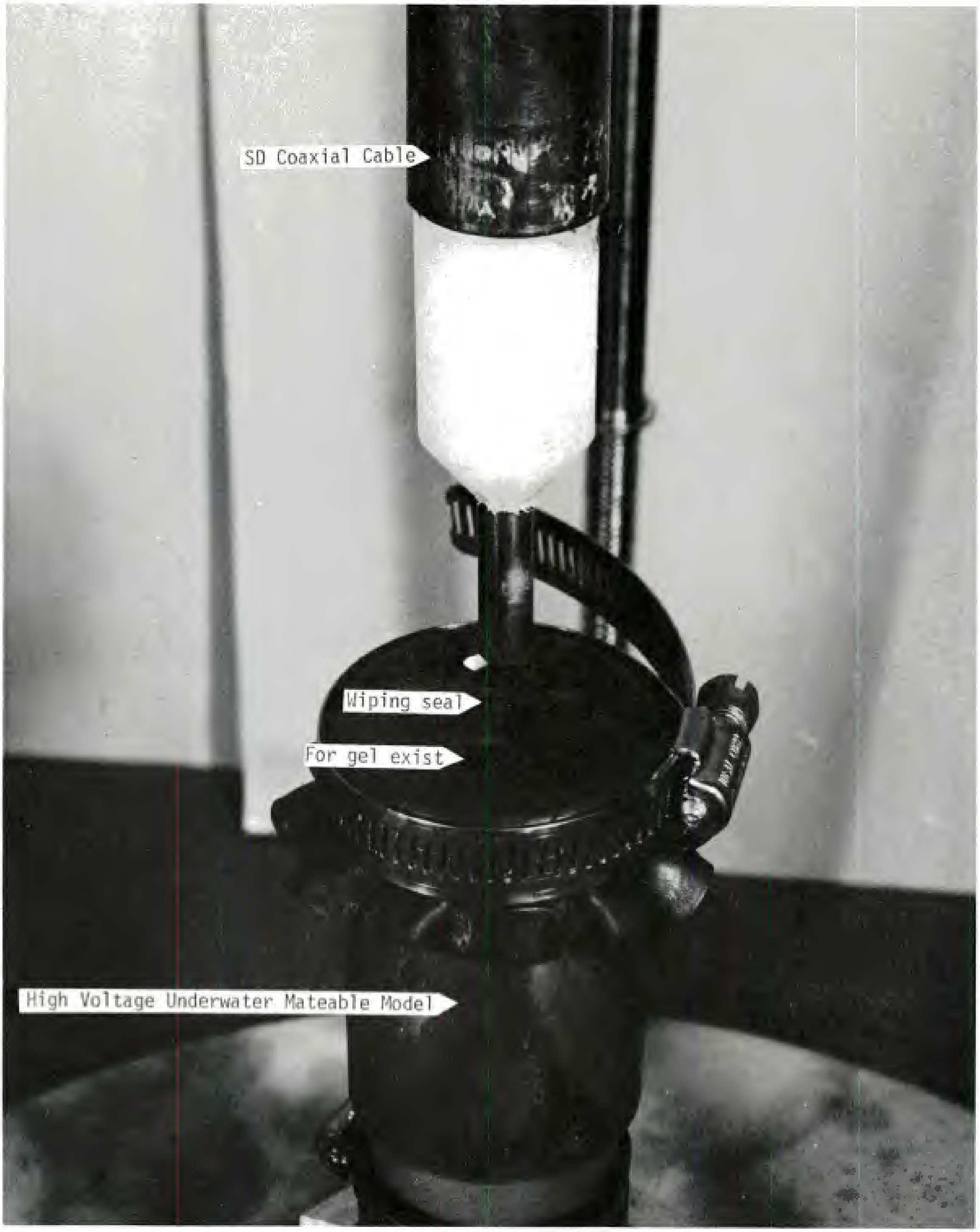


Figure 5. Experimental wiping seal for the SD cable splice.

