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NAVY DEPARTMENT

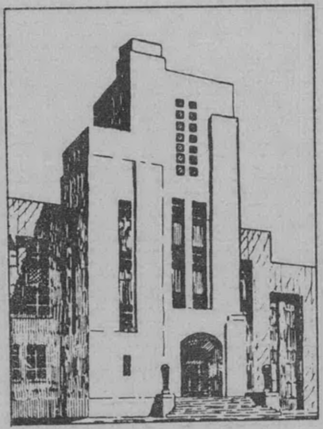
THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

TECHNIQUES FOR PROTECTING AND WATERPROOFING RESISTANCE WIRE STRAIN GAGES

by

Mills Dean, III



RESEARCH AND DEVELOPMENT REPORT

March 1956

Report 797

Second Printing May 1956

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ABSTRACT

This report describes new waterproofing techniques and materials for protection of strain gages and associated wiring. Certain synthetic rubber compounds and two wax products have been found to be very satisfactory waterproofing materials. Techniques for the use of these materials are described in detail. In addition to providing good waterproofing, the synthetic rubber compounds afford considerable mechanical protection from turbulent water flow, underwater explosion shock, particle abrasion, and direct mechanical contact.

Other potentially useful waterproofing materials, including a vinyl plastisol, are discussed. Information is given on satisfactory types of wire and cable for use with gage installations subject to water immersion. Details are presented on the dehydration and reactivation of gages that have become unusable due to absorption of moisture. Details are given for an entirely new method for protecting gages on the exposed surface of underwater ship hull plates in which connecting cables can be replaced without disturbing the strain-gage wiring.

INTRODUCTION

Many experimental research and testing projects conducted at the David Taylor Model Basin require that multicomponent strain gage balances be operated in water or other fluids for varying periods of time. The problem of providing adequate waterproofing for such installations led to the initiation of a comprehensive investigation of waterproofing materials and to the development of techniques for efficient use of these materials. It should be noted that much has been accomplished in the past on the problem of waterproofing strain gages for installation on large surfaces such as ship hull plates.[1-5] Problems of a different nature, however, are encountered in waterproofing small multicomponent strain-gage force balances in that the sealing area available around the gages is limited and the flexures to which a waterproofing material must be applied are usually quite thin.

Materials for waterproofing resistance-wire strain gages should be free from moisture, active acids, and salts since these might cause corrosion of the gage elements or the connecting leads. They should be free from solvents that might adversely effect the gage bonding cement. Water absorption, if any, should be at a very slow rate. They should be pliable over a wide range of temperatures and should adhere tenaciously to metallic surfaces. In addition, it is desirable that the materials be rugged enough to provide some mechanical protection for the gages, yet additional stiffness and bulk must be kept at an absolute minimum. These are major requirements. They are not necessarily compatible with one another. Nevertheless, they provide standards which aid in the evaluation of waterproofing materials.

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[1] References are listed on page 30.

This report is mainly concerned with materials which in large measure meet the above standards and have proved satisfactory in actual use. The techniques for the use of these materials are also described.

In addition, as an outgrowth of this investigation, an entirely new technique has been developed for waterproofing strain gages on the exposed underwater hull surfaces of ships. Details of the "Dean Shim Cap Method" of gage waterproofing are given in the section on Techniques of Application. This technique was first reported in the Bureau of Ships Journal for August 1955.

Results from actual field use of the materials and techniques presented in this report have been very successful. Strain-gage balances protected with Di-Jell 171 will withstand submergence in still water for as long as four to six months. 3-M compounds are used where turbulent water flow is expected. Figures 1, 2, and 3 are typical examples of such uses on small balances. Gages and wires on the exposed surfaces of hydrofoils protected with 3-M compounds have withstood water flow at velocities of 60 knots. Gages on exterior underwater hull plates of a destroyer have operated satisfactorily during three and one-half months of Atlantic cruising.

Techniques have also been developed for the reactivation of gage circuits that have become water saturated after long periods of exposure; these are discussed in Appendix B.

A preliminary, informal report on waterproofing of strain gages was issued in October 1952 and revised in February 1953 and again in June. The main text of the June revision was published in Volume 8 of Baldwin-Lima-Hamilton's "Testing Topics" for October 1953. Some of the material included in the present report was discussed by the author, with illustrations, at a session of the Strain Gage Techniques Panel during the spring meeting of the Society for Experimental Stress Analysis at Cincinnati, Ohio, on 15 April 1954; it was also presented as one section of a paper delivered at the 10th Annual Instrument-Automation Conference and Exhibit of the Instrument Society of America, 13 September 1955, in Los Angeles, California.[7]

To date, no single material or technique has been found which is distinctly superior to all others for general use in waterproofing strain gages. The search for the ideal material is continuing. Perhaps this report will stimulate further work and result in the discovery of an ideal "do all" material. The author welcomes comments.

GENERAL CONSIDERATIONS

Resistance-wire, SR-4* strain gages that are immersed in water or used in humid atmospheres must be completely protected from moisture if they are to function properly. The effect of moisture or water in contact with the gage is to produce an undesired electrical leakage path, shunting the gage elements to one another and to the metal in which the gage is mounted, i.e., "ground." This usually results in a decrease in gage sensitivity and a shift in

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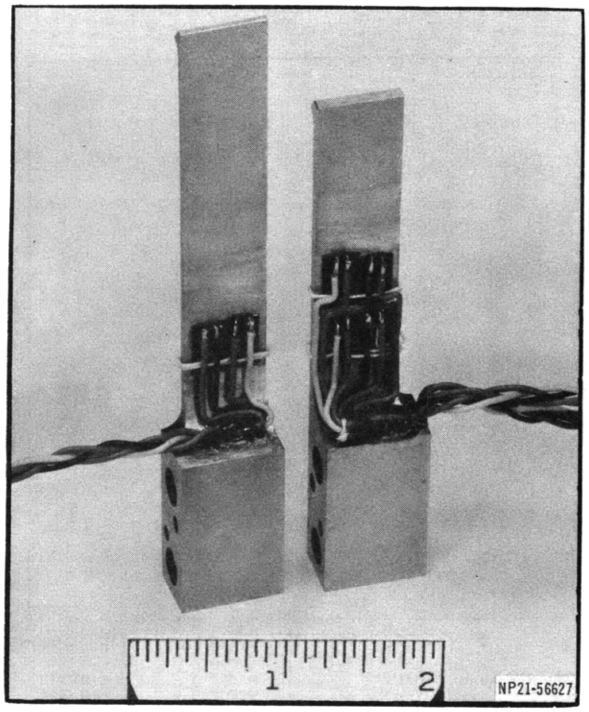

Figure 1 - Gaged Flexures for Underwater Use - Before Waterproofing

These bending flexures are fitted with bakelite gages wired into bridge circuits. The left flexure has one complete 4-arm bridge; the right, two separate 4-arm bridges. The gages and wiring had to be protected from handling during installation and from a 10-foot static head of water during use. Protection was provided by 3-M synthetic rubber over Di-Jell wax.

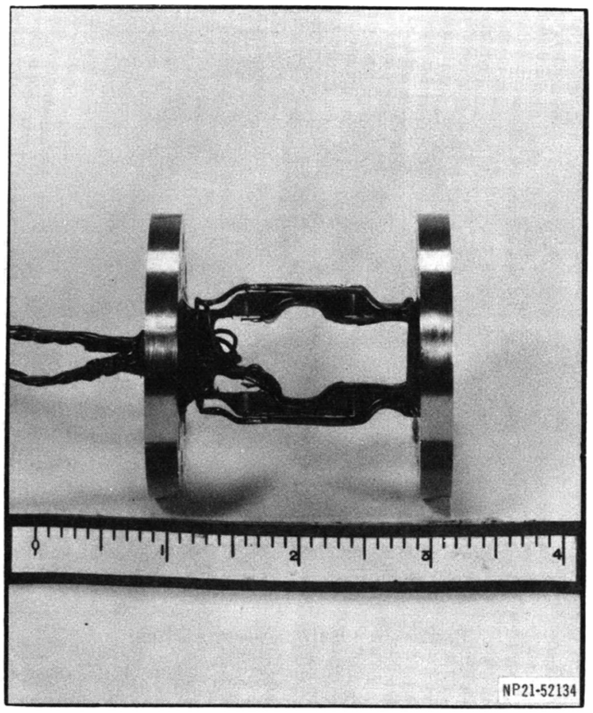

Figure 2 - Two-Component Balance – Before Waterproofing

This two-component strain gage balance was designed for 2 lb lift and 10 in-lb moment. The lift gages are mounted in the four interior corners of the two parallel columns. The moment gages are mounted in pairs, side by side longitudinally in the center of the outer flat faces of the columns. This balance was initially waterproofed with the 3-M compound. This introduced a hysteresis effect of ± 8 microinches strain, which was about ½ of 1 percent of the full-scale lift signal. To reduce the hysteresis to an even lower value, the balance was re-waterproofed with the soft wax, Di-Jell 171. No hysteresis was noted after the Di-Jell was substituted for the 3-M.

bridge-balance zero. Depending on the magnitude of these changes, the measurement accuracy may be seriously impaired or the gage installation may be completely unusable. Moisture also gradually weakens nitrocellulose cements with which paper gages are assembled and destroys the bond between the gage and the mounting surface. Bakelite base gage material and bakelite cement usually withstand the effects of moisture, but exposed gage wires are still adversely affected.

The initial resistance to "ground" of a properly applied and dried strain gage, either paper or bakelite, will usually be in the order of 1000 to 10,000 megohms. There is little adverse effect on the electrical response of the gage as long as this leakage resistance does not fall below about 25 megohms, the tolerable lower limit being dependent on the accuracy and stability requirements of the particular test at hand. The effectiveness of any waterproofing coating is judged by the degree to which it helps maintain this high leakage resistance when gages are exposed to moisture or submerged in water.

