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SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM (STRIP).(U)
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18. SUPPLEMENTARY NOTES

The Sonar Transducer Reliability Improvement Program (STRIP) is sponsored by Naval Sea Systems Command (SEA63X5).

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Transducers	Connectors	Environmental tests	Shielding
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Transducer fluids	Pressure release	O-rings	
Encapsulation	Material evaluation	Ceramics	
Cables	Water permeation	Metal matrix composites	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the second quarter of FY81, efforts in the various tasks of STRIP have resulted in progress in the following program goals: (1)

The quantization of the failure mode of electrical breakdown between the two electrodes on a ceramic surface in a transducer has been completed. Formulae are given for calculation of the reliability and operational lifetime which can be applied to any transducer design, (2) → [illegible]

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- The investigation of the mechanical strength of shielded and unshielded cables and the effectiveness of clamps on connector-boot bonds has been completed. Two reports are being published.

(3) The hardness of the neoprene acoustic windows on the TR-316 projectors increased predominantly after the 71°C dry heat and UV exposure. The largest increases are in the wide-beam sections, reaching a durometer value of Shore A75 from a pre-CUALT value of Shore A55 in two-years equivalent of CUALT on projector A3. (4)

- The investigation of loss mechanisms in cement joints of K33 ceramic stacks indicates solid metal electrodes are superior to expanded metal electrodes.
- STRIP is in the progress of being reorganized.
- STRIP annual review was held on 12 and 13 March 1981 at the Naval Research Laboratory in Washington, DC.

CONTENTS

SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM

FY81 SECOND QUARTER PROGRESS REPORT

1. INTRODUCTION

1.1. PROGRAM OVERVIEW

The general objective of this program is to perform relevant engineering development which addresses the operational requirements for fleet transducers for active sonar, passive sonar, surveillance, counter-measures and deception devices, navigation, and acoustic communications. The approach is to develop, test, and evaluate improved transducer design, materials, components, and piece-parts that will meet specified requirements in the operational environment during the entire useful life of the transducer. Standards will be prepared to ensure that results obtained during preliminary testing will be obtained consistently in production. This program should result in improved performance and reliability and reduced costs through better utilization and a more comprehensive characterization of materials and design data.

The Sonar Transducer Reliability Improvement Program (STRIP) is a part of Program Element 64503N. Major task areas with specific objectives to achieve the program goals have been described in the Program Plan and include:

Task Area A - Encapsulation Methods
Task Area B - High-Voltage Engineering
Task Area C - Cables and Connectors
Task Area D - Transducer Material Standards
Task Area E - Environmental Test Methods
Task Area F - Transducer Tests and Evaluation

The FY81 Program Plan for STRIP has been funded at the $1017K level. The specific tasks and their principal investigators for FY81 are listed below:

TASKS		PRINCIPAL INVESTIGATORS	
A	Encapsulation Methods	NRL-USRD	C.M. Thompson
B	High-Voltage Engineering	NRL-USRD	L.P. Browder
C-1	Handbook for Harness Design	EB/GD	R.F. Haworth
C-2	Standard for O-Ring Installation	APL/University of Washington	C.J. Sandwith
C-3	Cable Shielding	Georgia Tech.	H.W. Denny
C-4	Cable Specifications	EB/GD	R.F. Haworth

D-1	Alternative Materials: Plastics	NWSC	K. Niemiller
D-2	Pressure Release Materials	NUSC	C.L. LeBlanc
D-3	Specification of Elastomers	NRL-USRD	C.M. Thompson
D-4	Transducer Ceramics	NRL-USRD	A.C. Tims
E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.J. Steele
F-1	Failure Modes due to Water	TRI	P.E. Cassidy
F-2	Ceramic Stack Joints	NOSC	C.I. Bohman
F-3	Reliability & Life Prediction Specification	TRI	R.I. Smith
F-4	TR-122 FMA & Improvements	NRL-USRD	R.W. Timme
F-5	Metal Matrix Composites	Honeywell	O.L. Akervold
F-6	Improved Hydrophone Analysis	NWSC	M.P. Canty
F-7	Engineering Documentation	NRL-USRD	R.W. Timme

1.2. SUMMARY OF PROGRESS

During the second quarter of FY81, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- The quantization of the failure mode of electrical breakdown between the two electrodes on a ceramic surface in a transducer has been completed. Formulae are given for calculation of the reliability and operational lifetime which can be applied to any transducer design. See Section 3.3.
- The investigation of the mechanical strength of shielded and unshielded cables and the effectiveness of clamps on connector-boot bonds has been completed. Two reports are being published. See Section 6.3.
- The hardness of the neoprene acoustic windows on the TR-316 projectors increased predominantly after the 71°C dry heat and UV exposure. The largest increases are in the wide-beam sections, reaching a durometer value of Shore A75 from a pre-CUALT value of Shore A55 in two-years equivalent of CUALT on projector A3. See Section 10.3.
- The investigation of loss mechanisms in cement joints of K_{33} ceramic stacks indicates solid metal electrodes are superior to expanded metal electrodes. See Section 13.3.

- **The STRIP is in the progress of being reorganized. See Section 16.3.**

The annual review for the STRIP was held on 12 and 13 March 1981 at the Naval Research Laboratory, Washington, DC. The 108 in attendance represented a cross-section of the sonar community-program managers, sonar engineers and designers, transducer restoration engineers, and scientists:

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1.3. PLANS

The Program Plan for the FY82 STRIP is currently being reviewed and will be presented to the Naval Sea Systems Command in May 1981.

1.4. REPORT ORGANIZATION

The remaining sections of this quarterly report will discuss the objectives, progress, and plans for the specific tasks included in the STRIP.

2. TASK A - ENCAPSULATION METHODS

C.M. Thompson - NRL-USRD

2.1. BACKGROUND

A material to be used for filling a sonar transducer must meet a wide variety of specifications. The requirements imposed by the electrical nature of the device include high resistivity, high dielectric constant, as well as resistance to corona and arc discharges. The water environment of the transducer necessitates low water solubility and other attractive solution properties. In addition, the fluid must maintain its electrical and other properties in the presence of any water which permeates the covering. The acoustic requirements are a close acoustic impedance match with seawater and resistance to cavitation at high drive levels. Other obvious properties include compatibility with other components, stability to degradation, and suitable surface tension and viscosity.

With such a wide variety of requirements, it is not surprising that compromises have to be made. The most commonly used fluid for many years has been castor oil. This use is in spite of its high viscosity. Each of the fluids proposed, so far, as a replacement has serious drawbacks. Silicone oils tend to creep onto and wet all of the surfaces of the transducer. This greatly complicates bonding the components together. Polyalkylene glycol (PAG) has the disadvantages of high water solubility and low electrical resistivity. The various hydrocarbon liquids have too low an acoustic impedance and are frequently incompatible with the various plastics and rubbers in the transducer. Further research is necessary to find and qualify fill-fluids which represent the best match to all the requirements imposed upon it.

Transducer encapsulants have long presented a source of transducer failure. The necessity that the encapsulants be resistant to water, have a sufficiently long pot-life for degassing, bond well to the other components, and have high strength has proved to present a very difficult problem. Many other requirements also apply in special cases. The best choice for a polyurethane encapsulant to date has been a toluene diisocyanate (TDI)-polytetramethylene glycol (PTMG) prepolymer which is chain extended with a 4,4'-methylene-bisorthochloroaniline (MOCA). This encapsulant has a long pot-life, good strength, and good water resistance. However, there is serious concern for the health hazards of both the MOCA and the TDI residue in the prepolymers.

2.2. OBJECTIVES

The objectives of this task are:

- To evaluate alternative transducer fill-fluids including fluids specifically for use in towed arrays and to produce specifications for those fluids found suitable.

- To define the relative importance of the properties of transducer encapsulants and to produce a non-hazardous replacement for currently used materials.

2.3. PROGRESS

2.3.1. A Request for Proposal (RFP) has been written for designing and producing a hazard-free, non-proprietary encapsulant for general sonar transducer use. This RFP has been submitted to the NRL Contracting Office for approval and processing. Some unexpected delay has been experienced at the contracting office but the problem is being resolved. It is still hoped that the contract can be awarded in time for a significant amount of work to be accomplished this fiscal year.

2.3.2. Work under the NRL-funded 6.1 research problem has successfully produced a candidate transducer fluid. This synthesis is a phase-transfer catalyzed reaction between a mono-alkyl terminated polypropylene oxide, sodium hydroxide, and alkyl balide. The success of this 6.1 work has been transitioned to STRIP. Samples of this new material have been tested for water solubility and preliminary results showed a water solubility limit of 0.6%, which is significantly lower than the 1.8% value for the unmodified PAG fluid. This lower water-solubility limit is sufficiently encouraging to make further testing desirable. Density and sound speed testings are now underway. Electrical properties and viscosity testing will also be carried out. Further testings such as compatibility and vapor pressure studies will require large quantities of samples, which will become available as the synthesis conditions are optimized.

2.3.3. A series of compatibility tests for a number of polymer samples are underway. Elastomer and plastic samples including Neoprene 5109, butyl, chlorobutyl, natural rubber, polyurethanes, Tefzel and Hytrel are being exposed to castor oil and towed-line fill-fluids such as Shellsol 71 and an Isopar. The results will be available for reporting in the next report. Data will also be incorporated into the "Handbook of Sonar Transducer Passive Materials" as an additional part of the data base being established at NRL-USRD.

2.4. PLANS

- Publish RFP on encapsulants (30 Apr 1981).
- Award contract on encapsulants (15 Jun 1981).
- Continue testing on modified polyethers fluids.
- Publish a report on water permeation in sonar transducers and the effect this has on operation and lifetime (cooperative between Tasks A-1 and F-1).
- Prepare and publish a report on transducer fluid properties with a detailed discussion of fluid selection criteria (4th Qtr FY81).

3. TASK B-1 - CORONA ABATEMENT

L.P. Browder - NRL-USRD

3.1. BACKGROUND

A significant percentage of transducer failures is due to voltage breakdown of insulating materials developing from corona erosion mechanisms. It is not practical to test the completed transducer to measure the effects of corona erosion on lifetime and reliability. To establish reliability factors and quantify protection requirements, corona must be studied as a failure mechanism at the component or piece-part level. Transducer reliability improvement may then be achieved by control of design parameters and construction processes.

3.2. OBJECTIVES

The objectives of this task for FY81 are:

- Study tests, specifications, and procedures that may be used to select coating materials suitable for corona reduction.
- Test various corona reduction coating materials on PZT ceramic to identify the voltage breakdown mechanisms and measure voltage lifetime functions with the coating materials that show improvement.

3.3. PROGRESS

3.3.1. Various conformal coating materials are in the process of being tested to determine their usefulness as electrical protection for the surfaces of PZT ceramic. The ceramic surface tends to be the weakest part of the insulation system of a sonar transducer. The highest typical electrical stress used on PZT ceramic in transducer design is in the range 2 to 4 kV/cm (5 to 10 V/mil).

The coating materials under test generally are in three categories: (1) epoxy, (2) polyurethane, and (3) acrylic. Epoxy coatings are only available as two-component systems; they have good resistance to humidity, abrasion, and chemicals. Polyurethane coatings may be either one- or two-component; they offer excellent humidity and chemical resistance and the dielectric properties are stable for extended periods of time. The acrylic coatings are generally one-component systems; they have good electrical and physical characteristics, and they apply easily and cure fast. The coating can be easily removed with solvents, but this same characteristic means poor chemical compatibility.

The chosen coating materials appear to meet the requirements for evaluation as determined from the manufacturer's specifications. These include: (1) good electrical and dielectric properties, (2) flexibility, (3) ease of use, (4) low curing temperature, and (5) nominal cost.

Difficulties are the failure to adhere strongly to PZT ceramic and the tendency to form bubbles while curing.

Electrical tests have been performed on some of these coating materials that were brush applied to PZT ceramic. In all cases the corona inception voltage (CIV) is lower than the comparable value obtained with uncoated ceramic. Also, the breakdown voltage on the surface (flashover) was increased only a small amount, typically less than 10%. There did not appear to be a consistent pattern to the voltage breakdown paths; many were over the outer coating surface; some were on the coating/surface interface, and some were combinations.

A coating material often touted as exceptionally good is Parylene, which is vacuum deposited onto the ceramic. Twelve PZT ceramic doublets of the type used in the Mulloka transducer have been coated with Parylene and are currently being evaluated. Preliminary results indicate these units have an average CIV of 2.15 kV with a standard deviation of 0.46 kV or about 20%. Physical inspection has not been effective as a method to determine the units with high and low CIV. Further tests will be made to establish if there are external factors that can be changed to improve the CIV value.

It is believed that the bulk of the PZT ceramic and its surface is not involved in developing low level corona discharges. There is a small area, perhaps less than 1 mm wide, bordering the electrodes that is mainly associated with these discharges. Corona only forms at specific points in this border and is connected to micro-imperfections on or near the surface. A theory that can explain the lower CIV level with coated ceramic is that the coating entraps tiny pockets of air on the electrode edge-to-ceramic joint. The electric stress inside such pockets is greater than the comparable stress in an open configuration and therefore gas ionization (including corona) occurs at a lower operating voltage. At this preliminary stage of the investigation, it appears that many "corona-reducing" coatings are of little value.

3.3.2. Work is progressing toward obtaining some PZT material with the surface modified to seal it from water adhesion. This appears promising, but no electrical tests have yet been made to determine its usefulness. Another approach that is being investigated is to modify the surface of PZT so that there is chemical bonding in the insulator coating material. Either of these methods may reduce the corona.

3.3.3. The semiconductor coating material "Coronox" is a proprietary product of Westinghouse and is not available for outside use. An attempt is being made to locate a similar product to be evaluated.

3.3.4. The quantization of the failure mode in a transducer of electrical breakdown between two electrodes on a ceramic surface has been completed. The formulas to compute the electrical reliability of this mode using known design factors will be presented in a journal paper in the near future. The basic information is previewed here to make it immediately available to the sonar community.

The master electrical strength formula to compute the flashover breakdown of PZT ceramic is:

$$S_a = S_a'(RF)(DF)(FF)(GF)(PF)(TF)(WF) \tag{1}$$

where S_a' is the long-term breakdown strength value (3.6 kV) over a 1-cm wide PZT surface at a frequency of 1 kHz in dry air at 25°C temperature and a gas pressure in the transducer of 1-atm (101.4 kPa). The strength S_a is the product of S_a' and seven normalized modifier factors.

- RF is the random factor and it is taken from a cumulative normal distribution function where the standard deviation of the electrical strength values is 10% of the mean. Approximate values to use for RF with the percentage of failed units are:

	RF		RF
1%	0.77	10%	0.87
2%	0.80	25%	0.93
3%	0.81	50%	1.00
4%	0.83	75%	1.07
5%	0.84	90%	1.13

- DF is the distance factor that adjusts for the distance between electrodes on the PZT ceramic. The formula is:

$$DF = (d/d_o)^{0.4} \tag{2}$$

with d expressed as cm and d_o is 1 cm.