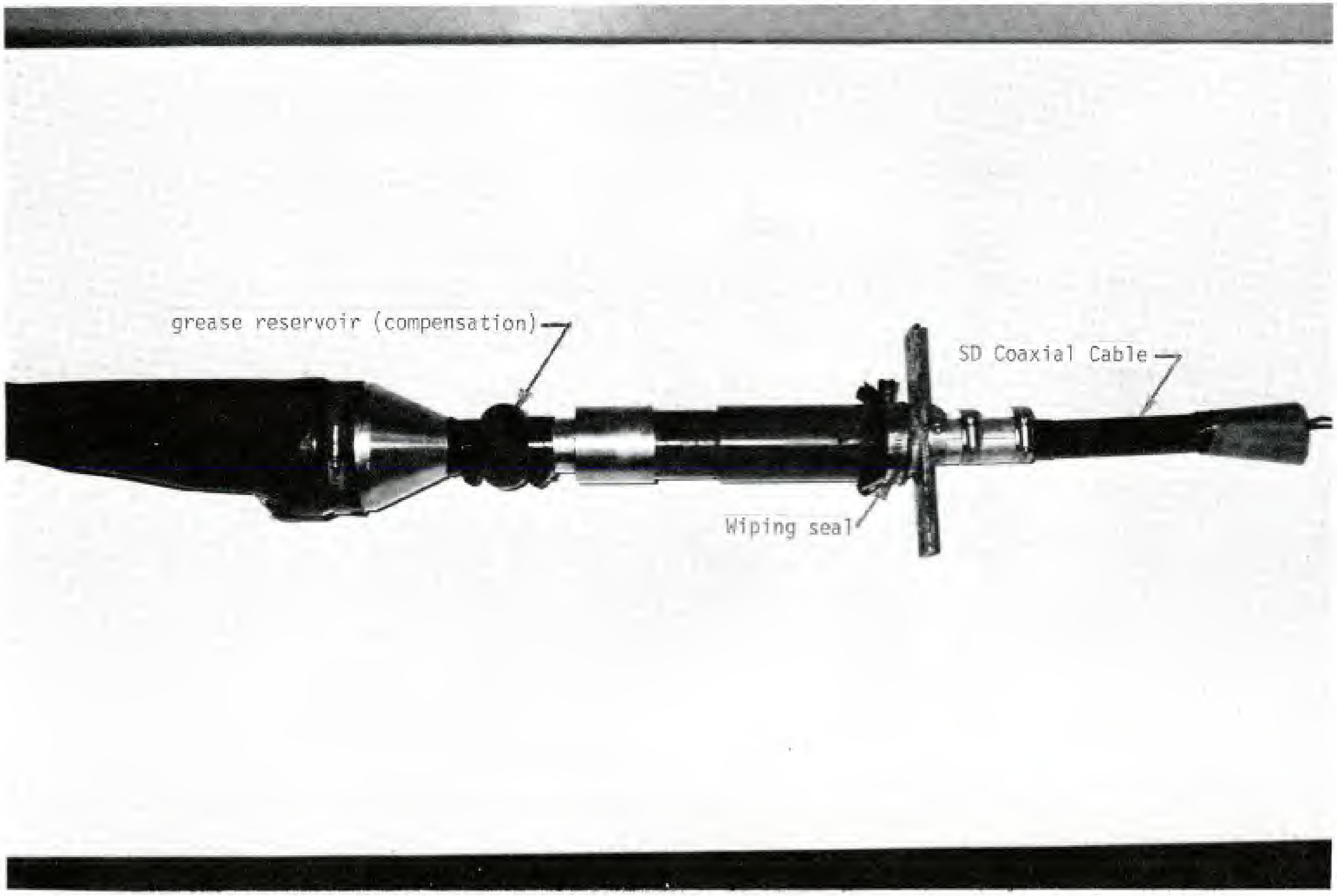


Figure 6. Complete elctrical model.

