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SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM (STRIP) FY82.(U)

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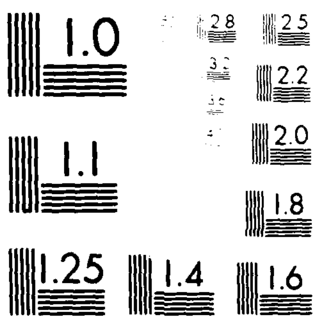

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The Sonar Transducer Reliability Improvement Program (STRIP) is sponsored by Naval Sea Systems Command (SEA63X5).

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

Transducers	Connectors	Environmental tests	Shielding
Corona	Noise & vibration	Plastics	Rubbers
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)

Progress was extremely limited in the second quarter of FY82 because of the delay in funding which resulted from the very late approval of a national budget. However, there was significant progress in several of the work units as summarized below:

- A preliminary specification for a Navy-formulated neoprene rubber has been developed and is being exercised on SQS-56 transducers.

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- Electrical resistivity in neoprene rubber has been quantitatively linked to carbon black content.

- The dependence of the corona inception voltage upon electrode dimensions, gas gap dimensions within the transducer, and gas type and pressure is reported.

- The instruction entitled "O-ring Installation for Underwater Components and Applications," by C.J. Sandwith, has been published as NRL Memorandum Report 4809.

- A report entitled "A Generalized Handbook Reliability Description of the DT-513A Preamplifier," by R.L. Smith, has been issued as Texas Research Institute Report No. 8185.

CONTENTS

SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM
FY82 SECOND QUARTER PROGRESS REPORT

1. INTRODUCTION

1.1. Program Overview

The primary purpose of this program is to develop Critical Item Product Fabrication Specifications to support the acquisition of reliable, cost-effective fleet sonar transducers. This program will provide the technology base for the development of overall transducer design specifications through: the definition of extraneous noise criteria, the definition of reliability and life prediction models, the analysis of failure modes, the collection of a statistical data base, the characterization and specification of materials, the development and application of new design concept and diagnostic procedures, and the development/application of methods and facilities for accelerated life testing and extraneous noise T&E measurements.

The output of this program will consist of the specifications, standards, and formal documentation for the materials, components, and processes necessary for the design, test evaluation, and ultimate procurement of reliable fleet transducers. These deliverables will define the required chemical composition and mechanical properties of materials, interpret gathered reliability data to define failure rates and mechanisms, define assembly, quality control, and diagnostic procedures, and define the required methods for the performance and lifetime evaluation of transducers.

The program is organized into four major Task Areas, each of which contains 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 organizational structure is shown in Fig. 1.1.

The FY82 Program Plan for STRIP has been described in detail in Appendix A of NRL Memorandum Report 4615 [1]. The specific work units and their principal investigators for FY82 are given in Table 1.1.

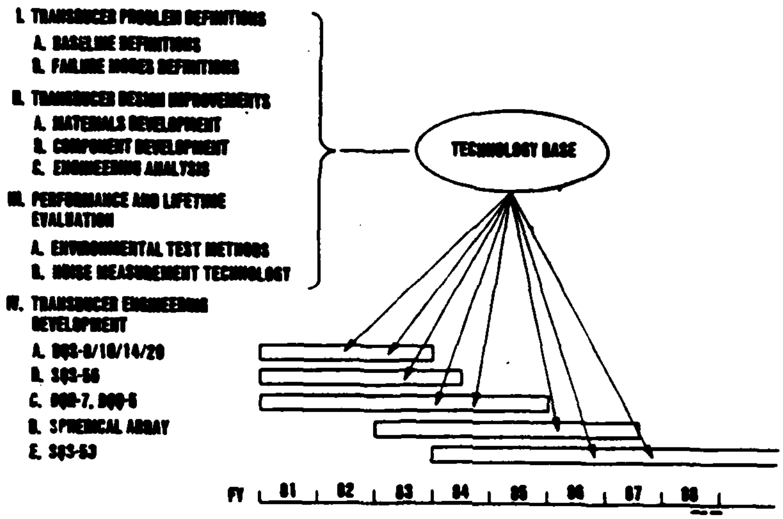

Fig. 1.1 - Sonar Transducer Reliability Improvement Program

Table 1.1 - STRIP FY82 Work Effort

WORK UNITS		PRINCIPAL INVESTIGATORS	
I.A.1	Noise Criteria and Standards	NOSC	C.I. Bohman
I.A.2.	Identification of Noise Characteristics	NWSC	T.J. Laughlin
I.A.3.	Noise Data Analysis and Acquisition	DTNSRDC	G.M. Jebsen
I.A.4.	Lifetime Reliability Definitions	TRI	R.L. Smith
I.B.1.	Failure Modes from Water and CUALT Analysis	TRI	D.D. Barrett
II.A.1.	Transducer Elastomers	NRL	C.M. Thompson
II.A.2.	Transducer Ceramics	NRL	A.C. Tims
II.A.3.	Alternative Materials	NRL	R.Y. Ting
II.B.1.	Unshielded Cables	Georgia Tech	H.W. Denny
II.B.2.	Cable Splices	TRI	D.E. Glowe
II.B.3.	Corona Control	NRL	L.P. Browder
II.B.4.	Ceramic Stack Joints	NOSC	J.C. Lockwood
II.B.5.	Acoustic Emission Applications	NUSC	T.J. Mapes
II.C.1.	Engineering Analysis	NRL	R.W. Timme
III.A.1.	Composite Unit Accelerated Life Testing	NOSC	J. Wong
III.B.1.	Measurement Methodology	NRL	A.L. Van Buren
III.B.2.	Experimental Measurement Correlation	NOSC	C.I. Bohman
III.B.3.	Measurement Correlation Models	BBN	N.C. Martin
IV.A.1.	TR316/DT605 Product Fabrication Specification	NOSC	D.L. Carson
IV.B.1.	SQS-56 Product Fabrication Specification	NOSC	D.L. Carson
IV.C.1.	DT-276( ) Product Fabrication Specification	NWSC	J.A. Parks

1.2. Summary

Progress was extremely limited in the second quarter of FY82 because of the delay in funding which resulted from the very late approval of a national budget. However, there was significant progress in several of the work units as summarized below:

- A preliminary specification for a Navy-formulated neoprene rubber has been developed and is being exercised on SQS-56 transducers. See Section 5.

- Electrical resistivity in neoprene rubber has been quantitatively linked to carbon black content. See Section 5.

- The dependence of the corona inception voltage upon electrode dimensions, gas gap dimensions within the transducer, and gas type and pressure is reported. See Section 9.

- The instruction entitled "O-ring Installation for Underwater Components and Applications," by C.J. Sandwith, has been published as NRL Memorandum Report 4809.

- A report entitled "A Generalized Handbook Reliability Description of the DT-513A Preamplifier," by R.L. Smith, has been issued as Texas Research Institute Report No. 8185.

1.3. PLANS

The primary problem at the moment is restarting the various work units of the program and meshing together the various cooperative efforts in accordance with the previously published program plan. Additional travel restrictions on Navy laboratory personnel make it unlikely there will be an Annual Reveiw of the program this year.

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.

1.5. REFERENCE

1. R.W. Timme, "Sonar Transducer Reliability Improvement Program (STRIP) FY81 Fourth Quarter Progress," NRL Memorandum Report 4615, Oct 1981.

2. WORK UNIT I.A.1. NOISE CRITERIA AND STANDARDS

C.I. Bohman - NOSC

2.1. BACKGROUND

Most transducers generate some noise when undergoing hydrostatic pressure changes. While this self-noise may or may not degrade sonar performance or contribute to its detectability by other platforms, it has caused sufficient concern that many transducers are now required to pass self-noise tests before being accepted by the Navy. Most of the standards for transducer noise developed thus far have been in response to a particular need and specific transducers and are, therefore, not applicable in a general sense to all types of transducers. There is a need to develop standards and criteria for transducer self-noise in terms of allowable far-field radiated acoustic levels, near-field acoustic interference, and electrical feedback, which will be applicable to all of the major transducers.

2.2. OBJECTIVES

The objectives of this task are to identify and quantify sonar system(s) parameters and acoustic radiation criteria which will define the threshold at which hydrostatically induced transducer noise constitutes a threat by detection or degraded system performance.

2.3. PROGRESS

During the first quarter of FY82 presentations were given at the Naval Underwater Systems Center (NUSC) and at the David W. Taylor Naval Ship Research & Development Center (DTNSRDC) to generate discussion and solicit comments on the rough draft report "Development of a Detection Criterion for Transducer Extraneous Noise," which is soon to be published. This report was originally scheduled for publication during the first quarter, but has been delayed because of the late receipt of funding (Mar 82).

Generally, the report and the presentations have been well received. The main response has been a concern on how to relate the "idealized" criterion with the practical testing of transducers in pressure tanks. While there seems to be no simple solution, the problem of relating measurements of transducer noise in tanks to measurements of transducer noise in-situ is a common concern for both peak pressure and energy methods of detection. The problem is the subject of several tasks in the FY82 STRIP.

A meeting was held with Dr. Don Johnson of Rice University to discuss the problem of detecting transducer radiated noise by coherent detection methods. He has developed an algorithm under contract with the Naval Ocean Systems Center (NOSC) for the purpose of addressing the coherent detection problem. This algorithm has not been fully tested and may be changed as data is analyzed. Therefore, it is not appropriate to describe it at this time.

Dr. Johnson has also been furnished with samples of actual transducer noise to be tested against his algorithm. Additional samples will be sent to him in the form of digital tape recordings as soon as more data becomes available through DTNSRDC and NUSC.

The current funding for Rice University will expire in June 1982. A new tasking statement will be written with additional funding to support efforts through Jun 1983.

2.4. PLANS

- Final editing will be completed on the report "Development of a Detection Criterion for Transducer Extraneous Noise" and the report will be sent to the publishers.
- Data from DTNSRDC will be digitized and analyzed.
- A meeting will be held with other principal investigators who are working with related transducer extraneous noise tasks. The overall investigation along with specific data requirements will be discussed.