- FF is the frequency factor and it is computed using the formula:

$$FF = (f/f_o)^{-0.3} \tag{3}$$

with f expressed as kHz and f_o is 1 kHz.

- GF is the gas factor and it has a value of 1.0 when the insulator gas used is air and 1.18 when it is sulfur hexafluoride (SF_6). When there is a mixture of air and another insulator gas, GF is modified using the equation

$$(GF)mix = 1 + N^{0.65}[(GF)gas - 1] \tag{4}$$

where N is the partial pressure concentration fraction of the insulator gas. For the use of SF_6 gas, Eq. (4) is written

$$(GF)mix = 1 + N^{0.65}(0.18). \tag{5}$$

- PF is the gas pressure factor. It is computed using the formula

  $$PF = (p/p_o)^{0.25} , \tag{6}$$

  where both p and p_o are expressed in the same absolute units and p_o is the equivalent of 1 atm (101.4 kPa).

- TF is the temperature factor and it is obtained by using the formula

  $$TF = (T/T_o)^{-0.5} , \tag{7}$$

  where T is the gas temperature inside the transducer in °K and T_o corresponds to the standard test temperature of 298°K (25°C).

- WF is the water vapor factor and it is computed using the formula

  $$WF = 1 - (p_w/p_t) , \tag{8}$$

  where p_w *is the partial pressure of the water vapor* in the gas and p_t is the total pressure of the gas. Typical values for WF is 1.0 for dry gas and 0.97 for 100% RH at atmospheric pressure.

There are two fomulas that are used to compute either time to breakdown, t_b, or the breakdown voltage, S. There are

$$t_b = 0.004[(S/S_a) - 1]^{-4} , \tag{9}$$

$$S = S_a[1 + (0.004/t_b)^{0.25}] . \tag{10}$$

The units for t_b is hrs and for S is kV. S_a is computed using Eq. (1) and this is the asymptote to the curve where t_b is large.

The time expression for t_b refers to continuously applied ac voltage and therefore a duty ratio (d.r.) must be used that relates real time to voltage exposure time. One way to write the expression is

$$d.r. = \text{pulse length} \times \text{pulses per unit time} . \tag{11}$$

The reliability formulas needed are the following:

$$\lambda(t) = \lambda = d.r./t_b = d.r./MTBF \, , \tag{12}$$

$$R(t) = \exp(-\lambda t) \, , \tag{13}$$

where λ is assumed to be a constant failure rate and $R(t)$ is the reliability.

Two of the most important things this set of formulas will accomplish for a transducer design are

- Estimate the electrical reliability for a sonar transducer from the design parameters.
- Compute the maximum drive voltage that corresponds to the transducer electrical reliability requirements.

It is believed that the results that are obtained are slightly conservative toward being safe.

3.4. PLANS

- Continue tests to evaluate the use of high dielectric strength coatings on PZT ceramic.
- Evaluate the effectiveness of surface modification techniques on PZT ceramic for corona reduction.
- Finish testing on the Mulloka doublet coating material and report.

4. TASK C-1 - STANDARD FOR O-RING INSTALLATION

C.J. Sandwith - APL, University of Washington
G.D. Hugus - NRL-USRD

4.1. BACKGROUND

The reliability of sonar transducer arrays can be significantly improved by the adoption of standard procedures for the installation and assembly of O-ring seals. The problem is that no such standard procedure exists. Presently, the installation procedures are determined by the installer and the materials available at the time of installation.

The results of analyzing failures of O-ring seals in connectors used in underwater applications over decades show that roughly eight out of thirteen O-ring failures have resulted from improper installation and assembly or improper quality control and inspection procedures at the time of assembly. Stated another way, the results showed that even though O-ring seal design may be perfected by the proper O-ring type selection (piston, face, or crush) by the maximum crush section thickness, by selecting the proper O-ring size and material, and by using two O-rings in series (double O-rings) a substantial number of the O-ring failures will occur due to improper installation and inspection procedures.

4.2. OBJECTIVE

The objective is to compose, critique, edit, and present in final form a standard procedure for the installation of O-ring seals in electrical connectors and undersea static applications. The standard will be composed in the form of similar military standards in handbook form. Once it is approved by Naval Research Laboratory and Naval Sea Systems Command authorities, it will be submitted for approval as a military standard.

4.3. PROGRESS

Work to fulfill this objective is being performed under contract by the Applied Physics Laboratory of the University of Washington.

The handbook contents have been outlined in previous quarterly reports.[1,2] The first draft of all sections of the handbook has been reviewed and commented on by four authoritative reviewers. The format of the final draft of the handbook will be modified, as the result of these reviews, to allow easier reference and use. Its sections will be divided into three main parts:

- Part 1 will contain sections addressing O-ring installation to be used by assembly personnel.

- Part 2 will be sections covering O-ring engineering application.

- Part 3 will be the appendices with background data.

Because of changes as a result of the review and the necessity for additional information in the handbook, the final draft of the handbook has been delayed.

4.4. PLANS

The final draft of the handbook will be completed and submitted for approval by 31 May 1981. It will be published and distributed, as an NRL Report, during the fourth quarter of FY81.

5. TASK C-2 - CABLES AND CONNECTORS

D.E. Glowe - Texas Research Institute, Inc.
G.D. Hugus - NRL-USRD

5.1. BACKGROUND

The use of cables and connectors is an area of concern for long-term sonar reliability because of a history of failures. Deficiencies can be generally categorized in the four areas of: design of cables and terminations; specification and testing; handling; and repair and maintenance. Specific problems have been identified in a recent failure modes and effects analysis of cables and connectors prepared for the Naval Sea Systems Command by the Electric Boat Division of General Dynamics Corporation. They concluded that, of all the problem areas, the loss of bond of the molded boot to the connector shell or to the cable sheath is the most probable cause of failure. Cable jacket puncture in handling, at installation, or in service is considered to be the second most probable cause of failure.

5.2. OBJECTIVES

The general objective of the task is to provide improved reliability in the cables, connectors, and related hardware for the outboard elements of sonar transducer systems. Specific objectives for the FY81 task area are to document the following completed tasks:

- Investigate the strength of shielded and unshielded cable to determine reliability and failure modes.
- Investigate the use of cable/connector book clamps to determine the effect of their use on reliability and failure modes.

5.3. PROGRESS

5.3.1. Work by Texas Research Institute, Inc. on the specific objectives given above has been concluded and documented. The final report on the first objective is being published as NRL Memorandum Report 4468 entitled "Investigation of the Strength of Shielded and Unshielded Underwater Electrical Cable."

5.3.2. The final report on the second objective has been completed in first draft form; it is entitled "Investigation of Mechanical Clamps Applied to Portsmouth Connectors."

This investigation addressed the efficienty of mechanical clamps applied to the molded boot of Portsmouth connectors. The specific questions that were pursued were:

- Does a clamp prevent leakage in unbonded connectors?
- Does a clamp lose effectiveness with time in service?

- Can a "best" clamp design be identified?
- Does a clamp decrease bond degradation rate?
- Can the lifetime of a connector be determined?
- What is the efficiency of clamps applied to connectors?
- What cost trade-offs are associated with connectors?

A mission profile for underwater connectors was prepared and used to design laboratory test sequences to evaluate connector leakage. A test connector was designed that incorporated the important features of the Portsmouth connector with the addition of leakage monitors in the construction so that leakage paths in the connector could be identified during test. Construction variables of polyurethane or neoprene boot (both bonded and unbonded), clamp design, and shielded or unshielded cable were investigated using factorial experimental design and analysis. A preferred clamped connector configuration was determined. Preferred test connectors were manufactured using bonded neoprene boots, shielded cable, and Band-It Preform clamps, and compared to a standard, non-clamped, polyurethane-molded connector in accelerated life testing (ALT).

It was determined that a mechanical clamp inhibits leakage in a connector. Although applying a clamp to a connector does not insure water tight integrity, it was found that after 32 weeks of ALT the number of leaking connectors with clamps was decreased by 78% over connectors without clamps. The data also indicated that neoprene and polyurethane bonds degrade with time, but connectors made with neoprene-molded boots were less likely to leak through a bond interface than those made with polyurethane-molded boots. It was also found that the pressure qualification tests specified in MIL-C-24231 do not necessarily identify unbonded connectors, and that construction variables other than bond quality may greatly influence the leakage characteristics of connectors.

5.4. PLANS

An NRL report on the results of the use of cable/connector boot clamps will be published during the third quarter of FY81. This will conclude all work on these two specific objectives.

6. TASK D-1 - ALTERNATIVE MATERIALS: PLASTICS

K. Niemiller - NWSC

6.1. BACKGROUND

Corrosion, cost, and acoustic characteristics are parameters that must be considered when selecting a material for the design of a sonar transducer. In the past decade, plastics have decreased in cost and increased in strength to the point that they are in strong competition with metals for specific applications. Plastics could be used as a design material for sonar transducers in order to lower costs and lengthen service life if they can withstand the ocean environment. An additional advantage is that plastics generally are electrically nonconductive and acoustically transparent.

Specifically, the injection molded thermoplastics are the best materials for consideration as an alternative assembly material since they can be molded to close dimensional tolerances and in many configurations. Metals and electronic connectors can be molded directly into the plastics thus reducing the number of separable parts and insuring in-service reliability.

Naval facilities equipped with the proper molding equipment can fabricate replacement parts for sonar transducers when parts are not in stock or readily available. This would be extremely helpful when emergency repair is necessary and the time for normal procurement procedures is not available. In the event that a shortage of material should occur, thermoplastics can be easily recycled.

Presently there are no general long-term ocean immersion data available for thermoplastics. It would take many years of testing and analysis to determine the long-term life expectancy, but there is an immediate need for information. The only approach for determining this information in a reduced time period is to perform accelerated life testing (ALT), but this must be used with caution. When this method is used, it is always recommended that comparison be made to parts which have been exposed to the actual environment in question.

6.2. OBJECTIVE

The objective is to evaluate the ability of plastics to withstand an ocean environment and the reliability of the ALT method for use in determining long-term material life expectancy.

6.3. PROGRESS

The approach to the objective has been to perform a two-year equivalent ALT on eight types of glass-filled thermoplastics. The choices of material have been described in the STRIP FY80 Second Quarter Progress Report. Parallel to this, the same materials will be exposed to an ocean environment for two years. Water absorption, volume change, tensile and shear strengths, and sound speed will be measured on all samples. A comparison of the results of the ALT and the ocean test will allow a prediction of the life expectancy of these plastics in sonar applications.

The ALT portion of the program was completed 27 February 1981. The data is being analyzed to determine activation energies and aging factors. Table 6.1 presents baseline tensile and shear strengths for each material and the tensile and shear strengths after exposure in simulated seawater for 2048 hours at 75°C.

Table 6.1

MATERIAL	% GLASS-FILLED	TENSILE STRENGTH (PSI)		SHEAR STRENGTH (PSI)	
		BASELINE	2048 HRS @ 75°C	BASELINE	2048 HRS @ 75°C
Polyphenylene oxide/styrene	30	15768	9902	8463	8736
Polycarbonate	40	16392	7277	8229	8051
Polysulfone	30	12364	9706	7922	7896
Polyphenylene sulfide	40	16378	13064	7669	6795
6/10 nylon	40	19435	14072	8602	7356
PBT polyester	40	16732	6723	8349	3902
High-strength nylon	40	15739	8016	7873	4611
Amorphous nylon	40	19939	17343	9733	9694

Analysis of the ALT data has not been completed; however some preliminary findings can be stated:

- Degradation is accelerated by increased temperature.
- Amorphous nylon (40% glass-filled) shows promise in the ALT environment.
- Polycarbonate (40% glass-filled) does not retain tensile properties in the high temperature ALT environment.

- PBT polyester (40% glass-filled) and high-strength nylon (40% glass-filled) do not retain tensile or shear properties in the high temperature ALT environment.
- The remaining plastics (polyphenylene oxide/styrene, polysulfone, polyphenylene sulfide, 6/10 nylon) show some potential for use depending on the application.
- Appropriate inspections and tests should be included with any procurement of parts to insure that desired mechanical properties are obtained.

The ocean test portion of the program has completed four of the seven test intervals. No significant degradation of mechanical properties has been observed with testing samples following 17 weeks in an ocean environment at the Naval Research Laboratory's Corrosion Testing Laboratory in Key West, FL. Some marine growth, not yet identified, has occurred on specimens of each type of plastic material. The marine growth is heaviest on the polyphenylene oxide/styrene specimens.

6.4. PLANS

- Compile and analyze ALT data.
- Submit interim technical report on ALT findings.
- Continue ocean environment exposure.
- Prepare procedures for evaluating creep, stress degradation, and machined plastics degradation.

7. TASK D-2 - MATERIALS EVALUATION

C. LeBlanc - NUSC

7.1. BACKGROUND

Pressure release materials are used to mechanically and/or acoustically isolate some components of sonar transducers to improve overall acoustic performance. Normally the pressure release materials must operate effectively under bias stress anywhere from 0.3 MPa (50 psi) to 20 MPa (3 kpsi) over a discrete temperature range, e.g., 5 to 40°C. To predict performance it is essential to know the properties of the materials under the imposed constraints. Previous measurement methods for determining the properties of some pressure release materials, such as Sonite (an asbestos-glass fiber composite), onion-skin paper, syntactic foams, Hytrel (a thermoplastic polyester elastomer), etc., have given relative results with a hydraulic press or bulk effects with an impedance tube. There is a strong need to correlate existing measurement data and to establish a standard measurement system to be used by the Navy for incorporation into specifications and/or acceptance tests on pressure release materials.

7.2. OBJECTIVES

The objectives of this task are:

- To initiate and evaluate a standard static and dynamic measurement system to determine the properties of pressure release materials over the ranges of stress from .34 to 21 MPa and at temperatures from 5 to 40°C.
- To measure and evaluate candidate pressure release materials, such as Sonite, onion-skin, corprene, etc.

7.3. PROGRESS

7.3.1. Measurement Assembly

The initial measurement assembly described in previous STRIP reports is repeated in Fig. 7.1 to enhance the following math modeling techniques which were used to evaluate the unknown properties of the sample being measured. Conditions of free support were approximated by suspending the complete assembly on two nylon threads such that losses in the assembly were accounted for only in the driver unit and the detachable sample holder. Losses in the driver unit are accounted for by measurements on the driver alone, exclusive of the sample holder. Any additional losses measured thereafter on the complete assembly can be attributed to the sample itself (i.e., including losses associated with the mating surfaces of the sample holder and the driver unit). This is the approach taken by the Raytheon Company in modeling the composite assembly from the electrical input terminals of the driver unit. An alternate approach is to simply model the low-frequency phenomena associated with the unknown sample itself and its loading mass, the NUSC approach. For either approach the complete measurement assembly as initially established (designed to eliminate adverse effects associated with previous dynamic measurement schemes employing hydraulic presses to apply static loads) weighs roughly 14 kg and attachment of the sample holder to the driver unit is a cumbersome task. Since initial measurements using this scheme proved favorable in defining the complex elastic properties of a *trial* sample material (Hytrel - a thermoplastic polyester elastomer) versus applied longitudinal static stress, a reduction in the overall size and weight of this initial measurement assembly is of prime consideration for future work to insure simplicity of results and the ability to easily expand measurements to include both frequency and temperature effects.

