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PERFORMANCE OF WATERPROOFING COMPOUNDS APPLIED TO ELECTRICAL RESISTANCE STRAIN GAGES SUBJECTED TO HYDROSTATIC PRESSURE

by

Peter M. Palermo

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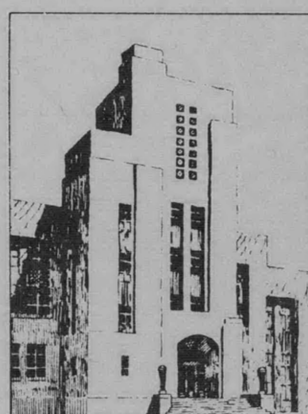

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Report 760

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ABSTRACT

Experiments have been performed to find a method of waterproofing strain gages subjected to hydrostatic pressure which is quick, economical, and reliable and which requires a minimum amount of special skill on the part of the workman. Three of the more promising methods are described in detail.

INTRODUCTION

Over the past several years projects at the Taylor Model Basin have required the application of strain gages subjected to hydrostatic pressure. Several techniques of waterproofing were found satisfactory[1] but comprehensive tests of performance were lacking. Thus new studies described herein were undertaken and three methods were proved acceptable for pressure-vessel work and submarine deep-submergence trials conducted by the Taylor Model Basin.

No distinctively superior method of waterproofing strain gages has been found, but tests are continuing on new methods and materials in the hope of finding one method which is superior both from the standpoint of ease of application and of performance in service.

Before any waterproofing method can be satisfactorily judged, the strain gage must be properly attached to the surface under study. A faulty technique of gage installation will render useless a perfect waterproofing technique and vice versa. This report describes a proper method of applying strain gages (see Appendix 1) and tests of some waterproofing methods. The step-by-step procedures of the three most acceptable methods are presented in Appendixes 2, 3, and 4.

HISTORY OF STRAIN-GAGE WATERPROOFING AT TMB

In the conduct of deep-submergence trials of submarines, SR4 strain gages were mounted on the outside of the pressure hull and in tanks open to sea water. When properly waterproofed, these gages function properly and give an exact measurement of the strains produced. However, if water reaches the gage, it is useless, and valuable information is lost.

The USS K-1 (SSK1) was the first submarine instrumented with wet-side gages by the Taylor Model Basin; shortly thereafter, the USS TANG (SS563) and USS TRIGGER (SS564) were also instrumented with wet-side gages.

A large number of the wet-side gages were lost on these three submarines. However, the waterproofing method was not entirely to blame; the pressure-proof boxes that were used to bring the gage leads through the hull were flooded. These boxes contained a terminal strip for each gage to which was connected both the wire from the gage and the wire leading to the

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[1] References are listed on page 8.

switch box. Thus, when water leaked into a pressure-proof box, all the gages that were connected to that box were shorted out. The total number of wet-side-gage failures was therefore not a true indication of the success of the different techniques used on these submarines.

The performance of the gages in all these tests are shown in Table 1. The wet-side gages on the SSK1, SS563, and SS564 were checked for gage resistance and resistance to ground, by cutting the gage leads at the gage immediatly after the test. As can be seen in Table 1, the failures of five gages on the SSK1, eight gages on the SS563, and one gage on the SS564 could be directly attributed to the waterproofing. No inspection of this kind was performed on the gages used in the other tests shown in Table 1. The failures on the other tests were attributed to the waterproofing. However it is possible that mechanical damage could have been inflicted on the gage cable in some of these instances.

The results shown in Table 1 indicate (1) that the barrier-coat* and rubber-patch method, and the Okonite-tape method are of about equal merit and (2) that the barrier-coat and neoprene-compound method merits further study because of its ease of application.

In later trials, different pressure-proof fittings and waterproofing methods were tried. The feed-through shown in Figure 1 was used on the USS T-1 (SST1) along with the barrier-coat and neoprene-compound method of waterproofing (Appendix 3). A modified pressure-proof box shown in Figure 2 and the Okonite method of waterproofing (Appendix 2) were used on the USS ALBACORE (AGSS569). The Okonite-tape method was used on full-scale models of the SS563 and on proof-pressure tests on the 30-ft test tank at the Portsmouth Naval Shipyard.