3. WORK UNIT I.A.2 IDENTIFICATION OF NOISE CHARACTERISTICS

T.J. Laughlin - NWSC

3.1. BACKGROUND

The establishment of performance standards implies the ability to make test and evaluation measurements to those standards. Before such measurements can be made, however, the quantities to be measured and the measurement methodology must be defined. Past experience with selected transducers has revealed noise characteristics associated with certain mechanisms used in transducers. However, there has been little or no experience with other types of fleet transducers and the type of signals likely to be emitted. The need exists to determine the type(s) of signal characteristics likely to be emitted from various types of fleet transducers as they are subjected to varying hydrostatic pressure.

3.2. OBJECTIVES

The objectives of this task are to gather initial data for the determination of emitted extraneous noise from submarine sonar transducers, hydrophones, and transducer materials, and to characterize any such emissions for further analysis.

3.3. PROGRESS

The compilation of a prioritized list of transducers, hydrophones, and transducer materials (and the evaluation of listed items with respect to emitted extraneous noise) will remain as a continuation of work begun in FY81. The listed items will undergo cyclic changes in hydrostatic pressure at the Sonar Extraneous Noise Facility at the Naval Weapons Support Center and will be instrumented with additional sensors and measurement equipment if emissions are detected. Any detected noise emissions will be analyzed and described by the techniques developed in FY81. Information obtained during analysis will be cataloged (in a standard format agreed upon in cooperation with other STRIP principal investigators) and stored on magnetic tape for future use.

In the past, completion of some tasks has been delayed because the existing noise facilities were unavailable due to production and first-article test schedules. During FY82, separate pressure vessels will be installed for R&D use. One large vessel (2 m in internal length × 0.68 m in inside diameter) and two or three (depending upon availability) small vessels of the same type presently used in the Sonar Extraneous Noise Facility will be utilized. Although these R&D pressure vessels will share some operating equipment and instrumentation with the production test facility, they can be operated independently and will not interfere with ongoing production work.

Although funding for this work unit was not received until March 1982, some progress has been made. Preliminary computer programs for controlling the six-channel system for digitizing measured noise events have been written and are presently being debugged. The testing of items from the prioritized list resumed at the end of the second quarter and any pertinent noise data collected during ongoing production work will be duplicated for the STRIP noise file.

3.4. PLANS

Plans for the remainder of this fiscal year include:

- 3rd Quarter: In cooperation with other STRIP noise task principal investigators, develop the preliminary concepts and format for cataloging noise data. Continue evaluation of listed transducers and hydrophones.

- 4th Quarter: Finalize data cataloging format and implement the hardware for utilization of the selected format. Small R&D pressure vessels available for use. Report on the evaluation of listed items tested during FY82.

4. WORK UNIT I.A.3 NOISE DATA ANALYSIS AND ACQUISITION

G.M. Jebsen - DTNSRDC

4.1. BACKGROUND

In order to resolve the transducer extraneous noise problem, access to operational platforms and systems is required to experimentally verify laboratory methods and proposed solutions.

The Ship Acoustic Department at the David W. Taylor Naval Ship Research & Development Center (DTNSRDC) has a large submarine acoustic data base, acquired both through the full-scale NAVSEA acoustic trials program and through special systems trials such as those conducted under the TUBA program. This accessibility to submarines, and familiarity with acoustic data collection procedures, will result in the most efficient determination of future data acquisition methods for operational evaluation of the transducer extraneous noise problem.

The Sonar Systems Interface Division (also at DTNSRDC) currently possesses, and utilizes for various purposes, substantial data processing and signal analysis capabilities. These capabilities can be employed for detailed acoustic analysis of presently available (and also future) data in order to characterize transducer noise emissions.

4.2. OBJECTIVES

The objectives of this task are:

- Conduct a review and analysis of at-sea data available at DTNSRDC.
- Identify subsequent data acquistion and analysis needs, the determination of optimum measurement methods and data format, the design of at-sea experiments, and the collection of at-sea data during scheduled full-scale acoustic trials.

4.3. PROGRESS

Both of the original first-quarter milestones have been met: (1) existing DTNSRDC data has been reviewed and (2) two tapes of at-sea transducer noise data have been forwarded to the Naval Ocean Systems Center (NOSC) (Work Unit III.B.2) together with supporting information.

The data review has encompassed all NAVSEA acoustical trials from 1975 to 1981, on 594-, 637-, and 688-class submarines. The data are self-noise (near-field) data.

The data tapes forwarded to NOSC include approximately 10 minutes each of near-field transducer noise.

The analysis of existing data is at present well underway. Examples of transducers popping are processed to provide signal waveform plots and estimates of characteristic parameters, i.e., sound pressure level, duration, spectral energy content, time-envelope spectra, and total transient energy.

4.4. PLANS

Based upon the results of the review of existing data, additional data requirements will be identified and methods for additional data acquisition will be defined and proposed. This may include the design of specific experiments to acquire transducer extraneous noise data, as well as the determination of methods to gather the data concurrently with DTNSRDC standard submarine acoustic trials and special systems trials. DTNSRDC will function as the clearing house for STRIP investigators who require full-scale acoustic measurements, integrating these data needs with current data collection methods. Any at-sea experiments and data formatting will be planned in cooperation with other STRIP principal investigators whose tasks share an interest in such data. In particular, DTNSRDC will interact with the Naval Weapons Support Center (NWSC)(Work Unit I.A.2) to investigate the possibility of a standard format for at-sea/in-tank data.

5. WORK UNIT II.A.1 TRANSDUCER ELASTOMERS

R.Y. Ting and C.M. Thompson - NRL-USRD

5.1. BACKGROUND

A major concern for fleet transducer reliability is in the area of elastomers because transducer elastomers have been identified as the source of a large portion of reported failures. Many reasons contribute to elastomer failure, including: (1) the severe stresses imposed by environment, (2) designer's application of proprietary formulation, and (3) the lack of meaningful quality control in the procurement cycle. Basically, the presently used materials were developed without property optimization for short-term operation and with little consideration for long-term performance requirements. Furthermore, a rubber material was usually selected without sufficient property characterization, and a user can never be sure of its reproducibility. Therefore, it is necessary to take an alternative but more fundamental approach to the elastomer problem. First, necessary research is being carried out such that the performance of transducer elastomers, both initial and long-term properties, is well understood as functions of elastomer composition, cure conditions, and environmental parameters. An optimized rubber formulation can then be designed and quality control techniques also developed to guarantee the reproducibility of the produced elastomers. Then, specifications can be carefully prepared to ensure that the elastomers have the proper composition and are correctly processed so the users may be assured of the reproducibility and the performance of the elastomers in transducers.

The effort of this work unit is coordinated closely with that under the Sonar Transduction Sciences Program (STSP). Compositional analysis techniques and property correlations are being developed with the funding support from STSP at 6.2 level. This STRIP work unit, on the other hand, concentrates on the analysis of engineering properties and the development of materials design specifications for transducer elastomers. Both efforts will support the ultimate STRIP goal of developing Critical Item Product Fabrication Specifications for the acquisition of reliable, cost-effective fleet sonar transducers.

5.2. OBJECTIVE

The objective of this task is to establish elastomer design specifications to enable the Navy sonar community to acquire optimized, reproducible elastomers.

5.3. PROGRESS

5.3.1. Neoprene 5109 Specification

The first draft of a design specification for Neoprene 5109 has been prepared and is currently under review. Previous research results for this neoprene formulation developed under the STSP were used to specify the rubber composition and the instrumental techniques and procedures for compositional analysis. Analytical requirements and allowable limits for composition variation are also established. The specification includes the detailed procedures for material processing and vulcanization such as polymer mastication, compounding, mixing, forming, and storage. Sampling requirements for quality control tests are also given. It is expected that the review cycle will be completed by the end of the third quarter of FY82. Revision will then take place for the final publication of this design specification.

5 .3.2. Electrical Resistivity

A drastic decrease in electrical resistivity in the neoprene rubber used in many transducers after seawater exposure has been linked to the failure of these transducers. Work on the effects of compositional changes on the electrical resistivity is therefore continuing. Emphasis during this reporting period has been on the establishment of the relationships between the concentration and type of carbon black fillers and the electrical resistivity of neoprene samples. Both volume and surface resistivities were measured by using a standard HP 16008A Resistivity Cell. Improvements made in cell grounding and meter calibration have greatly enhanced the accuracy and precision of the measurements with improved results over the data reported earlier [1]. Standard deviations of 5% relative are now routinely possible, as opposed to 25% relative achieved previously.

Figure 5.1 shows both the volume and surface resistivities of neoprene GRT as a function of the concentration of FEF N550 carbon black. It can be seen that as the FEF black content exceeds 40 parts per hundred rubber (PHR) the resistivity decreases very rapidly. It therefore indicates a definite disadvantage of formulating the rubber in this region. Small errors by the manufacturer in either proportion or homogeneity — would cause a drastic change in resistivity. This idea was tested by determining the electrical resistivity on test samples of a rubber manufacturer's actual production runs of a GRT composition having a FEF concentration in the middle of the transition region. Variations from near 10^{11} Ω-cm all the way down to 10^{7} Ω-cm were observed.

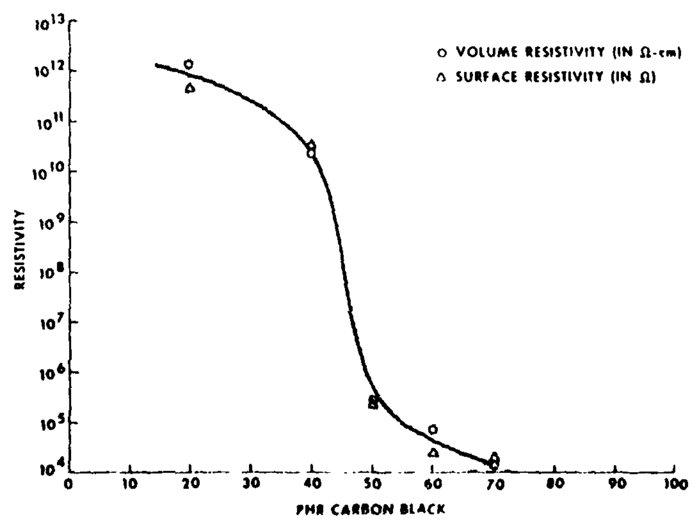

Fig. 5.1 - Resistivity of neoprene GRT with FEF N550 carbon black

The electrical resistivity for a Neoprene GRT loaded with an SRF black (N774) is given in Fig. 5.2. When compared with Fig. 5.1, it is noted that the region of rapid decrease in resistivity is seen to fall at a much higher carbon content for the SFR-filled neoprenes. Since electrical resistivity is so important, as the fleet experience now shows, a much greater margin for error may be possible with a black like SRF.