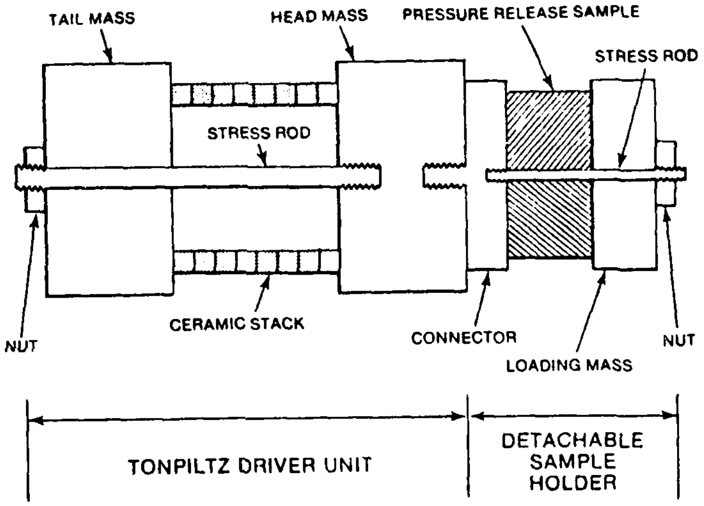
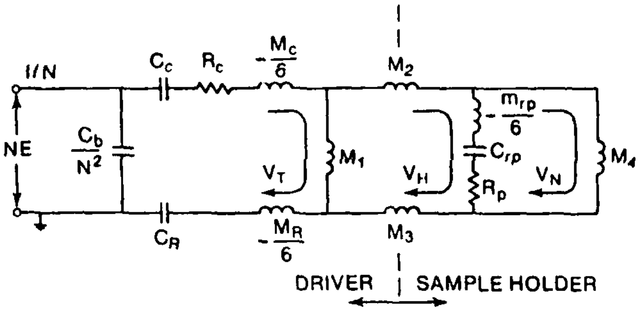


Fig. 7.1 - Measurement assembly

7.3.2. Mathematical Modeling Approaches

Math modeling of the composite assembly begins stepwise. Each component is treated separately using plane wave theory (single mechanical degree-of-freedom) and then all components are connected together as required. Making the additional assumption that both the driver unit and the sample holder are mass loaded structures (low-frequency approximation) leads to the circuit shown in Fig. 7.2. The elements representing the sample holder are shown in the extreme right side of the circuit where C_{rp} and m_{rp} are the equivalent series combinations of compliance and mass associated with the small stress rod and the sample, R_p represents the losses in the sample, and m_2 ($>>m_N + m_{rp}/2$) represents the loading mass on the sample.



$$M_1 = M_T + M_N + \frac{M_{cR}}{2} \qquad M_3 = \frac{M_R}{2} + \frac{m_r}{2}$$

$$M_2 = \frac{M_c}{2} + M_H + M_{CN} + \frac{m_p}{2} \qquad M_4 = m_2 + m_N + \frac{m_{rp}}{2}$$

Fig. 7.2 - Low-frequency circuit approximation (lumped element)

Three mathematical approaches were considered for evaluating the same properties:

- The low-frequency resonance phenomena associated with the sample loop (i.e., the loop containing the velocity V_N of the loading mass). The main assumption is that $M_2 >> m_2$. The measured quantities are the resonance frequency f_v and the mechanical quality factor Q_v which are defined as

  $$f_v \equiv \frac{1}{2\pi} \sqrt{\frac{1}{m_2 C_{rp}}} \quad \text{and} \quad Q_v \equiv \frac{2\pi f_v m_2}{R_p} \ ,$$

  where m_2 is a known quantity. The loss element R_p was introduced into the circuit by assuming that the compliance C_p of the sample was complex; i.e., $C_p = C_p' - jC_p''$. Thus, the final equations for the unknown quantities become

  $$C_p' = \frac{C_s}{(1 + \frac{1}{Q_p^2})} \quad \text{and} \quad Q_p = \frac{Q_v}{(2\pi f_v)^2 m_2 C_s} \equiv \frac{C_p'}{C_p''} \ .$$

  where C_s has been introduced for simplicity and is defined as

$$C_s \equiv \frac{C_{rp}}{1 - \frac{C_{rp}}{C_r}} \quad .$$

Note: C_r is the compliance of the small stress rod and is a calculated quantity.

- The amplitude and phase associated with the velocities V_H and V_N appearing on either side of the sample. In principle this approach has no frequency limits but best accuracy is obtained about f_V with present instrumentation capabilities. The measured quantities are V_H/V_N, $\emptyset$, and f. When it is stipulated that

$$\frac{V_H}{V_N} \equiv K \quad \text{and} \quad \text{Tan}\ \emptyset \equiv P \ ,$$

then the unknown quantities of the sample may again be solved for:

$$C_p' = \frac{C_r(1 - K)}{(2\pi f)^2 m_2 C_r (1 + KM) - (1 - K)}$$

and

$$Q_p = \frac{(1 - K)^2}{(2\pi f)^2 m_2 C_p' PK(1 + M)} \quad ,$$

where $M \equiv \frac{m_{rp}}{6m_2}$ and $0 \leq K \leq 1$.

- The high-frequency resonance phenomena associated with the electrical response of the driver unit. The main assumption is that the ceramic stack parameters of the driver unit are known - actually determined from measurements on the suspended driver assembly alone. This was the approach taken by the Raytheon Company. The mathematical model has been completed, computerized, debugged, and delivered. The measured quantities are the magnitude of the input admittance $|Y|$ or $|I/E|$, the electrical phase angle ϕe, and the frequency f.

Figure 7.3 shows the measured frequency responses ($|V_H|$, $|V_N|$, and $|Y|$ versus f) associated with the three mathematical approaches. The two lower profiles are expected responses and indicate that the first and last math modeling techniques are viable candidates for evaluating the unknown properties of the sample material. The upper profile shows an unexpected behavior for the velocity $|V_H|$ of the driver head mass and puts a damper on the use of the second mathematical approach which contains the ratio of $|V_H|$ to the velocity of the sample loading mass $|V_N|$. However, it is felt that this approach is the easiest and most accurate to pursue if the odd behavior can be explained. The low-frequency circuit approximation shown in Fig. 7.2 was modeled on a Hewlett Packard General Circuit Analysis Program and yielded responses similar to all three cases shown in Fig. 7.3. This tool can now be used to investigate the odd behavior in $|V_H|$ and direct redesign efforts for the assembly to insure a response similar to $|V_N|$ so that the second mathematical approach can be used with credance.

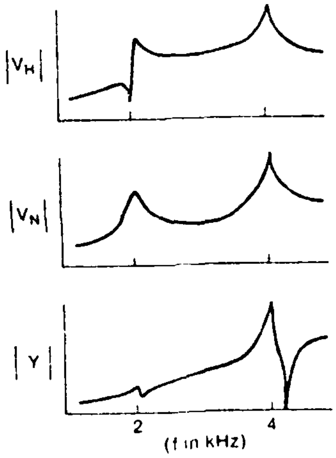


Fig. 7.3 - Relative frequency responses

7.3.3. Experimental Results

Static Measurements: Four washerlike Hytrel samples (1.4-cm od, 0.30-cm id, and 0.35-cm thick) were closely machined (0.0004 cm on all surfaces) and two were subjected to static stress cycling with a hydraulic press to determine the number of stress cycles required to stabilize the material before any dynamic measurements were attempted. Data for the first and tenth stress cycle to a maximum stress level of 17.2 MPa (2.5 kpsi) are shown in Table 7.1. Y_t is the longitudinal elastic modulus, Y_r is the transverse (circumferential) elastic modulus, and σ is the ratio of Y_t to Y_r. (The ratio σ is sometimes referred to as Poisson's ratio when certain ideal boundary conditions are satisfied.) The data indicate that the material has essentially stabilized after the tenth static stress cycle.

Table 7.1 - Effective static modulii

	1st CYCLE			10th CYCLE		
SAMPLE	Y_t	Y_r	σ	Y_t	Y_r	σ
RING 2A (1.4 cm dia)	28	60	.47	33	68	.49
RING 3A (1.4 cm dia)	30	67	.45	33	71	.46
SOLID PUCK (0.79 cm dia)	18	34	.53	18	33	.54

DuPONT — 12 kpsi FOR EXTRUDED SAMPLE
(ASTM D695)

Data on a solid puck of the same Hytrel material is also shown. The solid puck was used to determine density variations vs stress level. The density of Hytrel was found to be constant to 20.7 MPa (3 kpsi) and equal to 1183 kg/m^3. The lower values of Y_t and Y_r for the solid puck, compared to the washerlike samples, show the effects of lateral clamping on dissimilar surface areas. That is, as the loading areas of the samples become smaller od approaches the compressional elastic modulus of 83 MPa (12 kpsi) quoted by DuPont. These data point out the fact that in order to predict the modulus values for washerlike samples of elastomeric materials, a "shape-factor" correction must be applied. This technique was not used due to the lack of sufficient data points. The static value for Y_t of 228 MPa (33 kpsi) measured for these samples compares well with R. Vogelsong's measured value of 241 MPa (35 kpsi).[3]

The values given in Table 7.1 were derived from a linear approximation of the high-level stress data as shown in Fig. 7.4. The nonlinear behavior at low stress level was shown to be due to the pressure gauge reading. The "offset" stress shown in the stress level required to properly seat the sample in the hydraulic press.

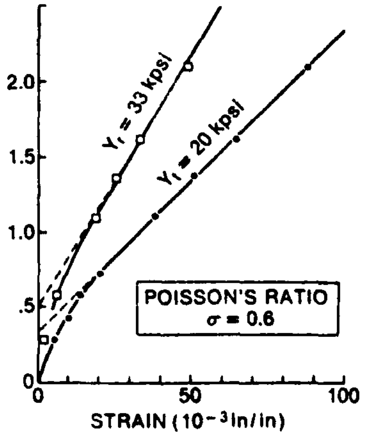


Fig. 7.4 - Stress vs strain (solid puck -- 15th cycle)

Dynamic Measurements: The four Hytrel samples, after static stress stabilization, were tested dynamically. The low-frequency resonance mathematical approach was used to interpret the measured results. The real part C_p' of the complex compliance of the "unknown" sample versus longitudinal stress is shown in Fig. 7.5. The load was applied using a stress bolt torquing technique. The marked points represent measured data: ① signifies the spread in four individual samples, ② signifies a double layer of material (two samples), and so forth. The idea was to increase the length of the sample to eventually approximate boundary conditions (cross-sectional area < length) for determining a true dynamic Young's modulus.

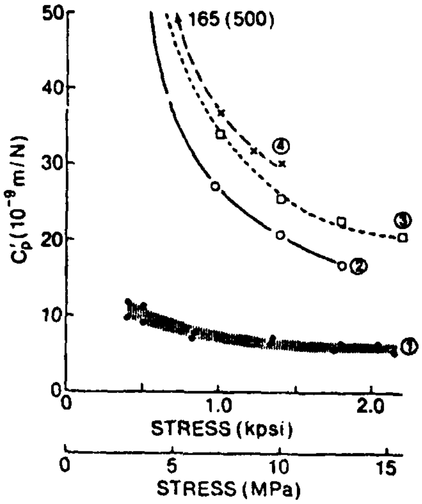


Fig. 7.5 - Dynamic compliance versus stress

Note: The marking at the top of Fig. 7.5 means the four-layer sample had a compliance value of 165 X 10^{-9} m/N at a stress level of 500 psi.

Since compliance is directly proportional to length (i.e., assuming elastic modulus and cross-sectional area are constant) one would expect a doubling and tripling of values as the number of samples is increased. This is somewhat true at the higher stress levels. [For the four-layer sample the stress was limited to 10.3 MPa (1.5 kpsi) because of stress rod thread degradation.] At low stress levels, however, this rationale does not apply. For single samples the curves are adequate. As the sample length increases it becomes harder to compact and seat the samples at low stress levels, so the data are questionable. There is no apparent reason why the material *itself* would change so drastically, so most of the apparent change must be associated with the stress application technique.

Figure 7.6 shows the material quality factor Q_p of the Hytrel samples. The marked points again represent measured data and ①, ②, etc., have the same meaning as before. The losses are high (low Q_p) at low stress level and stabilize to a constant value at high stress levels. From the plots it appears that the quality factor becomes minimum for a two-layer structure and then tends to increase as the sample becomes longer. The reason for this phenomena is not immediately explainable.

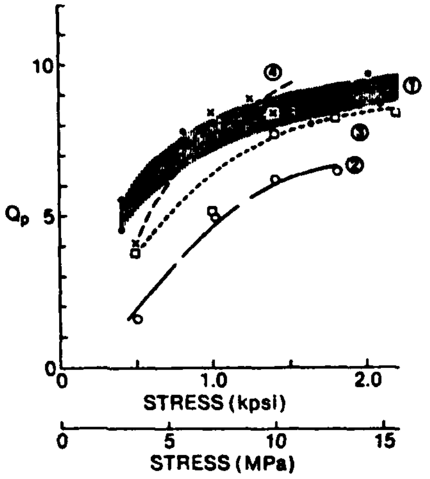


Fig. 7.6 - Compliance quality factor Q_p versus stress

An effective dynamic Young's modulus (Y_{eff}) can be calculated from the compliance values shown before (Fig. 7.5) and the dimensions of the sample. The results are shown in Fig. 7.7. The single samples ① have higher modulii than the longer four-layer sample ④. This result is commensurate with the fact that single-layer samples are more laterally constrained by the containing masses than longer samples (Table 7.1). In other words, a clamped sample would have a higher modulus than a laterally free sample.

From the previous data and the measured fact that the density was constant, an effective speed of sound c_{eff} was calculated for Hytrel and is shown in Fig. 7.8. Data for the two- and three-layer samples were not plotted but would fall between the curves for ① and ④ . Remember that the data shown here were determined from low-frequency mechanical resonance measurements. High-frequency electrical resonance measurements were also taken and the data were used as input for the Raytheon computer program which backed out a value of 700 m/sec for the same sample - a difference of only 3%. [Only one point - ⊡ - is shown because of time constraints.] The mechanical quality factor determined by the two approaches gave a value of 8 and 30, respectively. The reason for this large difference is not immediately apparent.