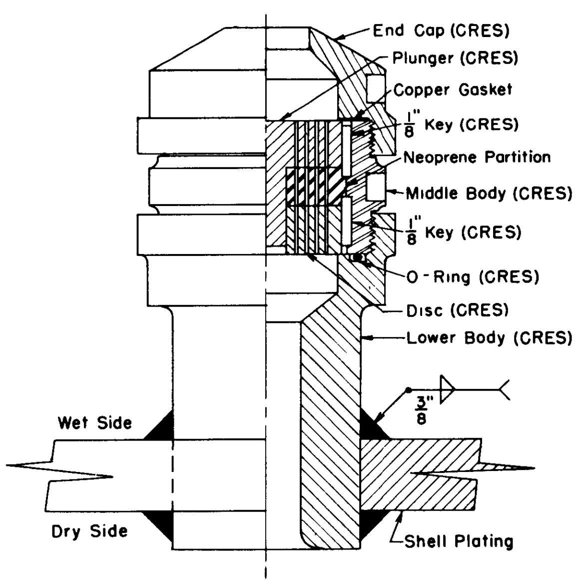


Figure 1 - Assembly of Feed-Through

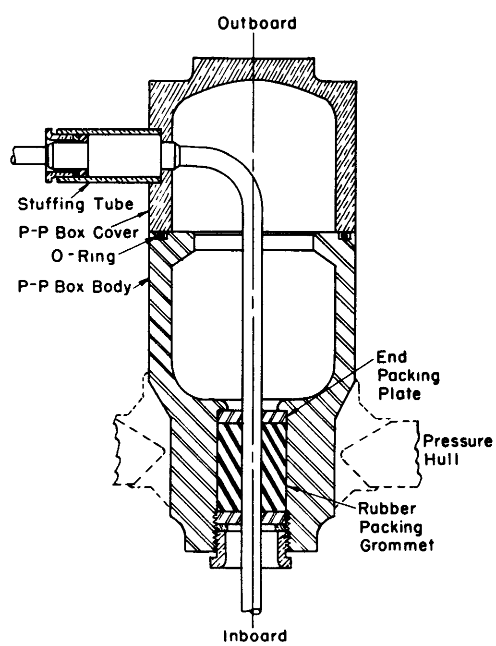


Figure 2 - Assembly of Modified Pressure-Proof Box

*U.S. Navy Hot Plastic Formula 89.

TABLE 1

Waterproofing Results under Actual Field Conditions*

Subject of Test	Type of Test	Waterproof Method	No. of Outside Gages	Failures		
				Waterproofing	Flooding of Pressure-Proof Box	Total
SSK1	Deep Dive	Ozite and Rubber Patch	43	5	28	33
SS563	Deep Dive	Ozite and Rubber Patch	36	8	8	16
SS564	Deep Dive	Barrier-Coat and Rubber Patch	50	1	28	29
SST1	Deep Dive	Barrier-Coat and Neoprene Compound	48	8		8
AGSS569	Deep Dive	Okonite Tape	118	6		6
SS563 Model 1	Full-Scale Model Test	Okonite Tape	87	12		12
30-ft Tank Portsmouth	Proof Test	Okonite Tape	328	6		6

*These are only the results of the final test and do not show failures that were repaired by reinstrumentation.

PERFORMANCE TESTS OF WATERPROOFING

Before testing a method of waterproofing, the conditions under which the strain gage must operate should be investigated. For instance, if a strain gage is to be mounted on the pressure hull of a submarine for use during initial deep-submergence trials, it will probably be submerged at low pressure for some time before the trials. During sea trials, the submarine may be taken to a depth of 50 to 100 ft, and, finally, during the deep-submergence trial, the gages are subjected to the maximum operating pressure of the submarine. Therefore a short-duration waterproofing method is to be avoided.

A test was run in the laboratory that was believed to simulate the conditions that might be expected during full-scale trials, and in structural tests. The gages were soaked for 30 days at 50 psi, then they were subjected to water pressure of 300 psi during 8 hr a day for 10 days, and during 24 hr a day for the next 5 days. The pressure was then raised to 700 psi during 8 hr a day for 10 days and, finally, was allowed to remain at 700 psi for 5 full days. At the completion of this time, the gages which had failed were removed from the pressure tank for study. It is believed that a waterproofing method which survives this test should be acceptable for full-scale trials if ample protection against physical damage is provided.

A total of 40 gages were tested at the Taylor Model Basin with five different waterproofing methods. Each method was employed on two Ax-5, four A-5-1, and two A-7 gages. The procedures used in the Okonite-tape, barrier-coat and rubber-patches, and barrier-coat and neoprene-compound methods are presented in Appendixes 2, 3, and 4.

The gages were tested in the 20-in. test tank, with the leads brought out by means of a feed-through developed at the Model Basin (Figure 1). The gages were connected using No. 22 wire from the switch box through the feed-through to the gages. The Okonite samples, however, had TCOP-2 cable vulcanized to the No. 22 wire from the pressure side of the feed-through to the gage. The gage leads were soldered to a switch box to facilitate taking daily resistance-to-ground readings. The results of this test and of certain other tests are shown in Table 2. Figure 3 shows the test setup.

The Okonite-tape method was developed at the Portsmouth Naval Shipyard and has shown excellent results when applied with careful workmanship. It was retested extensively in the laboratory at the Model Basin for a comparison on a standard basis with other methods. Figure 4 shows a scale model of a submarine section with three different methods of waterproofing employed in order to give a visual comparison of the three methods.

OKONITE-TAPE METHOD RESULTS

Out of 33 gages waterproofed by the Okonite-tape method, the resistance to ground of only six fell below 50 megohms. Of these six, five were caused by "nicks" in the gage cable. The high pressure in the test tank caused the gage cables to push partially back through the feed-through, with the result that some of them were jammed on the edge of the feed-through and the outside insulation was cut. Water then seeped into the cable and hosed through it to the switch box. The water could not reach the gages, themselves however, because of the manner in which the cables were jammed against the feed-through.

This problem of cut gage cables occurred only when large diameter cable was used in the feed-through. In order to overcome this, No. 22 wire was used through the feed-through, vulcanized to a piece of TCOP-2 cable that ran to the gage. Another possible method of combating this problem is to insert a vulcanized end-seal on the cable just ahead of the gage. This method, described in Appendix 2, is recommended for full-scale trials.

The one other gage whose resistance to ground fell below 50 megohms* was still capable of being balanced on a Baldwin strain indicator. Only Gage 20, could not be so balanced. Therefore, 32 out of 33 gages that were waterproofed with Okonite tape performed satisfactorily in laboratory tests for approximately 60 days under conditions similar to those likely to be encountered in service in full-scale installations. The main disadvantages of the Okonite method are the skill required by the workman and the time necessary to waterproof a gage approximately

*The final resistance to ground is a more important factor than the amount of change in resistance to ground; this fact will be shown in Appendix 5.

