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Strain Gage Instrumentation of a Buoyant Cable

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LINCOLN LABORATORY

STRAIN GAGE INSTRUMENTATION OF A BUOYANT CABLE

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Group 66

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ABSTRACT

The strain gage instrumentation of a buoyant cable used for submarine ELF receiving antennas is presented in this report. Techniques were developed to bond the strain gage reliably to the polyethylene cable jacket and to seal the jacket using an injection molding process. The design of a low noise strain gage amplifier for dynamic strain measurements is discussed, and the general problem of measuring strain at a remote point is considered.

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I. INTRODUCTION

Two buoyant cables have been instrumented with strain gages to measure the dynamic cable strain when towed from a submarine. The strain measurements are required for the investigation of the noise mechanisms encountered with the ELF flexible loop receiving antennas.[1]

Three pairs of gages have been installed in each cable to measure the longitudinal and bending strain. The principle axis of the strain gage lies along the longitudinal axis of the cable, and a pair of gages are placed parallel to each other and equidistant from the center (Fig. 1). The gages are bonded to the foamed polyethylene cable jacket using a mylar clad polyethylene tape interface, and the cable is sealed with polyethylene to prevent sea water penetration and to protect the gages during submarine deployment.

Placement of the strain gages on the two buoyant cables is shown in Fig. 2. One pair of gages is placed close to the deployment point to determine the cable excitation near the submarine. The amount of cable deployed can be varied during a test to study the region between 0-300 ft. from the sail. Two pairs are placed in the region of the cable where an antenna would be located. It is planned that during a submarine measurement the tail will be shortened to study the cable strain near the end of the cable.

Two major considerations in the installation of the strain gages in the buoyant cable were to provide good dynamic coupling of cable strain to the gage and high reliability of the gage and electrical connections. Extensive tests were conducted to test various methods of installation and the effect on the gage when the cable was repeatedly bent over a 12 inch diameter to simulate deployment of the cable from a submarine. Because the cable is stored on a reel, reliability tests were also performed over a three month period to insure that prolonged tension or compression was not detrimental to the gage bond.

Instrumentation for the strain gages consists of a set of specially designed low noise strain gage amplifiers. The equivalent noise input for the

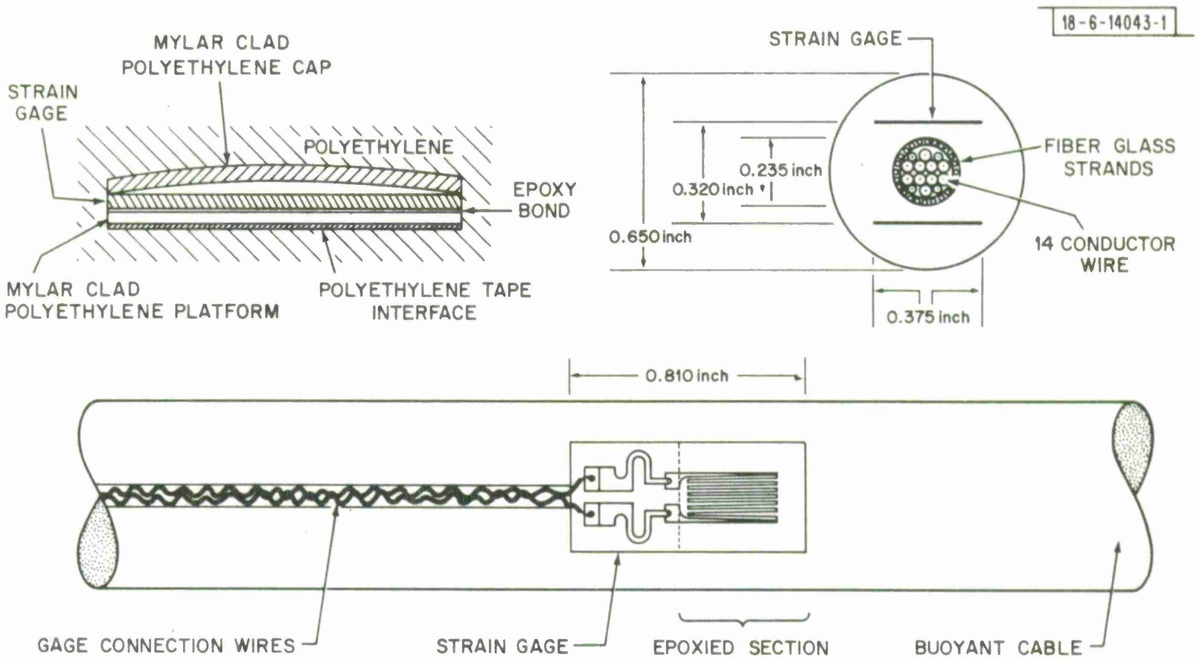


Fig. 1. Strain gage installation in buoyant cable.

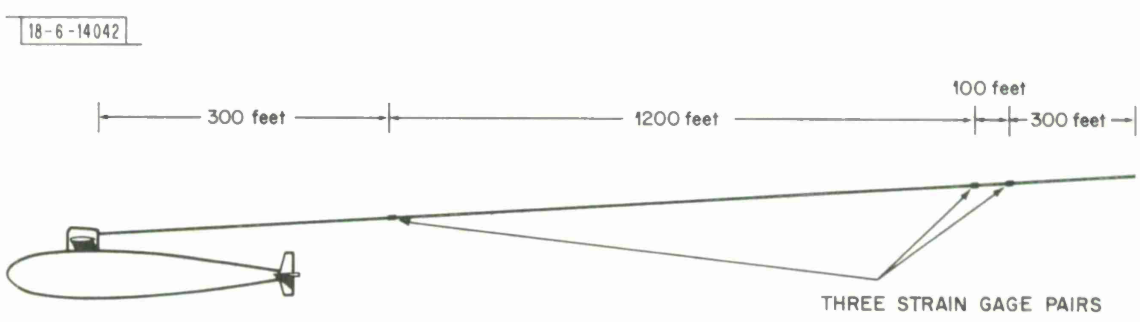


Fig. 2. Placement of strain gages on buoyant cable.

amplifiers is -181 dB with respect to unity strain in a 1 Hz bandwidth at 45 Hz, and this represents a noise figure of 5.5 dB. A calibration circuit is included in each amplifier to test the electrical connections to the strain gage and the operation of the amplifier. The frequency response of the amplifiers is from 1-500 Hz with the option of moving the low frequency cut-off point to 5 or 20 Hz.

II. STRAIN GAGE INSTRUMENTATION

The strain gage used for the buoyant cable measurements consists of an annealed constantan etched foil grid bonded to a thin, flexible backing. When a load is applied to the gage material, the resistance of the grid changes. The ratio of the change in resistance to the change in length along the principle axis of the gage is defined as the gage factor. If the gage factor were dependent entirely on dimensional changes, a gage factor of approximately 1.7 would be expected using Poisson's ratio. However, it is found that the gage factor is dependent more on the properties of the grid material and the gage factor for the annealed constantan gage is 2.02.

A. Strain Measurements

A basic technique for measuring strain is to drive a strain gage with a constant current source and measure the change in voltage across the gage. This technique is not satisfactory for the buoyant cable measurements though because the electrical connections to the gage are long and subject to strain themselves.[2] In order to minimize the effect of straining the connections, a three wire connection is made to the strain gage and a bridge circuit is used to cancel out the effect of conductor strain (Fig. 3). Resistance R_1 is equal to the strain gage resistance R_g under zero strain, and the value of R_2 is chosen to maximize the output voltage V_o for a given strain input. For the case where resistance of the electrical connection is negligible ($R_w = 0$), the change in bridge voltage for a change in gage resistance is

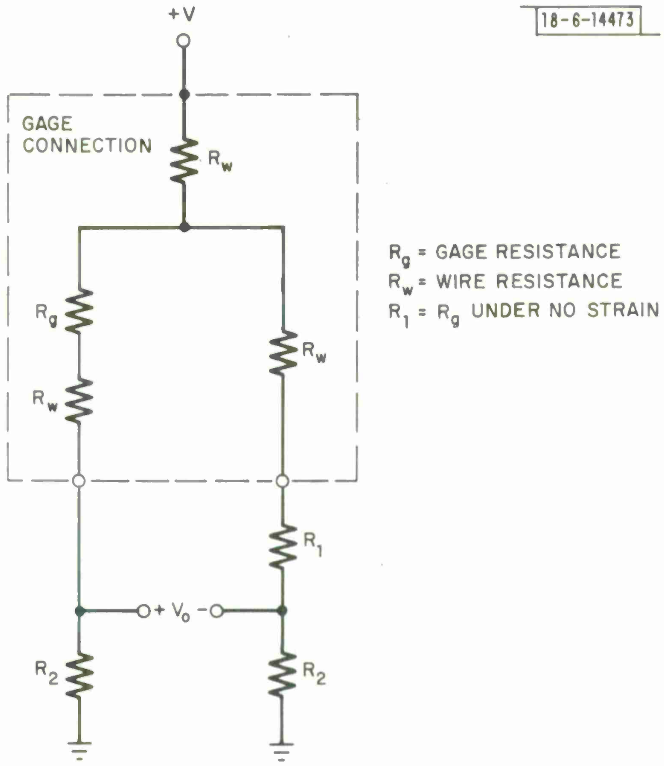


Fig. 3. Strain gage connection to bridge circuit.