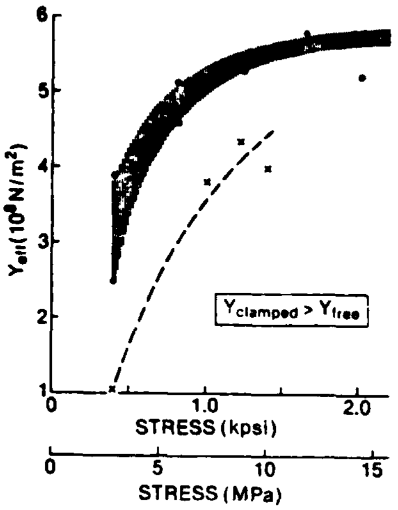


Fig. 7.7 - Effective Young's modulus versus stress

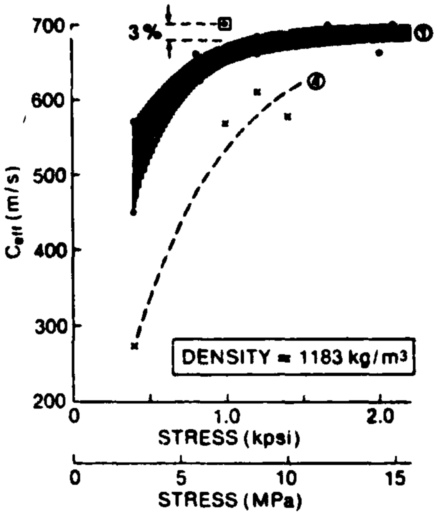


Fig. 7.8 - Effective speed of sound versus stress

The effective longitudinal dynamic and static elastic moduli for Hytrel were compared and yielded a ratio of 2.50. The dynamic value of 572 MPa (83 kpsi) was taken from Fig. 7.7 at 13.8 MPa (2.0 kpsi). Both of these values were also measured by Vogelsong on other Hytrel samples at the David W. Taylor Naval Ship Research and Development Center between 100 and 600 Hz. The value determined here applies at roughly 2.0 kHz.

7.3.4. Summary

The initial experimental setup has been established and descriptive math models for both low- and high-frequency have been completed. Static and dynamic measurements have been completed on Hytrel samples to approximately 17 MPa. From these measurements the compliance, speed of sound, and longitudinal modulus have been calculated.

7.4. PLANS

- Complete math modeling.
- Compare measurement techniques.
- Write a report.

8. TASK D-3 - SPECIFICATION FOR TRANSDUCER ELASTOMERS

C.M. Thompson - NRL-USRD

8.1. BACKGROUND

The high cost of maintenance, replacement and repair of fleet transducers has become so inhibitive that the reliability of sonar transducers has received a great deal of attention in recent years. Improvement in the reliability of such systems through failure analysis and material development and modification is emphasized. It is hoped that such an effort will, in the end, provide the fleet with more effective systems having an extended operational lifetime and also that the overall life cycle cost will be minimized. Indeed, the most severe stress that can be imposed on a system or the materials used in the system is that of time. The necessity of a transducer elastomer to maintain its physical strength, electrical resistivity, and acoustic properties in the face of years of temperature extremes, UV radiation, seawater, pollutants, and physical abuse is a most difficult requirement. Small wonder then that transducer elastomers have been the source of a large proportion of failures in sonar transducers.

The most frequent scenario for the choice of a transducer elastomer is that the design engineer, having developed a list of performance requirements, requests from a rubber manufacturer a material to meet these requirements. Unfortunately, the performance requirements are frequently, at best, an educated "guess" of the properties expected of the material based on past experiences. The requirements list may not include all of the important short-term properties and likely will not include any long-term properties. Consequently, the material developed by the rubber manufacturer is not likely to have been optimized for short-term operation; moreover, it may not even have been considered in its design for the extended lifetime performance required in a sonar transducer system.

A recent example of this type of failure has been with a neoprene rubber formulation which was designed to meet a variety of specification tests. Unfortunately, the specification did not require a high electrical resistance after water immersion and this deficiency has apparently produced an alarmingly high rate of transducer failure.

It is therefore desirable to establish specifications for transducer elastomers that are based on a consideration of all the stresses imposed. This requires that the performance of transducer elastomers, both initial and long-term properties, be well understood as functions of elastomer composition, cure conditions, and environmental parameters. Only then can the composition and processing procedures of the elastomers be carefully chosen and specified. In this task, the results obtained in other more basic R&D programs will be incorporated in the development of specifications for transducer elastomers. Appropriate engineering studies will also be carried out for candidate materials as needed so that the preparation of complete rubber specifications may be possible.

8.2. OBJECTIVE

The objective of this task is to establish specifications for elastomers for use as transducer windows and cable jackets.

8.3. PROGRESS

8.3.1. Under funding support of the Sonar Transduction Science Program (Program Element 62711) instrumental techniques have been developed for the compositional analysis of a neoprene rubber, Neoprene 5109. This Navy-developed elastomer was considered most suitable for underwater sound application as confirmed by recent progress in that program. By using techniques including HPLC and GPC, a series of studies was conducted to relate the analyzed composition of the material to their physical properties. The results allow one to establish limits on the deviations of composition such that elastomer composition may be fine-tuned for specific applications.

This work is being transitioned to the STRIP for preparation of procurement specifications. The specifications will include composition and methods of compositional analysis for Neoprene 5109. The first draft will be published for comment during the fourth quarter of FY81.

8.3.2. An extensive study has been designed and begun to lend support to the sonar engineers in their transducer failure analyses. The effect of changes in composition of an elastomer on transducer-related properties will be examined. Specifically, for a Neoprene GRT rubber the changes in curing agent (lead oxide vs MgO/ZnO or ZnO), the amount of carbon black, the type of carbon black, substitution of other fillers for a portion of the carbon black, and some combinations of these changes are included. The rubber samples are being exposed to seawater and fresh water and their weight change, volume change, and hardness change are being monitored. The effect of these compositional changes on the permeability and on the electrical resistivity will also be studied.

8.4. PLANS

- Complete study on compositional changes on Neoprene GRT and report results (15 Jul 1981).
- Perform study on transducer-related properties of Neoprene 5109 (30 Jul 1981).
- Prepare draft specification for Neoprene 5109 (30 Sep 1981).

9. TASK D-4 - TRANSDUCER CERAMICS

A.C. Tims - NRL-USRD

9.1. BACKGROUND

Because of the fragile nature of piezoceramic ceramic materials, transducers using these materials are shock hardened by the technique of winding glass filament under tension onto the ceramic element to produce a constant compressional stress in the ceramic material. The compressional bias reduces the probability of tensional fracture of the ceramic when subjected to high acceleration due to explosive loading. However, variations in the winding technique may produce a variability in the finished transducer element that greatly exceeds any variability in the properties of the ceramic itself.

Evidence of the variations caused by glass wrapping is shown in Table 9.1. These data were compiled from the measurements on 129 ceramic rings. Note that there are greater variations in the electrical parameters after prestress than before prestress.

Table 9.1 - Effects of glass wrap on SQS-26(CX) ceramic rings

	RADIAL MODE			LENGTH MODE			5 VOLTS/CM	
	RESONANCE	ANTI-RESONANCE	K_{31}	RESONANCE	ANTI-RESONANCE	K_{33}	CAPACITY	D.F.
	Hz.	Hz.	%	Hz.	Hz.	%	PFD.	%
BEFORE GLASS WRAP	16,110 ± 1.18 %	16,370 ± 1.16 %	17.73 + 3.8 % −10.6 %	86,800 ± 1.25 %	93,750 ± 1.22 %	37.80 + 2.7 % − 1.9 %	1,489 ± 2.3 %	0.524 ± 4.8 %
AFTER GLASS WRAP	16,470 ± 1.5 %	16,680 ± 1.6 %	15.63 + 7.7 % − 15.6 %	85,230 ± 1.7 %	92,160 ± 1.36 %	38.04 + 2.4 % − 7.8 %	1,452 ± 2.1 %	0.503 + 4.5 % − 9.4 %

SAMPLE POPULATION: 129 CERAMIC RINGS

9.2. OBJECTIVE

The objective is to investigate the effects of filament winding on piezoelectric ceramic in transducer configurations.

9.3. PROGRESS

Task D-4 is a new start for the STRIP in FY81. The first step was to initiate a literature search to determine if any prior work has been formally documented. A search by the NRL library and the National Technical Information Service (NTIS) disclosed some reports on the effect of filament wrap on the electrical parameters of the ceramic. Typically, the application of glass wrap to a ceramic cylinder or ring decreases the transverse coupling coefficient k_{31} and the capacitance while the longitudinal coupling coefficient k_{33} is increased. However, the literature search did not disclose any information on the technique or more simply, "how to do it." Another NTIS search has been initiated using an expanded list of key words, but the results have not been reviewed.

The next approach was to delineate the variables involved in the process such as filament material properties, resin type, wrapping tension, wrap geometry, etc. Visits and communications with Edo Western, General Electric, ITC, and Raytheon have shown variations in the process such as filament size and type, winding tension, determination of prestress magnitude, resin types, and cure cycle. All of the manufacturers except one were open and willing to discuss their methods; the one was guarded in responses to questions about materials and techniques and considered their process to be proprietary. It appears that the specific techniques and equipment used by a manufacturer have been developed in-house to meet certain manufacturing requirements. The information received thus far indicates that filament wrapping of piezo-ceramic is more an art than a science. No one should be surprised at this conclusion as it is certainly not alone in the gallery of transducer art.

In general, the prestress is obtained by wrapping a cyclinder or ring or stack with layers of fiberglass while simultaneously applying a resin coating. The ceramic is wrapped using a planar or level wind wrap where the roving is always perpendicular to the axial length of the ceramic. The roving is applied at a tension ranging from 22 to 58 N and with a number of layers-turns that will produce the required prestress.

Manufacturers have revealed the following commonality and differences in their process. Three manufacturers use 12 strands of 204 filaments - nominal filament dia 1.3×10^{-3}cm - (12 End roving) made by Owens-Corning. One uses a 20 End roving with the resin pre-impregnated in the fiber (prepreg) made by U.S. Polymeric. The most common resin used is the Epon 800 series made by Shell Chemical. Two manufacturers use Epon 815, one uses Epon 828, and the other uses the prepreg roving which does not require the addition of a resin. For the curing agent, one uses agent D with Epon 815, another uses agent M with Epon 815, and another uses agent D with Epon 828. The roving tension is controlled in various manners; one manufacturer uses lower tension meters made by Tensition Inc.; another uses a system of weights; while still another employs a magnetic clutch arrangement. The resin cure cycle used by each manufacturer is obviously controlled by the resin type and curing agent, and the time-temperature required to obtain optimum properties. No common cure cycle exists between the manufacturers. The variation between manufacturers is obvious, but there are several common points which show that the process could be standardized.

The contemporary method for determining the stress in a cylinder or stack is by the use of strain gauges attached to the inside diameter. Sometimes surrogate cylinders with strain gauges are used to evaluate the stress magnitude for a specific configuration. When the desired properties of the surrogate are obtained, the tension, roving size, number of layers and turns, and resin-curing agent are specified for the production run. The circumferential stress in a cylinder of inside radius a, outside radius b, at any radius r, due to external pressure p is

$$T_\theta = -p\left[\frac{(1 + a^2/r^2)}{(1 - a^2/b^2)}\right]. \tag{1}$$

If the force per unit area in the fiber wrap is substituted for p in Eq. (1) then

$$T_\theta = \frac{nF_s}{b}\left[\frac{(1 + a^2/r^2)}{(1 - a^2/b^2)}\right], \tag{2}$$

where n is the total number of turns per unit length; F_s is the tension applied to the roving; and b is the outside diameter of the ceramic cylinder - actually the roving-cylinder interface.[4] The maximum stress in the ceramic occurs where r=a then

$$T_{\theta_{max}} = \frac{2nF_s}{b(1 - a^2/b^2)}. \tag{3}$$

With strain gauges on the inside diameter of the cylinder, Eq. (3) can be used to compare the theoretical stress with the stress indicated by the strain gauges (via Hooks law). This method for determining the stress has proved to be practical and suitable for engineering or design purposes.

It appears at this point in the investigation that there are two major causes for the variability between prestressed ceramics. The first major source may be in the winding tension. Fiber wrapping induces two compressional stresses in the ceramic, one circumferential or normal to the radii and the other parallel to the radii. The two compressional stresses are known to reduce the piezoelectric voltage moduli and the dielectric constant in k_{31} mode ceramics. Unless the roving tension is accurately determined and held constant during wrapping, the value of the prestress will vary. Variations in the prestress magnitude on a group of ceramics will certainly cause the electrical parameters of the wrapped ceramic to vary more than the unwrapped ceramic did before prestressing.

The other major cause of variations between glass prestressed ceramics probably results from the ceramic itself. If the diameter of the ceramic is irregular (ellipsoidal) and/or the wall is not uniform the resulting stresses in the material will not be uniform. Again, irregular stresses produce more variability. It should be noted that ellipsoidal shapes are not unusual in as-fired ceramics.

9.4. PLANS

- Forty ceramic rings have been obtained to evaluate prestress variations. These will be divided into two groups of 20 each.

- Measurements of the coupling coefficient and capacitance will be made on each ring prior to prestressing.

- When rings are returned they will be remeasured and the results will be documented indicating the variations between manufacturers and differences between each group.

10. TASK E-1 - STANDARDIZED TEST PROCEDURE

J. Wong - NOSC

10.1. BACKGROUND

It is at present not possible to subject a transducer specimen to a series of environmental stresses over a short time period and prove, if it passes certain operating parameter tests, that the specimen is a reliable transducer with a certain minimum expected life in fleet use. Of course, if we could simply use a set of transducers for the desired fleet life, we could check the failure rates against acceptable replacement or repair rates. But the approach here is to accelerate the environmental stress actions and thereby subject the transducer specimen to seven years of life cycle stresses in a few weeks or months.

10.2. OBJECTIVE

The objective of this task is to develop a set of standardized procedures based on environmental stress requirements to accelerate the aging of transducers.

10.3. PROGRESS

10.3.1. TR-316 Projectors and DT-605 Hydrophones

Composite unit accelerated life tests (CUALT) on two Ametek/Straza TR-316 projectors (serials A1 and A3) and two Hazeltine Corporation DT-605 hydrophones (serials A1 and A5) continued. TR-316 projectors A1 and A3 are in the second-year equivalent of CUALT and both DT-605 hydrophones are in the fourth-year equivalent of CUALT.