TABLE 2

Waterproofing Results under Laboratory Conditions

Method	Test No.	Gage and No. Type	Maximum Pressure psi	Pressure Cycle	Resistance to Ground, Megohms Initial	Resistance to Ground, Megohms Final	Pressure at Which Flooding Occurred	Approximate Time to Apply Waterproofing hr	Remarks
Okonite Tape	1	1 A-5-1	1,000	Constant Pressure for 50 hr	30,000*	30,000		1 1/4	
		2 A-5-1			30,000*	30,000			
		3 A-5-1			30,000*	30,000			
	2	4 A-5-1	1,000	Constant Pressure for 20 hr	5,000	3,000	1,000 After 18 hr	4	Failure caused by cut gage cable
		5 A-5-1			6,000	3,000			
		6 A-5-1			8,000	3,000			
		7 A-5-1			5,000	3,000			
		8 A-5-1			6,000	10			
		9 A-5-1			6,000	10			
		10 A-5-1			5,000	3,500			
		11 A-5-1			4,000	3,500			
	3	12 A-5-1	1,000	Constant Pressure for 26 hr	15,000	10,000	Hosed After 20 hr	4	Failure caused by cut gage cable
		13 A-5-1			15,000	100			
		14 A-5-1			15,000	7,000			
		15 A-5-1			15,000	7,000			
		16 A-5-1			10,000	20			
		17 A-5-1			10,000	20			
	4	18 Ax-5	300	1 day at 300 psi 1 day at 1200 psi 1 day at 0 psi 1 day at 1300 psi	5,000	1,500	100	4	Failure caused by cut cable
		19 Ax-5			5,500	700			
		20 Ax-5			3,500	0.6			
		21 Ax-5			5,000	1,500			
	5	22 Ax-5	700	30 days at 50 psi 5 days at 300 psi (8 hr/day) 10 days at 300 psi 5 days at 700 psi (8 hr/day) 10 days at 700 psi	4,000	100		4	
		23 Ax-5			5,000	110			
		24 A-5-1			4,000	60			
		25 A-5-1			5,000	80			
		26 A-5-1			6,000	50			
		27 A-5-1			3,500	250			
		28 A-7			2,200	200			
		29 A-7			4,000	40			
	6	30 A-5-1	800	Constant Pressure 8 hr/ day 5 days	400	100		2	
		31 A-5-1			400	100			
		32 A-5-1			300	300			
		33 A-5-1			300	300			
Barrier-Coat and Neoprene Compound	1	1 Ax-5	700	30 days at 50 psi 5 days at 300 psi (8 hr/day) 10 days at 300 psi 5 days at 700 psi (8 hr/day) 10 days at 700 psi	15,000	4,000	700	4	
		2 Ax-5			3,500	150			
		3 A-5-1			2,000	4,000			
		4 A-5-1			10,000	5,000			
		5 A-5-1			5,000	4,500			
		6 A-5-1			10,000	20			
		7 A-7			1,000	50			
		8 A-7			700	60			
	2	9 A-5-1	800	Constant Pressure 8 hr/day, 5 days	500	70		1/2	
		10 A-5-1			500	70			
		11 A-5-1			600	90			
		12 A-5-1			600	90			
Barrier-Coat and Rubber Patch	1	1 Ax-5	700	30 days at 50 psi 5 days at 300 psi (8 hr/day) 10 days at 300 psi 5 days at 700 psi (8 hr/day)	7,000	100	700	4	
		2 Ax-5			15,000	50			
		3 A-5-1			7,000	15			
		4 A-5-1			10,000	50			
		5 A-5-1			3,000	5,000			
		6 A-5-1			5,000	4,000			
		7 A-7			3,000	1,500			
		8 A-7			4,000	3,000			

*Gages read after pressure-proofing and a 2 week curing period.

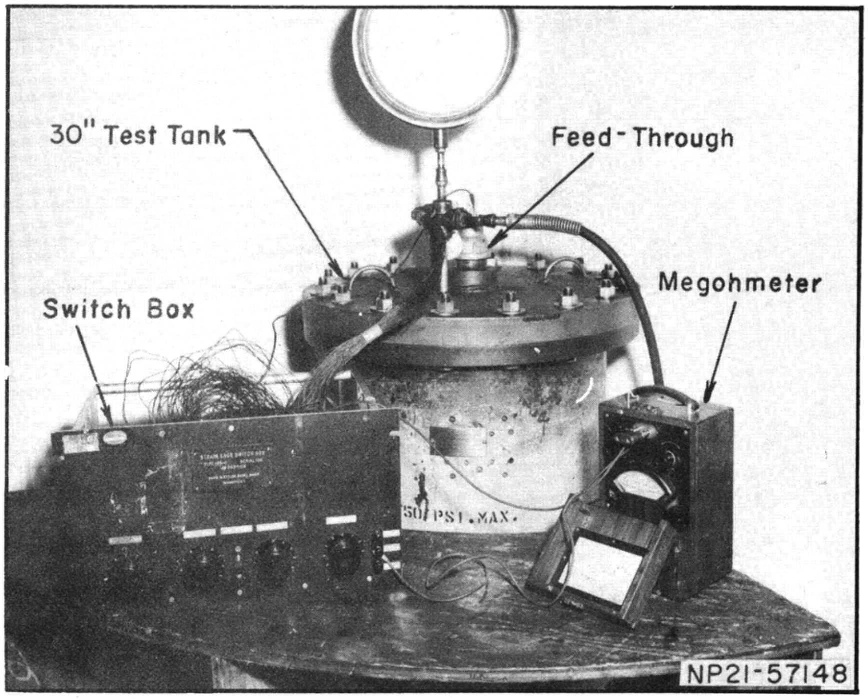
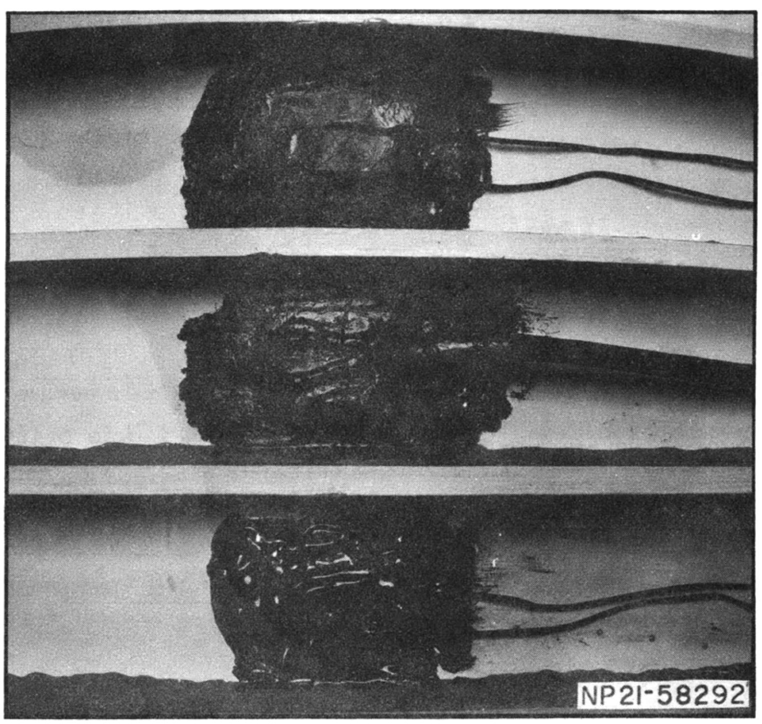