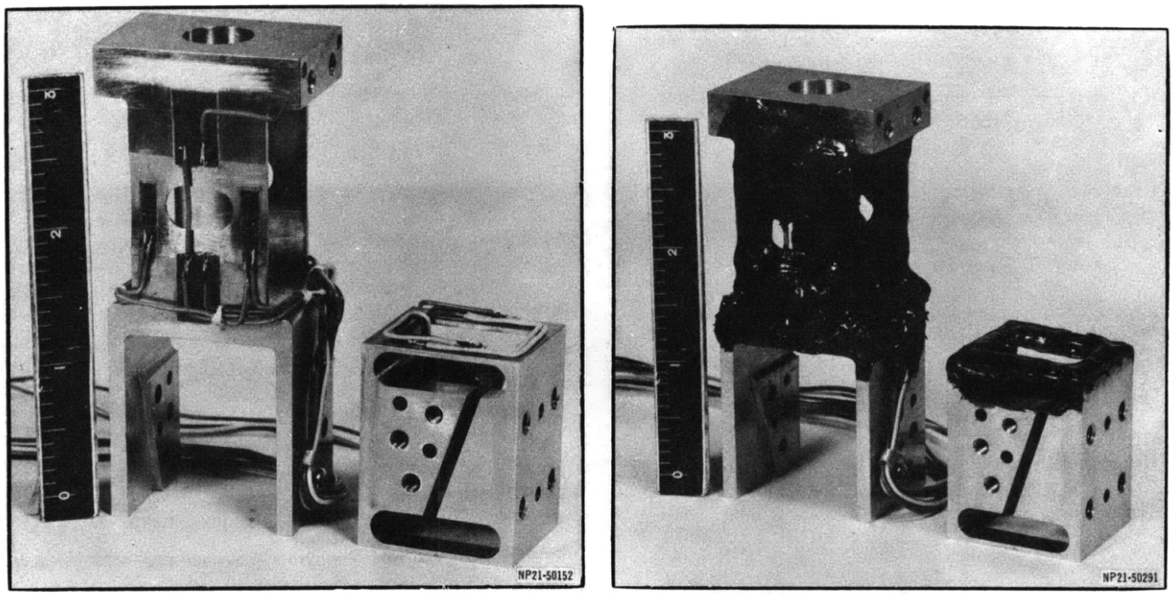

Figure 3a - Before Waterproofing **Figure 3b - After Waterproofing**

Figure 3 - Three-Component Balance

The strain-gage balance, shown here disassembled, was designed to measure three components, viz. drag, lift, and torque. AB-19 and AB-11 gages were used for the three separate 4-arm bridges. In Figure 3a, the balance is shown gaged, wired, and ready for calibration. In Figure 3b, the waterproofing has been applied and the balance is ready for recalibration. The waterproofing material did not affect the calibration. The 3-M waterproofing material firmly protected the gages and connecting wires against damage from handling and water penetration. The balance has been in use periodically for 3 years.

The need to waterproof strain gages on multicomponent balances, with which this investigation is particularly concerned, presents many especially difficult requirements. Usually these balances are very small and compact with narrow and thin flexure elements on which the gages must be installed. There is usually only a very small area around the gages to which waterproofing material may adhere. Also, since the flexures are thin, the characteristics of the balance would be changed by any noticeable stiffness, lack of compliance, or hysteresis of the waterproofing material. These balances are usually intended for precision measurements, with required accuracies in the range of 0.1 to 0.5 percent, and the mechanical properties of the waterproofing coating must, therefore, have a negligible effect on the characteristics of the balance. At the same time, the waterproofing qualities of the coating must be adequate to maintain a high and stable leakage resistance so that the electrical characteristics of the gage circuits are also not disturbed.

One vital factor in the waterproofing problem is the length of time over which the gage is to be submerged. Ideally, the waterproofing should be good indefinitely, and this remains the ultimate goal of this project. However, in practical application of strain-gage balances and similar instrumentation, submersion of several days to a week or two at a time is frequently all that is required. Sometimes it is possible to remove the instrument from the water occasionally, e.g., overnight, and dry it out. These are considerations which enter the picture in each individual application and which may ease the problem in some cases.

EVALUATION PROCEDURES

Certain general criteria were established as guides for the selection of suitable waterproofing materials and the development of application techniques:

1. The material should provide adequate mechanical and electrical protection for gages that may be subjected to high static or dynamic water pressures or turbulent water flow.

2. It should provide mechanical protection for gages and connecting wires so that dynamometers, balances, and other devices fitted with strain gages can be handled without undue danger to the gage installation.

3. It should be tough and resistant to abrasive action, yet sufficiently resilient to adjust to strain. The application of the material to sensitive flexure elements should not introduce noticeable mechanical hysteresis effects.

4. It should be easily formed so it can be faired over streamlined shapes in order not to create unwanted water flow patterns.

5. It should resist water penetration for an extended period of time.

A definite sequence of elimination tests was established in order to have the investigation and evaluation of waterproofing materials proceed in an orderly fashion. Each material was put through a series of three basic tests:

1. The materials were inspected visually. Materials that were watery or thin were generally eliminated directly unless the curing process effected a desirable change in form.

2. Actual gages were mounted on small 2- × 5-inch test panels of cold-rolled steel and waterproofed with test materials (see Figure 4). If the material contained solvents that might unbond paper-base gages, bakelite gages were used. These panels were submerged in fresh water. Some materials absorbed moisture and caused the gages to fail, as indicated by electrical leakage resistance measurements. An even larger number of materials allowed water to reach the gage bonding cement, rapidly destroying the bond of paper-base gages. The few materials that were judged satisfactory by the test were subjected to a third test.

3. Gages were mounted on slender, stainless-steel test flexures (Figure 5) which were then mounted in a special test tank which could be filled with water (Figure 6). These flexures were then subjected to continuous cyclic reversal of strain, and measurements of electrical leakage resistance were made periodically until, in each individual case, the leakage resistance dropped to an unsatisfactory value.

One particular caution should be noted in regard to the measurement of high resistances associated with strain-gage circuits. Many commercial megohmmeters or "meggers" employ high-voltage potentials (in the order of 500 volts) at the probe terminals in order to obtain a readable current on an indicating meter. If such high potentials are applied to a strain-gage circuit, a very high potential gradient is set up due to the minute spacing between gage wires and the mounting surface. This may result in an electrical breakdown at weaker spots in the

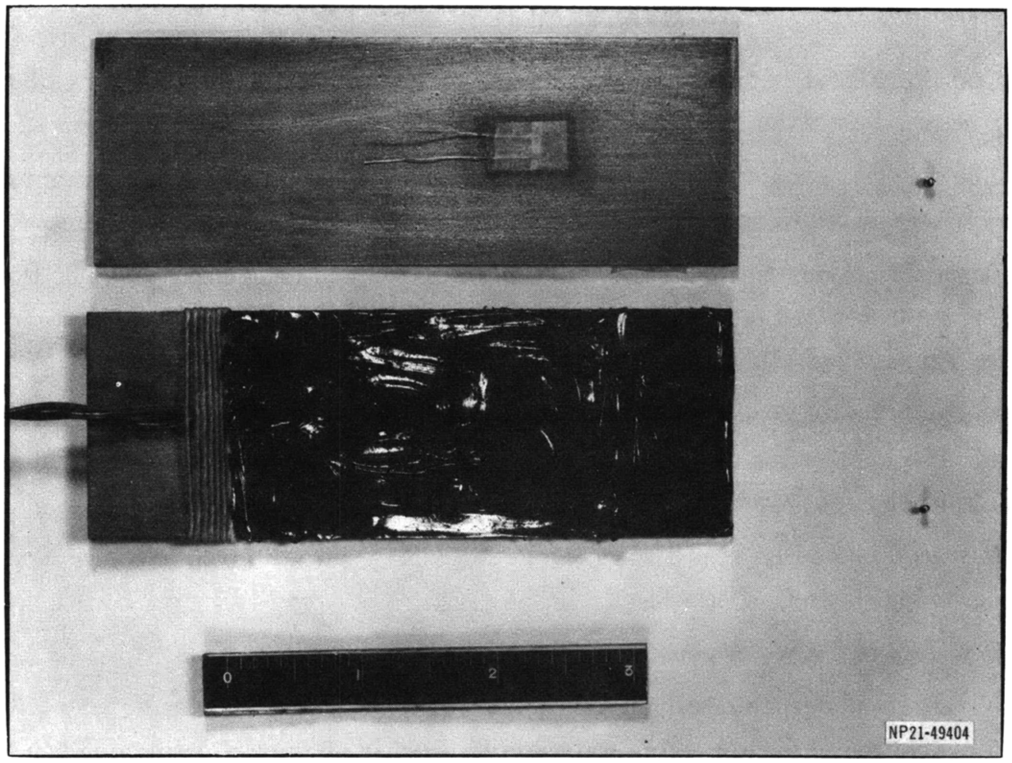

Figure 4 - Test Panels for Preliminary Evaluation of Materials

The top panel shows a Type A-8 strain gage before wiring and waterproofing. The lower panel has a similar gage which has been wired and waterproofed with 3-M synthetic rubber. (Later tests indicated that the best practice is to precoat gage only with wax before application of 3-M.) Many of the initial tests of promising materials for strain gage protection were made on simple test panels such as these.