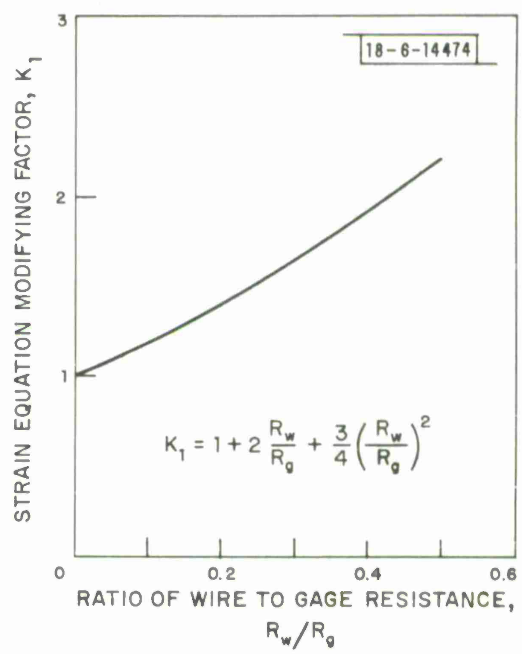


Fig. 4. Effect of wire resistance of electrical connections on strain equation.

$$\frac{d\,V_o}{d\,R_g} = \frac{-R_2\,V}{(R_2 + R_g)^2}$$

and this derivative is maximum when $R_2 = R_g$ under zero strain. The incremental output voltage e_o for an incremental change in gage resistance R_g is then,

$$e_o = \Delta V_o = -\frac{V}{4}\,\frac{\Delta R_g}{R_g}$$

and the strain, $S = \Delta L/L$, is,

$$S = \frac{4}{FV}\,e_o$$

using the gage factor, $F = \dfrac{\Delta R/R}{\Delta L/L}$.

The resistance of the electrical connections is usually small compared to the gage resistance, and therefore R_2 is chosen equal to R_g. Calculating the strain relationship to the output voltage when the electrical connection resistance R_w is included,

$$S = -\frac{4}{FV}\left[1 + 2\frac{R_w}{R_g} + \frac{3}{4}\left(\frac{R_w}{R_g}\right)^2\right] e_o = -\frac{4}{FV}\,K_1\,e_o$$

and a plot of the modifying factor in the brackets is plotted in Fig. 4 as a function of the ratio of the electrical connection resistance to gage resistance.

B. Sensitivity to Straining Electrical Connections

If an imbalance occurs in the bridge circuit caused either by a static load applied at the gage or tolerances limitations of the resistors making up the bridge, straining the electrical connections will cause a signal at the bridge output. Considering the case where the nominal values for the three fixed bridge resistors are equal to the gage resistance, let ΔR be the net imbalance of one arm of the bridge with respect to the other arm. A tensile strain S_w in the electrical connections will cause an increase in the conductor resistance R_w, and an output voltage e_{ow} will be generated. Comparing this output with a signal e_{og} caused by straining the gage by an amount S_g, the ratio of the output signals (to a first order approximation) is,

$$\frac{e_{ow}}{e_{og}} = \frac{2\frac{R_w}{R_g}\left[1+\frac{3}{4}\frac{R_w}{R_g}\right]}{1+2\frac{R_w}{R_g}+3\left(\frac{R_w}{R_g}\right)^2} \cdot \frac{\Delta R}{R_g} \cdot \frac{S_w}{S_g} = K_2 \frac{\Delta R}{R_g} \frac{S_w}{S_g}$$

where the gage factors of the strain gage and conductors are considered to be equal. A plot of the term K_2 containing the ratios of wire to gage resistance appears in Fig. 5.

This analysis is a worst case situation since it assumes that the conductor strain is uniform along the complete length of the conductor. The wavelength of the dynamic strain being measured in the buoyant cable is short compared to the length of the conductors, and therefore the signals generated by the conductors will be less than expected from a point measurement. Typically the tolerance of the gage resistance is ± .2%, and the bridge resistors are less than ± .3%. The major imbalance occurs at high towing speeds where up to a 1% tensile strain can occur, changing the gage resistance by 2%. For a wire resistance 1/10 of the gage resistance, then, over 47 dB of rejection is provided by the bridge circuit.

C. Effect of Amplifier Input Impedance

Ideally, the amplifier used to measure the bridge voltage should have a very high input impedance. Noise figure consideration, however, place limitations on the input impedance because of the matching transformer. An amplifier with a complex input impedance Z_i will modify the strain equation by

$$S = -\frac{4}{FV}\left[1+\frac{3}{4}\frac{R_g}{Z_i}\right] e_o$$

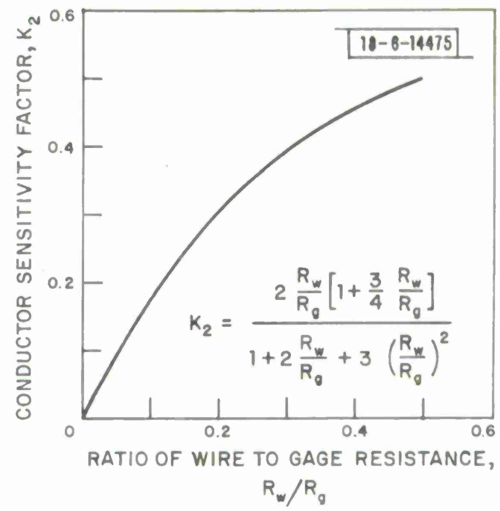


Fig. 5. Effect of wire resistance on the sensitivity to conductor strain equation.

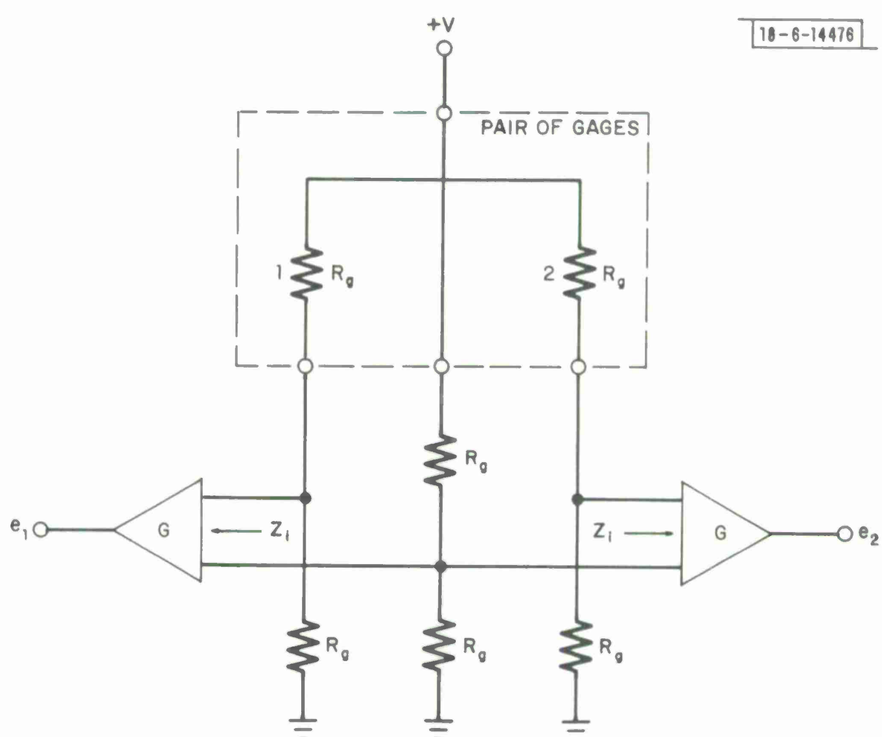


Fig. 6. Strain gage pair connected to dual bridge circuit.

for the case where the wire resistance of the electrical connections is zero.

At each measuring point a pair of strain gages are utilized to measure the longitudinal and bending strain of the cable. In order to minimize the number of electrical connections to a pair of gages, the gages can be connected to a dual bridge circuit (Fig. 6). An undesirable effect of this type of bridge circuit is that crosstalk will occur between gages due to the finite input impedance to the amplifiers. If e_1 is the voltage output of amplifier one due to straining gage one, and e_{21} is the output of amplifier two due to straining gage one, then the crosstalk caused by the amplifiers input impedance Z_i is,

$$\frac{e_{21}}{e_1} = \frac{R_g}{Z_i} \frac{1}{1 + 2\frac{R_g}{Z_i} + \frac{1}{2}\left(\frac{R_g}{Z_i}\right)^2}$$

when the wire resistance is zero. A crosstalk analysis of the amplifier designed for the buoyant cable measurements is presented in the next section.