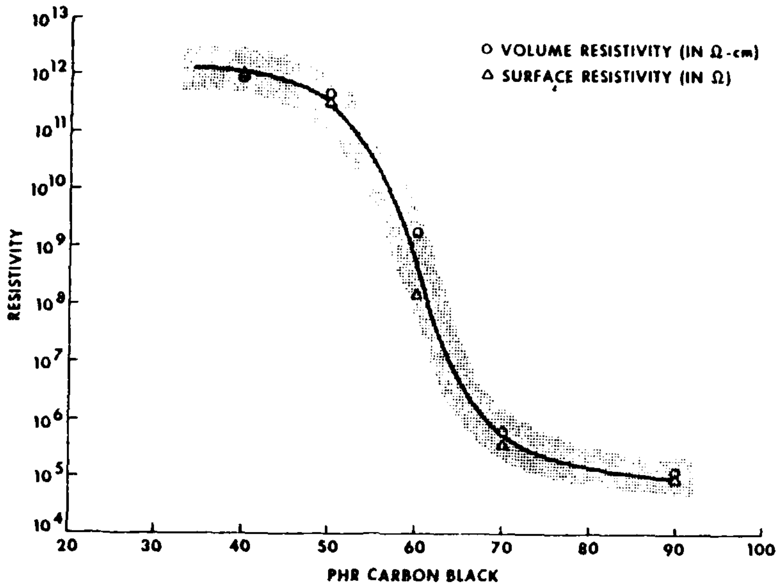

Fig. 5.2 - Resistivity of Neoprene GRT with SRF N774 carbon black

5.3.3. Water Permeability

Continuing research into the effects of compositional parameters on the water permeability of neoprene elastomers has yielded a number of important results. The permeation constant for a wide variety of Neoprene GRT materials has been determined to be 25 ng-cm/cm^2-hr-torr at 25°C, a value significantly lower than literature values for various other neoprene formulations. Both Pb_3O_4- and Z_nO/MgO-cured neoprene GRT give permeability constants of this magnitude. This seems to suggest that the permeability constants of neoprene rubbers are independent of the type of curing agent. However, the permeability constant does seem to be related to proportion of carbon black in the rubber. An increase from 40 PHR FEF black to 70 PHR FEF black causes the permeability constant to decrease from 27 to 17 ng cm/cm^2-hr-torr (at 25°C). An increase from 60 PHR SRF black to 90 PHR SRF black causes the permeability constant to decrease from 18 to 14 ng cm/cm^2-hr-torr.

The effect of temperature on the permeability constant of elastomers is of great importance because of the interest in the application of accelerated life testing for sonar transducers. Measurements have been performed on samples of lead oxide-cured neoprene GRT, zinc/magnesium oxide-cured neoprene GRT, and on each of these with silica as a replacement for part of the carbon black, all as functions of temperature. The Arrhenius activation energy in all cases was determined to fall between 18 and 25 Kjoules/mole.

5.3.4. Urethane Elastomer

In addition to conventional elastomers such as neoprenes, this work unit also examines the potential of using urethane elastomers for transducer encapsulation. Work is now underway in conjunction with Products Research and Chemicals Corporation to develop a non-proprietary polyurethane material that is suitable for general sonar transducer use in the Navy. The detailed requirements for such a material were given in Ref. 2. Briefly, the properties under consideration include the following:

- Chemical hazards to workers
- Pot life (application life)
- Mix viscosity
- Hardness
- Elastomer color and clarity
- Tear strength
- Tensile strength
- Ultimate elongation
- Volume electrical resistivity
- Surface electrical resistivity
- Electrical insulation resistance
- Density
- Sound speed
- Electrical power factor
- Moisture stability (gravimetric and hardness)
- Castor oil stability (gravemetric, hardness, and tensile modulus

A two-fold approach is taken for the testing under this task. Limited numbers of commerically available polyurethane prepolymers are investigated on the one hand, whereas some innovative prepolymer compounds are studied on the other.

A mixture of diol and diamine curing agents was first examined for their effects on the properties of resulting urethane compounds. These materials are intended as a non-hazardous replacement for methylene bis (orthochloroaniline) (MOCA). The ingredients in this mixture consist of

COMPONENT	SUPPLIER	PARTS BY WEIGHT (%)
2-ethyl-1,3-hexanediol	Union Carbide	14.70
N,N-(2-hydroxypropyl)aniline	Upjohn Co.	36.75
Amine Component	(See separate list)	22.05
N,N,N',N'-tetrakis-(2-hydroxypropyl)ethylenediamine	BASF Wyandotte	26.46
Ferric Acetonyl Acetonate	Harshaw Chemical	0.04
		100.00

Seven amine components were used to prepare castable urethane samples. Three commercially available urethane polymers were studied: Permapol U-84, U-55, and U-47, which represent 5%, 7.1%, and 8.8% available isocyanate polymer, respectively. The test results show that the 5% isocyanate polymer provides excellent low initial mixed viscosities, desirable long application lives, but unacceptably low hardnesses, tear strengths, tensile strengths, and ultimate elongations. The 8.8% isocyanate polymer is an overcorrection. Application lives are far too short, hardnesses too high, and ultimate elongations too low. On the other hand, the 7.1% isocyanate polymer approaches an acceptable balance between the above two extremes, yet application lives and ultimate elongations require improvement.

A series of Du Pont Adiprenes were prepared using these curatives. Based on the considerations of initial mix viscosity, application life and ultimate elongation, only three amine-based accelerators were selected for final reactions with the prepolymers. Sound speed measurements were carried out and the results are shown in Table 5.1.

Table 5.1 - Sound speeds of polyurethanes (m/s)

Amine / Prepolymer	Cyanacure	Polycure 1000	Permapol D-562
Adiprene L100	1599	1604	1605
Adiprene L167	1647	1659	1658
Adiprene L200	1714	1718	1730
Permapol U-47	1799	1801	1819

Seven of these samples exhibiting lower sound speeds will be used in compatibility and hydrolytic stability testings for the final selection of a transducer encapsulant.

A second area that has been investigated was the preparation of random copolymers of hydroxy-terminated polybutadiene (PBDOH) and polyethers such as polypropylene glycol (PPG) and polytetramethylene glycol (PTMG). These materials were selected because of the superior hydrolytic stability of the PBDOH-based polyurethanes and the good oil-compatibility of the PPG-based polyurethanes. Isocyanate termination has been achieved in these compounds by using both methylene bis (4-cyclohexyl isocyanate) and isophorone diisocyanate. The cured samples from these copolymers exhibited very low tensile strength and Shore A hardness. Future work will concentrate on property improvement by increasing isocyanate contents and modifying curatives.

5.3.5. Design Support for DT-276 and SQS-56

One of the tasks for this work unit in FY82 is to provide technical support of trouble-shooting on existing systems and design recommendations for upcoming new procurements of DT-276 and SQS-56 transducers. Considerable interactions have taken place between NAVSEA 63X51, NRL-USRD, DTNSRDC (Annapolis), and a previous DT-276 transducer manufacturer. The discussion has been centered upon the improvement of current performance specification for the rubber to be used and the selection of the neoprene elastomer formulation. Presently, the rubber specification contains 17 ASTM tests, one sound speed test, one rheometer test, and a void-free elastomer/ceramic bond requirement. The ASTM tests specified are for (1) density, (2) hardness, (3) tensile strength, (4) ultimate strength, (5) modulus, (6) tear, (7) compression set, (8) T-100 stiffness, (9) water absorption, (10) volume swell, (11) permeability, (12) volume resistivity, (13) dielectric constant, (14) dielectric strength, (15) ozone resistance, (16) cold compression set, and (17) heat aging. The validity of each required test was discussed. Since cold compression set is a very good measure of crystallization resistance, the latter, although initially included, was deleted from the specification. Proper values for each required test was also determined. The void-free adhesion requirement still lacks a proper test methodology for inspection. An autopsy sampling for each production lot of transducers was recommended for the time being. A lead-oxide cured neoprene formulation has also been recommended as a potential rubber candidate in order to minimize water permeation. Carbon black is included in this formulation as fillers instead of silica. Because of the rapid curing action of lead-oxide there was some concern about the applicability of this rubber if a transfer-molding operation is to be involved in the production. A possible remedy in that case would be to cut down the carbon black content for viscosity reduction. The resulting decrease in mechanical strength apparently can be tolerated for DT-276 transducers.

Discussions with NOSC (Work Unit IV.B.1) on the SQS-56 system have led to a laboratory trial of using Neoprene 5109 for molding a limited number of transducer units. Since it was a compressional molding process, no apparent difficulty has been encountered. The successfully assembled units will be tested for their acoustic performance and mechanical integrity. The usefulness of Neoprene 5109 for SQS-56 low temperature operation was questioned. Dynamic mechanical measurements were therefore carried out by using a resonant string instrument. The result is shown in Fig. 5.3, where the storage Young's modulus E' and mechanical loss tangent at 2 kHz are plotted as a function of test temperature. A glass transition temperature of -14°C was identified at that frequency. Based on the WLF superposition for linear viscoelasticity, the glass transition temperature is still considerably below 0°C at the operating frequency of SQS-56. This is a considerable improvement over the rubber material on current SQS-56 transducers, which, according to the manufacturer, has a glass transition at 24°C. This company has also evaluated a Neoprene 5109 sample and reported a glass transition of 3°C. The discrepancy with NRL-USRD results may be attributed to the fact that the company used a Rheovibron apparatus at 3 to 110 Hz and extrapolated the data to the acoustic frequency range. Nearly two decades of extrapolation outside the frequency range where test data were obtained is not acceptable and could have contributed some errors.