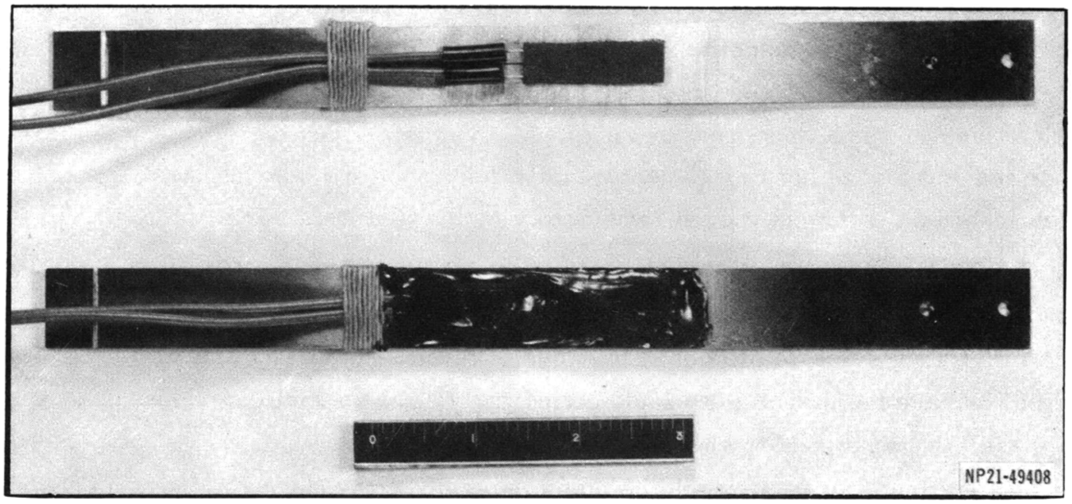

Figure 5 - Flexures for Evaluating Materials in Test Tank

A trimmed Type A-1 strain gage is shown mounted on the top flexure. The narrow sealing space on either side of the gage should be noted. The lower flexure shows 3-M rubber waterproof coating over the gage. (Later tests indicated that best practice is to precoat gage only with wax before application of 3-M.) Excess material over the edges was trimmed away. Other flexures were used to evaluate other materials.

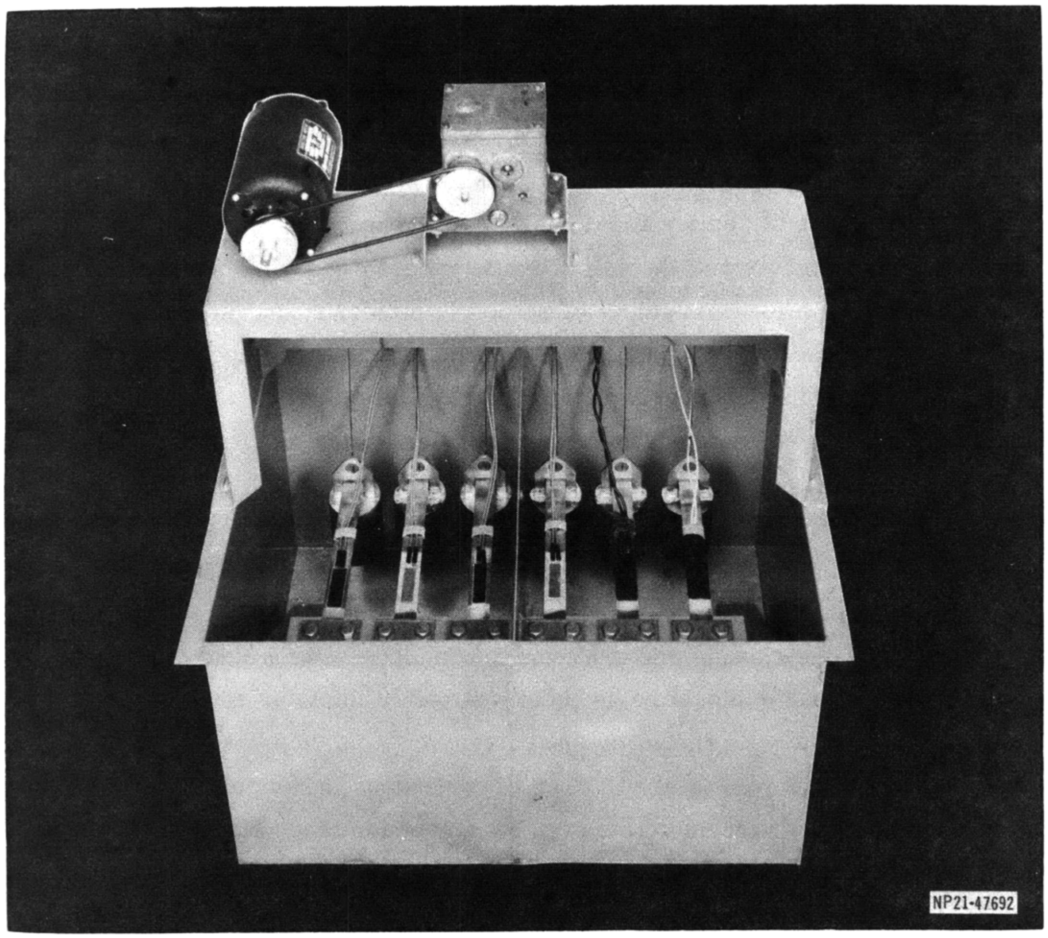

Figure 6 - Test Tank for Evaluation of Waterproofing Materials

This tank is used as an aid to evaluate gage waterproofing materials. It closely simulates actual test conditions by providing alternating loads on the submerged test flexures. An alternating bending load is applied simultaneously to all six flexures. The motor and gear system lifts the flexures compressing the gages; weights then carry flexures downward to complete the bending cycle in tension. The strain level is approximately ± 500 micro-inches per inch. The sealing area on the sides of the gages 5/32 inch. There are two individual compartments which can be filled with the same or different liquids.

insulation. A carbonized path results, the leakage resistance is permanently lowered, and the gage installation may be completely ruined. The above possibility can be avoided by using megohmmeters that employ low terminal potentials. One such instrument for this resistance measurement is the General Radio Company Type 729-A Megohmmeter. This is a very useful portable, battery-operated instrument.

RESULTS OF TESTS

Elimination tests were carried out on over 100 different types of materials and usually on several samples of each material. The laboratory testing has been interspersed with field trial application of the most promising materials.* Three general types of materials, combined with certain techniques or application, have proved highly satisfactory, both in the general test programs and in several critical field applications. These materials are (1) black synthetic rubber compounds, (2) certain synthetic waxes, and (3) vinyl plastisols. No one of these is the ultimate all-purpose material. Each has certain characteristics which make it suitable for certain types of applications. However, by the proper choice of one or a combination of two of these materials and the use of suitable techniques, the user can be reasonably sure of a satisfactory job for most gage waterproofing problems. (A tabulation of other materials found acceptable in certain limited uses is available in Appendix A.)

The synthetic rubber compounds are preferable where there is a flow of water or where mechanical protection is required. These compounds are tough and resilient and can be made to adhere tenaciously to most surfaces. The synthetic wax materials are satisfactory for static underwater conditions. So far, vinyl plastisol can be used only when the object to be coated can be dipped in the compound and withstand the high curing temperature (355 F).

The effectiveness of all of these materials as waterproofing agents depends largely upon the thickness of the coating and the amount of sealing area around the gages. For sensitive balances, the coating should be as thin as possible to minimize hysteresis effects. Very thin coatings of synthetic rubber on small, sensitive balances and flexures will give adequate protection for approximately 10 days of continuous immersion. A thin coating of one of the synthetic waxes will provide protection for a gaged balance submerged in *still* water for as long as 4 to 6 months.

SYNTHETIC RUBBER COMPOUNDS

Characteristics

The two synthetic rubber (polysulfide) compounds found most useful and versatile are Minnesota Mining and Manufacturing Company products identified as EC-864 and EC-801.** Each has to be mixed with an accelerator, EC-807, before use to effect self-vulcanization. Both materials have a viscosity, prior to curing, comparable to that of a viscous paste. When cured, both are very resilient and tough. Hardness ranges from 50 to 60 Shore "A" Durometer at 70 F. The flexibility and adhesive properties are good for temperatures as low as – 50 F and the compounds remain firm up to 250 F.

EC-864 can be built up to a good thickness in one coat and may be applied to vertical surfaces without resulting sag. When cured this material has a rough dull surface and shows good resistance to lubricating oils and to many solvents.

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*Names and addresses of suppliers for the various products mentioned throughout the report are listed in Appendix G.

**Manufactured by the Thiokol Chemical Corporation under the trade name "Thiokol" (R), these products are compounded and distributed by a number of suppliers; see Appendix F. The trade name 3-M Brand and the EC-designation are those of the Minnesota Mining and Manufacturing Company.

EC-801 is not so viscous and requires multiple coatings to develop a thick section. It has a smooth shiny surface. EC-801 meets military specifications MIL-S-7502 for contact resistance to aircraft fuel and oil. It is recommended for use on small flexures and balances, but it may introduce excessive hysteresis in delicate low-range balances or flexures.

Typical Uses

Strain gages have been successfully waterproofed with synthetic rubber compounds in combination with synthetic waxes in several critical test installations. This is known as the 3-MD-3 technique.* Some of the uses are listed below:

1. On several three-component precision balances such as shown in Figures 2 and 3.

2. On a whip antenna on a submarine at sea.

3. On the exposed surfaces of several underwater bodies subjected to free flow of both salt and fresh water at velocities up to 60 knots. In one of these free-flow cases, the waterproofing compound over the gage had to be streamlined and built up to a thickness of 1/8 inch and tapered to a feather edge so that the flow of water over the test section would not be disrupted. In this application, the waterproofing combined the three functions of waterproofing the gages, fixing and embedding the connecting wires, and preventing the entire gage and wiring installation from being torn away by the water flow.

4. On small steel test strips (Figure 4) which were waterproofed and then subjected to hydrostatic pressures of 1000 psi for upward of 48 hours. The sealing space around these gages was 1/4 to 3/8 inches wide. The electrical leakage paths, which were initially of the order of 10,000 megohms, dropped to not less than 25 megohms.

5. On heavier coated test panels with a wider sealing space of 1 1/4 inches around the gage. These were subjected to an average hydrostatic pressure of 950 psi continuously for two months. The electrical leakage dropped from 3000 megohms to not less than 1400 megohms.

6. On specimens subjected to hydrodynamic shock pressures from small underwater explosions. Fast-rising peak pressures of 2000 to 5000 psi from these explosions failed to rupture or tear loose the coatings or to change the gage-leakage readings.