D. Calibration of Strain Gage Circuit

A true calibration of the strain gage circuit would require that a known mechanical strain be applied to the measuring point. With the buoyant cable deployed behind a submarine, such a feat would be more complex than the gage installation itself. Instead, an adequate dynamic electrical calibration of the gage, electrical connections, bridge and amplifier can be made by forcing an incremental change in the strain gage resistance. Switching a series resistor into the gage connection is the most desirable method, but is not practical because of switch resistance. Switching a parallel resistance across the gage eliminates the switch resistance problem. However, because the wire resistance of the electrical connection is in series with the gage, the effect of the wire resistance on the calibration must be taken into consideration.

Switching a resistance R in parallel with the gage, the incremental per unit change in the resistance is R_g/R when the wire resistance is zero and $R >> R_g$ (Fig. 7). Taking the wire resistance into consideration, the effective incremental per unit change in resistance becomes,

$$\frac{R_g}{R} K_3 = \frac{R_g}{R} \cdot \frac{1 + 3\frac{R_w}{R_g}}{1 + \frac{R_w}{R_g} - \frac{R_w^{\;2}}{4 R_g (R_g + R_w)}}$$

and a plot of the factor modifying R_g/R is plotted in Fig. 8 as a function of the ratio of R_w to R_g.

III. STRAIN GAGE AMPLIFIER

A. Noise Figure

Based on the submarine tests and laboratory measurements[3] made on the ELF flexible loop antenna, it is concluded that the longitudinal cable strain levels are below -150 dB with respect to unity strain $/\sqrt{Hz}$ at 45 Hz. The noise level of the strain gage is determined by thermal noise generated by the gage resistance and the bridge circuit. For a balanced bridge with R_1 and R_2 equal to R_g (Fig. 3 with $R_w = 0$), the effective source resistance across the amplifier input is equal to R_g. The thermal noise power density is

$$\overline{e_o^{\;2}} = 4kT R_g$$

where k is Boltzmans constant and T is the average temperature in ^oK of the gage and bridge resistors. The strain noise power density is then

$$\overline{S^2} = \frac{64kT R_g}{F^2 V^2} \quad .$$

Since the noise power density is inversely proportional to the square of the bridge voltage, the highest practical voltage consistent with the current capacity of the gage was chosen. The strain gage resistance is 350 ohms

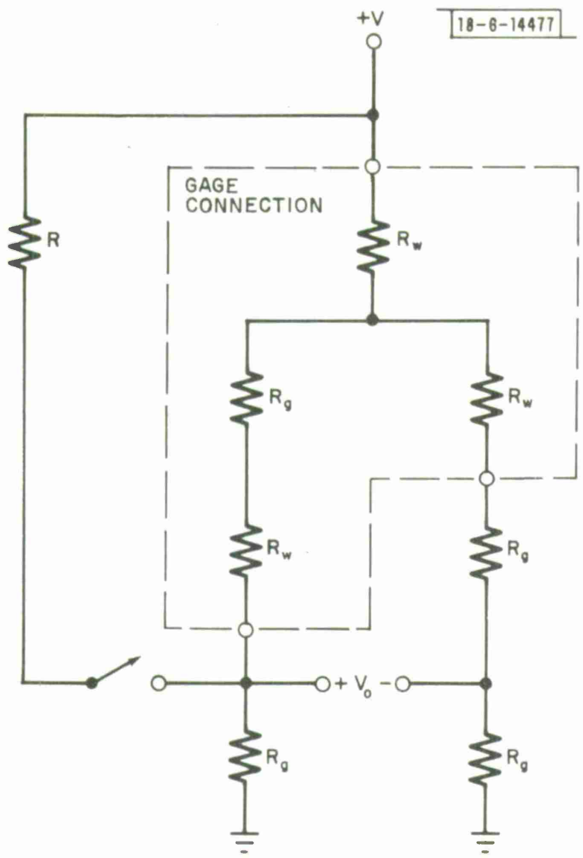


Fig. 7. Shunt calibration of strain gage circuit.

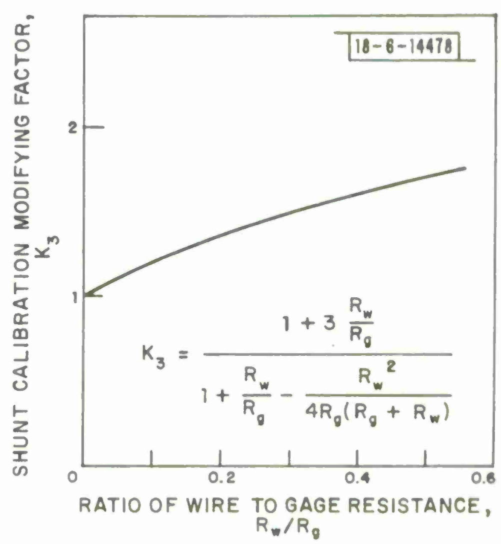


Fig. 8. Effect of wire resistance of electrical connections on shunt calibration.

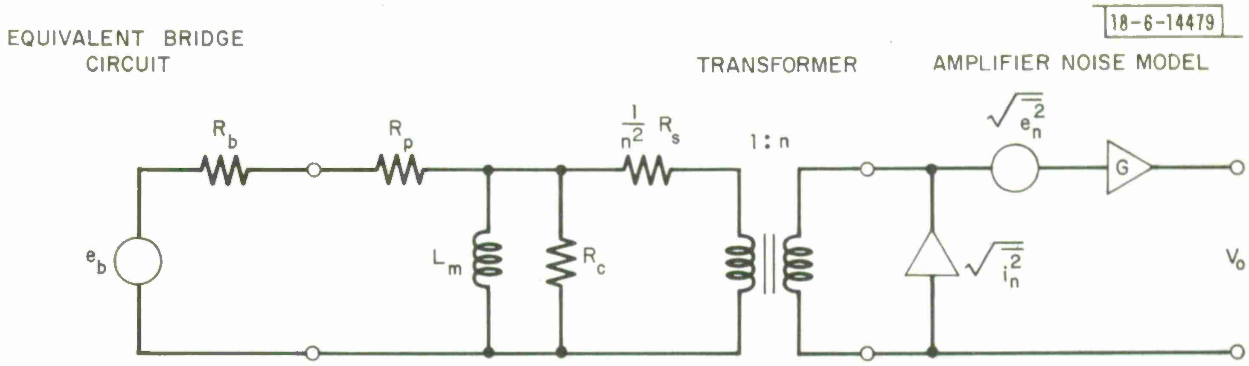
and a value of 10 volts was chosen for the bridge voltage. The gage factor is 2.02, and thus the strain noise for the balanced bridge circuit at 300^{o}K is -186.5 dB with respect to unity strain $/\sqrt{\mathrm{Hz}}$. Since the anticipated strain levels to be measured may approach the noise level of the gage, a low noise figure amplifier is required.

A low frequency equivalent circuit for the matching transformer, and a noise model for the amplifier were used to determine the requirements for a low noise figure circuit (Fig. 9). The noise figure is

$$F = 1 + \frac{R_p}{R_b} + \left|1 + \frac{R_b + R_p}{Z_1}\right|^2 \left\{ \frac{R_s}{n^2 R_b} + \left|\frac{Z_2}{R_c + Z_2}\right|^2 \frac{R_c}{R_b} + \frac{\overline{e_n^2}}{4kTn^2 R_b} + \left|Z_2 + \frac{R_s}{n^2}\right|^2 \frac{n^2\,\overline{i_n^2}}{4kTR_b} \right\}$$

where Z_1 is the parallel impedance of L_m and R_c, and Z_2 is the parallel impedance of L_m and (R_p+R_b). For a low noise figure it is important to keep the primary and reflected secondary resistances small with respect to the gage resistance, and the magnetizing inductance impedance and core loss resistance must be large compared to the gage resistance. The turns ratio should be selected such that the noise voltage generated across the secondary of the transformer due to the input noise current is equal to the input noise voltage for the amplifier.

The frequency response required for the strain measurements was also taken into account in choosing a matching transformer. A flat response from 1-500 Hz is required to analyze the dynamics of the cable. In order to attain the low frequency response, the impedance at 1 Hz for the transformer magnetizing inductance must be equal to or larger than (R_b+R_p). To meet the high frequency response the transformer winding capacitance must be small so that its impedance is large compared to the impedance of the magnetizing inductance.



TRANSFORMER PARAMETERS		TRIAD G-5TS
PRIMARY RESISTANCE	R_p	235 Ω
SECONDARY RESISTANCE	R_s	15.5 kΩ
MAGNETIZING INDUCTANCE	L_m	68 H
CORE LOSS RESISTANCE	R_c	∞ (1 Hz), 100 kΩ (45 Hz)
TURNS RATIO	n	11.75
AMPLIFIER NOISE		ANALOG DEVICE 118
INPUT NOISE VOLTAGE	$\sqrt{\overline{e_n^2}}$	20 nV/$\sqrt{\text{Hz}}$ (45 Hz)
INPUT NOISE CURRENT	$\sqrt{\overline{i_n^2}}$	0.25 pa/$\sqrt{\text{Hz}}$ (45 Hz)

Fig. 9. Equivalent circuit for the bridge, matching transformer, and amplifier.