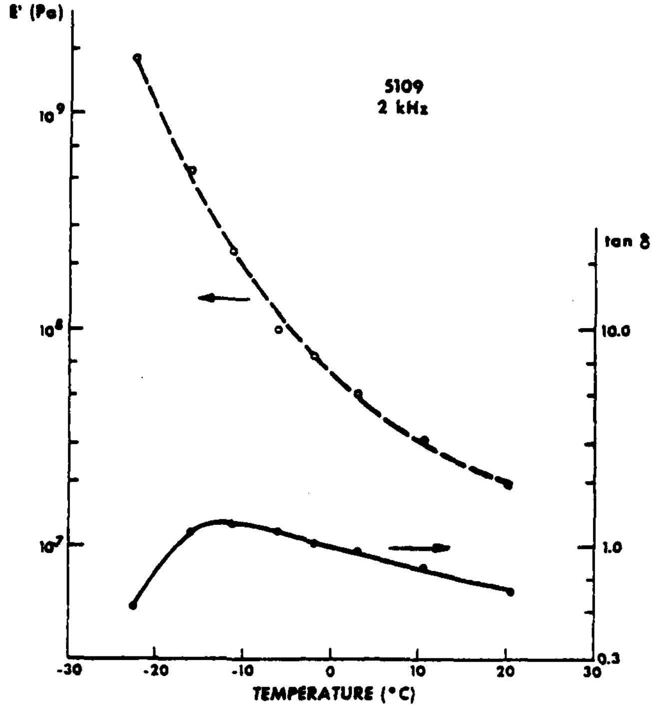

Fig. 5.3 - Dynamic property of Neoprene 5109 at 2 kHz

5 .3.6. Pressure Release Cork Rubber Material

It was reported by NAVSEA63X55 that the acoustic testing of DT-605 hydrophones from the latest production revealed failures to meet a back lobe requirement of -20 dB by 5 to 6 dB. Temperature was found to be a significant factor in that the transducers were not able to meet the specifications when exposed to cold water conditions of 2 - 3°C. The specified back lobe value of -20 dB for this hydrophone was obtained by isolation of the active areas from acoustic energy coming from the rear. The active areas included the rear side of the front mass and the rear mass of the resonant element. The acoustic isolation was achieved with a cork-rubber composite material for pressure release. A layer of this composite material was sandwiched between the front mass and the lead frame, between the stave plate and the housing back plate, and was also applied around the rear mass. Some of the surfaces were exposed to the fill-fluid (castor oil) and could, in time, be saturated with the fluid through absorption.

The possibility that the failure of DT-605 units at low temperatures may be related to the glass transition behavior of the elastomer matrix of the cork-rubber composite was investigated. Four composite samples have been evaluated:

- NC-711 - Aged cork/nitrile rubber from supplier of DT-605 parts
- NC-711 - Fresh material from the manufacturer

NC-775 - Fresh material from the manufacturer, a high quality cork/nitrile rubber having a better cork particle distribution and dispersion than NC-711.

LC-800 - Cork/silicone rubber composite from the manufacturer.

Dynamic mechanical measurements were carried out by using a resonant-string apparatus. Dynamic Young's modulus, E', and mechanical loss tangent, tan δ, were determined as functions of temperature and frequency. The results at 5 kHz are shown in Figs. 5.4 and 5.5. A large decrease in modulus with increasing temperature is seen accompanied by a loss tangent maximum at approximately 25°C. This suggests that the material does contain a glass transition. The aged NC-711 sample seemed to have a slightly lower glass transition temperature than the fresh NC-711 sample. However, one should exercise care in interpreting the glass transition process of a composite material such as cork-rubber. With a dispersion of cork particles in a rubber matrix, one may usually expect two distinct transition peaks on a plot such as Fig. 5 .5, each corresponding to one phase of the structure. The locations of the peaks on the temperature axis depend on the molecular structure of each component, the homogeneity of the dispersion, and the interfacial condition of the two phases. Therefore, for an engineering material such as cork-rubber, it becomes very difficult to interpret the data, since only a limited amount of information is available. The rubber composition is unknown at this time. The quality of the cork particles, their size distribution and the dispersion condition apparently all vary from one type to the other. One may conjecture that the observed glass transition process is mainly representative of cork particles' responses to the input dynamic signal. The corresponding rubber peak presumably lies at very low temperatures, depending on the rubber formulation. Within the temperature range of this series of tests, a low temperature peak for LC-800 sample was observed at -53°C, which is a resonable value for silicone rubbers. In any case, the test results show that the operating temperature of 2 - 3°C where DT-605 failure was observed falls between the cork and the rubber glass transition. The cork components at all times exhibit a glassy behavior at that temperature and the operating frequency.

The densities of the cork-rubber samples were also determined, and the results included in Table 5.1. It is noted that the fresh NC-711 sample has a density considerably lower than aged sample of an earlier batch. A reduced density indicates an increased amount of cork content in the composite, which may result in an increased amount of fill-fluid absorptions on cork-rubber materials for pressure-release has been demonstrated by Horsley and Thompson [3]. It should also be pointed out that the densities of both NC-711 samples are lower than the 1.05 (Type I) or 1.30 (Type II) value cited in the manufacturer's material specifications.

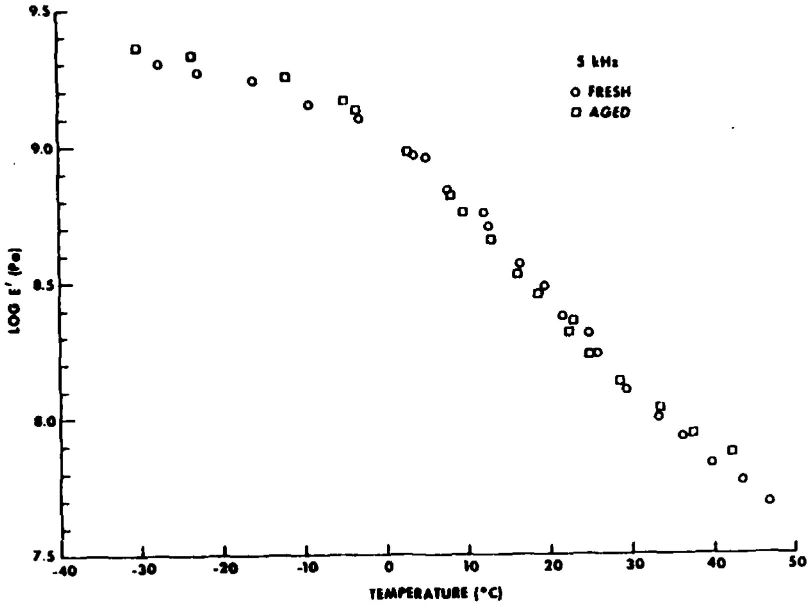

Fig. 5.4 - Dynamic Young's modulus of NC-711 cork-rubber samples at 5 kHz

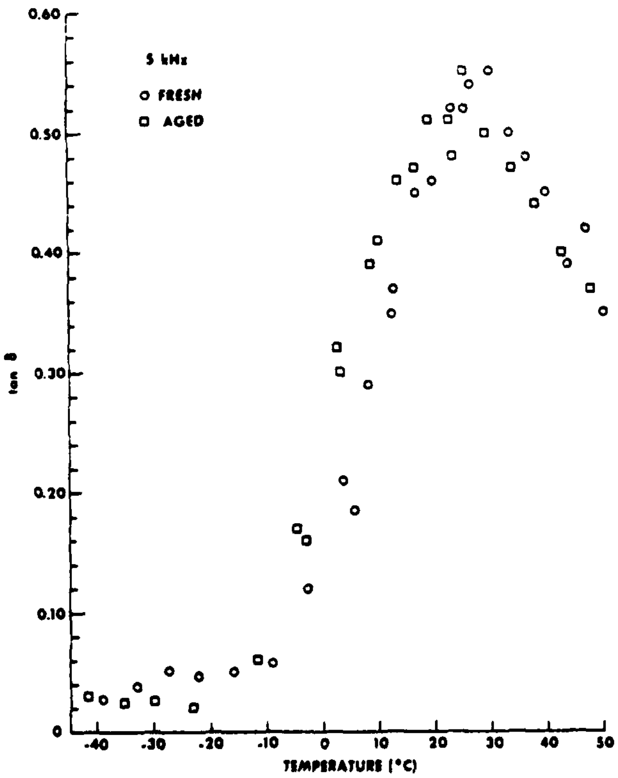

Fig. 5.5 - Loss tangent of NC-711 samples at 5 kHz

Table 5.1 - Properties of cork-rubber composites

Material	Glass Transition Temperature @ 5 kHz (°C)	Density (g/cc)
NC-711 (Fresh)	28	0.808
NC-711 (Aged)	24	0.918
NC-775	26	0.878
LC-800	22	1.06

5.4. PLANS

- Complete the review of Neoprene 5109 preliminary specification (3rd Qtr).
- Complete the electrical resistivity and water permeation study on neoprenes GRT and WRT (4th Qtr).
- Complete Neoprene 5109/fluid capability study and prepare report (4th Qtr).
- Complete initial evaluation of elastomer/ceramic bonding and provide input to Work Unit IV.C.1. for DT-276 application (4th Qtr).
- Complete the revision of Neoprene 5109 specification and publish report (4th Qtr).

5.5. REFERENCES

1. R.W. Timme, "Sonar Transducer Reliability Program (STRIP) FY82 First Quarter Progress," NRL Memorandum Report 4724, Jan 1982.
2. R.W. Timme, "Sonar Transducer Reliability Program (STRIP) FY81 Third Quarter Progress," NRL Memorandum Report 4543, Jul 1981.
3. L.E. Horsley and C.M. Thompson, "The Aging of Cork-Rubber Decoupling Materials," NRL Report 8458, Mar 1981.