SYNTHETIC WAX PRODUCTS

Characteristics

The two most versatile synthetic wax products tested are Di-Jell 171 and Zophar Mills C-276. Di-Jell 171 is a soft wax which is applied in paste form and does not require

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*A generic term used to identify the techniques of application of two or more waterproofing materials in combination as described above. The designation 3-MD-3 is drawn from 3-M Brand, the trade name of the Minnesota Mining and Manufacturing Company, and from the initials of the writer's name, M.D. III.

melting for application. Zophar Mills C-276 is a viscous syrup when melted. At ordinary temperatures, it is tough, sticky, and tenacious.

In one application under controlled laboratory conditions, bakelite strain gages were protected with Di-Jell with a sealing area extending only 5/32 inch beyond the edges of the gage. The gages were then subjected to a 12-inch static water head. The metal test panels (Figure 4) on which the gages were mounted were not flexed during the test. The gages were in satisfactory electrical condition for six months.

In other tests, paper-base gages were protected with Di-Jell and the strips were flexed to produce a strain at the gage of $\pm$ 500 μ in/in at 1 cpm for periods of 40 hours a week. The gages operated satisfactorily for 30 days.

Typical Uses

Di-Jell was a satisfactory waterproofing material for an actual strain gage balance application for 2 months of continuous use. At the end of that time, it was a simple matter to dry out the bakelite gages by heating to about 220 F. The leakage resistance was thereby raised again to a high level and the gages were re-waterproofed with Di-Jell.

Zophar Mills C-276 or Di-Jell 171 was used as a precoat over the gages on several of the synthetic rubber typical uses reported above.

VINYL PLASTISOL

Vinyl plastisol, which is essentially a dispersion of finely divided vinyl resins and plasticizer, has excellent waterproofing characteristics. Thin coatings inhibit water penetration for long periods of immersion. Water penetration is virtually zero. Moreover, the thickness of the coating can easily be controlled by repeated dippings.

There are, however, certain unsolved difficulties that limit the utility of this material for waterproofing resistance-wire strain gage installations. For instance, the present vinyl plastisol does not retain its bond to metals or to the general run of vinyl metal primers after approximately 10 days of immersion in water. Also, the fusion temperature of 355 F limits the type of structure, the type of gage, and the type of wiring to which the material may be applied. Nevertheless, preliminary studies have been promising, and further investigations of the possibilities of vinyl plastisol appear warranted on the basis of the results obtained so far.

TECHNIQUES OF APPLICATION

In the following sections, specific instructions are given for the use of synthetic rubber and wax compounds for the waterproofing of strain gages.

It is assumed that the reader has a prior knowledge of the general techniques of gage mounting. The choice and handling of connecting wires is discussed in detail in Appendix D;

this should be reviewed when planning a gage installation. A technique for waterproofing cable splices is outlined in Appendix E. Special techniques for mounting bakelite gages on curved surfaces and on stainless steel are discussed in Reference 8. Appendix C gives a method of removing 3-M waterproof coatings without damaging bakelite gages.

SYNTHETIC RUBBER COMPOUNDS

Before the actual application of these materials, test batches of the compounds and primers should be tried on the specific type of metal on which the gages are mounted. The bonding characteristics of the materials can be observed and the application procedures perfected.

The following step-by-step procedures are for the application of 3-M compounds over gages mounted on carbon steel, stainless steel, or "ST" types of aluminum:

1. Carefully clean the gaging areas to ensure that all surfaces to be waterproofed are free from grease, oil, and fingerprints. After the gages are mounted and dried, scrape off excess cement from the metal around the gages to within 1/16 inch of the gage. Using absorbent cotton dampened with acetone, swab around the gage and up and down the wires until a fresh piece of cotton shows no discoloration. Discard cotton swabs as they are used, and do not contaminate the solvent bottle with used swabs. Care must be taken to keep the solvent from any direct contact with paper-base gages. Bakelite-base gages may be swabbed directly.

2. For paper-base gages, apply a wax buffer precoat of Zophar C-276 or Di-Jell 171 to extend at least 1/4 inch beyond the perimeter of each gage. This prevents direct contact of the 3-M compounds with the gages. It has been found that direct application of these compounds over paper-base gages, tends to lower the gage leakage resistance. Bakelite gages ordinarily do not require this precoat.

3. If EC-864 is to be used as the principal coating, a single thin coating of a 3-M metal primer should be applied next. No primer is needed for EC-801 as it contains added bonding resins. EC-853 primer* may be used for all steels, including stainless, and for "ST" types of aluminum. Brush the primer over the area of freshly cleaned metal around the gage. It need not be applied over the wax gage buffer coating nor over bakelite gages, but should cover all adjacent bare metal surfaces thoroughly. Allow the primer to dry for at least 1 hour at room temperature or longer if the humidity is high. Mild heat (110 to 130 F) will speed the drying. No adverse effects have been noted if the primer is allowed to dry for an extended time prior to application of a 3-M compound provided the installation has been kept free of oils, fingerprints, dust, etc. Clean plastic-insulation on connecting wires with acetone and prime thinly with EC-1217.* Clean rubber insulation with acetone and naptha solvent, then prime thinly with EC-853. Primer application brushes should be washed out with acetone.

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*Primers EC-853 and EC-1217 should be thinned 50 percent with methyl isobutyl keytone.

4. Prepare the material for the final waterproof coating by mixing either EC-864 or EC-801 base with EC-807 accelerator. Mix ten parts by weight of the base to one part of the accelerator in absolutely clean mixing vessels. Do all mixing thoroughly. (If the accelerator has settled out in storage, stir or shake jar vigorously until any top fluid is completely blended.) EC-864 may be mixed in clean cans or bowls. EC-801 requires more thorough mixing. Use a flat surface, such as a slab of safety glass, and stir and "fold in" the accelerator with a stiff spatula. Do not permit the accelerator to dry out around the edges and flake into the fresh mix. Do not mix more material than can be used in the next 30 minutes. EC-864 and EC-801 are available in 1-pint cans, and the proper quantity of accelerator is furnished in separate glass jars.

5. Next apply the mixed compound over the gage area with a putty knife or spatula and build up the desired thickness. The thickness usually required is of the order of 1/8 inch. Possible adverse hysteresis effects, space clearances, expected submergence period and conditions should all be considered in determining the thickness that should be built up. The materials can still be shaped up to 2 hours after application. The surface becomes firm and tack-free in about 12 hours, and the compounds are completely cured in 24 to 36 hours at room temperature. The curing process may be speeded up by application of mild heat (120 to 150 F). Air contact is not required for curing since the process is an internal chemical reaction. However, high humidity contact, such as on a rainy day, will tend to speed curing. Speedier oven cures are obtained at a given temperature by placing in the oven an open container of water with a large surface area.[9]

6. If the surface of EC-864 requires smoothing, trowel with a spatula dripping wet with alcohol before complete curing. After curing, the surface may be sanded. EC-801 does not respond to such working, but may be overcoated with EC-864 either when freshly applied or after complete curing. These materials will bond to each other in either order.

7. After the 3-M compound has cured, apply several coats of Herecrol RC-9 primer as a surface sealer. This is a quick-drying (10 to 20 minutes) glossy-surface, synthetic material that provides sealing protection over the main waterproofing compound. Stir or shake primer and apply by brush.

WAXES

1. Mount gages in the usual manner. Prepare gages, connecting wires, and sealing space around the gages for the application of wax in the same manner as outlined for the rubber compounds.

2. If possible, warm the metal sealing area to 125 to 150 F. A heat lamp is satisfactory for this purpose.

3. In the case of Di-Jell 171, knead the wax at room temperature or slightly warmer. "Butter" the kneaded wax over the gage and metal sealing area with the blade of a

screwdriver, knife, or spatula. The buttering technique overcomes the layer separation effects that are common when Di-Jell 171 and many other waxes are melted and brushed on. As with rubber materials, the exact thickness requred for waterproofing will depend on the contemplated gage service. Avoid leaving any "pin holes" and "pipe lines" in the wax. Be especially careful to check the easy-to-miss area underneath gage connecting wires.

4. In the case of Zophar C-276, melt the wax by heating to about 220 F. Then brush the wax over the gages and connecting wires. This wax may loosen from a surface after several months due to gradual contraction of the wax.

COMBINED USE OF RUBBER AND WAX COMPOUNDS

The synthetic rubber and wax compounds may be applied in combination to good advantage on certain gage installations.

One example is the use of a wax buffer precoat on paper-base gages before EC-864 or EC-801 is applied, as described above. Another use for the combination is to precoat bakelite gages to facilitate repairs that may be necessary after waterproofing has been accomplished. For instance, suppose the flexure shown in Figure 1 is to be submerged for extended periods and it is anticipated that it will be necessary to remove 3-M waterproofing compound in order to dry out and repair one gage in the bridge. In such cases, the rubber compound should be applied over Di-Jell and sealed to the clean metal areas at each end of the gages to form a cocoon-type of protection. Since 3-M will not adhere to wax surfaces, it will be possible to make repairs to any gage on the balance by carefully cutting and removing a narrow band of the 3-M compound directly over the proper area. Photographs which show wiring details of intricate gage installations before application of any waterproofing materials are invaluable guides for such repair operations.

THE DEAN SHIM CAP METHOD OF GAGE WATERPROOFING

This technique has been developed by the author at the Taylor Model Basin to provide a means of waterproofing strain gages on the outside hull plates of full-scale ships without introducing additional mass or stiffness to the plate. Since its development, many tests have been conducted by the Model Basin that could not have been accomplished successfully by previous methods.

The method used to waterproof the strain gages is illustrated in Figure 7. The gage is first mounted and coated with Di-Jell 171 wax, then a partial coating of 3-M EC-801 synthetic rubber is applied. A cap of thin stainless-steel shim stock 0.002 inch thick is rolled on and pressed down into the fresh 3-M waterproofing compound. Before the shim is completely placed, gage leads are soldered to glass-bead feedthroughs which have previously been soldered in the shim cap. Then the shim cap is seated the remaining distance into the rubber. The external cable connections are made, and a final coating of synthetic rubber is applied over the entire placement.