The best commercially available low frequency transformer which meets the frequency response requirements and has the lowest noise figure is a Triad G-5TS. If the amplifier were noise free, the noise figure at 45 Hz for the matching transformer is 2.9 dB. With a low noise FET amplifier an overall noise figure of 3.4 dB was attainable; however, with an inexpensive bipolar operational amplifier (Analog Device 118A), the overall computed noise figure was 5.1 dB. This operational amplifier was considered satisfactory for the measurements, and was used in the preamplifier stage of the strain gage amplifiers.

The preamplifier noise figure was measured as a function of frequency by measuring the noise output voltage $\sqrt{\overline{V_o^2}}$ in a 1 Hz bandwidth and the amplifier voltage gain $G = V_o/e_b$. The noise figure is then,

$$F = \frac{\overline{V_o^2}}{4k\,T\,G^2\,R_g}$$

and is plotted in Fig. 10 along with the equivalent strain noise referred to the input.

B. Input Impedance

The preamplifier stage must be capacitively coupled to the strain gage bridge to prevent DC current from flowing through the primary of the matching transformer. The value of the coupling capacitor was chosen such that the resonant frequency of the capacitor and transformer magnetizing inductance was close to the low frequency cut-off required for the preamplifier. This insures that the preamplifier frequency response rolls off quickly below 1 Hz in order to prevent very low frequency strain from overloading the preamplifier. The magnitude and phase of the input impedance is plotted in Fig. 11a.

As discussed in the previous section, the strain to voltage transfer function is dependent on the preamplifier input impedance. Since the input impedance around 1.5 Hz is comparable to the gage resistance, a peak occurs

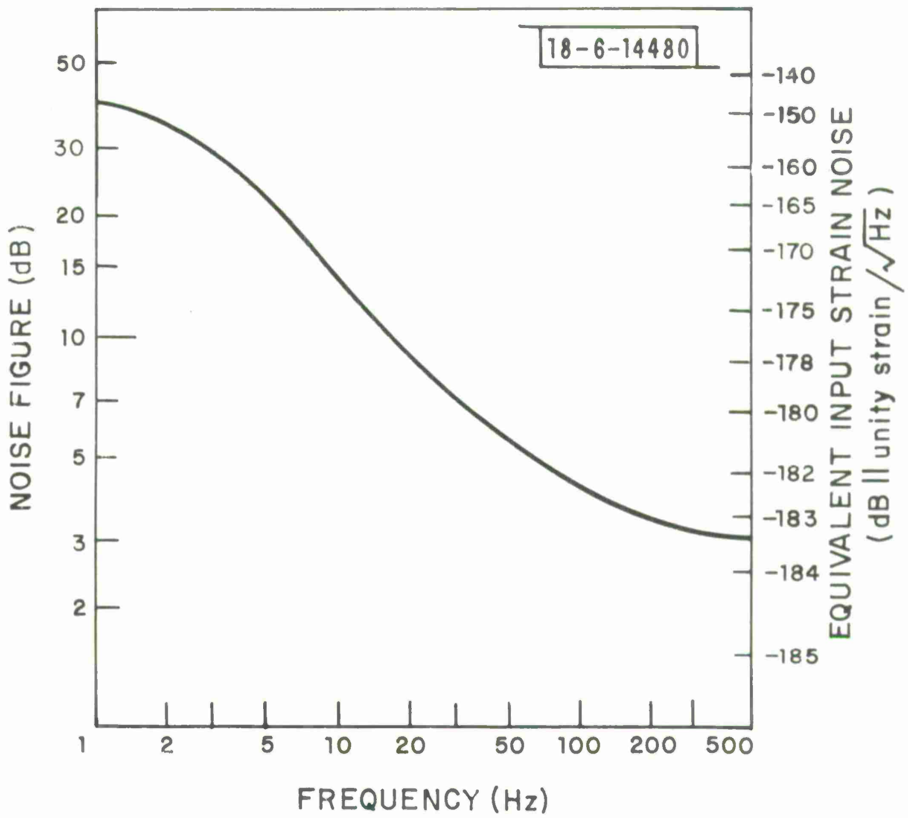


Fig. 10. Strain gage amplifier noise figure in a 1 Hz bandwidth and equivalent input strain noise with respect to unity strain in a 1 Hz bandwidth.

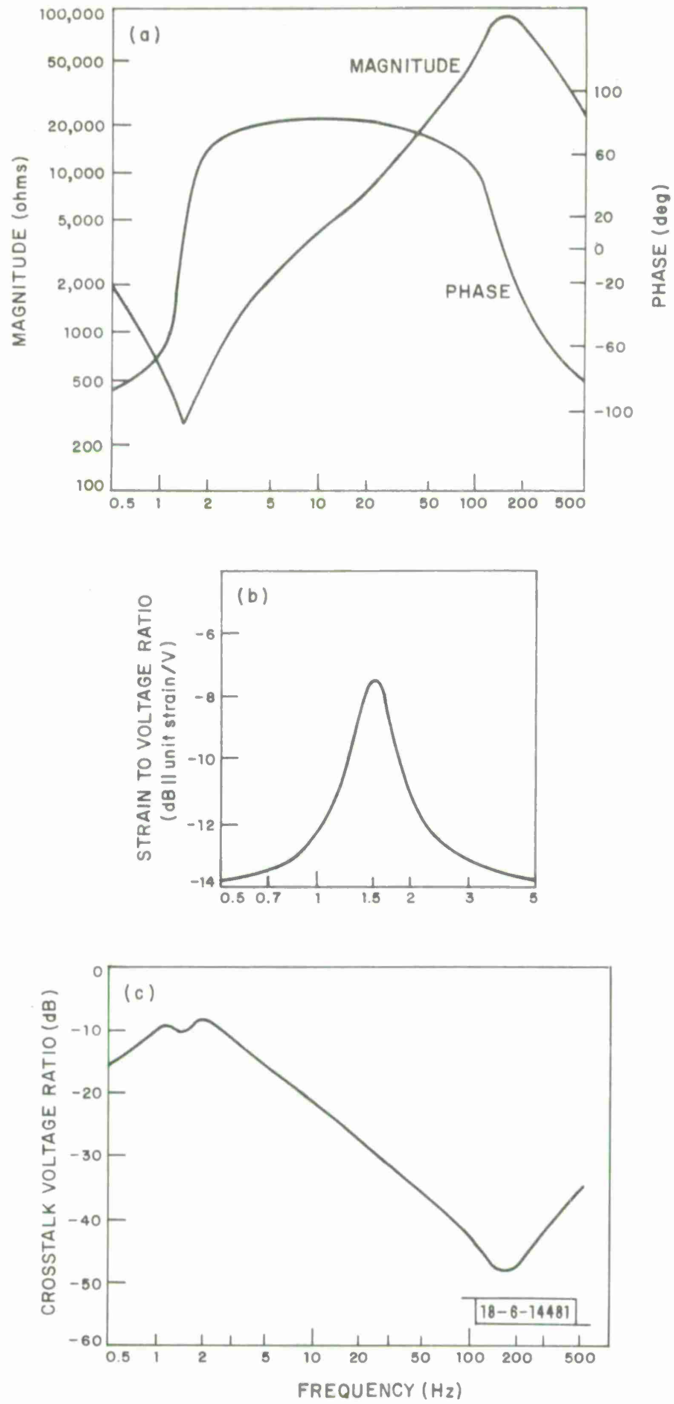


Fig. 11. Effect of amplifier input impedance. (a) Amplifier input impedance, (b) peak in strain to voltage ratio due to null in input impedance, (c) crosstalk voltage ratio e_{21}/e_1 for dual bridge circuit.

in the transfer function. The frequency response is plotted in Fig. 11b assuming a unity voltage gain preamplifier. The crosstalk for a dual bridge connection also becomes large in the frequency range of 1-2 Hz (Fig. 11c). Because it is necessary to extract the sum and difference signals from a pair of strain gages in order to determine the longitudinal and bending strain[4], it was decided that the crosstalk was too severe, and that a dual bridge connection was not suitable for the measurements.

C. Amplifier Circuit

The amplifier section contains two stages of amplification following the preamplifier stage (Fig. 12). With a total preamplifier voltage gain of either 40 or 60 dB, the amplifier section provides an additional 60 dB gain in 10 dB steps. The low frequency cut off for the amplifier section is switchable from 1 to 5 to 20 Hz so that high level, low frequency signals may be attenuated in order to increase the dynamic range at the higher frequencies. A 60 Hz notch filter is provided to attenuate pick-up at the power line frequency, and is adjusted to provide 40 dB of attenuation at 60 Hz with a Q of 6. The components of the notch filter are carefully bridge to within ± .1% and the trim pot in the leg of the twin-T bridge adjusts the notch frequency.