Figure 3 - Laboratory Test Setup



A-5-1 Gage Waterproofed by Barrier Coat and Rubber Patch

Ax-5 Gage Waterproofed by Okonite Tape

A-5-1 Gage Waterproofed by Barrier Coat and Neoprene Compound

Figure 4 - Basic Research Model, with three Different Waterproofing Methods Employed on the Gages

1 hr* because of the drying time of the cement. If they are all in the same area and can be waterproofed as if on an assembly line, such as under ideal laboratory conditions, up to 10 gages can be waterproofed in approximately 4 hr. Labor and time may be saved on field trips by cutting out the tape patterns in advance.

BARRIER-COAT AND NEOPRENE-COMPOUND METHOD

The barrier-coat and neoprene-compound method, described in Appendix 3, proved quite successful on deep-submergence trials of the SST1. Due to the limited availability of the ship during instrumentation, the heat curing cycle, described in Appendix 3, was omitted. Nevertheless the results were very good, with over 80 percent of the gages functioning properly.

However, to verify this method further, 12 gages were tested in the laboratory. Results showed that only one of the 12 had a resistance to ground of less than 50 megohms. The heat curing cycle was also omitted during the laboratory test because of the warm temperature in the laboratory. The time necessary to waterproof a gage by this method is approximately 20 min when the second to sixth coats of neoprene compound and the heat curing cycle are omitted. It is felt that this curing cycle may be omitted, if necessary, in a warm climate. Under ideal laboratory assembly-line conditions, up to 10 gages can be waterproofed in approximately 2 hr.

BARRIER-COAT AND RUBBER-PATCH METHOD

With the barrier-coat and rubber-patch method, described in Appendix 4, only one gage out of a total of eight fell below 50 megohms resistance to ground. Examination of this gage indicated that the patch used did not extend far enough beyond the edge of the barrier coat to give a good seal. The gage did not fall below 50 megohms until 700 psi had been reached; therefore it was assumed that the barrier coat alone afforded waterproofing qualities at the 300-psi level.

This fact was brought out in previous tests when only barrier coat was used as the waterproofing medium. However, barrier coat is very brittle when it hardens and is not considered very reliable on full-scale trials where mechanical damage could result. Another disadvantage is that the workman must take extra precautions to ensure that the patch is securely glued to the surface and that all air is expelled from under the patch. Expelling the air is the most exacting process in this technique and must be done with a hypodermic needle, as explained in Appendix 4. The time necessary to waterproof a single gage by this method is about 30 min.

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*Times given in this report are for application of the waterproofing materials only.

CONCLUSIONS

As a result of the laboratory tests and full-scale trial experience, the following conclusions have been drawn:

1. No one superior method is yet available for waterproofing.

2. Proper technique on the part of the workman is essential for good waterproofing.

3. Barrier coat and neoprene compound is a quick and easy method that takes average skill and gives good results, as shown in Table 2.

4. Results from full-scale trials indicate that the Okonite-tape method and the barrier-coat and rubber-patch method give results of about equal merit.

5. The particular method to be used for any waterproofing operation will depend upon the discretion of the engineer, and the accessibility of the gage location.

RECOMMENDATIONS

Research in strain gage waterproofing should be intensified in order to find one universal method which will enable gages to hold up under hydrostatic pressure for at least six months.

During the preparation of this report, other methods[2,3,4] have been found that should be studied, and plans are underway to continue the investigation.

ACKNOWLEDGMENTS

The barrier-coat and rubber-patch method was first used under the supervision of Mr. D. Peugh in July 1952. The barrier-coat and neoprene-compound method was first used under the supervision of Mr. B.F. Goldhammer in September 1953. The Okonite-tape method was devised by Mr. C. Randall of the Portsmouth Naval Shipyard.