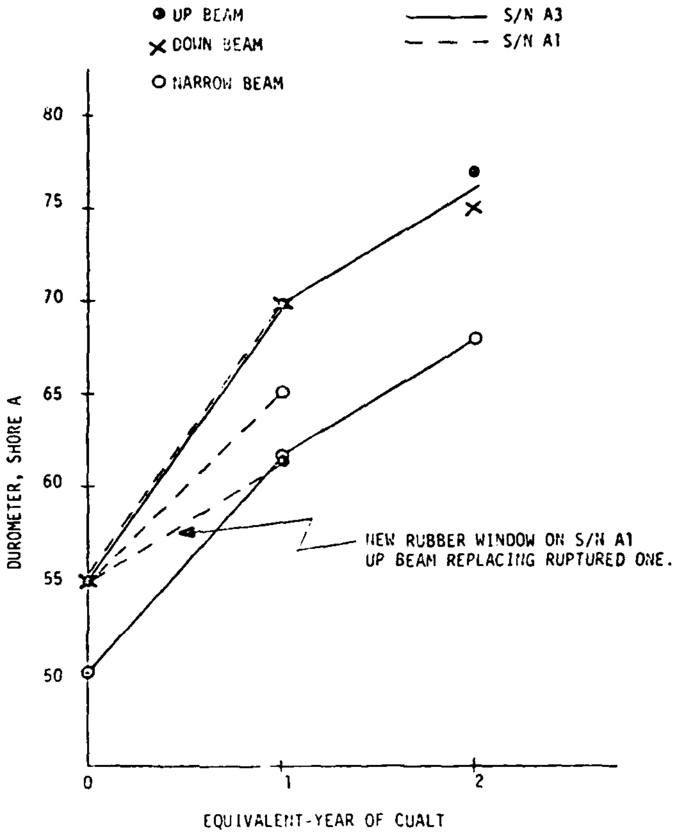
The facility at the Naval Ocean Systems Center (NOSC) for performing the pressure cycling and pressure dwell exposures has been shutdown for maintenance since December 1980. Because of delays in procurement and shipment of equipment the shutdown of the facility is further prolonged. It is doubtful whether the pressure test facility will be back in operation by May 1981.

Both DT-605 hydrophones are waiting for the pressure cyclings and pressure dwells exposures to complete the fourth-year equivalent of CUALT. Similarly, the TR-316 projector A3 will have completed the second-year equivalent of CUALT after the pressure cyclings and pressure dwells.

The TR-316 projector A1 has one-year equivalent of CUALT and the resonator elements in the narrow- and up-beam sections have completed the second-year equivalent of high-drive exposure. Acoustic checks after the high-drive exposure indicated that the three beam sections are still within the specifications of the Critical Item Production Specifications (CIPS), except for the marginal impedance magnitude, $|Z|$ at the upper operating frequency in the narrow-beam section. The measured $|Z|$ at the upper operating frequency is 48 ohms, 2 ohms below the CIPS minimum of 50 ohms and 5 ohms lower than the baseline value of 53 ohms measured before CUALT. Although there is an approximately 5 to 10% drop in the impedance magnitude over the operating frequency band, only at the upper operating frequency is the impedance below the CIPS values. This may indicate a deteriorating trend in the projector's narrow-beam impedance. The accuracy of the impedance measurements is within 4%.

In the first-year equivalent of CUALT of projector A3 the oven air temperature in the 71°C (160°F) dry heat and UV exposure (see Table 9.1 of the STRIP FY80 Fourth Quarter Progress Report) was maintained at 71°C. The rubber windows and the metal case surfaces that were exposed to the UV increased 11°C above the ambient oven air temperature to 82°C (180°F), indicating an absorption of the UV energy (this was reported in STRIP FY80 Fourth Quarter Progress Report). The 82°C temperature exceeded the maximum 71°C in the CIPS. During the second-year equivalent of CUALT of projector A3 and the first-year equivalent of projector A1 the oven air temperature was reduced to 62°C (144°F) such that the maximum temperature on the rubber windows that were exposed to the UV did not exceed 71°C.

Figure 10.1 shows the durometer values of the neoprene rubber windows of the TR-316, projectors A3 and A1, as a function of the equivalent years of CUALT. Measurements were made with a Type "A" durometer, manufactured by the Shore Instrument and Mfg. Company. The hardness of the rubber increases predominantly after the 71°C dry heat and UV exposure in the first-year equivalent approximately 66% of the increase in Shore A hardness from the pre-CUALT values occurred after the 411 hours of 71°C dry heat with UV irradiation and 244 hours of 71°C dry heat exposures for both projectors. Note the almost identical slopes between the corresponding beam sections of the two projectors in spite of the fact that projector A3 was subjected to 11°C higher than A1 in the dry heat and UV exposure. The largest increase in durometer values are the wide-beam sections, increasing from a pre-CUALT value of Shore A55 to 70. The exception is the new neoprene rubber window in the up-beam section of projector A1 where the hardness increased from Shore A55 to 62 almost entirely after the dry heat and UV exposures, but at a lower rate. This new rubber window was a replacement for the one ruptured during the first 68 hours of heat and UV exposure in the first-year equivalent. In the second-year equivalent, increase in hardness of the rubber in the three beam sections of projector A3 occurred entirely after the dry heat and UV. The rate of increase is about one-third of that which occurred in the first-year equivalent and the two wide-beams have reached a relatively high durometer value of Shore A75.



* MEASURED WITH TYPE "A" DUROMETER, SHORE INSTRUMENT AND MFG. CO.

Fig. 10.1 - Durometer values* of neoprene rubber windows on TR-316, serials A3 and A1.

10.4. PLANS

- Continue with CUALT on TR-316 and DT-605 transducers.
- Complete final documentation of FY80 effort by April 1981.
- Initiate CUALT plan on new SQS-56 transducers when available.
- Complete CUALT on TR-316 and DT-605 and document final CUALT procedure.

11. TASK E-2 - ACCELERATED LIFE TEST VERIFICATION

A. Phipps and D. Steele - NWSC

11.1. BACKGROUND

Until recently, sonar transducers that were used in the fleet were fabricated and put into operation with limited life testing. Some units performed quite well throughout the expected service life while others exhibited an early high-failure rate. Costs of transducers have increased dramatically and the life requirements have been increased to fit new overhaul schedules. These and other factors have mandated verifying the reliability of units for the entire service life. In order to determine the reliability of transducers for a given time of service, it was determined that the approach of composite unit accelerated life tests (CUALT) should be used. This method not only investigates the physical degradation of the materials used in the transducer assembly, but also the susceptibility of mechanical or electrical failures. Just as accelerated life tests (ALT) for materials need to be verified by using specimens that have been exposed for the full duration to the environment being evaluated, this must also be done for CUALT.

In July 1978, a complete array of 48 DT-168B hydrophones was removed from the USS STONEWALL JACKSON (SSBN-634) and retained intact for post-service evaluation at the Naval Underwater Systems Center (NUSC) in New London, CT. This array of hydrophones had undergone extensive evaluation at NUSC before being installed in the SSBN-634. It was decided that these hydrophones could be used to verify the acceptability of using CUALT for hydrophones.

The DT-168B is the passive sensor for the AN/BQR-2 sonar system. This set of 48 hydrophones was fabricated by the Naval Weapons Support Center (NWSC), Crane, IN, in 1972. Three sets of five air-backed cylindrical ceramics made of lead-zirconate-titanate (PZT-5A) wired in parallel-series are the main internal electrical components. The ceramics are protected by a steel cage that is covered by a butyl rubber acoustic window. The elements are isolated from the cage by rubber grommets. Shielded DSS-3 cable 38-m long is used to connect each hydrophone to the system.

By fabricating ten hydrophone units identical to those in the array and performing an established CUALT on these units it will be possible to compare the degradation of these units to the information retrieved from the post-service hydrophones.

11.2. OBJECTIVE

The objective is to verify the accuracy of the CUALT method by comparing results with a known real-time life test.

11.3. PROGRESS

As stated in the STRIP FY81 First Quarter Progress Report, ten new DT-168B hydrophones completed fabrication and began the testing sequence for the CUALT. Production tests such as capacitance, dissipation factor, null balance, dc resistance, and hydrostatic pressure were completed on 21 January 1981 and the qualification tests began. Qualification testing consisted of oven aging, vacuum, cold temperature, vibration and pressure cycling. During oven aging, one hydrophone developed a small leak in the rubber boot which allowed the fill oil to escape. Three of the post-service hydrophones removed from the USS STONEWALL JACKSON are traveling through tests along with the ten CUALT units. One post-service unit also developed a ruptured boot during oven aging. These two hydrophones were removed from the test and the remaining hydrophones continued the oven aging as well as the remainder of the qualification tests.

The qualification tests were completed on 18 February 1981 and the lake tests begun. These tests consisted of cutting the cables to 19 m, installing connectors, and testing beam patterns, capacitance, dissipation factor, and dc resistance. The lake tests were completed on 24 March 1981 and the ALT begun.

The ALT will run six cycles consisting of saltwater immersion and pressure cycling and is now scheduled for completion by the end of June 1981 at which time evaluation of the data obtained will start and the reliability of the CUALT will be determined. The only foreseeable problem at this time is the possibility of scheduling changes due to priority testing at the pressure cycling facility.

11.4. PLANS

- Complete ALT.
- Test and evaluate the hydrophones and data for degradation of physical and electrical properties.
- Compare the test data with that of post-service hydrophones for determination of CUALT reliability of effectiveness.

12. TASK F-1 - ENGINEERING ANALYSIS: FAILURE MODES DUE TO WATER

P.E. Cassidy - Texas Research Institute, Inc.

12.1. BACKGROUND

The ingression of water into sealed systems has been a subject of concern for sonar acousticians for some time. Early calculations involving permeation and solubility of water and seawater through neoprene rubber relied on assumptions concerning the ideality of the solutions and sealants. Failure mechanisms need to be more closely characterized to determine the degree of departure from ideality that the participants in water ingression experiments experience.

12.2. OBJECTIVE

The purpose of this study is to determine the effects of water or water vapor on the performance and lifetime of transducers and hydrophones. Specifically the effects of the neoprene seals on the permeant and the electronic changes caused by the permeant are to be investigated.

12.3. PROGRESS

The work is being done in phases which are designed to determine what happens to water once it gets into a transducer and how it affects the lifetime of the transducer. The first phase will determine the composition of the permeant - the quantity and type of dissolved solids which come through with water, whether they are from seawater or contaminants from the elastomer. The second phase will be to test the effect of water on the lifetime functions of a transducer.

12.3.1. Phase 1 - Permeant

Permeation experiments are underway to determine whether species are carried through rubber by permeating water and whether these species originate in the rubber or the water permeant. This should also confirm whether extraction and permeation processes have the same effects on the rubber in question. The two permeation samples of Neoprene-G that were begun early in the program have reached a steady-state equilibrium. The cell containing deionized water shows a permeation rate of 2.08 mg/cm^2/day, and the other cell, containing simulated seawater (3.5% wt. NaCl), shows a rate of 1.43 mg/cm^2/day. A change in the slope of the line representing the deionized water sample occurred at approximately 100 days. The rate changed from 1.69 mg/cm^2/day to 2.08 mg/cm^2/day, whereas the slope for the saltwater sample has been constant since a few days into the test. Two new samples were begun at a later date, and the slope for the saltwater sample is essentially equal to its corresponding sample in the older experiment (1.44 mg/cm^2/day). However, the fresh water sample shows a current permeation rate of 1.55 mg/cm^2/day which is less than before, but this rate may increase in the vicinity of 100 days like its corresponding sample, so data will continue to be gathered. Likewise, there may be a point at which the slope (rate) of the saltwater samples will increase so this experiment will continue for at least another 100 days to determine this constancy. This will delay the neoprene surface analysis investigation until the termination of this experiment.

Permeation constants were calculated both for the two older samples and the two newer ones. These constants and other pertinent data appear in Table 12.1.

Table 12.1 - Permeation Data

SAMPLE DESIGNATION	TEMP (°C)	RATE*	P**
First Experiment fresh water	60	2.08	1.48×10^{-7}†
First Experiment seawater	60	1.43	1.03×10^{-7}
Second Experiment fresh water	60	1.55	1.09×10^{-7}
Second Experiment seawater	60	1.40	1.03×10^{-7}

* Permeation Rate, mg/cm^2/day

** Permeation Constant, g-cm/cm^2-hr-torr

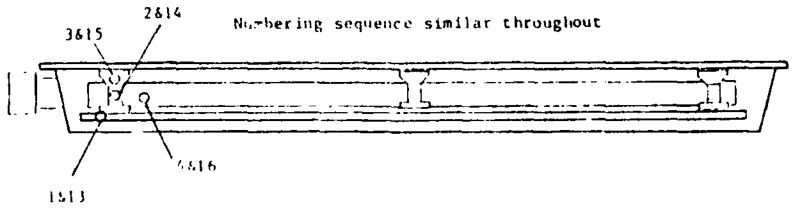
† P for first 100 days was 1.20×10^{-7}g-cm/cm^2-hr-torr

12.3.2. Phase 2 - Effect of RH on Transducer Performance

Acoustic measurements are being made on the modified TR-208 transducers as a function of internal RH. Three TR-208A transducers (serials 16955, 17121, and 17161) were thoroughly dried at Texas Research Institute, Inc. (TRI) and characterized at NRL-USRD, Orlando, for four properties: free-field voltage sensitivity (FFVS), transmitting current response (TCR), transmitting voltage response (TVR), and directional response (DR). The three transducers were returned to TRI where their internal atmosphere was equilibrated at 55% RH; then they were sent again to NRL-USRD for the same series of tests. A comparison of FFVS and TCR for the three transducers in both wet and dry conditions did not show distinct trends in the effects of the internal moisture.

Two of these transducers (16955 and 17161) were then aged by equilibrating their internal atmosphere at 89% RH at ambient temperature then heating them at 70°C for 30 days. Following the aging treatment the elements were once again equilibrated at 55% RH and sent to NRL-USRD for electronic property characterization.

A series of experiments has been started to determine the most likely point of water condensation in a transducer and the effect this would have on its reliability. Two temperature-instrumented transducers will be subjected to slowly changing environmental temperatures and the internal temperatures recorded. These transducers will also be subjected to a simulated duty cycle and the temperatures recorded. From these temperature profiles and a design analysis, an estimate can be made of the condensation. The tests will also consider other common fill materials in place of air. Two DT-308 hydrophones were chosen as special test vehicles and modified to become X-308's. They were instrumented with 12 Type J thermocouples (T_c) each at different internal sites. Sites for T_c attachments were (1) ceramic stack, (2) headmass, (3) printed circuit board, and (4) heat sink, at three locations along the length of each hydrophone. These sites are shown schematically in Fig. 12.1. The bundles of T_c leads were attached to a multi-pin connector, the other side of which was attached to a 24 thermocouple-pair cable. The butyl window for one of the hydrophones (#2) was adhered to the faces of each stack element using rubber cement. This hydrophone was then flushed for 30 minutes with air that first flowed through a desiccant cartridge. The hydrophone was then sealed. The other hydrophone (#4) was flushed with dry air for 30 minutes, then filled with dry castor oil. The two elements were then immersed in an insulated tank containing artificial seawater (Instant Ocean, sp. gr. 1.022 @ 24°C). The T_c cable ran to a 24-channel temperature recorder which was calibrated with ice water and boiling water. Temperature in the tank was adjusted using heat exchanger coils running from an adjacent tank. A starting temperature of 28°C was achieved using heating tapes on a section of the heat-exchanger coil that was between the tanks. From this 28°C starting point, the hydrophone tank water was cooled using a cooling solution in the heat-exchanger bath of ice and 20 wt. % sodium chloride (freezing point - 16°C). The solution inside the coils was methanol-water (specific gravity 0.938) whose freezing point was about -35°C.