6. WORK UNIT II.A.2 TRANSDUCER CERAMICS

A.C. Tims - NRL-USRD

6.1. BACKGROUND

To reduce the probability of tensional fracture when subjected to high acceleration, transducer ceramics are shock-hardened by the technique of winding glass filament, under tension, onto the ceramic to produce a constant compressional stress in the material.

It is well known that fiber wrapping of ceramics causes *significant* changes in the electromechanical coupling coefficients k_{31} and k_{33} and also changes in the capacitance and dissipation factor. Therefore, 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.

6.2. OBJECTIVE

The objective is to investigate the effects of filament winding on piezoelectric ceramics in transducer configurations with a final goal of establishing a basic specification for fiber-wrapped ceramics.

6.3. PROGRESS

The general procedure to fiberglas prestress a cylinder, ring, or stack, is to wind a number of layers of continuous fiberglas roving onto the ceramic while simultaneously applying an epoxy resin coating. The roving is applied under constant tension in a number of layer-turns that will produce the required prestress. The magnitude of the prestress is determined in various manners with the exact method usually determined by a manufacturer's past experience. The contemporary method of determining prestress magnitude is to use resistance strain gauges, Hooks Law, and shell theory. The technique and equipment used by a manufacturer have been developed in-house to meet certain manufacturing requirements or specifications in transducer contracts.

There are two major causes for the variability between fiberglas-wrapped ceramics. The first is variation in the winding tension from ceramic to ceramic. The second is irregular (ellipsoidal) shape and/or nonuniform wall thickness. The latter cause is most evident in single-element k_{31}-mode ceramics.

To support the latter conclusion, diametrically uniform k_{31}-mode cylinders were prestressed by two manufacturers and reported previously [1]. There was sufficient statistical evidence to conclude that the ceramics were more uniform after prestressing than before. The results are attributed to the uniform dimensions of the ceramic.

To gain more insight into prestressed ceramics and to provide a large statistical data base, a request has been made to add contract data requirements to the next SQS-56 buy. The same type of data are also anticipated on the next TR-317/318 contract.

During this reporting period, several questions which relate to fiberglas prestress were considered. For instance:

- Since there is a good understanding of the process by the manufacturers — *Does the Navy need a standard on fiberglas prestressing?* The answer to this question is, YES! In general, all manufacturers perform the prestressing in about the same manner, but the end results are not the same. There are nuances in this process that cause differences [1].

- The next question of concern is — *Will standardizing the process give one manufacturer an advantage over another?* Probably not, and should not.

- Another significant question is — *How does one determine the exact amount of prestress required for the ceramic?* (Use the maximum dynamic tensile strength of the ceramic as the prestress level? Does one use the maximum drive voltage level? Does one use the peak pressure expected from an explosive shock test? Or, does one choose whatever survives the explosive shock test and then say, "let's build them all just like that one"?) At present, there does not appear to be any uniformity among the manufacturers as to the answer.

- After a specific level of prestress has been determined — *How does one relate it to the ceramic?* (Does one relate the prestress to an equivalent pressure at the outer diameter (o.d.) of the ceramic, or to the hoop-circumferential stress at the inside diameter (i.d.)? Does one consider the ceramic to be a thin-wall case and use the general equations for the stress at the average diameter instead of using the exact equations for the stress? If this is done for a TR-317/318 element, it results in a 12.5% error in the actual stress at the i.d.) Obviously, it should be related to the i.d. by the exact equation where the strain can be measured for verification — but, such is not always the case in practice.

- There are several methods of applying the axial prestress to a ceramic stack or cylinder: by measuring the charge generated by the ceramic; by applying a specific static load; by applying a specific torque to the bias bolt, etc. — *Which method produces the most uniform axial prestress?* (Since uniformity of transducers from manufacturer-to-manufacturer and from lot-to-lot is the objective of this work, should an axial prestress specification be included in or be supplementary to a specification for fiberglas wrapping?) The answer appears to be YES because even a perfect (uniform from ceramic to ceramic) circumferential prestress can be degraded by the application of a nonuniform axial prestress via the Poisson's ratio of the ceramic.

Dr. Paul Smith (NRL) will be assisting in this program to answer many of the questions.

A major objective for FY82 is to develop an in-house fiber-wrap capability to give insight over all phases of the prestress process. Except for the tension-measuring device, the objective has been met. To support this work, a quantity of k_{33}-mode ceramics were ordered. Three hundred TR-317/318-size (8.57-cm o.d., 6.67-cm i.d., and 2.17-cm long) k_{33}-mode, Type III ceramic rings have been obtained via the competitive bid process from Channel Industries. The rings are dimensionally uniform; all diameters are within ±0.13 mm and the lengths within ±0.05 mm. The capacitance of each ring was measured on a Hewlett Packard 419A Impedance Analyzer. The ceramics were then arranged and grouped into stacks of six and four rings, each with the capacitance between the stacks normalized by mixing and matching [2]. Since the rings are dimensionally uniform and the capacitance between each stack of rings is normalized, the statistical variations between the stacks has been reduced. This tends to emphasize the effects of glass wrapping and makes it easier to evaluate the effects of prestress and variations from stack to stack. It is expected the k_{33} stacks, because of the effects of normalization, will not be as statistically variable after prestressing as are k_{31}-mode cylinders.

The grouping of the rings into stacks gives 30 stacks of six rings each and 30 stacks of four rings each. Chemical milled nickel electrodes 0.05-mm thick have been ordered. The electrodes are similar to those used in the TR-317/318 ceramic stacks. When they are received, EA 6 industrial adhesive will be used to consolidate the rings and electrodes. An alignment fixture has been designed and is currently being made to maintain the electrode tabs and ceramic rings in precise alignment. The fixture allows several stacks to be consolidated and cured simultaneously.

The effects of process variations on the stress magnitudes will be determined by the use of strain gauges. On each stack, f_r, R_r, f_a, R_a, f_m, f_n, C, and D will be measured before and after prestressing. A computer-compatible Hewlett Packard model 4192A Impedance Analyzer has been programmed to provide accurate high resolution measurements of the above electrical parameters.

6.4. PLANS

- Determine a method for precisely controlling the winding tension from one transducer element to another.

- Measure electrical parameters before and after prestressing and determine variations.

- Determine prestress magnitude on ceramics by use of strain gauge.

- Evaluate prestressed rings and correlate all collected data. Document results in a formal report.

- Provide fiber-wrap assembly procedures for TR-317/318 ceramics to NUSC.

6.5. REFERENCES

1. R.W. Timme, "Sonar Transducer Reliability Improvement Program (STRIP) FY81 Fourth Quarter Progress," NRL Memorandum Report 4615, Oct 1981.

2. A.C. Tims, "Versatile Experimental Kevlar Array Hydrophone: USRD TYPE H78," NRL Report 8288, Apr 1979.

7. WORK UNIT II.A.3. ALTERNATIVE MATERIALS: METAL MATRIX COMPOSITES

O.L. Akervold - Honeywell, Inc.

7.1. 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.

7.2. OBJECTIVE

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

7.3. PROGRESS

It was planned to complete this task by the end of this quarter. Completion has been delayed because of two unexpected problems in the head analysis calculations, and because the new silicon carbide particulate aluminum heads which were originally scheduled for delivery in early February will not be received until mid-April.

The most significant accomplishment this quarter was the development of the computer analysis program to its current status. Although it is not quite complete yet, we have validated its operation with the desired boundary conditions, the number of nodes, the number of degrees and master degrees of freedom, and the driving points. It also included development of a post processor to calculate figure of merit indices to aid in interpretation and use of the results, and verification of calculated head displacement values which initially appeared to be erroneous.

<u>Analysis of Head Vibrations</u>. The head analysis activities were directed to the development of a method of making the calculations which would provide the desired results in an easily useable form. The desired information is:

- The displacement (amplitude and phase) of each of the face nodes relative to the driving point displacement.
- To provide the above mentioned displacement over a range of frequencies.

- To provide a "figure of merit" indicator of the "flatness" of the face motion to guide the reader in evaluation of the results.

In the course of the calculations, it was observed that in some cases when the face motion was quite uniform (not experiencing a flexural resonance), the amplitude of the face was two to four times the amplitude of the driven nodes at the back side of the head. This was puzzling and did not seem correct. After considerable study, it was concluded that the calculations were correct. This is verified by the equations used in such analysis programs as TAC [1] and SEADUCER [2] for defining the strictly longitudinal displacement of conical-shaped sections. Figure 7.1 shows this type of section and the associated forces and velocities.

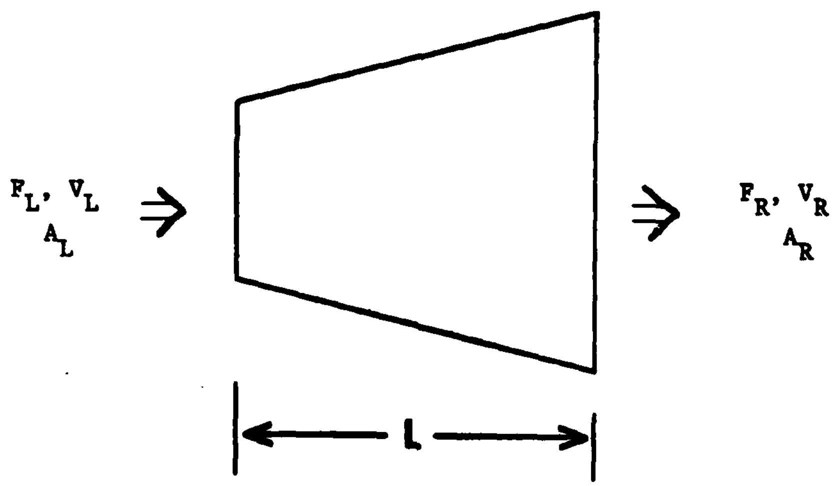

Fig. 7.1 - Conical-shaped section with associated forces and velocities.