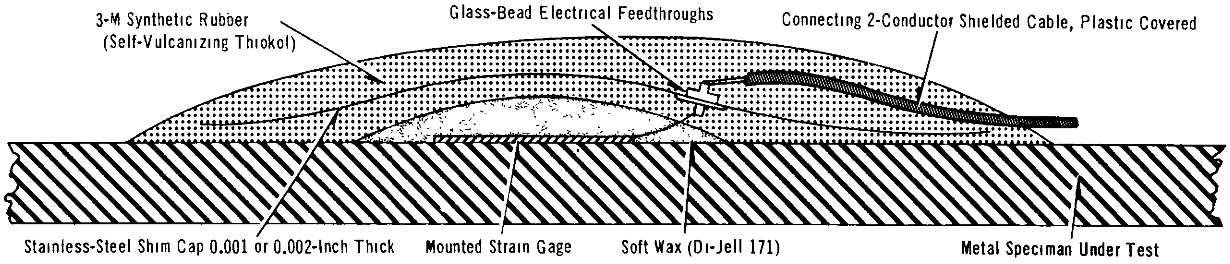

Figure 7 - The Dean Shim Cap Method of Waterproofing Strain Gages

Before water can penetrate this installation and reach the strain gage, it must follow a path parallel to the specimen surface and pass through several inches of waterproofing. The stainless-steel shim cap provides an impervious barrier to moisture from other directions.

When used with EC-864, the stainless-steel shim cap requires a primer such as EC-853. It does not require a primer coat when EC-801 is employed as the waterproofing compound.

Although, as in other techniques, this method may give rise to a cable-sealing problem, it is a much simpler operation to replace the 3-M protection at the connection point outside the cap if a leak does develop than it is to replace the whole gage installation. The feedthrough also serves to protect the gage in the event of accidental rupture or damage to the cable jacketing, which would "hose" water to the gage area.

A specific example of the use of this technique is shown in Figure 8. Paper-base gages were mounted on the outside of the hull plates of a destroyer while the vessel was in drydock. The gage location was near the bow and 15 feet below the waterline. Test requirements were such that bulky mechanical protection could not be used for the gages. The waterproofing material had a maximum thickness of 1/2 inch and was streamlined and tapered over an area approximately 30 by 18 inches. The glass-bead feedthroughs were not used in this installation as the connecting cables were passed through stuffing tubes into the ship a few inches from the gages and within the sealed area. The plastic cable was cleaned with acetone and primed with EC-1217, thinned 50 percent. This same primer technique using EC-853 thinned 50 percent has been employed to bond EC-801 to some types of polyethylene.

The procedures were as follows:

1. The sealing area, which had been sanded to a bright metal surface before the gages were mounted, was thoroughly cleaned with acetone, taking care not to get acetone on the paper-base gages.

2. The gages were precoated with Di-Jell 171.

3. Three 10- by 6- by 0.002-inch strips of stainless-steel shim stock were cut and their edges overlapped 1/4 inch on the longest dimension.

4. They were then soft-soldered together, using a stainless-steel soldering flux, and the joined pieces were trimmed to an oval shape of 17 by 10 inches and then thoroughly cleaned with acetone. (It is essential that all surface film or cloudiness be removed.)

5. No metal primer was used in this case. EC-801 was mixed and applied over the entire area of the ship plate to be sealed (30 by 18 inches).. The bonding characteristics of EC-801 are superior to those of EC-864.

6. The specially prepared oval shim cap was rolled and pressed down into the soft and as yet uncured EC-801. Care was taken to avoid entrapping air.

7. Fingerprints were washed off the exposed face of the shim cap with acetone, and the entire area of the shim cap was completely covered with a thin coating of EC-801.

8. The entire area of the gage placement was overcoated with EC-864, which has better building qualities than EC-801, but this compound was not permitted to extend beyond the perimeter of the EC-801 that had previously been applied.

9. Mild heat was applied to expedite curing because the air temperature was about 40 F.*

10. After the curing process was complete, three coats of Herecrol RC-9 primer were applied during a 1-hour interval.

The completed waterproofed area is shown in Figure 8c. Two pints of EC-864 and one of EC-801 were required for this installation. In order for water to penetrate this installation, its path would have to be parallel with the ship's hull and pass through approximately 5 inches of waterproofing material.

This gage installation functioned satisfactorily during 3 1/2 months of active service during which time the destroyer traveled from Norfolk, Va., to the Carribean area and back. Opportunity for visual inspection was provided at the end of 2 months when the ship was drydocked for minor repairs to the propulsion system. At that time, the gage installation appeared to be as bright and new as the day it was affixed to the ship. The waterproofing coating did not noticeably affect the stiffness or the flow characteristics over the hull plate insofar as could be determined by the structural evaluation measurements obtained from the strain gages.[10]

The success of this test led to a similar successful installation on a weather ship of the United States Coast Guard. This installation was on the forward keel approximately 50 feet from the bow and was subjected to 4 months of periodic slamming in heavy seas during winter months in the North Atlantic.

Quite recently, the shim cap method was used to waterproof and mechanically protect five strain-gage locations on one of the after-propeller shaft struts of the USS SARATOGA (CVA60), a FORRESTAL-Class Carrier. The gage locations will be exposed to continuous

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*Application of 3-M is not recommended for waterproofing strain gages when the temperature of the metal specimen cannot be raised above 40 F. Chilling 3-M increases curing time appreciably.

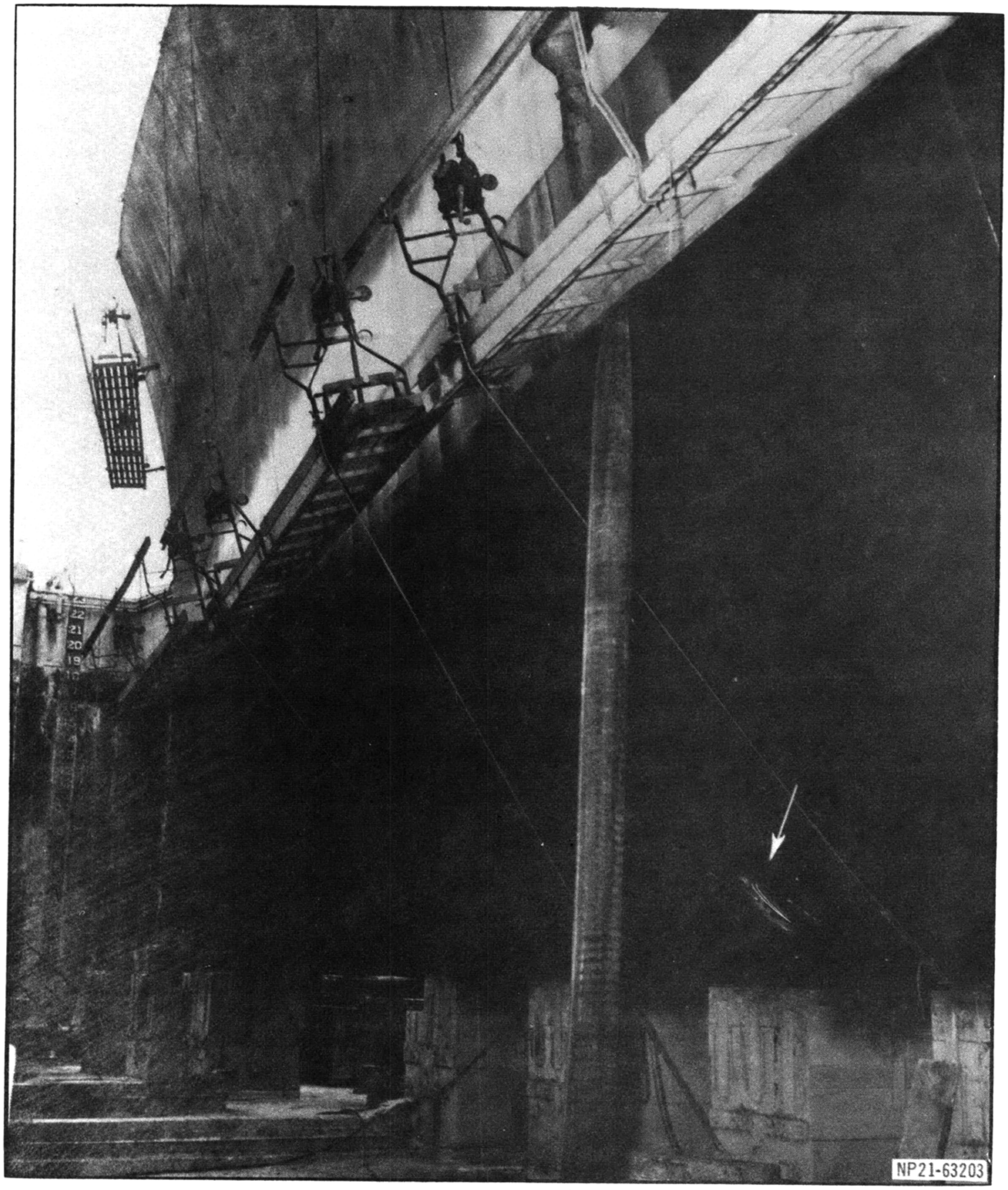

Figure 8a - Drydock View

The location shown by arrow is 15 feet below the ship's waterline. The requirements of the test were such that bulky mechanical protection, such as heavy welded or gasketed steel boxes, for the gages could not be used.

salt water immersion, underway water flow, and to spurious water flows created by proximity of the propeller. Under these severe conditions, the gage installation is expected to last 6 months.