A switching circuit is provided in each amplifier to calibrate the system and test the amplifier circuit. The 17.5 kohm resistor tied to the strain gage arm of the bridge is switched across the strain gage to simulate a 1% change in strain when the wire resistance is zero. With a square wave applied to the calibration input, the 17.5 Kohm resistor is alternately connected and disconnected from the bridge supply voltage through the collecter of Q_2. The transistor was selected because of its low saturation voltage and low leakage current.

The frequency response for the output voltage to input strain transfer function was determined using the calibration circuit (Fig. 13). To determine the absolute gain for the transfer function, the total voltage gain for the

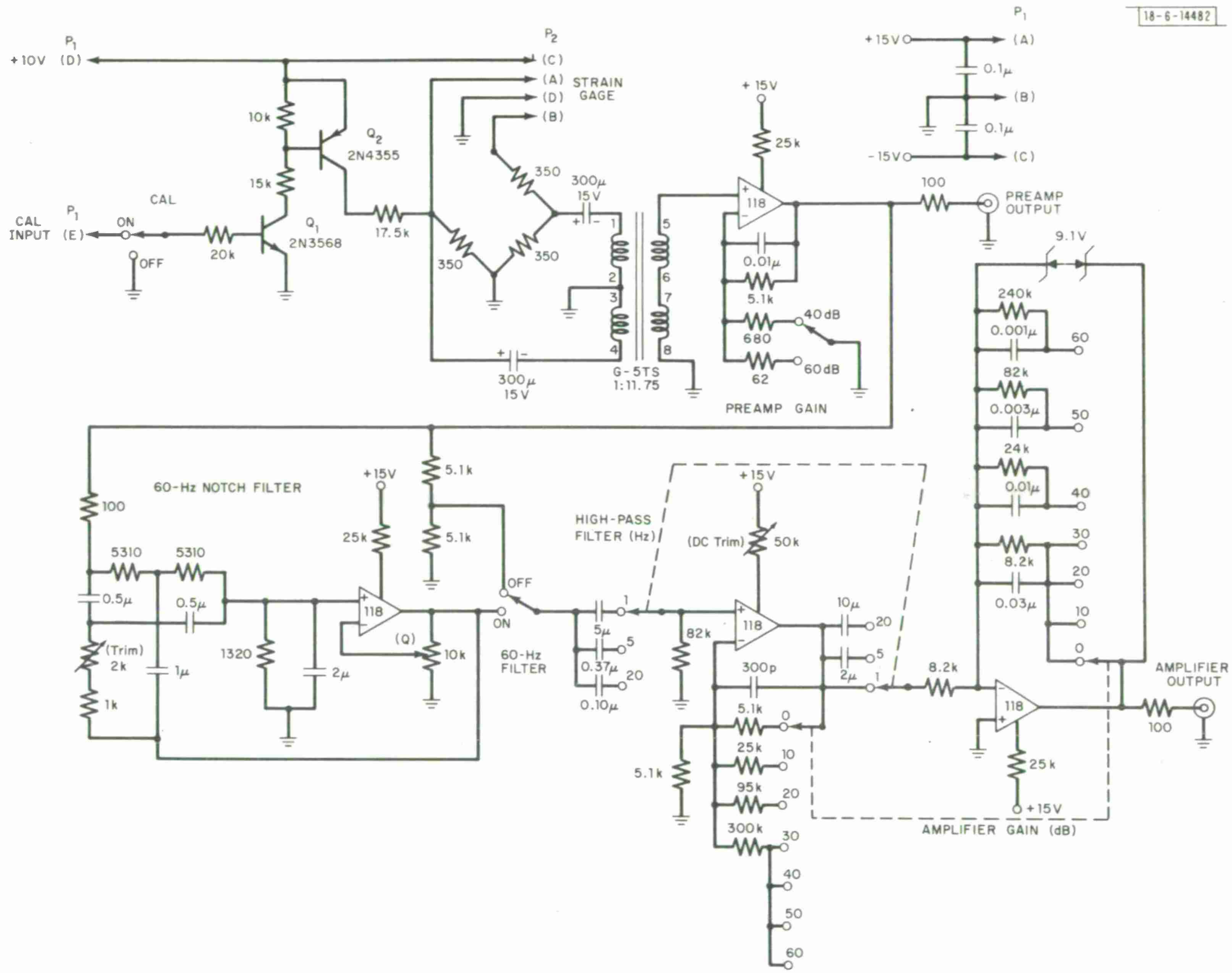


Fig. 12. Strain gage amplifier circuit.

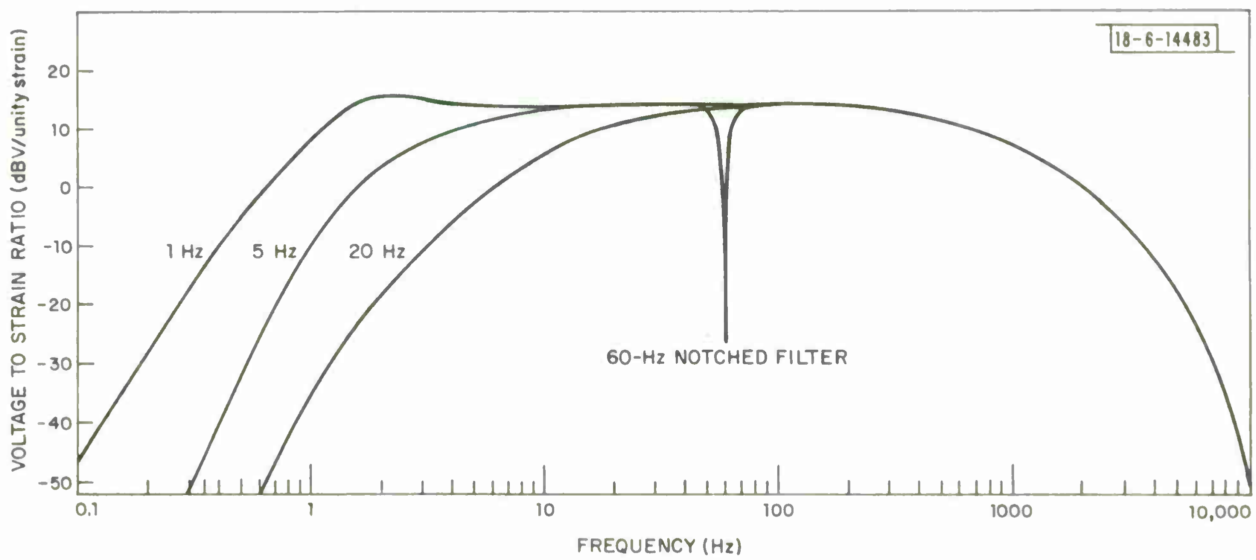


Fig. 13. Voltage to strain response at amplifier output normalized for unity voltage gain.

preamplifier and amplifier stages must be added to the response shown. Also the calibration correction due to the electrical connection resistance must be applied to the response. The method used to determine the transfer function involved taking the ratio of the amplitudes of the fundamental output voltage to the fundamental strain component for the square wave excitation. At the resonant frequency of the coupling capacitor and transformer magnetizing inductance at 1.5 Hz, there is a peak in the voltage gain of the preamplifier. However, since there is a null in the bridge output voltage to input strain transfer function at the same frequency (reciprocal of that shown in Fig. 11b), the two effects tend to cancel and produce a slight peak in the overall response of 1.5 dB.

Seven strain gage amplifiers are mounted in a modular rack (Fig. 14). A common power supply module provides power for the strain gage bridges and operational amplifiers. Also, a common high gain amplifier is provided to convert a sinusoidal input signal to a square wave for driving the calibration circuits.

IV. INSTALLATION OF STRAIN GAGES

Development of a technique for bonding the strain gage to the foamed polyethylene cable jacket was the key step in the project. The measurements required that the strain gage follow the cable strain accurately and reliably. Bonding to polyethylene is extremely difficult because there is no known cement which will provide a reliable bond in shear to polyethylene. After extensive testing of various techniques, the problem was solved by using a mylar clad polyethylene tape as an interface for the bond. The polyethylene surface is fused to the foamed polyethylene jacket, and the gage is epoxied to the mylar surface. This provides an excellent mechanical coupling to the cable jacket without sacrificing cable flexibility.