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APPENDIX 1

INSTALLATION OF SR-4 STRAIN GAGES

The procedure to be used in installing SR-4 strain gages is as follows:

1. Clean the metal surface of rust and scale by grinding and smoothing with emery cloth. The surface should be even but not mirror smooth. A 180-grit emery cloth will give the desired roughness. Center lines for positioning the gages should not be scribed too deep, but they should extend beyond the edges of the gage. If the surface is damp, it should be dried with a heat lamp.

2. Clean the surface with a cotton swab saturated in acetone. The surface is clean enough for gage installation when a fresh swab remains colorless after being rubbed across the metal surface.

3. Check the resistance of the gage, being careful not to touch the gage surface with the fingers. The gage may be checked while still in the protective folder by sliding it part way out of the folder and bending the leads perpendicular to it.

4. Using Duco household cement, bond the gage to the surface. First expel the initial drop of cement from the tube, then apply the cement generously to the gage surface. Immediately mount the gage to the prepared surface. Using the finger tips, press the gage against the surface, working out all air pockets and excess cement from under the gage. After the gage is properly cemented down, allow it to air dry for approximately 1 hr.

5. Heat lamps may now be used to hasten the final drying process. Take care to have the lamps far enough away from the gage to prevent charring (10 to 15 in.). The temperature should never exceed 140 F.

6. Recheck resistance of gage and resistance to ground. Gage is ready to be waterproofed if the resistance to ground is greater than 500 megohms.

7. If the gage is not to be waterproofed immediately, it should be protected by some mechanical means. However, it is recommended that some moisture-proofing be done to the gage if there is to be a time lapse between installation and waterproofing. Also clean the excess cement from metal around gage with acetone.

APPENDIX 2

OKONITE-TAPE METHOD

After the gage has been installed as described in Appendix 1, waterproof it as follows:

1. TCOP-2 cable is used in this method. About 1 1/2 in. of the outer covering of the cable should be removed and the leads bared for about 1/4 to 3/8 in. If the third lead is not to be used, it should be cut off where it emerges from the outer covering. The cable leads should be tinned before soldering. The cable covering should then be roughened and cleaned with acetone for approximately 3/4 in.

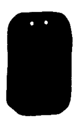
Piece 1

2. Cover entire gage area with utility cement* and let dry for approximately 20 min (see Figure 5a).

Piece 2

3. Cut six pieces of Okonite tape** in shapes shown. Size of pieces will pend upon type of gage used and surrounding area available.

4. Apply Piece 1 under gage leads (Figure 5a).

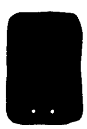


Piece 3

5. Apply Piece 2 over gage and slightly overlapping Piece 1 (Figure 5a).

6. Apply coat of utility cement to entire area and let dry for approximately 20 min.

7. Apply Piece 3 over gage with gage leads through holes (Figure 5b).



Piece 4

8. Push cable leads through Piece 4. Solder gage leads to cable leads (Figure 5c). Cover connection and let dry approximately 20 min.

9. Press down Piece 4 and cover with utility cement. Let dry for approximately 20 min (Figure 5d).

Piece 5

10. Apply Piece 5 with throat of opening 1/4 in. up on outer covering of cable. Wrap the tongues around the cable, one overlapping the other. Work the piece down over the gage making sure that all air is expelled. Cover with utility cement and let dry approximately 20 min (Figure 5e).

Piece 6

11. Apply Piece 6 from behind gage with throat approximately 1/4 in. on cable. This piece covers the "splice" of Step 10 (Figure 5f).

12. Wrap cable starting at gage with Okonite tape 1/2 by 4 in. (Figure 5f).

13. Apply utility cement over entire patch and let dry for approximately 1 hr (Figure 5g).

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*One manufacturer of utility cement is the Knowles Rubber Company, Inc., 655 Atlantic Ave., Boston, Mass.