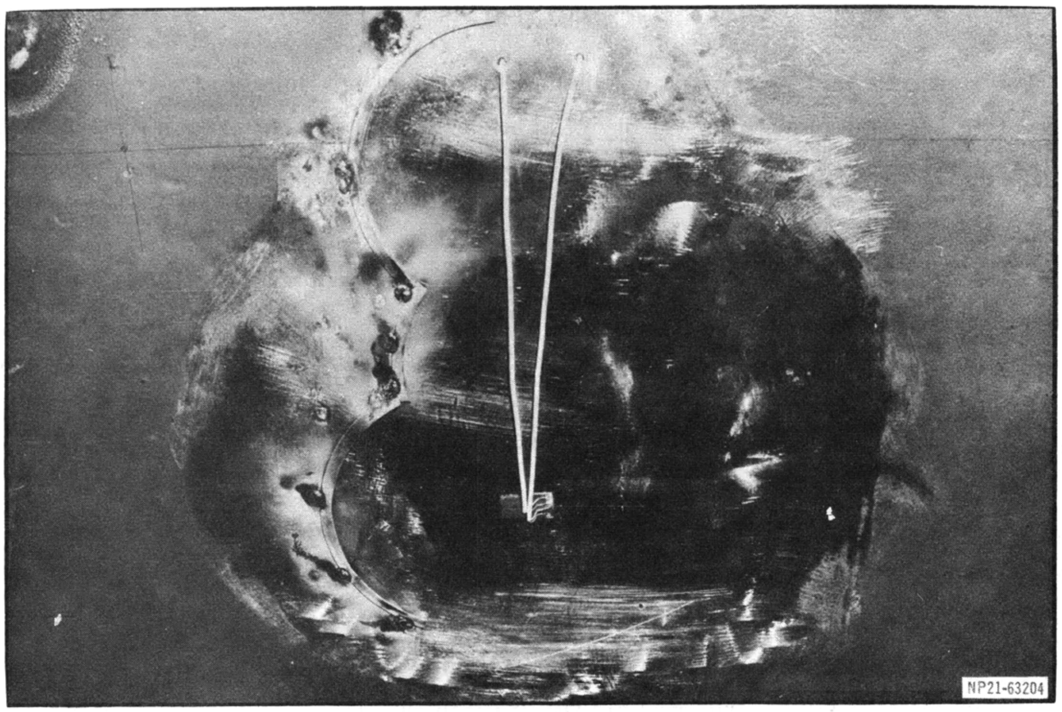

Figure 8b - Gages Ready for Waterproofing

Two AD-3 gages are mounted side by side in the center of the plate in a fore-and-aft orientation. One gage is for a bending bridge, the other for a tension-compression bridge. Matching gages are mounted on the inside of the hull plate. Notice the large sealing area prepared for waterproofing. The beveled and curved stainless steel strips, welded in place, provided a protective leading edge for the 3-M waterproofing material.

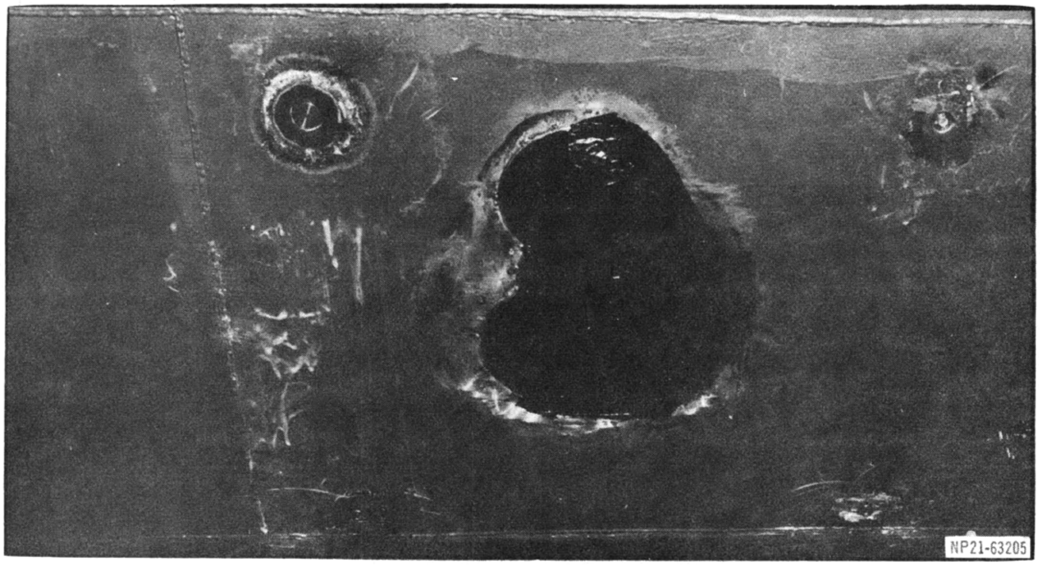

Figure 8c - Waterproofed Gages

The completed waterproof installation. See text for description of procedures.

Figure 8 - Gaging on the Outside of a Ship Hull Plate

CONCLUSIONS

The materials and techniques outlined in this report are suitable for the protection and waterproofing of strain gages in a variety of applications. They are especially adaptable to precision balances and other instruments which must be immersed in water for extended periods of time.

ACKNOWLEDGMENTS

For advice, information, and assistance contributed during the long period of time covered by this investigation, the author is indebted to many persons, some of whom he would like to mention in particular.

Mr. Ernest W. Fisher of the Minnesota Mining and Manufacturing Company rendered valuable technical assistance. In addition his company freely provided complimentary samples of 3-M Brand materials for evaluation. Acknowledgment is also made to Mr. Allen H. Morris of the same company, who provided much helpful information.

Acknowledgment is made to Taylor Model Basin staff members Mr. Jesse E. Stern of the Instrumentation Division and Mr. Paul Golovato of the Hydromechanics Laboratory whose interest in Di-Jell wax led to the test work on this British wax product.

Sincere appreciation is extended to Mr. Vernon E. Benjamin and Mr. Frederick B. Bryant of the Instrumentation Division for their encouragement during the experimental work on waterproofing and for their assistance in the preparation of this report.

APPENDIX A

THE EVALUATION OF OTHER WATERPROOFING MATERIALS

Many other materials have been tested or are on hand for continuation of the evaluation program planned. Figure 9 shows some of the many different compounds.

Materials which have already been investigated and found acceptable for waterproofing in certain limited uses are listed in Table 1.

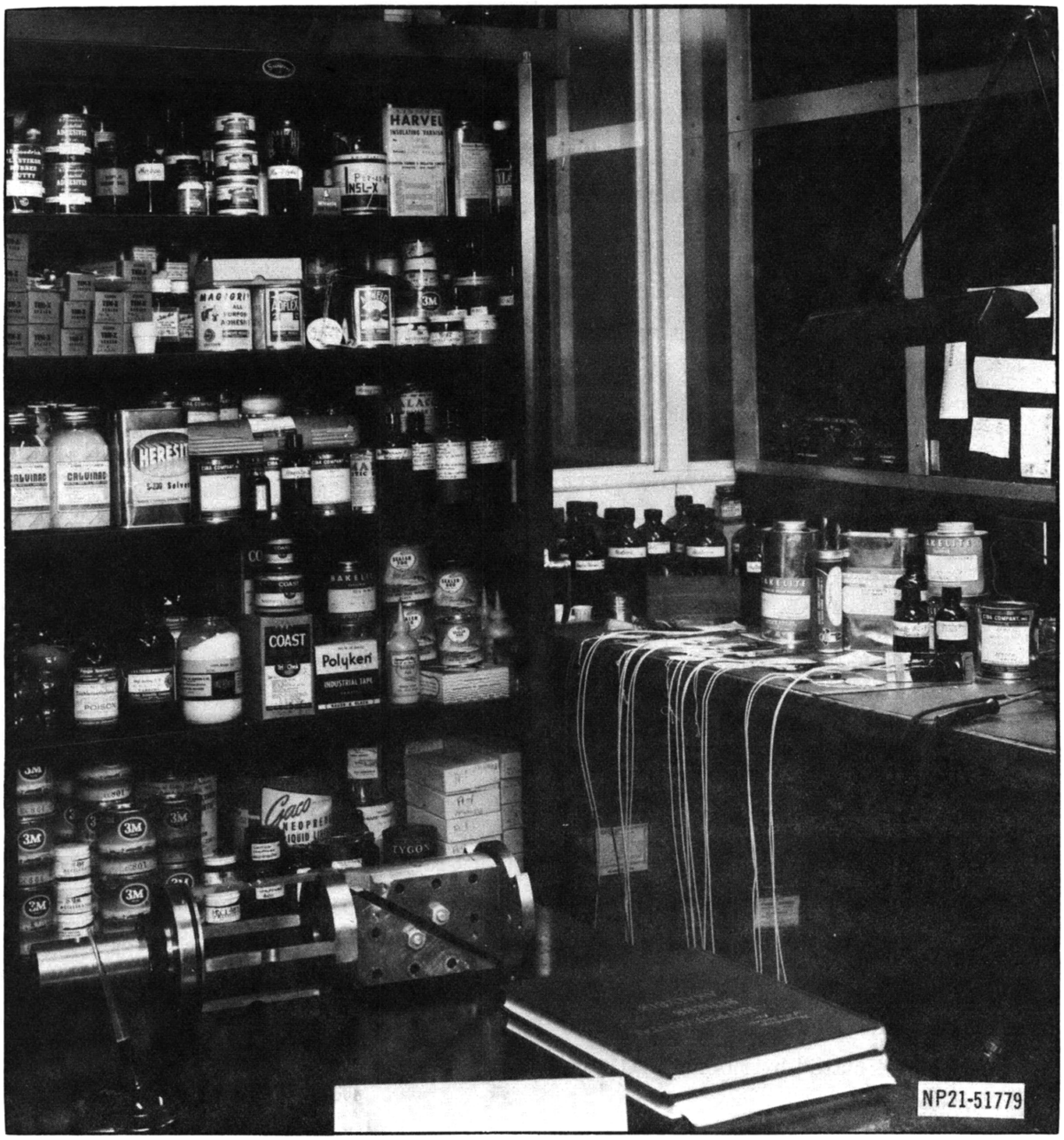

Figure 9 - Waterproofing Materials on Hand

Approximately 100 materials have been investigated for possible usefulness in waterproofing strain gages. Some of these materials for Model Basin use are shown here.