The left and right forces and velocities are related as follows [3]:

$$F_L = A_{11}V_L + Z_{12}V_R \quad , \qquad (7.1)$$

$$F_R = Z_{12}V_L + Z_{12}V_R \quad . \qquad (7.2)$$

For air-loading on the head, F_R is essentially zero so that

$$\frac{V_R}{V_L} = -\frac{Z_{21}}{Z_{22}} \quad . \qquad (7.3)$$

The Z's are defined as

$$Z_{12} = -j\rho c\sqrt{A_L A_R}\,\csc(kL) \ , \qquad (7.4)$$

$$Z_{22} = j\rho c A_R[\cot(kL) - 1/(kL)] + j\rho c\sqrt{A_R A_L}(1/(kL)) \ . \qquad (7.5)$$

Substituting these into the expression for V_R/V_L and simplifying, we obtain:

$$\frac{V_R}{V_L} = \sqrt{\frac{A_L}{A_R}}\left[\cos kL - \frac{\sin kL}{kL}\left(1 - \sqrt{\frac{A_L}{A_R}}\right)\right]^{-1} \ . \qquad (7.6)$$

When $A_L = 0.5\ A_R$ and $kL = 60° = 1.047$ radians, then $V_R/V_L = 2.74$. This is comparable with the values obtained from the finite element head calculations and serves to validate those results.

The first head motion calculations were based upon driving the head with a unit velocity at the nodes where the ceramic would contact the head. These calculations show a fairly substantial local curvature of the rear face of the head right next to the innermost node being driven. This was considered to be a poor representation of the real condition. To improve this, we changed the drive conditions from an imposed displacement to an imposed force to allow the curvature to vary based upon the node impedance.

Unfortunately, this change also produced some changes in the face node velocities as printed out. This is requiring some additional adjustments to get back to the desired face node printouts.

Experimental Test and Validation. All of the parts and equipment necessary to measure the head displacement profile have been fabricated and assembled except for the heads made from the metal matrix composite aluminum. The bulk material has been made and is now being machined to final dimensions. Delivery is promised by mid-April. The material was originally scheduled for receipt in early February.

The Fotonic sensor measurement equipment was set up and checked out using a transducer element which was available. This verified the general setup but some additional adjustments are expected when the actual heads are used.

7.4. PLANS

Plans for the third quarter of FY82 are:

- Complete incorporation of the drive mode changes and make the final calculations.
- Receive metal matrix aluminum heads.

- Measure profiles of selected conventional and metal matrix aluminum heads.

- Correlate calculated and measured results.

- Prepare final report.

7.5. REFERENCES

1. "TAC PROGRAM USERS MANUAL," Naval Underwater Systems Center, New London Laboratory, Mar 1972.

2. "Computerized Sonar Transducer Analysis and Design Based on Multiport Network Interconnection Techniques," Naval Undersea Center (now Naval Ocean Systems Center) NUC TP 228, Apr 1973.

3. ibid, p. B7.

8. WORK UNIT II.B.1 CABLE SHIELDING

H.W. Denny - Georgia Tech Engineering Experiment Station

8.1. BACKGROUND

Certain advantages such as better waterproofing, better water-blocking, and lower cost would result from the use of underwater electrical cable without the internal shielding. The use of unshielded vs shielded cable has already been investigated from a mechanical strength viewpoint. The approach will now to be consider the electronics viewpoint of using unshielded or shielded cable on the outboard side of a submarine. Concerns are primarily centered upon electromagnetic interference and ground loops.

8.2. OBJECTIVE

The objective is to determine whether the use of unshielded cable in place of shielded cable, exterior to the hull of a submarine, will affect the electrical performance and reliability of sonar systems. Three tasks are associated with the accomplishment of this objective. These tasks are:

- Survey and analyze the installation of the DT-276 hydrophone of the BQR-7 and BQQ-5 systems on submarines to determine the electromagnetic interference (EMI) environment and the present practices of utilizing shielding on cables.

- Develop the theoretical modeling of shielded vs unshielded cables necessary and sufficient to predict the electrical performance and reliability of individual and arrays of DT-276 hydrophones in the EMI environment found exterior to the hull of a submarine.

- Devise and implement experimental procedures to verify the predictions from Task 2, above.

8.3. PROGRESS

Work proceeded on all three tasks this quarter. Progress to date on each is as follows:

Task 1: Through personal contacts at the Naval Underwater Systems Center, New London, CT (NUSC-NL) several relevant documents on the external electromagnetic environment and other matters were identified. The review of these documents has not been completed; preliminary indications are that they will permit a reasonable assessment of the external environment to be made. Some information on present construction practices is also contained in the documentation received from NUSC-NL. Additional definitive information on construction practices were gathered on a visit to the Naval Weapons Support Center (NWSC), in Crane, IN.

The general impression gained to date from these efforts is that cable-to-cable coupling probably represents a greater concern than does environment-to-cable coupling. This impression is based on a general evaluation of typical construction practices which embody the routing of multiple cables inside a covered steel raceway. In reflection of this impression, the analytical and experimental activities are emphasizing cable-to-cable coupling.

Task 2: The theoretical efforts have resulted in the development and/or application of six computer models: XTALK, XTALKC, FLAT, SHLD, TWIST, and TML. XTALK was developed by Dr. Clayton Paul of the University of Kentucky. It has been successfully used to predict coupling between unshielded bare wires over a ground plane in a lossless medium (air). A comparison of the results produced by XTALK with measured values is provided by Fig. 8.1.

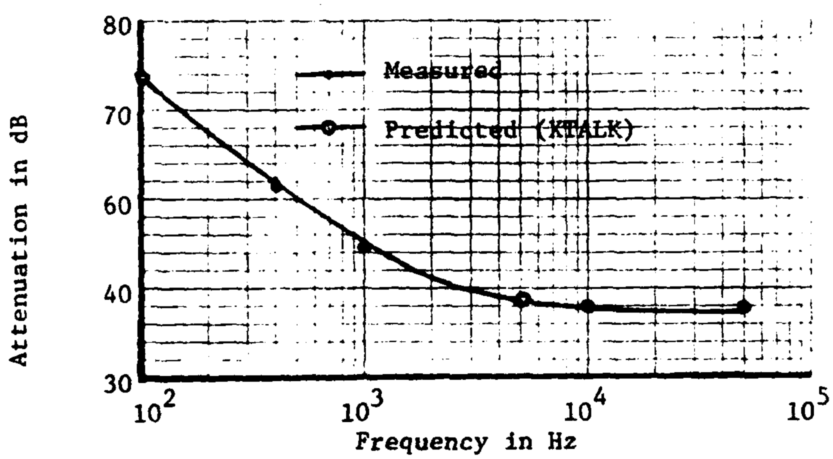

Fig. 8.1 - Comparison of measured and XTALK-predicted coupling for bare wires in air.

When the wires are imbedded in either fresh water or salt water, XTALK does not accurately predict coupling because of the presence of a conductivity factor arising from the water. XTALKC (an adaptation of XTALK) was formulated to incorporate a lossy medium. XTALKC proved to be applicable to the prediction of coupling between unshielded bare wires over a ground plane in a lossy medium.

The prediction of coupling between insulated conductors in air was achieved through the development of FLAT (an adaptation of Paul's FLATPAK). FLAT calculates the coupling between unshielded insulated wires over a ground plane with air as the intervening dielectric. [For a particular case of a pair of conductors over a ground plane, XTALK, XTALKC, and FLAT were integrated into a unified program called TML (Transmission Line)].

The prediction capabilities were extended yet further through the development of SHLD and TWIST. SHLD computes the coupling between an unshielded source wire and a shielded receptor wire over a ground plane in a lossless medium. TWIST computes the coupling between an unshielded source wire and an unshielded pair of twisted wires over a ground plane in a lossless medium.

Coupling between uninsulated conductors in both lossy and lossless dielectrics and between insulated conductors in a lossless dielectric can be successfully predicted with the above models. The cables of interest, however, employ insulated conductors and are generally immersed in salt water which is lossy. The presence of a loss term in the intervening dielectric seriously complicates formulation of the capacitance matrix on which the coupling models are based. Therefore, assessment of coupling between variously configured conductors in lossy media is proceeding experimentally.

Task 3: The measured coupling between insulated conductors in air, fresh (but not distilled) water and salt water is shown in Fig. 8.2. Also shown for comparison are the predicted values, as computed by FLAT, for the air dielectric condition. It is to be noted that both types of water exhibit an insulative effect in that the coupling in water is some 20 dB less than in air. The relative behavior of coupling between fresh and salt water was examined further by extending the measurements to higher frequencies and the results are shown in Fig. 8.3. As can be seen from the figure, the coupling is approximately the same below 50 kHz. At higher frequencies, some difference is noticed. These results are for high impedance loads in the presence of a ground plane, and the coupling is purely capacitive; however, independent observations indicate that similar behavior is to be obtained with typical (source = 600 ohms, load = 10,000 ohms) impedance.

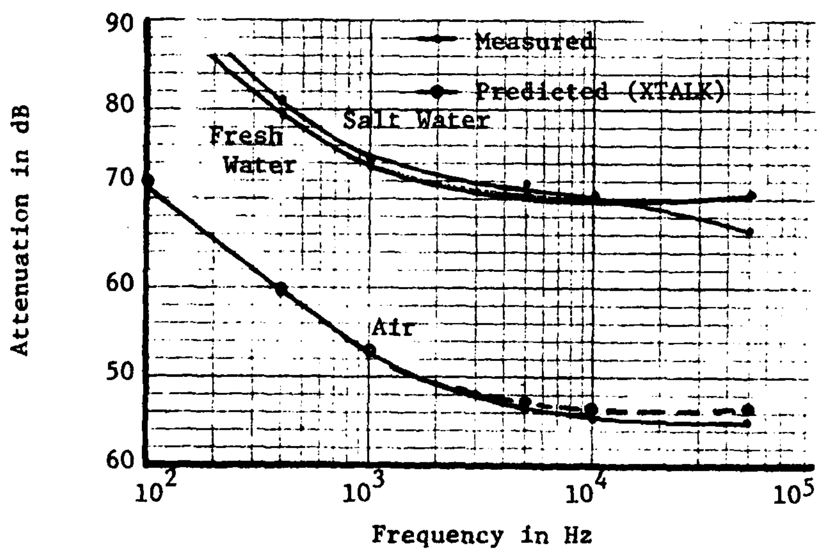

Fig. 8.2 - Coupling between insulated wires.