**Product of Okonite Corporation, Passaic, N.J.

14. Apply second coat of cement and let dry for approximately 1 hr (Figure 5g).

15. Entire patch may be covered with 3-M compound to provide additional mechanical protection.

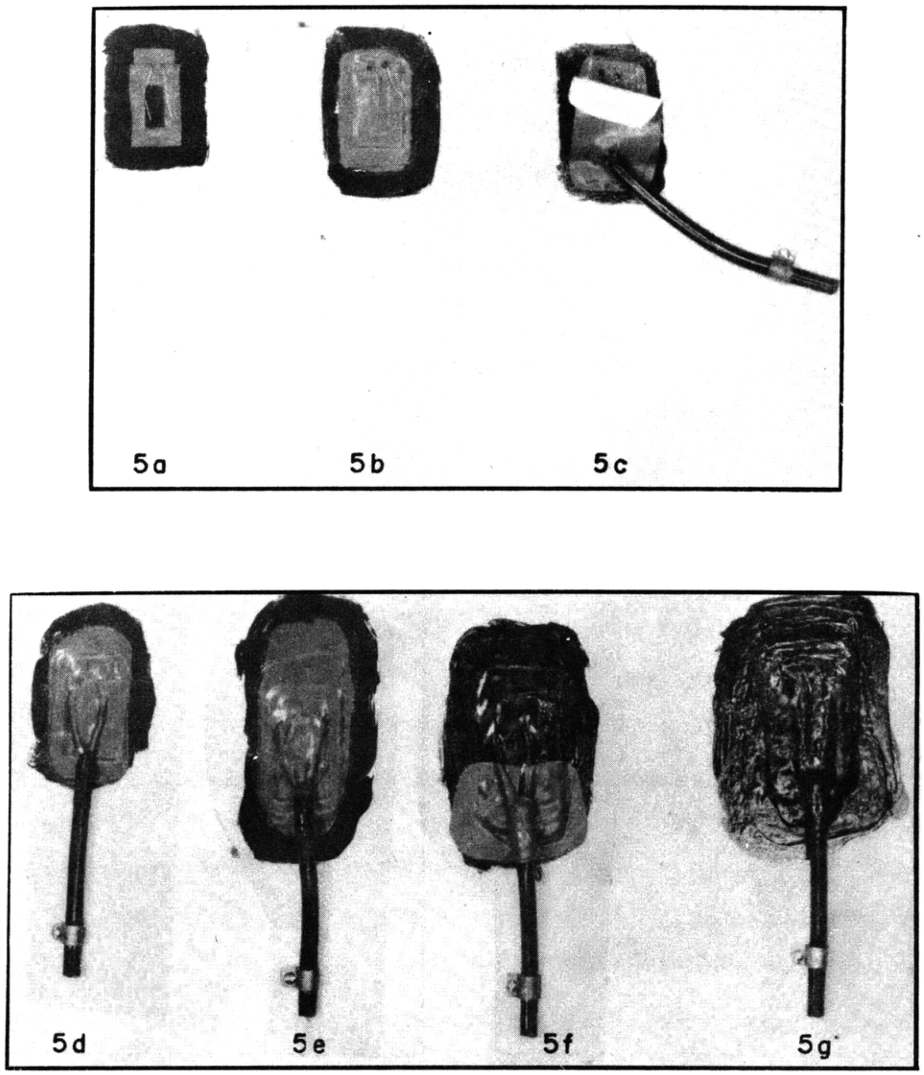

Figure 5 - Steps in Waterproofing Strain Gages by the Okonite-Tape Method

APPENDIX 3

BARRIER-COAT AND NEOPRENE-COMPOUND METHOD

After the gage is installed as described in Appendix 1, waterproof it as follows:

1. Apply a layer of hot barrier coat† to the gage, taking care to get as little as possible on the gage leads; temperature of the barrier coat should not exceed 170 F.

2. Solder gage leads to gage wires, using No. 22 gage wire.

3. Press wire back over gage and slightly into first layer of barrier coat.

4. Build up succeeding layers of barrier coat over the gage. Apply smoothly, see Figure 6.

5. Apply cold Gaco* N-100-1 neoprene primer or equivalent to area and let dry for approximately 20 min.

6. Apply first coat of Gaco N-200-1 neoprene brushing compound or equivalent and let dry for at least 1 hr.

7. Apply four to six more coats of brushing compound, letting each coat dry for approximately 1 hr. Allow 24 hr for air drying after the last coat has been applied (Figure 7).

**8. Cure under heat lamps for 6 hr by gradually bringing the temperature up to 140 F.

**9. Raise temperature gradually to 170 F over a 4-hr period.

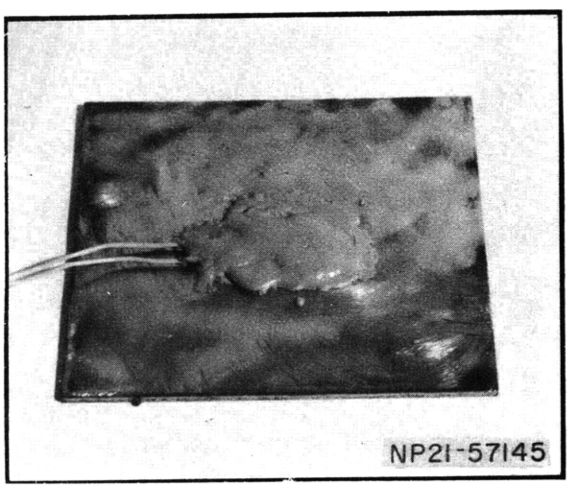

Figure 6 - Barrier-Coated Gage

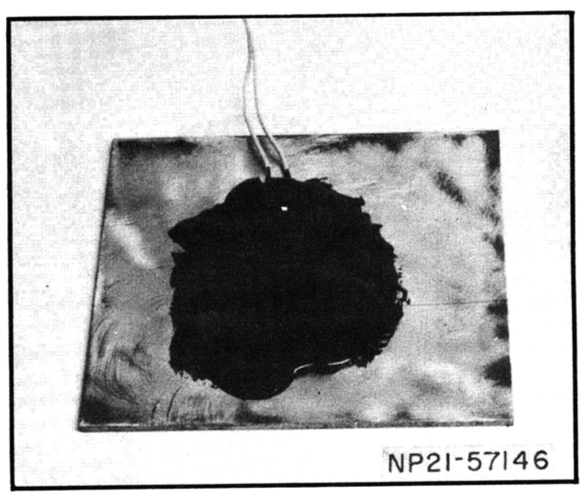

Figure 7 - Gage Covered with Neoprene Compound

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†U.S. Navy Hot Plastic Formula 89.

*Product of Gates Engineering Co., Wilmington, Delaware.

**The heat curing of Steps 8 and 9 has been omitted in the tests of Tables 1 and 2. This curing cycle may be omitted for temperatures above 60 F.

APPENDIX 4

BARRIER-COAT AND RUBBER-PATCH METHOD

After the gage is installed as described in Appendix 1, waterproof it as follows:

1. Apply a layer of barrier coat about 1/8 in. thick to the gage, taking care to get as little as possible on the gage leads. The barrier coat acts as an insulator and may result in a faulty soldered connection.

2. Cut a patch from 0.016 or 0.032 in. rubber sheet. The patch should extend over the barrier-coated gage at least 3/4 in. on all sides. By means of a small diameter punch, puncture two small holes in the patch to allow access of lead wires to gage.