HYDROPHONE #4/Castor Oil Filled: #'s 1, 5, 9 on heat sink
#'s 2, 6, 10 on ceramic stack
#'s 3, 7, 11 on headmass
#'s 4, 8, 12 on printed circuit board

HYDROPHONE #2/Air Filled: #'s 13, 17, 21 on heat sink
#'s 14, 18, 22 on ceramic stack
#'s 15, 19, 23 on headmass
#'s 16, 20, 24 on printed circuit board

Fig. 12.1 - X-308 schematic showing thermocouple sites

The chart shown in Table 12.2 summarizes the temperature data gathered during this experiment. The cooling rate of the hydrophone bath varied from 2.5°C/hour to 7°C/hour.

Table 12.2A - Temperature profile for castor oil-filled X-308 transducer

Tc No.	Tc Location		TEMPERATURE, °C AT ELAPSED TIME, HOURS							
			0	1	2	3	4	5	6	7
NA	TANK WATER		28	22	17	14	12	10	3	-1
1	Connector End	Heat sink	28.9	22.2	--	15.6	13.3	12.2	8.9	[illegible]
2		Stack	29.4	23.3	17.2	15.6	13.3	12.2	9.4	0
3		Headmass	29.4	22.8	17.2	15.6	13.3	12.2	7.8	-0.6
4		P. C. Board	29.9	23.9	17.2	16.1	13.3	12.2	10.6	0
5	Middle	Heatsink	28.3	22.2	17.2	15.0	13.3	11.7	7.8	-0.6
6		Stack	28.9	23.3	17.2	15.6	13.3	11.7	9.4	-0.6
7		Headmass	29.4	22.8	17.2	15.0	13.3	11.7	7.8	-0.6
8		P. C. Board	28.3	22.2	17.2	15.6	13.3	11.7	10.0	0
9	Back End	Heatsink	27.8	22.8	17.2	14.4	13.3	11.7	7.2	-0.6
10		Stack	28.3	22.2	17.2	15.0	12.8	11.7	8.9	0
11		Headmass	28.9	22.8	17.2	15.0	12.8	11.7	7.2	-0.6
12		P. C. Board	27.8	21.7	17.2	15.0	12.8	11.7	8.9	-0.6

Table 12.2B - Termperature profile for air-filled X-308 transducer

Tc No.	Tc Location		TEMPERATURE, °C AT ELAPSED TIME, HOURS							
			0	1	2	3	4	5	6	7
NA	TANK WATER		28	22	17	14	12	10	3	-1
13	Connector End	Heatsink	28.3	21.7	16.7	15.0	12.8	11.7	7.8	-0.6
14		Stack	28.9	22.2	17.2	15.0	12.8	11.7	8.3	-0.6
15		Headmass	28.9	21.7	16.7	14.4	12.8	11.1	6.7	-1.1
16		P. C. Board	28.3	22.2	16.7	15.0	12.8	11.7	8.9	-0.6
17	Middle	Heatsink	27.8	22.2	17.2	14.4	12.2	11.1	7.8	-1.1
18		Stack	28.3	22.2	16.7	14.4	12.8	11.1	7.8	-0.6
19		Headmass	28.3	21.1	16.7	13.9	12.2	11.1	6.1	-1.1
20		P. C. Board	27.8	22.2	16.7	14.4	12.8	11.7	8.9	-0.6
21	Back End	Heatsink	27.8	22.2	17.2	14.4	12.8	11.7	7.2	-1.1
22		Stack	28.3	22.2	17.2	14.4	12.8	11.7	7.8	-0.6
23		Headmass	28.9	21.7	16.7	14.4	12.8	11.1	6.7	-1.1
24		P. C. Board	27.8	22.2	16.7	15.0	12.8	11.1	8.3	-0.6

12.4. PLANS

The following tasks will be performed within the next quarter:

- Permeation experiments will continue.
- Accelerated aging will begin on two X-308 transducers.
- Impedance and phase angle curves will be generated for X-308 transducers.
- Temperature profiles for X-308 transducers under drive conditions will be completed.
- Electronic data for aged TR-208A transducers will be compared to data for dry and 55% RH conditions.
- Gas chromatographic analysis of water in castor oil will continue as necessary.

13. TASK F-2 - ENGINEERING ANALYSIS: CERAMIC STACK JOINTS

C.I. Bohman - NOSC

13.1. BACKGROUND

A severe deterioration in the electroacoustic performance of piezoelectric ceramic stacks that are assembled with epoxy adhesives has been observed at elevated temperatures that are due to either the environment or self-heating. Initial investigation has indicated that this degradation can be attributed partly, if not entirely, to a softening of the cement holding the ceramic stack together when high temperatures are encountered.

13.2. OBJECTIVES

The objectives are to identify and quantify the temperature dependent parameters of cements and ceramic that are used in transducer fabrications; to develop optimum cement joint configurations and fabrication techniques; and to develop math models of cement layers for use in transducer element design that account for the configuration of the cement joint as well as the temperature dependence of the cement.

13.3. PROGRESS

Three joint designs for stacked ceramic resonators have been tested in air for temperature sensitivity and performance (these measurements were carried out in relation to the NAVSEA TR-316 production contract). The joint designs differed in the type of electrode used, being either expanded nickel, solid nickel, or solid brass. The testing consisted of driving each resonator in air and measuring the input impedance vs drive frequency for a number of temperatures.

Figure 13.1 compares the results for a solid nickel electrode resonator (CTI 23) and an expanded nickel electrode resonator (STRAZA 735). Measurements were taken in an oven at the temperatures shown, starting at room temperature (start) and increasing the temperature in increments up to 240°F with one hour stabilization at each temperature before each measurement. Following the 240°F measurement the resonator was allowed to cool and after at least 16 hours another room temperature (return) measurement was taken. Comparison of the two plots shows that overall the solid electrode resonator is less sensitive to temperature degradation. Notice, however, that the temperature sensitivity of the resonant frequency is somewhat less for the expanded metal electrode resonator.

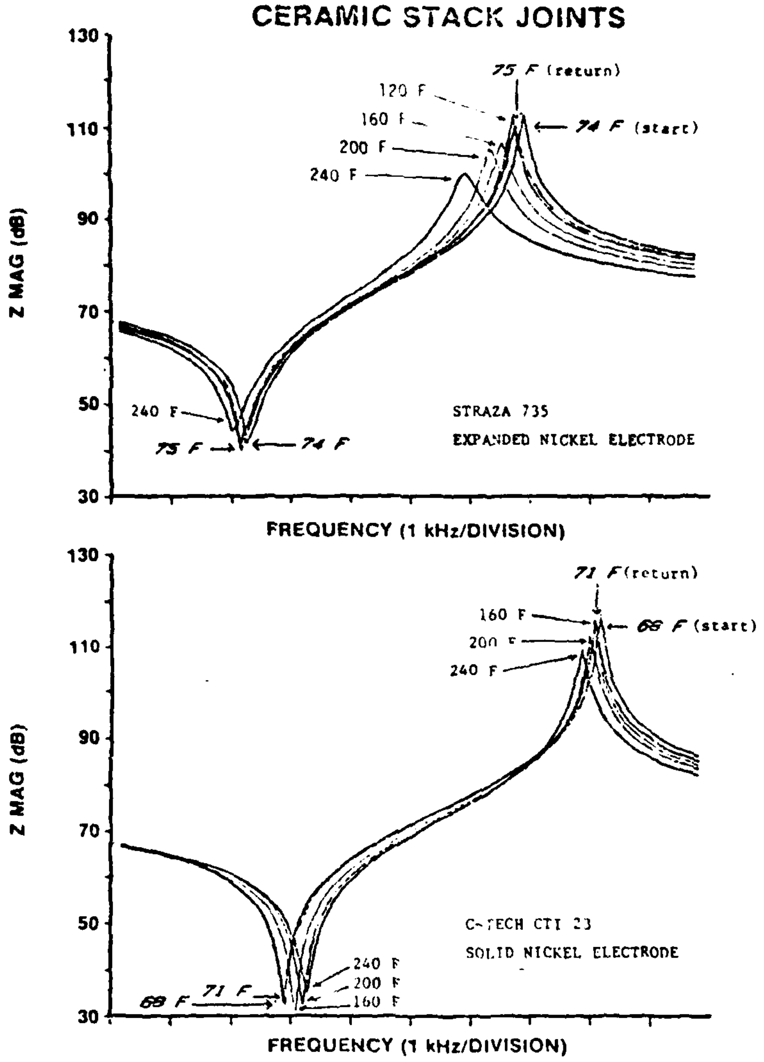
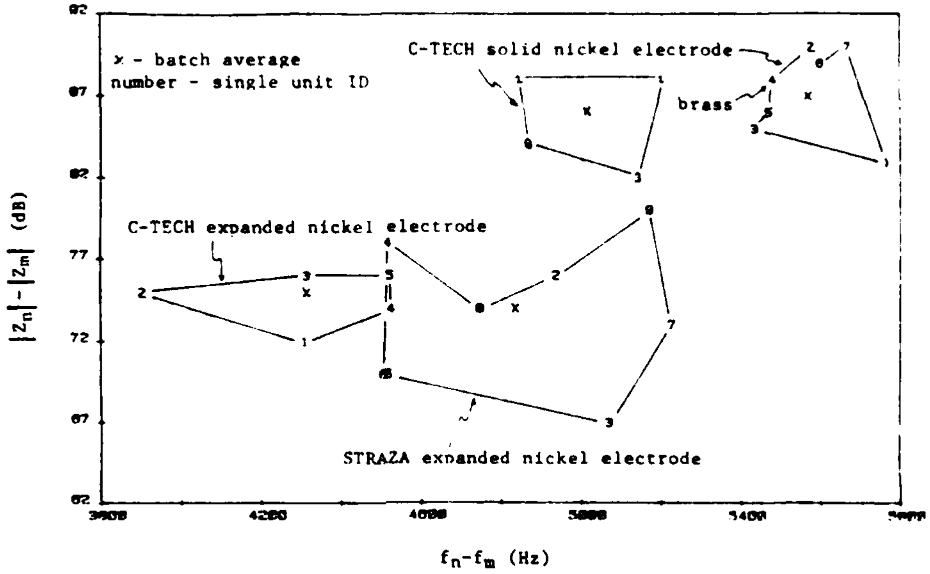
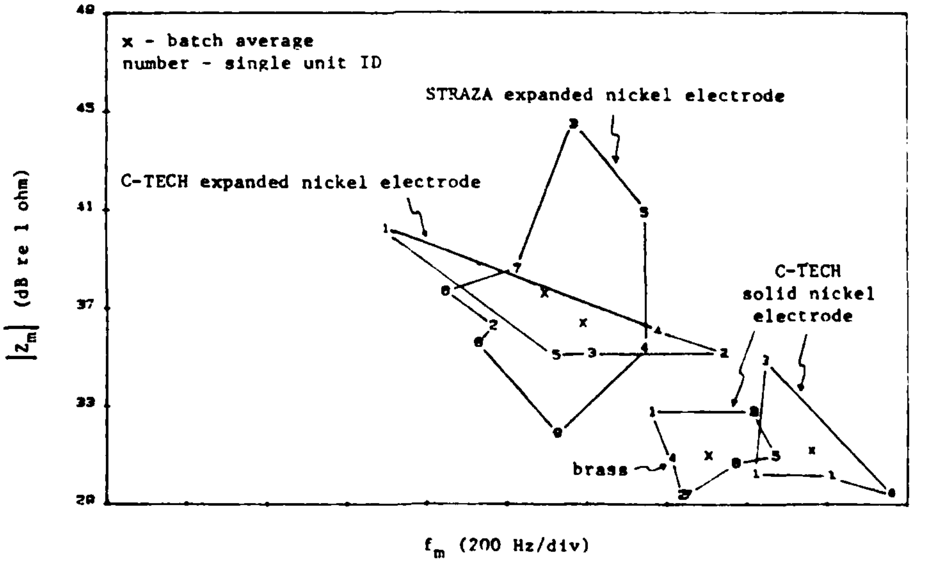


Fig. 13.1 - In-air impedance vs frequency vs temperature measurements for an expanded nickel electrode resonator (top) and a solid nickel electrode resonator (bottom).

Figure 13.2 shows room temperature results for two batches each of expanded metal electrode and solid metal electrode resonators. In the figure, f_m is the resonant frequency, the frequency at which the impedance magnitude is minimum ($|Z_m|$); and f_n is the anti-resonant frequency, the frequency at which the impedance magnitude is maximum ($|Z_n|$). The overall coupling in a resonator is proportional to $f_n - f_m$ while the overall resonator losses are inversely proportional to $|Z_n| - |Z_m|$ (actually the coupling is proportional to $f_n - f_m/f_m$, however, for our cases $f_n - f_m$ is sufficient).

In the middle and bottom plots in Fig. 13.2, f_m, f_n, and Z_n are generally larger and Z_m is generally smaller for the solid electrode resonators compared to the expanded metal electrode resonators. This could indicate that the solid electrode resonator has stiffer, less lossy joints. This appears to be reasonable since the solid electrode resonator should have stiffer joints due to less cement and a less springy electrode, and the losses would be smaller due to less cement in the joints; if indeed the cement is a significant loss factor.