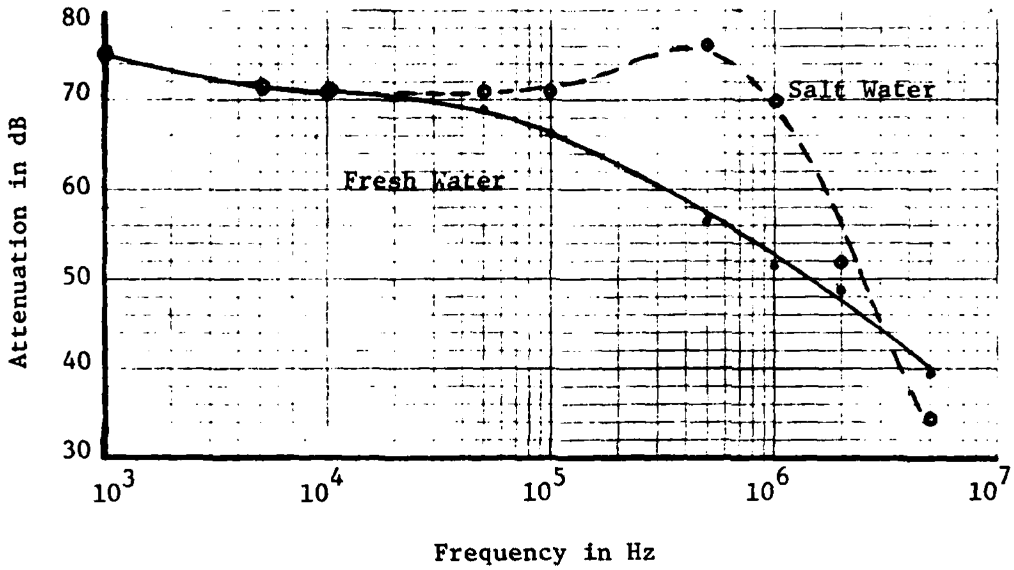

Fig. 8.3 - Coupling between insulated wires in fresh and salt water over extended frequencies.

The coupling between a straight wire and a pair of twisted wires and between a straight wire and a shielded wire has been measured. Special attention was given to the method of grounding the terminations and the shields. These were earlier indications that the coupling between insulated wires in either fresh water or salt water is dramatically affected by grounding to the ground plane which also is in contact with the liquid medium (the situation of primary concern to this investigation). Consequently, experiments were devised to test this behavior. In the first of these, the coupling between a straight wire generator and a twisted pair receiving wire was measured with various grounding conditions as shown in Fig. 8.4. There was no ground plane present — the reference conductor was a wire routed outside the tank. The coupling level in either medium was not affected by the supplemental ground, G1, made between the load and the reference. In water, however, the presence of G2, the connection between the reference and the water, strongly influenced coupling. In salt water, for example, the presence of G2 reduced the level of coupling approximately 50 dB over the entire frequency range.

These experiments were extended to include an examination of the coupling experienced between a straight generator wire (insulated) and a shielded receptor wire (coaxial cable). This test arrangement is depicted in Fig. 8.5. In this case, three types of grounds were used: either end of the shield could be grounded (G1 or G2) or the reference conductor could be grounded to the liquid medium (G3). The data showed that, with no ground plane in contact with the water and with no ground connected, there was a 14 dB increase in coupling level in fresh water and salt water with respect to the level measured in air. With G1 or G2 (or both) connected, the coupling in all three media suffered significant attentuation, with virtually no difference between the final levels. In fresh water and salt water, the greatest attenuation was achieved with all three grounds connected, with the attenuation in salt water the highest.

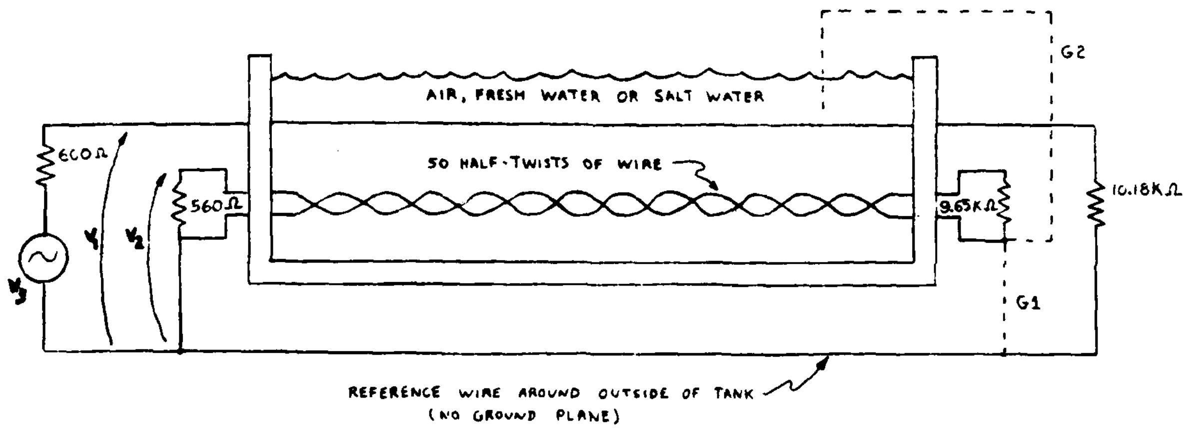

Fig. 8.4 - Experimental setup for straight wire to twisted pair coupling measurements.

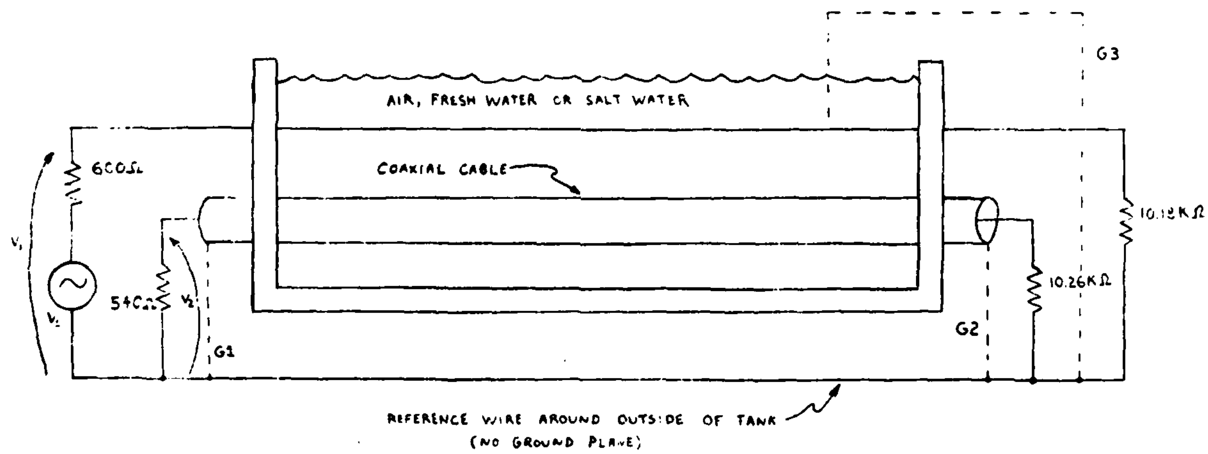

Fig. 8.5 - Experimental setup for straight wire to shielded wire coupling measurements.

These experiments indicated that the presence of the shield significantly reduces the level of coupling between pairs of wires, *if the shield is grounded at least at one end.* Since grounding both ends of the shields, as well as grounding both ends of the twisted pair receptor wire, appears to cause little change in the overall coupling level, problems with gound loop currents could be avoided by proper grounding and still significant reduction in cable-to-cable crosstalk can be achieved.

8.4. PLANS

These results indicated that the manner of grounding conductors in a conducting medium (salt water) does signficantly affect preformance. A more detailed examination of this behavior will be made during the large tank tests on DUS-3 and DSS-3 cables.

9. WORK UNIT II.B.3 CORONA CONTROL

L.P. Browder - NRL-USRD

9.1. BACKGROUND

A small but significant percentage of transducer failures is due to breakdown of electrical insulating materials. A physical phenomenon that contributes to these failures is corona. It is not practical to test the completed transducer to measure the effects of corona on lifetime and reliability. Corona formation and retardation must be studied at the component or piece-part level to locate and inhibit the damaging effects. Transducer reliability may then be improved by control of design parameters and construction processes.

9.2. OBJECTIVES

The objectives of this work unit for FY82 are:

- Study corona inception voltage characteristics of various electrode and material assemblies as used in transducers, including wiring, wire insulation, foil electrodes, and foil solder tab coatings.
- Provide recommendations, as required, for specific transducer improvements to avoid corona and for corona testing that will improve reliability.
- Prepare a handbook on transducer corona abatement and control that can be used to prepare transducer procurement specifications.

9.3. PROGRESS

9.3.1. A general principle for corona control in structures that contain high voltage is to avoid the presence of metal electrodes that have sharp edges and points. Common assembly elements used in sonar transducers are foil electrodes located between the piezoelectric ceramic discs or rings that serve the functional purpose of solder tabs for wires interconnecting the ceramic elements. The part of the foil electrode extending outside the ceramic element joint has sharp edges and can be a location where corona forms in the transducer.

Figure 9.1 is a sketch of a ceramic ring stack showing the foil electrodes and wiring. In a transducer like this, corona would form between the foil electrodes and a stress rod at the ring axis. If the foil electrodes were outside the ceramic stack, corona would form in the gap between electrodes and transducer housing. There can be many variations of the solder tab shape, but this particular type is well suited for illustrating the foil electrode corona characteristics.

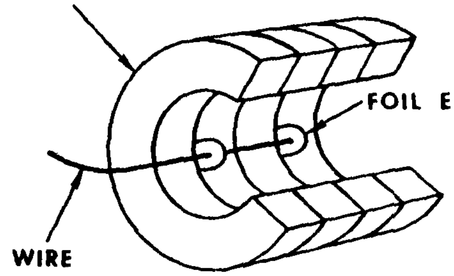

Fig. 9.1 - Sketch of piezoelectric ceramic stack showing foil electrodes and wiring.