Another important technique developed for the strain gage installation was an injection molding process for sealing the foamed polyethylene jacket. It is imperative that the molding process fill the area around the strain gage

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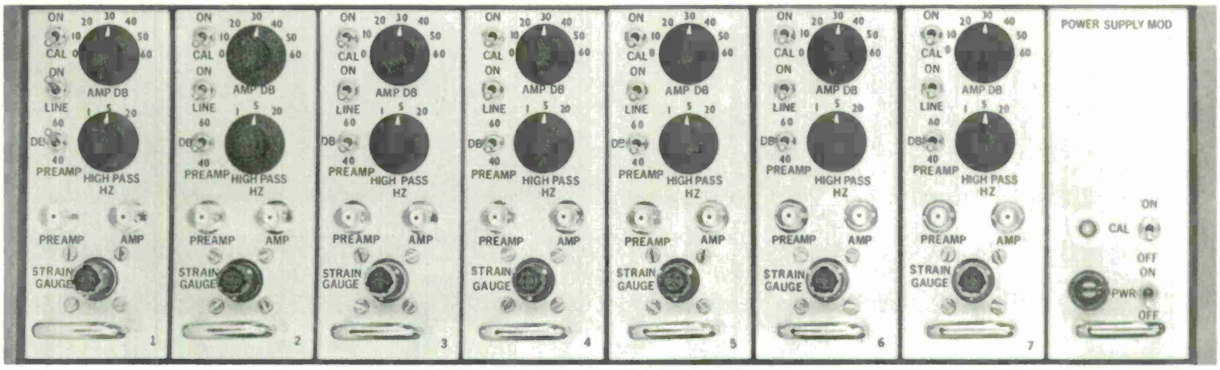

Fig. 14. Strain gage amplifiers.

and its electrical connections to provide mechanical continuity in the jacket and also to insure a watertight seal. The molding technique involves pre-heating the jacket area to be sealed and then injecting hot foamed polyethylene into the area under pressure. This process mixes the injected polyethylene with the jacket polyethylene to produce a bond as strong as the original jacket.

Although a high elongation, post yield strain gage was used for the measurements, tests showed that the electrical solder connections to the gage were easily broken during flexing of the cable when the complete gage was bonded to the jacket. In order to prevent this from occurring, only the grid section of the gage is epoxied to the mylar. Also, a cap of mylar is placed over the bonded gage to give the electrical solder connections freedom to move during flexure, and the electrical wires connecting the gage to the cable conductors are snaked through a tunnel of mylar to prevent breakage when flexed. This assures reliable electrical connections after successive bends over a 12 inch diameter.

The strain gage is a Bean type BAE-06-250BB-350 PTE with a 1 mil polyimide backing. The gage resistance is 350 ± 0.5 ohms with a gage factor of 2.02 ± 2%. The gage is capable of measuring strains up to 15% elongation with an accuracy of 5%.

A specification for the buoyant cable in which the strain gages were installed appears in the Appendix.

A. Bonding Gages to Cable Jacket

Two rectangular platforms the size of the gage backing are milled parallel to each other on opposite sides of the cable 0.160 inches from center. A trough 1/8 x 2 inches is also milled into the jacket level with the platform for the wires connecting the gage to the cable conductors (Fig. 15a). One mil polyethylene tape cut to the platform dimensions is first placed on the platform to act as a bonding interface. Similarly, 1.5 mil mylar clad polyethylene tape sand blasted over one-half of the mylar surface is placed on top of the 1 mil polyethylene tape with the polyethylene side down. Strips

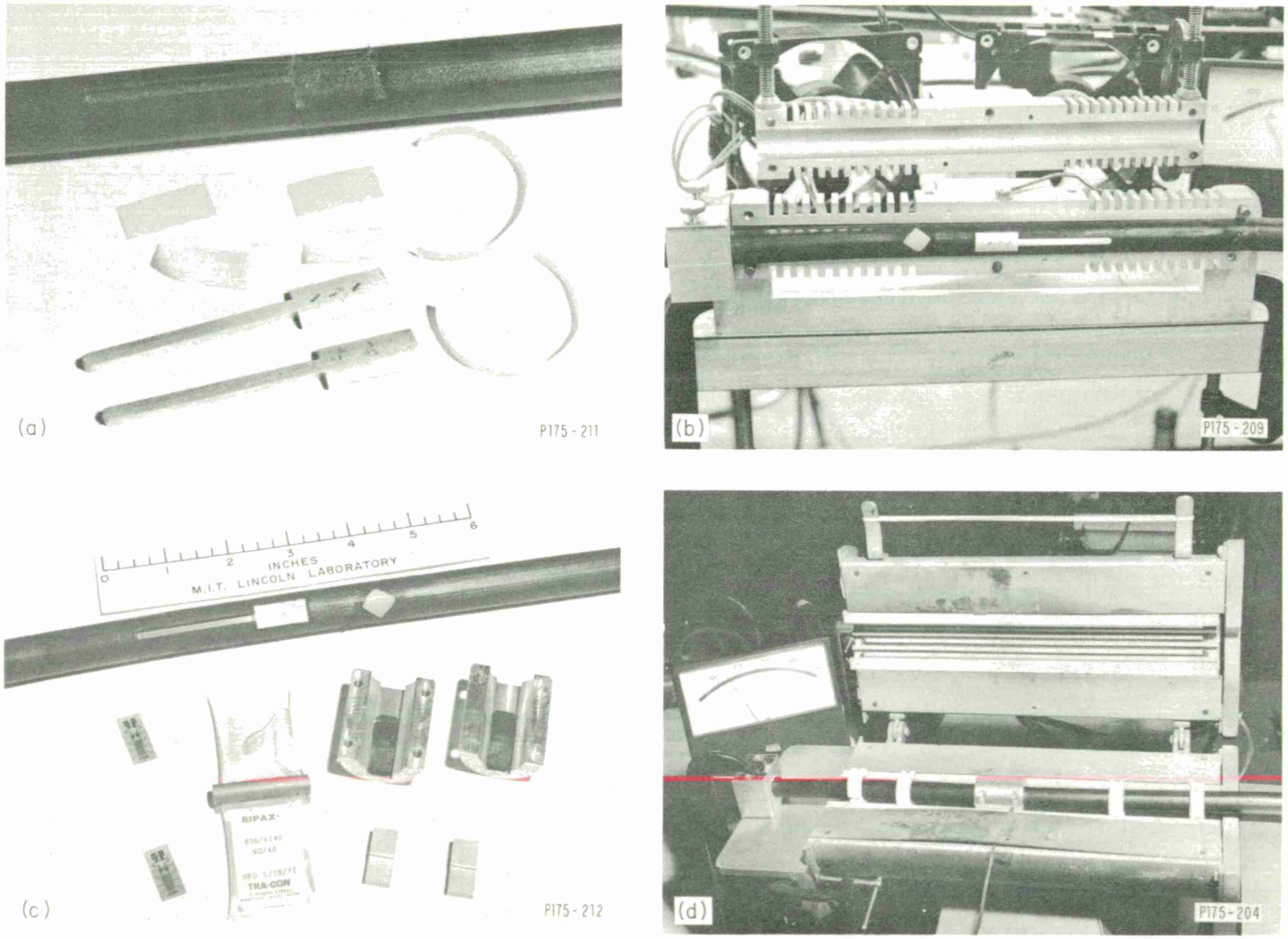

Fig. 15. Bonding gages to cable jacket.

for the trough are also cut to size and placed polyethylene side down. Aluminum filler blocks shaped to the milled area are placed over the tapes on both platforms. The assembly is placed in a preheated mold at 130^{o}C for 90 seconds, and then immediately cooled to below 50^{o}C before removing (Fig. 15b).

The gage is epoxied to the mylar using Bipax-826/V140-60/40 mix. The epoxy is applied only to the sand blasted area, and spring clips with stepped pressure pads are used to hold the gages in place (Fig. 15c). The assembly is cured in a tube oven at 80^{o}C for 2 hours (Fig. 15d).

B. Molding Gage Area

Electrical connections are made to the gage using no. 32 stranded, teflon insulated wire (Fig. 16a). A 12 mil mylar clad polyethylene cap is placed over the gage and wires with the mylar side down, and the jacket edges are melted over the cap to hold it in place (Fig. 16b). The injection mold is filled with 5 grams of polyethylene pellets premixed with foaming agent and heated to 130-135^{o}C. The cable is aligned with the strain gage platform normal to the injection slot, and an aluminum filler block is used to support the gage area on the opposite side. After preheating the assembly for 75 sec., the foamed polyethylene is injected, and the mold is then cooled to 50^{o}C (Fig. 16c, d). The same procedure is repeated for the strain gage on the opposite side of the cable. An indication of the "goodness" of the molding operation is the amount of penetration and mixing of the injected polyethylene with the jacket.