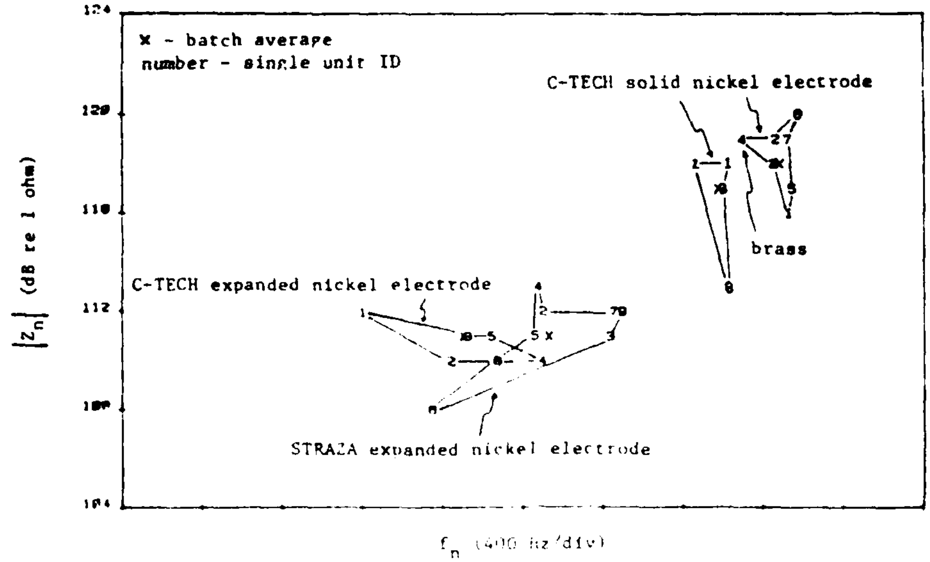
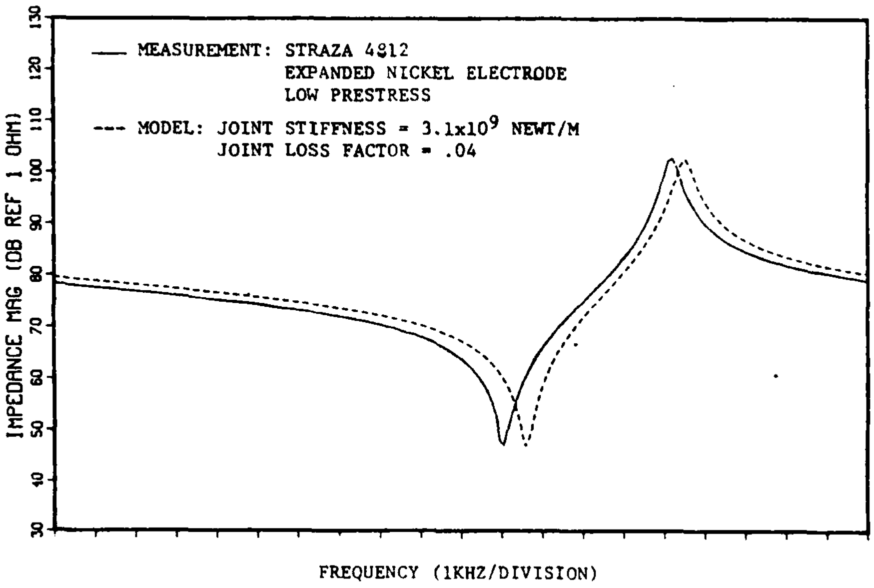
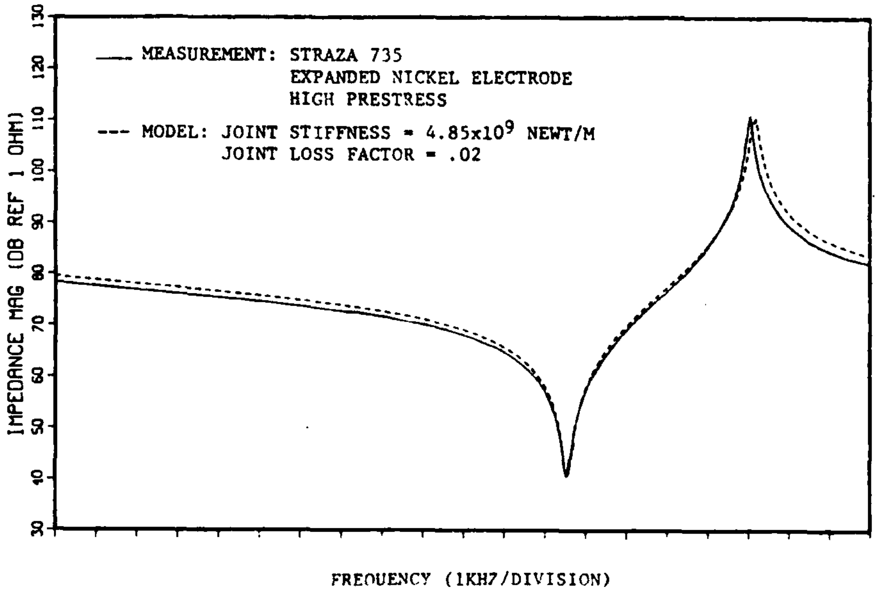


Fig. 13.2 - Results of in-air room temperature impedance vs frequency measurements for two batches each of expanded nickel and solid nickel electrode resonators

Finally, resonator 4 of the C-TEC solid electrode resonators contains a brass electrode. The brass electrode resonator does not appear to perform differently than the nickel electrode resonators.

An existing plane-wave computer model of a TR-316 resonator has been modified to include cement/electrode joints. The resulting model has two general modes of operation. First, given ceramic and cement/electrode parameters the model can predict various performance items such as electrical input impedance vs frequency, head velocity and displacement, radiated power (as a function of load), and losses in various parts of the resonator. Second, given certain measurable performance characteristics and some of the ceramic and/or cement/electrode joint parameters, the remaining ceramic and/or joint parameters can be estimated. This second mode of operation needs further testing to assure proper functioning. The TR-316 model was exercised in its first mode of operation in a brief cement/electrode joint analysis. Room temperature book values were used for the ceramic parameters and nine combinations of stiffness values and loss factors were used for the cement/electrode joint parameters. In-air impedance vs frequency calculations were carried out and plotted for each of the nine cases. Of these nine results three were picked which best matched the actual room temperature impedance vs frequency measurements of three different resonators. These comparisons are shown in Fig. 13.3. These results demonstrate some capabilities of the TR-316 model; but, in addition, another item is evident. The results suggest that the STRAZA 4812 resonator has the most compliant and lossy joints and that the C-TECH CTI 23 resonator has the stiffest and least lossy joints. Now, it seems likely that a solid electrode joint would contain less cement than a mesh electrode (expanded metal) joint for the same curing prestress on each. Also the amount of cement in a joint should decrease as the curing prestress increases. According to these thoughts, the STRAZA 4812 resonator should have the most amount of cement in its joints while the C-TECH CTI 23 resonator should have the least amount of cement in its joints. Now, if the joint stiffness is proportional to the amount of cement present and the cement is a significant loss factor, then the STRAZA 4812 resonator should contain the most compliant (least stiff), most lossy joints while the C-TECH CTI 23 resonator should contain the stiffest, least lossy joints. This is in agreement with the results of Fig. 13.3.





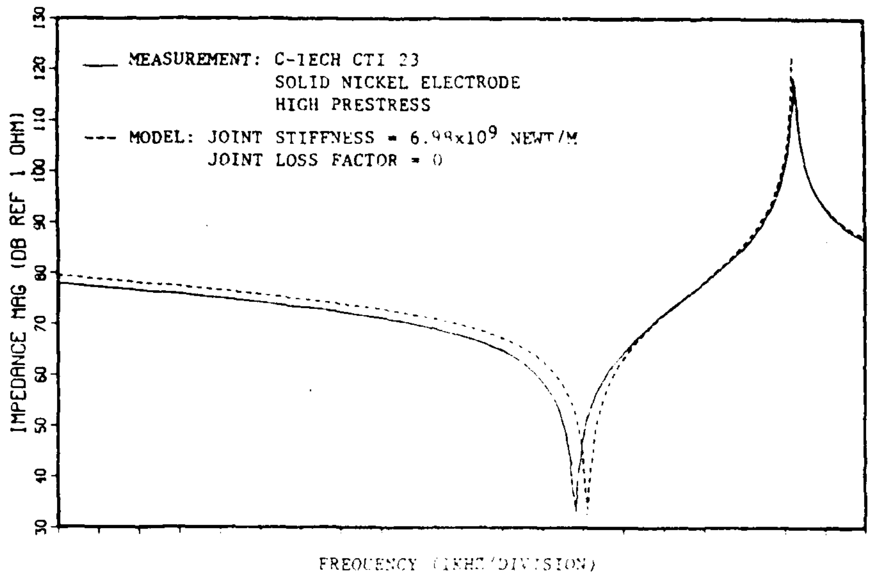


Fig. 13.3 - Comparison of experimental measurements and model calculations

Plans are being developed to study the cement/electrode joint by transient/steady-state excitation of a long metal rod made of material such as steel, evaluated first, and then cut and put back together with one or more cement joints. The rod can be struck (transiently) and a microphone can be used to pick up the natural vibrations. By beating with a known frequency source, or other methods, the resonant natural frequencies can be obtained, yielding that compliance of the joint. The rate of decay determines the loss factor for the cement joint.

Surface temperature measurements are to be obtained for a TR-316 dumiloaded resonator under high drive. One purpose of this is to provide direct insight into thermal characteristics of the resonator which may effect its operation. Another purpose is to provide temperature dependent values for the ceramic and cement/electrode joint parameters can be specified for use in the TR-316 computer model. The test setup and procedure have been formulated. Figure 13.4 illustrates the proposed test setup. Use of a noncontact infrared thermometer (.02 cm resolution) will allow variable positioning of the temperature sensor and will avoid the interference associated with contact temperature sensors. The infrared sensor will be attached to a stepping motor-controlled mechanical translation stage, allowing precise, rapid positioning. A system controller (HP9825) and associated instrumentation will be used to automate all required measurements to provide quick, precise measurements, thorough data analysis, and overall flexibility. The last of the necessary equipment has recently been received.

CERAMIC STACK JOINTS
INFRARED TEST SETUP

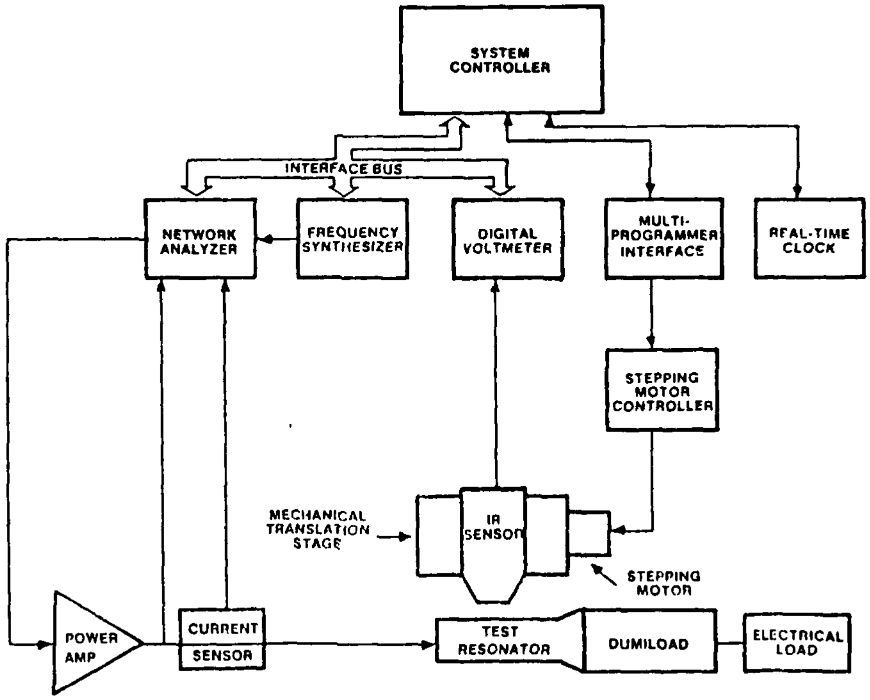


Fig. 13.4 - Test setup for infrared measurements

A nonlinear theory for ferroelectrics has been developed by Dr. Chen of Sandia Laboratories, NM. He has used his theory to accurately predict the hysteresis of ceramic pieces when cycled through a slowly varying electric field. The constants he uses for his theory are independent of frequency and the shape of the ceramic sample. His approach is being examined for possible application to the ceramic stack joint problem.

13.4 PLANS

Resonators will be constructed with various cement/electrode joint configurations for testing. Under consideration are cementless joints: soft copper, grease, and dry; various electrodes: grooved, and etched; and various cement thicknesses (controlled by the amount of prestress during curing).

Parametric variation studies will be conducted on the TR-316 computer model to determine the sensitivities and effects of ceramic and cement/electrode joint parameters. With experimental results of impedance vs frequency measurements, the model will also be used to estimate cement/electrode joint parameters, and perhaps ceramic parameters, vs temperature.

The evaluation of the applicability of Dr. Chen's theory and experimental techniques will be pursued. Also, in conjunction with a separate task, the investigation of cement/electrode joint measurement techniques will continue with the final goal ~~in mind~~ of obtaining measurements as a function of temperature.

The development of the infrared test setup and controlling software will begin in early April 1981. Temperature measurements of a dumiloaded TR-316 resonator under high drive will be taken for steady-state and initial transient conditions.

A major goal is to apply the ceramic, cement/electrode joint, and temperature measurements to the TR-316 model in order to provide understanding of the temperature effects on ceramic stack joints.

14. TASK F-5 - ENGINEERING ANALYSIS: METAL MATRIX COMPOSITES

O.L. Ackervold - Honeywell, Inc.

14.1. BACKGROUND

The main reason for considering metal matrix composites is to increase the bandwidth of the transducer. The bandwidth of the transducer is inversely related to the total energy stored in the vibrating system. If the stored energy is reduced in relation to the energy dissipated per cycle then the bandwidth will be increased. There is energy stored in the head, the ceramic, the tail, and some in the acoustic field. Of these, the head is unique because its velocity is the same velocity that flows into the load. So, in addition to the head being located where the velocity is maximum, that velocity cannot be reduced without reducing the energy radiated. Therefore the only way to minimize its stored energy is to reduce its mass. This mass reduction is what the metal matrix composite material is expected to provide.

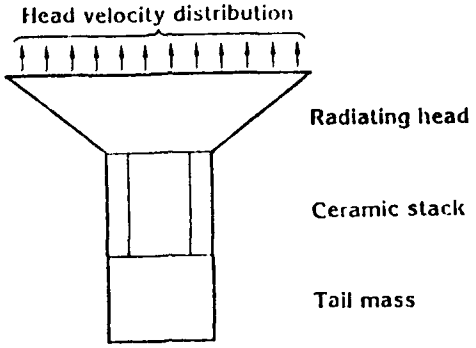
14.2. OBJECTIVE

The objective is to quantitatively compare and experimentally demonstrate the performance improvement possible with metal matrix composite materials for the head of longitudinal vibrator elements.

14.3. PROGRESS

This is a new task in FY81. Achievement of the lowest possible mechanical Q in vibrator elements has always been limited by the mass required to be in the head to accomplish the desired radiating area and make the head stiff enough to vibrate with a nearly uniform velocity distribution. It appears that significant gains might be made in this area by using metal matrix composite materials with either aluminum or magnesium as a base. The composites are lighter and have a much higher elastic modulus so smaller, lighter heads should result. The approach for the head evaluation is to model the head vibration modes using a finite element computer program to define the head flexual resonance frequency and the head velocity distribution for different head configurations and materials. The head velocity distribution will be defined at flexual resonance and at frequencies below resonance to determine where the velocity becomes reasonably uniform. The performance of both standard and metal matrix composites will be calculated and compared. These results will allow selection of minimum thickness (and hence mass and Q_m) head which produces the desired uniformity of head motion. For given degrees of uniformity, comparison can be made of the mass between heads of different materials, standard or composite. The second part of this study is to select representative samples of standard and composite head configurations and build sample heads and measure their masses and head velocity distributions. Head velocity will be measured by noncontact optical methods (a Fotonic Sensor). Comparison and correlations with the finite element computer calculations will be made.