TABLE 1

Materials Satisfactory for Limited Use in Waterproofing

Product*	Vendor
Horneblende (primer, heavy paste, and liquid)**	North American Fiber Products Co. Standard Building Cleveland 13, Ohio
Harvell insulating varnish No. 912-C	Irvington Varnish and Insulator Co. Irvington, New Jersey
Insulating varnish No. 9563 Insulating varnish No. 9574	General Electric Co. Pittsfield, Massachusetts
Insulating varnish No. 1202	General Electric Co. Schenectady, New York
Insl-X 27-0B-SA insulating varnish (discontinued)	Insl-X Co., Inc. 26 Rittenhouse Place, Ardmore, Pennsylvannia
Asphalt fibre coating** (intermediate bituminous material)	Benjamin Foster Co. 4635-37 Girard Avenue Philadelphia 31, Pennsylvannia
Ten-X sealing compound - black color only	Electro Cote Co. St. Paul, Minnesota
Thiokol EC-755	Minnesota Mining and Manufacturing Co. Detroit, Michigan

*Many other materials were tested but few proved satisfactory for waterproofing strain gages. Typical categories of materials tested include insulating varnish, resistant plastic paint, rubber and plastic putty, industrial-type adhesive and sealing compounds, paints for food containers, casting resins, two-part rubber mixes, and marine caulking compounds.

**These air-dry, tar-base materials demonstrated excellent waterproofing qualities, but their cold flow characteristics proved to be a serious problem for use with strain gages.

It should be brought out at this point that although this report has been concerned with the use of gages in water, strain gages can be operated very satisfactorily in certain other fluids as well. For instance, during early waterproofing experiments, a few gages were immersed in a tank of chemically pure glycerine. This fluid did not alter in any way the mechanical or electrical properties of either bakelite or paper-base strain gages. No protection other than dictated by mechanical considerations was required over the gages, solder joints, or cables.

APPENDIX B

REACTIVATION AND REPAIR OF STRAIN GAGE ASSEMBLIES

Properly waterproofed gage-balance elements may be submerged in water for periods ranging from several days to 2 or 3 months, depending upon the type and thickness of the material, environmental conditions, and so forth.

The determination of whether a particular gage circuit has absorbed excessive moisture can usually be made by checking the leakage resistance from gage elements to the mounting metal or to the water in which the gaged structure is submerged.

In test operations, this resistance should be measured with a low-voltage (22½ v) megohmmeter.* Higher voltages applied between the gage element and the metal specimen might cause a breakdown of the gage insulation. Breakdowns can also occur with hand-crank "meggers" or similar high-potential insulation testers.

Such leakage measurements help to spot incipient failures quicker and more accurately than observations of shifts in bridge balance zero readings. Accordingly, it is suggested that the data sheets employed to record measurement data of bounded resistance-wire strain gages include a column for periodic readings of gage leakage resistance. By keeping a running check of gage leakage resistance, faulty gage circuits can be quickly spotted.

Bakelite gages protected with 3-M compounds can generally be reactivated by a controlled heating or baking procedure. Heating the entire gage assembly to 220 F for one-half hour or more is usually sufficient to restore leakage resistance to an acceptable level. If this leakage value remains stable after cooling, the gage system may be reimmersed for a further period of use.

The dehydration of bakelite gages protected with Di-Jell may be accomplished by heating the assembly to about 220 F and continuing the application of heat for 30 minutes after the wax has melted off. If, after cooling, the leakage resistance is satisfactory, the gages and connecting wires may be rewaterproofed with fresh Di-Jell 171.

It is emphasized that heating at temperatures appreciably lower than recommended here will not adequately drive moisture from gage circuits. Since paper-base gages will not withstand the high temperatures, reactivating procedures following water contamination are usually limited to bakelite gages.

If Di-Jell is to be removed from paper-base gages, only the minimum amount of heat necessary to melt the wax should be used. This wax has a melting point of 172 F. Accordingly, prolonged heating should be limited to 150 F since the paper gage and its cement will be damaged by higher heats.

Reactivation procedures with Zophar Mills C-276 should be attempted only for bakelite gages. Removal of this wax requires heating to temperatures (220 F) which are above the allowable limit for paper-base gages.

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*See discussion pages 5 and 7 in main text.

APPENDIX C

REMOVAL OF 3-M WATERPROOFING COATINGS

When it is necessary to remove 3-M coatings from bakelite gages without damaging the gages, a dissolving technique can be used. A solution of 100 parts (by weight) of ethylene chloride and 2 1/2 parts of du Pont accelerator No. 552 will swell and dissolve the 3-M synthetic rubber compounds. The use of this solution eliminates the hazards of scraping, prying, and cutting which are impractical techniques for small precision balances and similar delicate instruments.

The waterproofing materials should be soaked in the solution for 18 hours or more, depending on the amount of material to be removed. Any specks of the material which remain following this treatment should be carefully scraped off, particularly at any points where they may come in contact with gage lead wires. Metal surfaces can be cleaned and brightened with acetone.

This removal technique is for use only with bakelite gages mounted with phenol formaldehyde resin (such as Baldwin bakelite cement). Paper-base gages and rubber or plastic insulation on connecting wires will not withstand the removal treatment.

APPENDIX D

SELECTION OF WIRE AND CABLE FOR GAGE INSTALLATIONS THAT REQUIRE WATERPROOFING

GENERAL DISCUSSION

The selection of proper wire and cable for a particular gage installation requires careful evaluation of (a) insulation properties, (b) overall diameter and length, (c) mechanical strength, (d) size and number of conductors, (e) shielding flexibility, (f) cross-sectional shape, and (g) factors peculiar to the test conditions.

It is very important to provide adequate mechanical anchorage of the connecting wires to the gaged structure. This is easier to accomplish on large flexures than on small ones. Where space precludes the use of machine screws and tapped holes for clamping wires in the conventional manner, wires may be cemented in place at the base of the flexure with an epoxy* resin cement. (See Figure 1, page 3.)

When test conditions require the use of large size cables, it is desirable to interpose a transition section of a few inches of smaller wire or cable between the main cable and the frail gage leads. This intermediate wire should be completely embedded in the waterproofing material around the gage. The main cable should be securely anchored near the gage area, and the connecting joints to the smaller wire should be waterproofed by extending the gage waterproofing compound to cover the main cable end.

Another approach is to select a small cable (such as item 7 or 8 of Table 2) and splice to the heavier cable at some suitable point away from the gage, above water level if possible.

SUBMERGED LIFE TESTS

Part of this continuing waterproofing evaluation program at the Taylor Model Basin is concerned with checking the submerged life of various types of wires and cables to determine their suitability for use with gage assemblies to be waterproofed.

Method

Six-foot sample lengths of wire and cable are coiled, tied, and submerged in ordinary tap water at a depth of 12 inches with both pigtailed ends of each conductor extending above the surface of the water. The insulation of these samples is tested periodically by measuring the electrical resistance path between the conductors and the water.

As new types of wire and cable become available, they are added to the test program.

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*Type A-6 epoxy cement.

TABLE 2

Representative Types of Wire and Cable Which Are Satisfactory for Gage Installations

Designation*	Possible Suppliers**	General Description
Navy types DSS, TSS, FSS, MSS	Anacondia Wire and Cable 423 Investment Building Washington, D.C.	Multi-conductor shielded, watertight resin impregnated cable to prevent water hosing.
Navy Type MCOS-2	Simplex Wire and Cable 79 Sidney Street Cambridge 39, Massachusetts	Two-conductor shielded, plastic covered, ½-inch outer diameter, manufactured under specification MIL-C-915
Navy Type MCOS-6		Two sets of two-conductor shielded cables, shields not insulated from each other, two unshielded conductors, overall plastic jacketing, ½-inch outer diameter.
Navy Type TTRS		Multi-sets (2 to 16) of two-conductor shielded, shields insulated from each other with cotton braiding, overall plastic jacket manufactured under specification MIL-C-915.
Navy Type DCOP		Two-conductor, plastic covered, manufactured under specification MIL-C-915.
Commercial Type A7-3Q52	Surprenant Manufacturing Co. 199 Washington Street Boston 8, Massachusetts	Single conductor, stranded AWG 18, plastic jacket.
Commercial Type 6364-B2		Single conductor, stranded AWG 28, plastic jacket.
Commercial Type 2S-735U-A10-JA10		Two-conductor shielded, conductors stranded AWG 28 overall white color plastic jacket, 1/8-inch outer diameter.
Commercial Type 9560		Two pairs, two-conductor, individually shielded pairs, shields insulated from each other, pairs run parallel with overall plastic jacketing, stranded inner four conductors AWG 28, 1/8- by 1/4-inch outer diameter.
Commercial Type 9490		Multi-sets (17) of two-conductor shielded, shields insulated individually with plastic jacketing, overall plastic jacket; cable comprises 15 sets of stranded AWG 20 and two of AWG 16, 1 1/8-inch outer diameter.
Commercial Type 6004		Four conductor, non-shielded, stranded AWG 28, plastic covered, overall clear plastic jacket 1/8 inch outer diameter
Commercial Type 8423	Belden Manufacturing Co. 4647 W. Van Buren Street Chicago 44, Illinois	Three conductor-shielded cable, stranded AWG 20, all rubber construction, overall *silver gray rubber* jacketing 5/16-inch outer diameter. (Submergence test has run four months to date).
Commercial Type 8412		Two conductor shielded, 1/4-inch outer diameter, other information same as No 8423

*Many of the Navy cables are obtainable in two different types of jackets. The type of plastic jacket which is acceptable and which is recommended for underwater use is a waterproof thermoplastic with a shiny surface finish; it is relatively soft and flexible and can be easily cut with a knife. The nonwaterproof type looks like rubber but is thermosetting plastic with a dull surface finish; it is relatively hard and stiff and is difficult to cut.