3. Push lead wires through holes and solder to gage leads; see Figure 8.

4. Apply layer of rubber cement to gage area and to underside of patch. Allow to dry until tacky.

5. Press patch down securely over gage.

6. Apply barrier coat at openings where wires pass through patch.

7. Work any air under patch into one general area. Insert a hypodermic needle into this air bubble and evacuate the air by drawing out the plunger of the hypodermic syringe. Before extracting the needle, apply barrier coat over the spot where it pierces the patch. This will prevent the entrance of more air through the needle hole. Repeat process untill there is no air under the patch; see Figure 9.

8. Cover entire patch with rubber cement; see Figure 10.

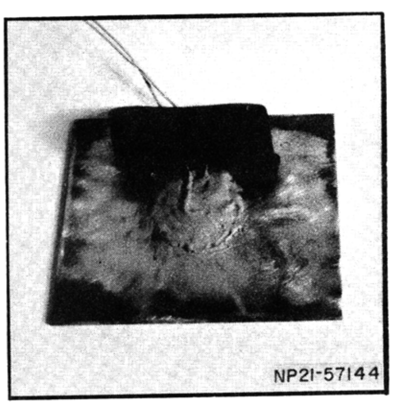


Figure 8 - Barrier-Coated Gage Prior to Cementing down of Patch

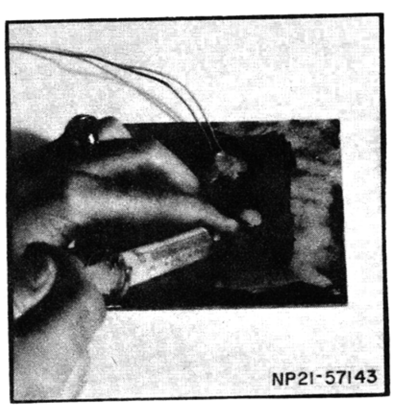


Figure 9 - Expelling Air from under Patch by Means of a Hypodermic Needle

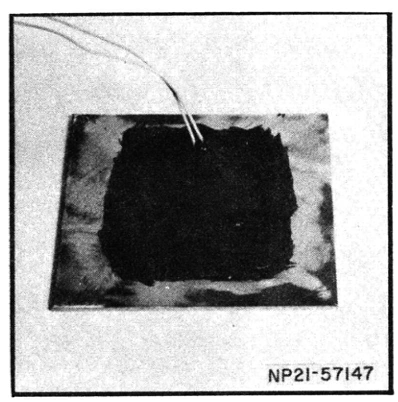


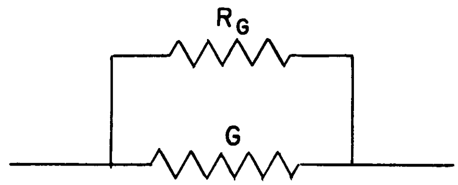
Figure 10 - Rubber-Patched Gage

APPENDIX 5

EFFECT OF CHANGE OF RESISTANCE TO GROUND ON RECORDED STRAINS

It is a known fact that a change of resistance to ground of electrical resistance strain gages causes an apparent change in strain as observed on a strain indicator. Since the resistance to ground changed for a number of the gages in Table 2, it appeared necessary to study this phenomena.

The initial gage circuit before any loss of resistance to ground may be depicted as follows:



The resistance of the initial circuit is then

$$R = \frac{GR_G}{G + R_G}$$

where G is the gage resistance and R_G is the initial resistance to ground.

If R_G decreases by δ, the resistance of the circuit becomes

$$R_2 = \frac{G(R_G - \delta)}{G + R_G - \delta} \quad [1]$$

and the change of resistance of the circuit is

$$\Delta R = \frac{G(R_G - \delta)}{G + R_G - \delta} - \frac{GR_G}{G + R_G}$$

$$= -\frac{\delta G^2}{(G + R_G)(G + R_G - \delta)} \quad [2]$$

and

$$\frac{\Delta R}{R_2} = -\frac{\delta G}{(G + R_G)(R_G - \delta)} \quad [3]$$

Since G is very small compared with R_G, we can neglect G in the denominator and

$$\frac{\Delta R}{R_2} = -\frac{\delta G}{R_G(R_G-\delta)} \qquad [4]$$

This change of resistance produces a change in electrical out-put signal that is equivalent to a signal produced by straining the gage an amount ϵ (unit strain). Since this is the case,

$$\frac{\Delta R}{R_2} = K\epsilon \text{ in/in.} \qquad [5]$$

where K is the gage factor.
Then

$$-K\epsilon = \frac{\delta G}{R_G(R_G-\delta)} \text{ in/in.}$$
$$= \frac{\delta}{R_G}\left[\frac{G}{1-\frac{\delta}{R_G}}\right]\frac{1}{R_G} \text{ in/in.} \qquad [6]$$

However this equation applies to the leakage resistance of the gage only and not to a mechanical shorting out, such as a bare lead wire touching the metal surface on which the gage is mounted.

Equation [6] is shown in Figure 11 in nomograph form with δ and R_G in megohms and $-K\epsilon$ in μ in/in. for ease of computing the amount of error in the strain indicator reading due to a loss of resistance to ground for a 120-ohm gage. The Baldwin strain indicator is accurate to 10 μ in/in. but can be read to 5 μ in/in. Therefore any changes of strain that are less than 5 μ in/in. can be disregarded.

By referring from Table 2 to the nomograph of Figure 11, it can be seen that none of the gages, excluding those that were shorted out, showed any appreciable change of reading on the strain indicator.