C. Electrical Connections to Cable

A section of cable jacket 1 inch long starting at the end of the trough is carefully removed using the pealing tool shown in Fig. 17a. The fiberglass strands are separated to gain access to the cable conductors, and the conductors chosen for the connection are cut and soldered to the strain gage wires with relief loops (Fig. 17b). With the fiberglass strands laced closed, the connection area is enclosed with 12 mil mylar clad polyethylene tape wrapped closed with tape (Fig. 17c). Note that a tongue extends from

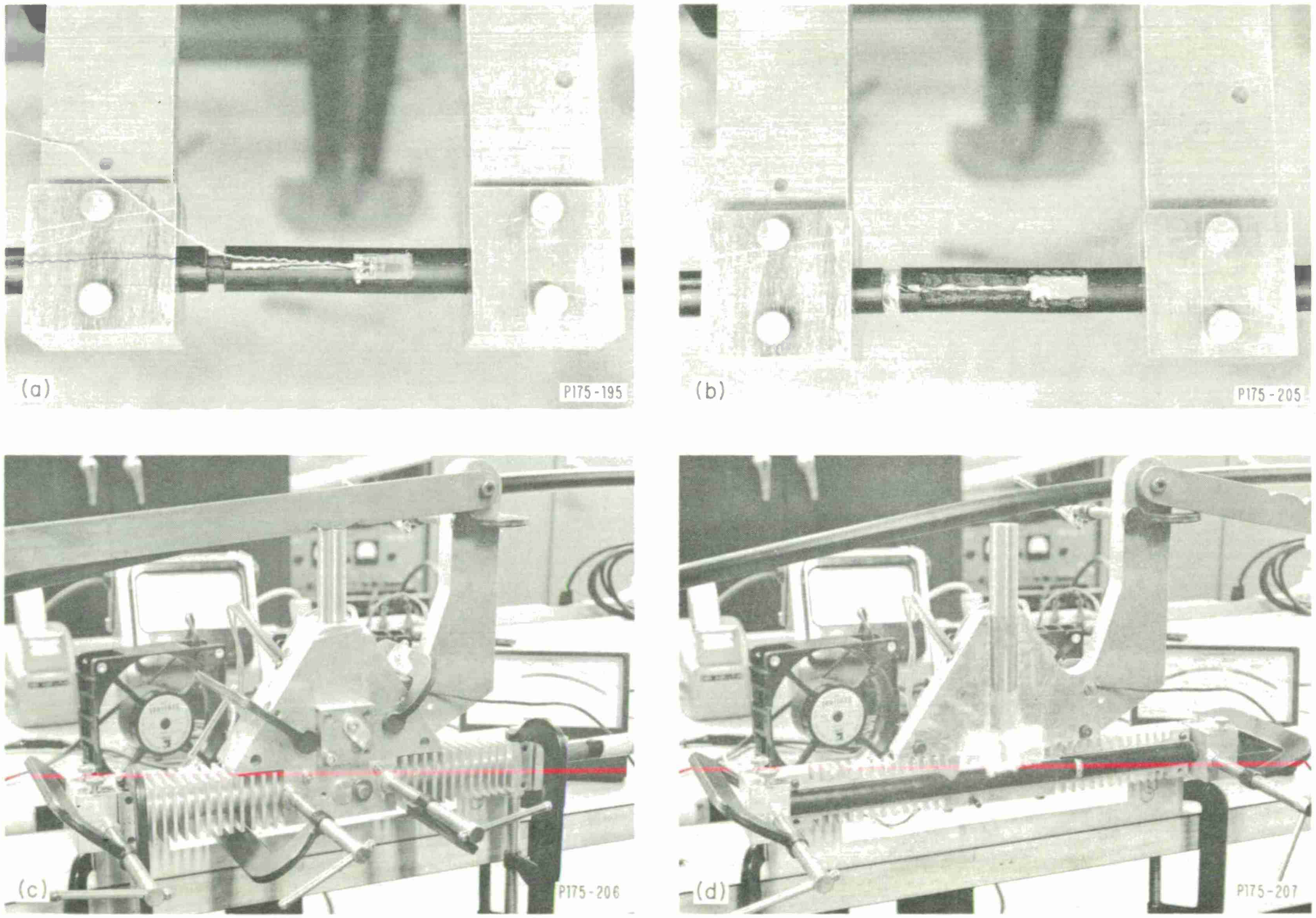

Fig. 16. Molding gage area.

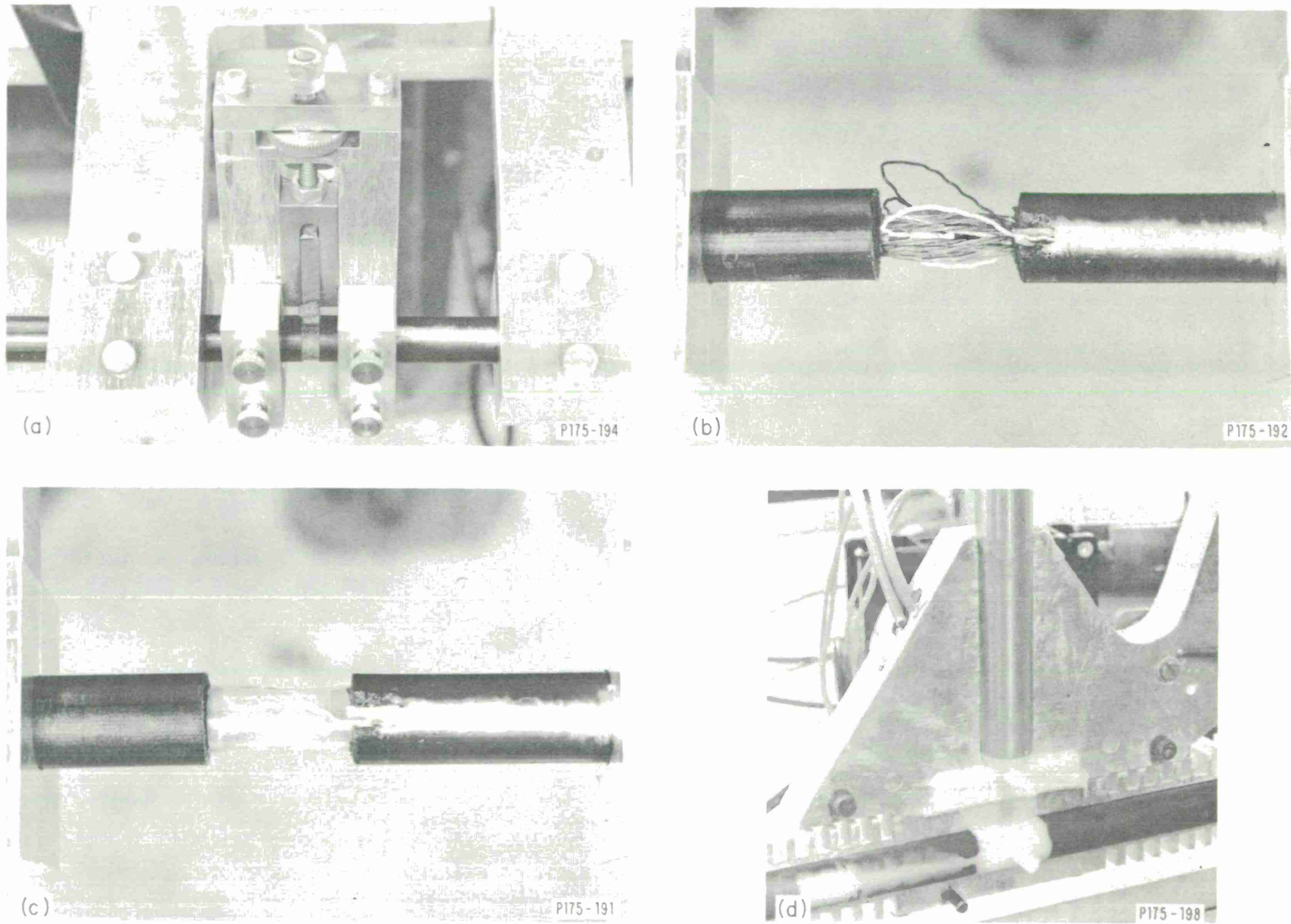

Fig. 17. Electrical connections to cable.

the connection area to under the mylar top cover for the trough. This insures that the wires are not molded in place at any point, and are free to move in the mylar tunnel.

The electrical connections area is placed in the preheated mold at 130 - 135°C for 75 sec. Nine grams of polyethylene pellets premixed with foaming agent are injected from both sides of the mold into the area, and then the mold is immediately cooled to 50°C (Fig. 17d). The reason the connection was made 2 inches from the gage was to prevent this molding process from disturbing the strain gage platform.

To prevent water penetration from the end of the cable shorting out the electrical connections, the ends of the cables were sealed using the technique described in Reference 1.

Three pairs of gages are installed in two cables at locations shown in Fig. 18. The color code for the gages and cable conductor resistance are also indicated in the figure. Note that a common electrical connection for the bridge voltage was made to the far pair of gages, and another common connection is made to the first two pairs of gages.

D. Testing of Strain Gages

The technique for installing the strain gages was tested for watertight integrity under pressure. A piece of buoyant cable 12 inches long with a pair of strain gages was used for the test. Drierite crystals which change color upon contact with water were placed beneath the solder connections of the strain gage, and both ends of the cable were sealed. The sample was subjected to 600 psi for 72 hours, and no water penetration was detected.