**Companies listed have supplied cables to the David Taylor Model Basin. Many other companies engage in the manufacture of similar cables.

Results

Most plastic covered or jacketed wire and cable have been found entirely satisfactory, and high-quality Neoprene* black rubber jacketing is also good.** Some samples have been submerged continuously for several years and have retained their initial high leakage resistance of 50,000 megohms. Progressive failure of others was observed until the leakage resistance dropped below an arbitrary lower limit of 25 megohms.

Experience indicates that samples which ultimately fail will show a loss in resistance during the first few days of testing. Accordingly, it is concluded that wire insulations which exhibit negligible change in leakage resistance during the first few weeks will probably be satisfactory for 6 months or longer.

A list of some wires and cables satisfactory for use with waterproofed gages is given in Table 2; this is merely suggestive of the wide range of types available. All specimens of this table have been immersed longer than 350 days. Items 6 and 7 have withstood constant immersion in the test tank for three years and show no signs of failure. Some of the more recent additions may have a life as good as some of the older samples which are still undergoing test.

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*Trade name E.I. du Pont de Nemours and Company, Wilmington, Delaware.

**Two types of 1/4-in.-outer diameter shielded microphone cables which were tested proved inadequate for continuous immersion – one had a thin-walled black rubber jacket and the other a jacket of inferior plastic. It is believed that the manufacturer did not intend them for immersion in water.

APPENDIX E

WATERPROOFING CABLE SPLICES

It is often necessary to have cable splices in strain-gage leads, particularly, to effect a transition in cable size and/or as a result of the desirability of working with short cable lengths during the initial gage installation and checking procedures. If the splice location is to be subjected to moisture or water submergence, the splice has to be waterproofed just as completely as the strain-gage circuits.

There are various methods by which a satisfactory waterproof housing for cable connections can be accomplished. One such method used on an aluminum hydrofoil is depicted in Figure 10. The general technique is outlined in the captions. More detailed techniques on the use of the waterproofing compounds are in the main text of the report.

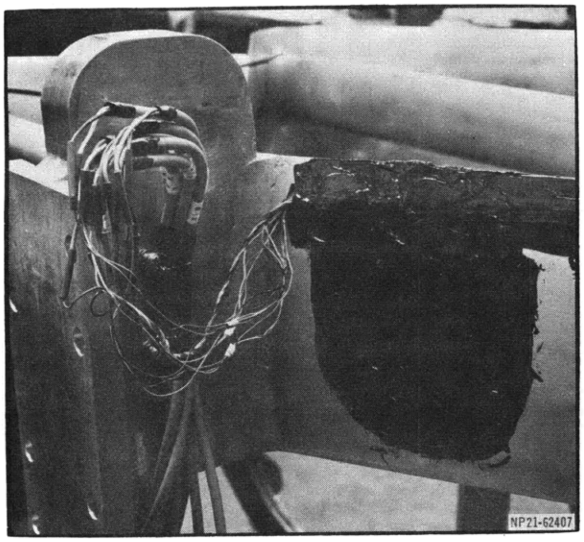

Figure 10a - Step One

The heavy rubber-covered shielded cable (Belden 8412) was just clamped securely to the hydrofoil mounting base. The small plastic covered wires from the waterproofed strain gages have been spliced to the shielded cables.

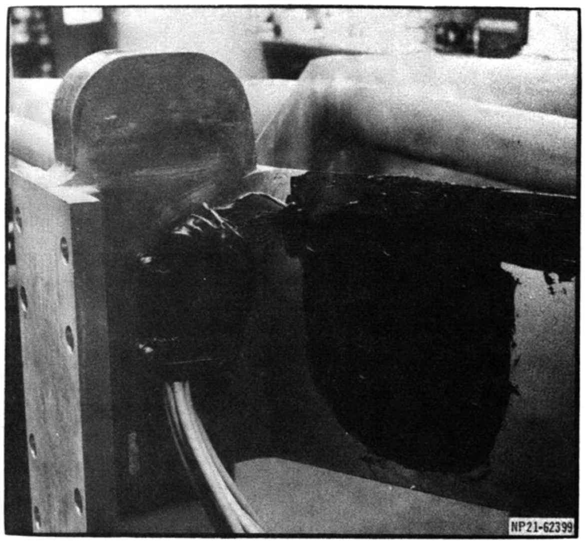

Figure 10b - Step Two

The splices have been taped and secured. All wires and cables have been cleaned with acetone prior to application of the waterproofing compounds. The small plastic covered wires were primed with EC-1217 (thinned 50 percent). Primer EC-853 (thinned 50 percent) should be applied to the rubber jacketed cable (refer to page 11). The metal behind the splice area was also cleaned and then primed with EC-853 (thinned 50 percent) as recommended for priming of ST aluminum.

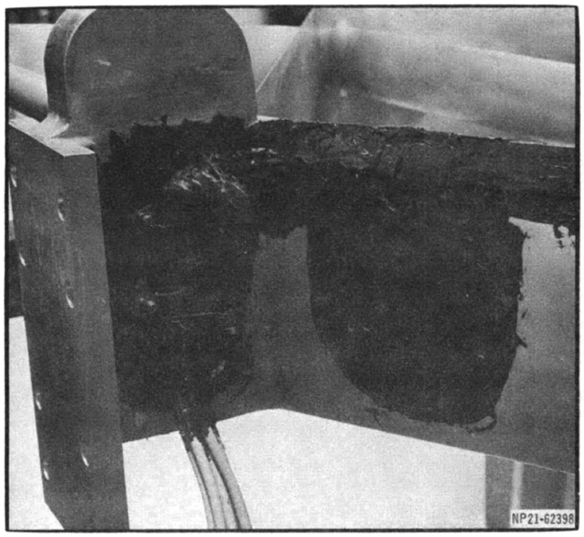

Figure 10c - Step Three

After the primers were dry, EC-801 was mixed and applied to all primed areas and to the previously cleaned rubber cables. The bundled cables were fanned out to make sure each cable was completely encompassed with EC-801.

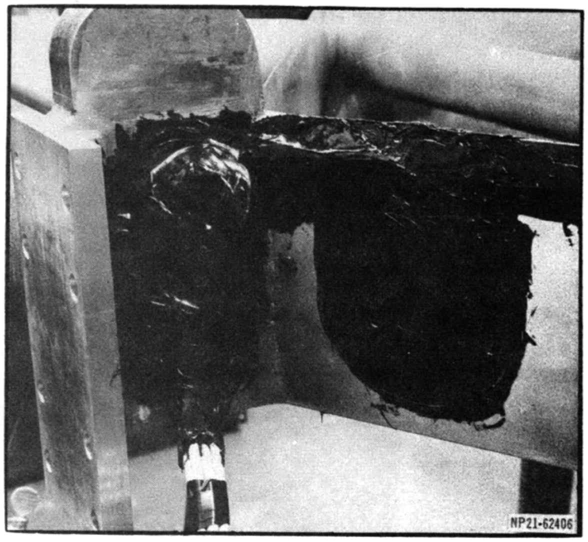

Figure 10d - Step Four

The entire splice area has been covered with EC-864 The splices are now completely waterproofed and the bundled cables are flexibly and securely joined to the hydrofoil assembly.

Figure 10 - Sequence in Making a Waterproof Splice

APPENDIX F

SOME MANUFACTURERS AND COMPOUNDERS OF THIOKOL MATERIALS

Minnesota Mining and Manufacturing Company
Adhesives and Coatings Division
411 Piquette Avenue
Detroit 2, Michigan

Products Research Company
3121 Los Feliz Blvd.
Los Angeles 39, California

Magic Chemical Company
121 Crescent Street
Brockton 2, Massachusetts

Coast Paint and Chemical Company
1507 Grand Vista Avenue
Los Angeles 23, California

R.L. Carlisle Chemical and Manufacturing
Company
Brooklyn, New York

Thiokol Chemical Corporation
Trenton 2, N.J.

APPENDIX G

SOURCE LIST FOR SUPPLIES MENTIONED IN REPORT

Product	Vendor
Cement, Type A-6 (Epon or epoxy resin cement)	Armstrong Products Co. Argonne Road Warsaw, Indiana
Chemicals	
Acetone (General cleaning)	Local chemical supply houses
Naptha solvent (General cleaning)	Local chemical supply houses
Methyl isobutyl keytone (Thinner for EC-1217, EC-853)	Local chemical supply houses
Ethylene chloride (For 3-M stripper)	Local chemical supply houses
duPont Accelerator 552	E.I. du Pont de Nemours and Co. Rubber Chemicals Division Wilmington, Delaware
Glass-bead feedthroughs	Fusite Corp. 6000 Fernview Avenue Cincinnati 13, Ohio
Di-Jell 171	Associated Wax-Refining Co. 300 Fourth Avenue New York 10, New York Astor, Boisselier, Lawrence Ltd. 1 Lancaster Place, Strand London W.C.2, England
Primer, Herecrol, RC-9	Heresite and Chemical Co. Manitowoc, Wisconsin
Sealers and primers, 3-M (All items with prefix "EC-")	Minnesota Mining and Manufacturing Co. 411 Piquette Avenue Detroit 2, Michigan
Stainless-steel shim stock (Type 302)	Precision Steel Warehouse, Inc. 4409-25 West Kinzie Street Chicago 24, Illinois
Stainless-steel soldering flux and Rosin flux remover	Division Lead Co. 7742 West 61st Place Summit, Illinois
Strain gages, SR-4	Baldwin-Lima-Hamilton Corp. Philadelphia 42, Pennsylvannia
Zophar C-276	Zophar Mills, Inc. 112-130 26th Street Brooklyn, New York

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