Gage 3 of the barrier-coat and rubber-patch method dropped from 7,000 to 15 megohms.* By referring to the nomograph, the amount of change of strain reading is found to be:

$$7{,}000 \text{ to } 700 \text{ megohms } \frac{\delta}{R_G} = 0.9$$
$$-K\epsilon = 0.15\ \mu \text{ in/in.**}$$

* 10^6 ohms = 1 megohm.

**10^{-6} in/in. strain = 1 μ in/in. strain

$$700 \text{ to } 70 \text{ megohms } \frac{\delta}{R_G} = 0.9$$

$$-K\epsilon = 1.75\ \mu \text{ in/in.}$$

$$70 \text{ to } 15 \text{ megohms } \frac{\delta}{R_G} = 0.79$$

$$-K\epsilon = 7.0\ \mu \text{ in/in.}$$

Therefore the total $-K\epsilon = 8.9\ \mu$ in/in.; the gage factor of this gage was 2.03. Hence the change in reading on the strain indicator for a change in resistance to ground from 7,000 to 15 megohms was 4.38 μ in/in. This gage had the greatest change of reading and yet its change of 4.38 μ in/in. was hardly discernible on the strain indicator.

While it has been shown that a change of resistance to ground has an effect on the recorded strain, it becomes evident that the most important factor is the final resistance to ground. In the case above, the final resistance to ground would have to have been 6 megohms in order to have a strain drift of 10 μ in/in. Therefore, if the final resistance to ground can be kept above 10 megohms, no appreciable change of reading will be encountered on the strain indicator due to change of resistance to ground.

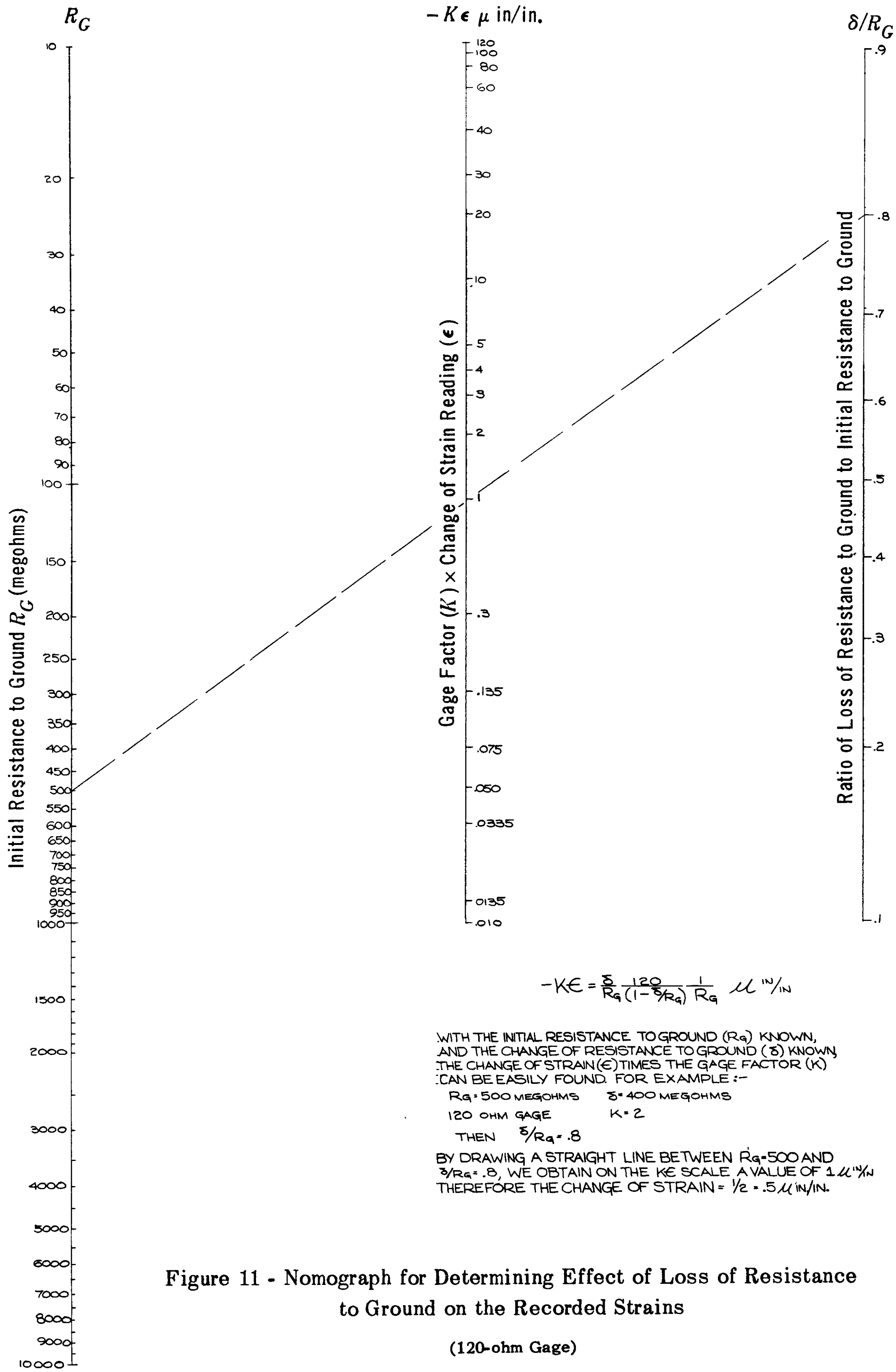


Figure 11 - Nomograph for Determining Effect of Loss of Resistance to Ground on the Recorded Strains

(120-ohm Gage)

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