Each pair of strain gages was tested after installation in the buoyant cable. The cable was stretched between two pulleys 10 feet apart, and two 25 lb. weights were tied to the cable to hold it in tension. With the strain gages centered between the pulleys, the center point was depressed by a 1 lb. weight and then released. The sinusoidal decay of the strain due to the

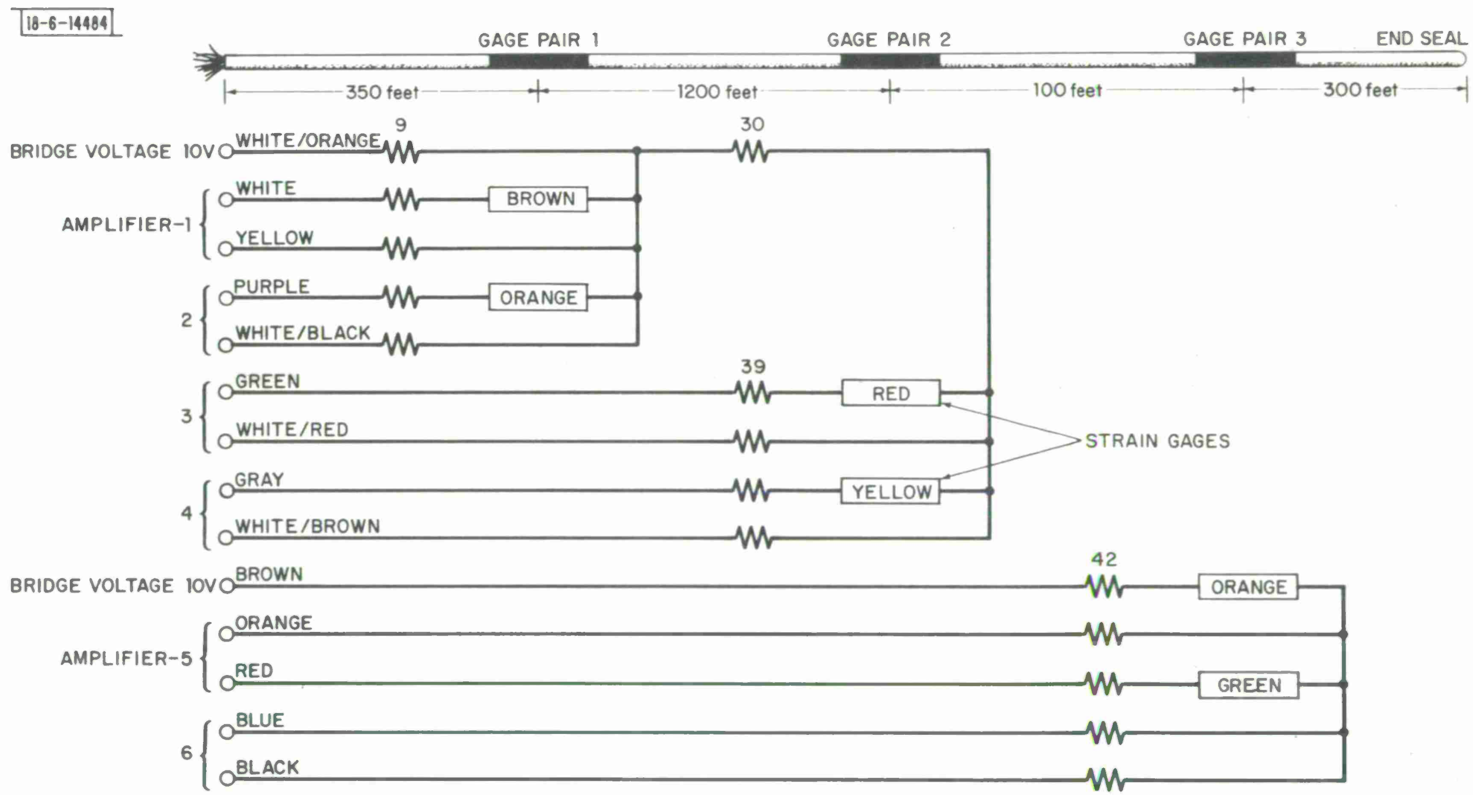

Fig. 18. Strain gage connections to buoyant cable, cable conductor resistance, and color code markings.

transverse motion was measured to check the calibration of the gage and to test the electrical connections to the gage.

A sample of the gage pair installation was subjected to both dynamic and static compression and tension tests. For the dynamic test the cable was treaded through a set of four 12 inch diameter wheels spaced on 14 inch centers. The gage pair was then pulled through the wheels at about 2 ft./sec. Both gages failed in several tests after being cycled about 50 times through the wheels. The failure occurred not in the gage connection, but rather the gage grid fractured and open circuited. The long term static test consisted of storing a sample on a 12 inch diameter form for three months. Every several weeks the sample was removed from the form, tested and replaced rotated by 90°. The test consisted of rigidly mounting one end of a short cable sample, deflecting the other end with a given force, and measuring the strain as a function of time. Over the three month interval, there was no perceptible change in the measurement.

APPENDIX

Buoyant Cable Specification

1. SCOPE

1.1 This specification covers a special 14-wire buoyant cable with high mechanical performance characteristics, such as high strength, flexibility, low compression set, low water absorption, low temperature properties, and good abrasion resistance.

2. REQUIREMENTS

2.1 Materials and Construction

2.1.1 Conductor - The fourteen (14) conductors shall be no. 24 AWG, solid, type S, drawn and fully annealed bare copper wire per QQ-W-343 in continuous lengths with no joints or splices.

2.1.2 Conductor Insulation - The conductors shall be insulated with high density polyethylene to a dia. of 0.045 ± .002 inches. Each conductor insulation shall be uniquely colored for identification. The insulation shall be bonded to the conductor to provide a non-hosing watertight seal with 600 psi hydrostatic pressure applied to the open end of a 5-foot piece for 2 hours.

2.1.3 Core - The 14 insulated conductors shall be bundled together with the 4 inner conductors having a left hand lay and the 10 outer conductors having a right hand lay. The lays shall be determined by manufacturing requirements.

2.1.4 Strength Members - The strength members shall consist of at least 18 strands of .038 inch diameter fiberglass (ECG 75-5/3 Latex 2.0 "S" coated) laid on the core with a minimum left hand lay of 20 inches.

2.1.5 Jacket - The jacket shall consist of two layers of a continuous homogeneous, unicellular polyethylene securely bonded together. The extreme O.D. of the cable shall be 0.650 ± 0.025 inches. The outer surface of the cable shall be smooth so that an O-ring of 0.360 inch cross section and 0.620 inch I.D. (Federal Stock No. H-5330-064-6585) will seal anywhere along the entire length of the cable without leakage at any pressure from 0-600 psig when applied for 2 hours. The outer surface shall be of uniform hardness and free of major imperfections such as blow holes, cuts, valleys and bruises and abrupt changes of diameter within the tolerance range.

2.1.6 Length - The cable shall be provided in not less than 1900 feet nor more than 2000 feet continuous (with no joint or splice) length.

2.2 Mechanical Characteristics

2.2.1 Specific Gravity - The cable shall have the lowest possible overall specific gravity consistent with the requirement specified herein.

2.2.1.1 The specific gravity shall not exceed .98 when measured under a hydrostatic pressure of 600 pounds per square inch gage (psig), and at room temperature in fresh water. The measurement shall be made after a continuous immersion time of 24 hours at 600 psi. The cable sample shall not be removed from the pressure tank nor the pressure reduced until after the measurement is completed. An approved test method is contained in the Navy Underwater Systems Center Technical Memorandum No. 220-74-62.

2.2.2 Cold Bend - The cable shall pass cold bend requirements of Specification MIL-C-17.

2.2.3 Crack Resistance - The cable shall be resistant to stress cracking when tightly wrapped around the mandrel three inches in diameter for a continuous 24 hour period of time.

2.2.4 Cable Strength - Minimum strength of the cable shall be 2000 pounds. The cable strength shall be determined by means of a power driven tensile machine. The rate of travel of the power actuated grip shall be adjusted to move at a rate of 12 ± 2 feet per minute. Distance between grips shall be five (5) feet prior to the application of the load. A reduction of the jacket diameter to .580 inch shall be considered a failure.

2.2.5 Strength Members and Jacket - The shear strength between strength members and jacket shall be a minimum of 100 pounds per linear foot of cable. A suitable device such as a Kellems grip shall be used to facilitate the measurement of the shear strength. At least two 1-foot specimens shall be tested. All specimens tested shall pass this test.

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4. M. L. Burrows, Private Communications.

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13. ABSTRACT

The strain gage instrumentation of a buoyant cable used for submarine ELF receiving antennas is presented in this report. Techniques were developed to bond the strain gage reliably to the polyethylene cable jacket and to seal the jacket using an injection molding process. The design of a low noise strain gage amplifier for dynamic strain measurements is discussed, and the general problem of measuring strain at a remote point is considered.

14. KEY WORDS

strain gage instrumentation
navy communications
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ELF antennas