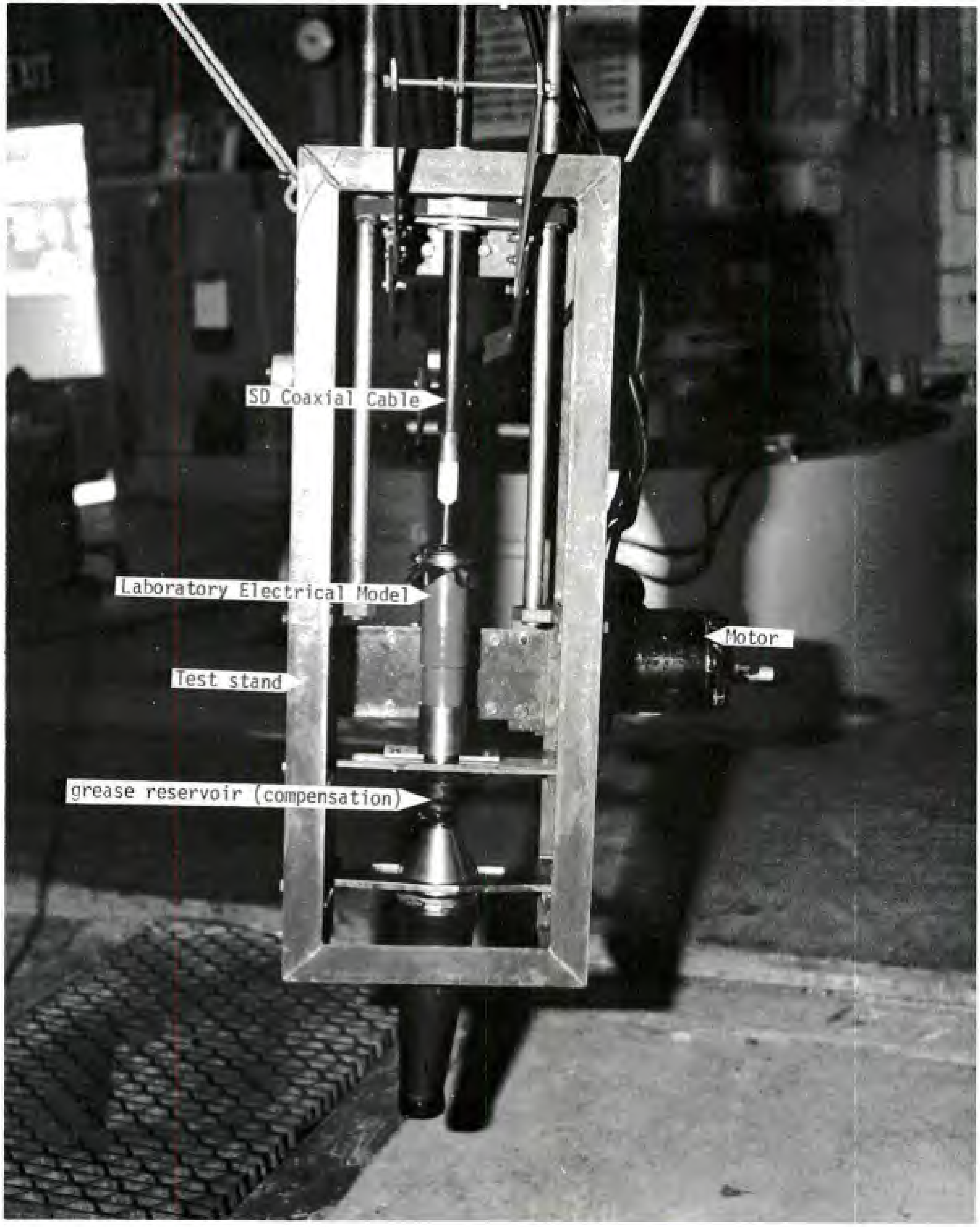


Figure 7. Motor driven mating test fixture.

APPENDIX A

Cab-O-Sil is the Cabot Corporation trade name for fumed silicon dioxide (silica) which is produced by the hydrolysis of silicon tetrachloride vapor in a hydrogen oxygen flame. Molten silica spheres of from 7 to 14 millimicrons (7 to 14 x 10^{-9} meters) can be formed by process variations and these fuse together to form branched, three-dimensional, chain-like aggregates. Agglomeration occurs as the aggregates cool below the fusion temperature of silica and entanglements take place. Further agglomeration takes place during the collection process. The residual hydrogen chloride adsolved on the surface of the Cab-O-Sil during its production is reduced to less than 200 ppm by calcination. Also, during formation of Cab-O-Sil, hydrogen groups become attached to the silicon atoms, thus making its surface hydrophilic and capable of hydrogen bonding with suitable molecules in vapor, liquid, or solid form, but especially between Cab-O-Sil aggregates. A network of silica will form when a sufficient concentration of Cab-O-Sil is thoroughly dispersed in most liquid systems, with the result that thickening and thixotropy are imparted to those systems.

Reference: Cabot Corporation Brochure, Cab-O-Sil Properties and Functions

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