Figure 14.1 shows a typical longitudinal vibrator and indicates the constraints imposed on the head. The function of the head is to couple the front of the ceramic stack to the radiation load. This provides an impedance matching, via a ceramic-to-load area ratio, from the high impedance ceramic to the low impedance radiation load. For maximum power transfer and other reasons it is usually desired to keep the head velocity distribution quite uniform. This requires a head which has minimum change of shape under vibration. This is normally accomplished by increasing the head thickness until it is "stiff enough." The problem stems from the fact that when the head is "stiff enough" the head mass is usually greater than desired.



- ■ Design constraints on head
  - Couple ceramic area to radiating area
  - Be stiff to provide a sufficiently uniform velocity distribution
  - Be light for minimum contribution to stored energy which controls Qm and bandwidth

Fig. 14.1 - Operational requirements of the head

The metal matrix material planned for study is the SiC particulate aluminum. The particulate material has isotropic properties and is potentially easier to produce than the filament type composite. Table 14.1 shows the parameters of conventional and SiC particulate aluminum and magnesium. This shows the 2.5 times increase in elastic modulus achieved by a 40 to 45 volume percent addition of SiC. Titanium and alumina ceramic are shown for comparison. The high modulus and moderate density of silicon carbide show why its addition can increase the modulus without significantly increasing the desnity when it is used as an additive. The "specific stiffness" is also shown. This parameter is often used for material comparison but its applicability to the dynamic case under consideration is uncertain. The table shows alumina ceramic to have the highest specific stiffness, but it is expensive and brittle. The improvement in specific stiffness produced by adding the silicon carbide is evident. The aluminum composite produces a slightly higher specific stiffness than does the magnesium composite.

Table 14.1 - Advantages of metal matrix material

Material	Elastic Modulus	Density	Specific Stiffness (E/ρ)
Units Mult by	Pa 10^{10}	Kg/m^3 —	M^2/sec^2 10^6
• Aluminum	6.9	2712	25.4
• SiC particulate/aluminum	17.25	2800	61.6
• Magnesium	4.5	1827	24.6
• SiC particulate/magnesium	10.4	1900	54.7
• Titanium	12.7	5065	25.1
• Alumina ceramic	34.5	3875	89.0
• Silicon carbide	65.5	3210	204.0

14.4. PLANS

- Design and math model transducer elements.
- Fabricate test elements.
- Perform testing.
- Analyze and evaluate results; prepare final report.

15. TASK F-6 - IMPROVED HYDROPHONE ANALYSIS

M.P. Canty - NWSC

15.1. BACKGROUND

It has been found that the DT-276 hydrophone is not the perfect sensor to be used with BQQ-5 and BQR-7 sonar systems. If a hydrophone could be developed that meets all the system requirements of the BQQ-5 and BQR-7, eliminates the DT-276 shortcomings, and adds findings from STRIP, it will be the optimum replacement sensor for the DT-276 hydrophone.

15.2. OBJECTIVE

The objective is to provide the engineering analysis and development of an improved, more reliable hydrophone for use in sonar systems such as the BQQ-5 and BQR-7.

15.3. PROGRESS

This is a new task for FY81. The DT-276 which has been used for the conformal hull mounted sensor on the AN/BQQ-5 and AN/BQR-7 sonar systems has not proven reliable relative to the system requirements. Several candidate replacement sensors appear to offer significant improvement over the DT-276. Thus, the purpose of this study is to compare the system sensor requirements to the characteristics of candidate replacement sensors. In addition, sensor design changes which would enhance sonar system performance shall also be identified.

A contract has been awarded to TRACOR to review the requirements for sensors in the submarine sonar systems which presently utilize the DT-276 hydrophone. Candidate replacement hydrophones shall be evaluated to determine conformance to the system requirements.

TRACOR will review and document the existing front-end requirements for the following submarine sonar systems: AN/BQQ-5, AN/BQR-7, and ISPE replacement. Using the resultant data, TRACOR shall investigate existing hydrophone and transducer capabilities for potential candidates to replace the existing DT-276 hydrophone. Possible areas of investigation include recommended design changes and/or performance requirements for the hydrophone including possible incorporation of a preamplifier, improved vibration isolation and perhaps horizontal directivity - all aimed at improving signal-to-noise ratio of the system and increasing the operating frequency band for the system. A report will be prepared describing the AN/BQQ-5, AN/BQR-7, and ISPE replacement system requirements, identifying possible candidate replacements, and providing recommended alternatives for the DT-276 hydrophone. This task is expected to be completed during the fourth quarter of FY81.

15.4. PLANS

- Continue with the engineering analysis of the requirements of the BQQ-5 and BQR-7 systems from the view of the transducer detection requirements.
- Compare CUALT on DT-276 hydrophones with a failure analysis of those returned from the fleet to uncover problem areas.
- Determine alternate design approaches such as integral vs in-board preamps; balanced vs unbalanced preamps; quick connect/disconnect vs a fixed cable; butyl vs neoprene boots; a butyl, unshielded cable vs the present DSS-3 cable; and other considerations such as improved back-baffling and even direct substitution of the DT-513 with modified mounting.

16. TASK F-7 - ENGINEERING DOCUMENTATION

R.W. Timme - NRL-USRD

16.1. BACKGROUND

Each of the other program tasks is expected to be fully documented as an essential part of that particular task. This task will provide an overview. It will link together the various tasks. It will insure that the failures as well as the successes will be discussed. The aim is to help avoid the continued "reinvention-of-the-wheel." All too often in the past, developments and redesigns that have resulted in successful hardware have not been documented in terms of why certain materials and/or construction details are chosen over others. Later, the same decisions must be remade. Based on the results of this program, consideration will be given to procurement via construction specifications rather than performance specifications. The approach here will be to determine and document the proper RDT&E of transducers and hydrophones as required for future acquisition.

16.2. OBJECTIVE

The objective of this task is to provide direction and documentation of the technology of transducer design and engineering that results from this program.

16.3. PROGRESS

The STRIP will be reorganized for the coming fiscal year for several reasons. There has been a certain awkwardness with the present organization in that new work units did not fit well, certain areas were ignored, management could not be expanded, and the important link to the user was weak. In addition, the existance of a separate STEN program, which was a spin-off from STRIP, gave the appearance of too many unrelated transducer R&D programs. Furthermore, there has been a significant change in the government's acquisition strategy which must be supported. A decision has been made to acquire transducers by design specification rather than performance specification. There are many arguments for each procurement strategy and it is inappropriate to argue them here. Given the decision - what should STRIP address? The key is to have confidence that the design specification is accurate and complete. From knowledge of when new or improved transducers are needed, it is necessary to plan through time so that the various R&D efforts are completed and put into a design package that is exercised in a sample buy, which is evaluated and proven before going into production.

To support this acquisition strategy the STRIP must be a technology base which is not too different from what we have been doing previously in STRIP, STEN, and the TR-155F investigation. We can list out subjects affecting transducers that we need to know more about, especially in terms of specifications, as shown in Table 16.1. This is not an exhaustive list;

it is not necessarily in priority although those near the top are usually viewed as most important. All of these topics can be placed into the program organization shown in Table 16.2 which eliminates many of the concerns about the previous STRIP and STEN.

Table 16.1 - Purpose of STRIP

To provide the technological base necessary to ensure complete and accurate design specifications, R&D is required in the following areas
Elastomers
Transducer noise
Accelerated life testing
Corona control
Ceramics
Diagnostic procedures
Lifetime prediction capabilities
Failure modes analysis
Encapsulants
Adhesives
Component assembly
Cables
Connectors
Alternative materials
Compatibility of components
New design concepts

Table 16.2 - New organization of the
Sonar Transducer Reliability
Improvement Program

I. TRANSDUCER PROBLEM DEFINITIONS
  a. Baseline definitions
  b. Failure modes definitions

II. TRANSDUCER DESIGN IMPROVMENTS
  a. Materials development
  b. Component development
  c. Engineering analysis

III. PERFORMANCE AND LIFETIME EVALUATION METHODS
  a. Environmental test methods
  b. Noise measurement technology

IV. TRANSDUCER ENGINEERING DEVELOPMENT
  a. BQS-8/10/14/20
  b. SQS-56
  c. BQR-7, BQQ-5
  d. WQC-2
  e. Spherical array
  f. SQS-53

There are four major task areas, each one of which has several project areas and, in turn, each one of which will contain several specific work units that will change each year in response to milestones established by the acquisition requirements.

- The Baseline Definitions project area will have the following objective:

  To gather, organize, and correlate information from all sources, especially the fleet, pertaining to transducer operations, practices, types of failure, environmental history, maintenance, extraneous noise, and impact of such noise for the purpose of defining a baseline of failure and acceptable performance from which improvements can be guided.

  Deliverables will be definition and specification of extraneous noise threat, determination of noise correlation functions, data base for cause-effect correlations, reliability and life prediction models, reliability specifications for transducer procurements, quality control guidelines, and guidance for design improvements and the development of each new transducer type.

- The Failure Modes Definitions project area will have the following objective:

  To analyze and characterize transducer failure modes, mechanisms and dynamics of failures for the purpose of providing direction to the R&D needed for improved transducers.

  Deliverables will be reports of problem materials needing correction, reports of faulty design, goals for materials and design development, values of hazard rates as a function of time for lifetime determination, and guides to acceptable tolerances in designs and materials.

- The Materials Development project area will have the following objective:

  To develop and characterize materials so that more nearly optimum and reproducible selections can be made and to provide the proper specifications of compositions, processing, and quality control procedures for the applications of the materials, design and production of improved transducer developments.

  Deliverables will be specifications for neoprene, butyl, and nitrile rubber, encapsulants, and piezoelectric ceramics and the complete characterization of alternative materials such as plastics and composites for incorporation into the improved transducer design specifications. Deliverables will be directly linked to the development of the designs of new fleet transducers.

- The Component Development project area will have the following objective:

  To evaluate transducer designs, materials, components, and piece-parts, including cables and connectors, proposed for use in new or improved transducers, to provide quantitative alternatives with respect to reliability, ease of manufacture, ease of quality control, availability of materials and imminent failure, and incorrect assembly.

Deliverables will be reports of corona control materials and design procedures, specifications of high voltages and tolerances, specifications for improved cables and connectors, proven design, and diagnostic test procedures and standards for transducer assembly for application to the improved fleet transducers.

- The Engineering Analysis project area will have the following objective:

  To develop and utilize math models to predict transducer operation, to make quantitative comparisons between predictions and evaluation results to understand and solve unexpected results, to provide guidance to R&D in materials, components, and noise, to provide contingency capability for coping with future problem areas and to provide engineering documentation interfacing the systems applications and R&D efforts.

  Deliverables will be engineering reports on design specifications and performance of improved fleet transducers and documentation of the entire program.

- The two project areas in the third task area will have the following objectives:

  To develop, test and evaluate, and verify the concept of composite unit accelerated life tests (CUALT), other environmental test methods, the characterization of extraneous noise signals, the definition of required measurement methods, and the development, fabrication, and evaluation of T&E facilities, all to provide the capability of determining the lifetime operational characteristics of transducers.

  Deliverables will be CUALT and extraneous noise test procedures and the accompanying test and evaluation facilities.

- The fourth major task area is the link between the R&D and the transducer acquisition programs. This is the area in which the STRIP has been greatly strengthened and where the move toward design specifications will culminate. The objectives will be:

  To implement the materials development, component development, engineering analysis, and the performance evaluation methods into the design and construction of fleet transducers, to proof the preliminary designs by performing CUALT, extraneous noise, and other T&E procedures, to provide feedback to other R&D phases, and to prepare final design specifications which will be used in the fleet transducer acquisitions.

Deliverables will be final and complete design specifications for the DT-605, TR-316, SQS-56( ), TR-232( ), spherical array, and SQS-53( ) transducers.

The program as outlined is in a period of growth. This is a program that is scheduled through the decade of the 80's and involves tens of millions of dollars. To be successful it must have the participation of Navy laboratories and contractors and it must have the commitment of participants to the goal of complete design specifications.

16.4. PLANS

- Progress report on the entire program.
- Program Plan for FY82.

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College Point, NY 11356
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S. Schildkraut

Edo Western Corporation
2645 South 300 West
Salt Lake City, UT 84115
ATTN: D. Bonnema
G.L. Snow

EMI (Australia) PTY Ltd
P.O. Box 161
Elizabeth, S.A. Australia
ATTN: J. Nankivell

General Electric
P.O. Box 4840
Syracuse, NY 13221
ATTN: J. Dietz

General Dynamics
Electric Boat Division
Groton, CT 06340
ATTN: E.C. Hobaica
R.F. Haworth

General Instrument Corporation
Government Systems Division
33 Southwest Industrial Park
Westwood, MA 02090
ATTN: D. White
A. Poturnicki

Gould, Inc.
Ocean Systems Division
18901 Euclid Avenue
Cleveland, OH 44117
ATTN: M.R. Collins
S. Thompson
A. Irons
J. Gray

Hazeltine Corporation
115 Baystate Drive
Braintree, MA 02184
ATTN: G.W. Renner

Honeywell, Inc.
Marine Systems Center
5303 Shilshole Avenue, NW
Seattle, WA 98107
ATTN: C. Sheets
O.L. Ackervold

Honeywell, Inc.
Honeywell Ceramics Center
5121 Winnetka Avenue N
New Hope, MN 55428
ATTN: D.W. Bacso

International Transducer Corporation
640 McCloskey Place
Goleta, CA 93017
ATTN: G.E. Liddiard

Magnavox Co.
1313 Production Road
Ft Wayne, IN 46808
ATTN: D. Kulpa

MAR, Inc.
1335 Rockville Pike
Rockville, MD 20852
ATTN: Dr. W. Cramer

Materials Research Laboratory
P.O. Box 50
Ascot Vale, Victoria, Australia
ATTN: Dr. D. Oldfield

Plessey Company Limited
Plessey Marine Research Unit
Templecombe, Somerset, England
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Plessey (Australia) PTY Ltd
Faraday Park Road
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Potomac Research
1600 N. Beauregard Street
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Raytheon Co.
Submarine Signal Division
P.O. Box 360
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Sperry Rand Corporation
Sperry Gyroscope Division
Marcus Avenue
Great Neck, NY 11020
ATTN: M/S D-18, G. Rand

Texas Research Institute, Inc.
5902 West Bee Caves Road
Austin, TX 78746
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TRACOR, Inc.
Systems Technology Division
1601 Research Blvd
Rockville, MD 20850
ATTN: P.D. Flannery
J. Guarnieri
J.W. McClung
D. Abraham

TRW, Inc.
One Space Park
Redondo Beach, CA 90278
ATTN: A. Samsonov, Head, Engr
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TRW, Inc.
7600 Colshire Drive
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Underwater Systems Acoustics
2627 Burgener Blvd
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Westinghouse Electric Corporation
P.O. Box 1488
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Electromagnetic Capability Division
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Defense Equipment Center
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8