A study was made to quantify the corona inception voltage (CIV) on foil electrodes with the following design parameters as the variables:

- foil electrode thickness
- foil electrode outer edge radius of curvature
- gas gap thickness between opposite polarity electrodes
- different gas types (air or sulfur hexafluoride)
- gas pressure

Similar studies of CIV for the point-to-plane electrode configuration have been reported as a part of the STRIP corona work unit [1,2]. The present work is more explicit about the application to sonar transducer design and also shows some features of the CIV characteristics not observed in the earlier studies. Figure 9.2 is a sketch of part of a transducer foil electrode and the physical parameters that are varied. The solder tab with radius curvature, r, and thickness, t, is the area from which corona emigrates a distance, d, to a ground plane and should simulate the conditions found in a transducer. A full range of tests were made on tabs with different t and r dimensions, in air and SF_6 gases, and at pressures of 35, 69, and 101 kPa.

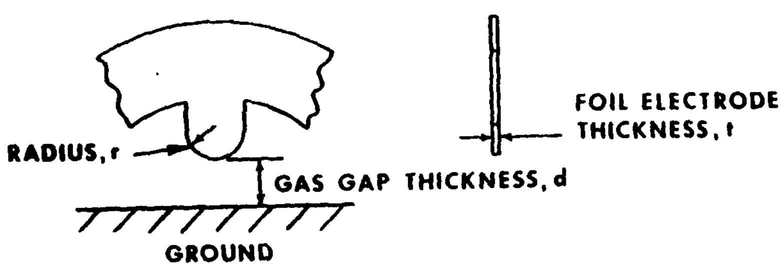

Fig. 9.2 - Sketch showing foil electrode test parameters

The equipment for this study was the same as used for the earlier studies. A Biddle corona measuring system was used for the high voltage source and corona detection. The receiving amplifier was set to a high gain for detecting the smallest corona signal available. The voltage source level was measured with a digital voltmeter and precision voltage divider calibrated using equipment traceable to NBS. The high voltage test chamber was equipped with a glass bell jar to control the gas environment around the test electrodes. The distance between the test electrode and the ground plane electrode was adjusted using a micrometer screw that moves the ground plane electrode. The ground plane electrode was a circular disc of stainless steel with a diameter of 10 cm, a thickness of 1.27 cm, and the edge was rounded. The test temperature was an average 25°C.

Figure 9.3 shows the measured CIV characteristics in air at 101 kPa (1 atm) pressure for foil electrode tabs with different dimensions. Curves B, C, and D are for tabs with 1.27 cm (0.5 in.) radius of curvature and different thicknesses of 0.0521 cm (20.5 mil), 0.0140 cm (5.5 mil), and 0.00254 cm (1 mil), respectively. Curves D, E, F, and G are for tabs with t of 0.00254 cm (1 mil) and radius curvature values of 1.27 cm (0.5 in.), 0.635 cm (0.25 in.), 0.316 cm (0.125 in.), and 0.159 cm (0.0625 in.). Curve H is for a sharp point on a 10° wedge cut from 0.00254 cm foil material. Curve A is the generally accepted characteristic for a uniform electric field spark voltage breakdown in air. Figure 9.4 shows the same CIV characteristics in sulfur hexafluoride (SF_6) gas.

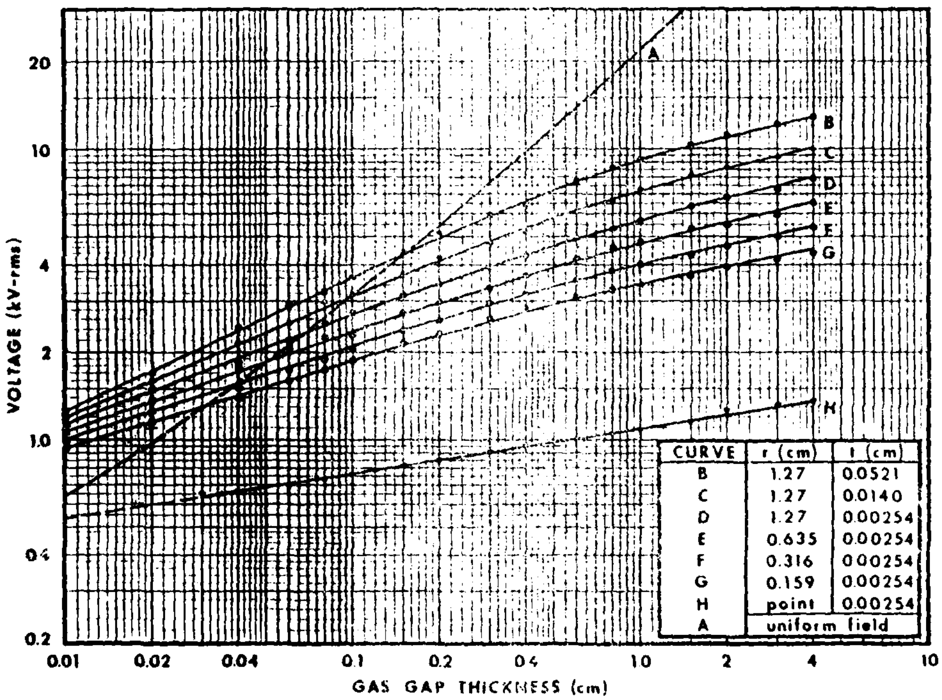

Fig. 9.3 - CIV characteristics in air at 101 kPa for foil electrode tabs with different dimensions.

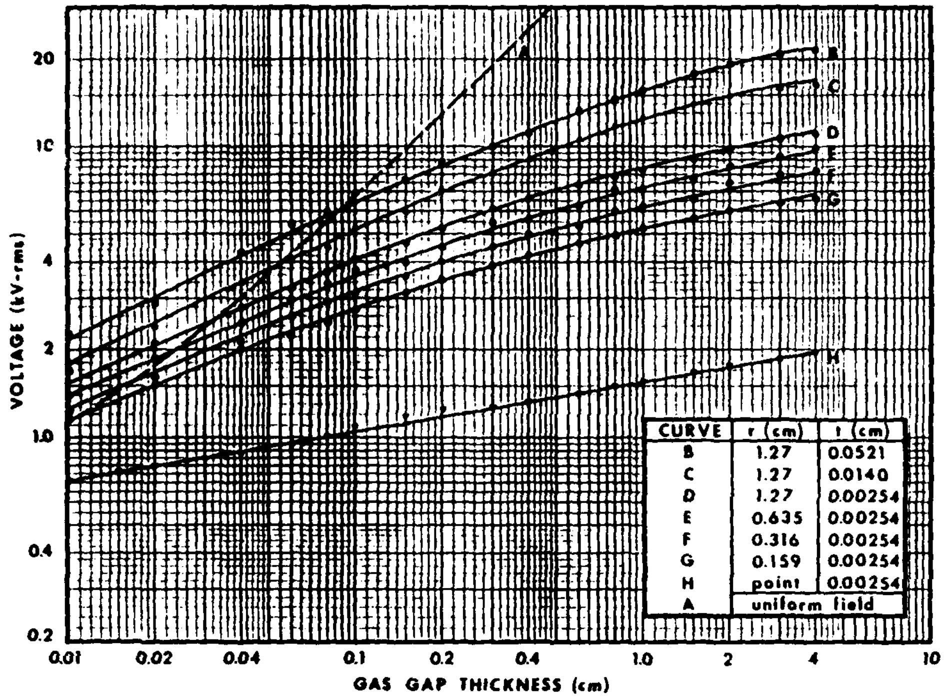

Fig. 9.4 - CIV characteristics in SF_6 at 101 kPa for foil electrode tabs with different dimensions.

An interesting feature of these curves is that they seem to radiate from approximately a common point at short gas gap thickness d. Unfortunately, control over the tests in the d range 0.01 to 0.1 cm is inadequate to assure precision. However, CIV values greater than the uniform field breakdown voltage (curve A) in this gas gap range is an apparent fact. This trend was observed in the earlier STRIP tests [3,4] but was not reported.

The change in CIV level with gas pressure was found to obey a power function relation describable by

$$V_c = V_o\left[\frac{P_c}{101\ (\mathrm{kPa})}\right]^n , \qquad (9.1)$$

where V_c is the CIV level at some pressure P_c between 35 kPa and atmospheric (101 kPa), and V_o is CIV level for a configuration of r, t, d, and gas type as shown on either Fig. 9.3 or Fig. 9.4. The exponent n was found to have an average value of 0.52. Preliminary additional data indicate this relation holds to two atmospheres (~200 kPa) gas pressure.

9.3.2. A visit was made to Raytheon Co., Portsmough, RI, to provide STRIP input for corona control in the TR-317 transducer. Out-of-specification corona was causing an excessively large rejection rate for the assembled stacks of ceramic rings. Efforts to reduce the rejection rate using better inspection and quality control methods were giving no statistical improvement.

Coating the ceramic stacks in a vacuum is probably the most significant change that can be made to reduce corona on the stacks. This is not a new idea because verbal communication with other transducer designers indicate this method has been used with some success. Piezoelectric ceramic has a small amount of porosity and this can vary with different manufacturers or production batches. Coating the stacks in a vacuum will provide at least partial filling of pores on the ceramic surfaces and will also fill surface air pockets at the bonded joint between rings. A low viscosity rating for the uncured coating material is desirable to give good penetration into the pores and pockets. Raytheon expects to have the equipment that implements coating the stacks in a vacuum operating in early April 1982.

Two changes are suggested for the stack wiring. The hook-up wire used to interconnect the ceramic rings is size #20 and has a CIV of about 4.8 kV. Increasing the wire diameter by using wire size #16 to #18 will increase the CIV to about 7 kV. Also, the foil electrode is 3 mils thick and the solder tab this forms has a sharp edge that can form corona. A metal sleeve should be placed over the solder tab edge to increase its apparent thickness. These two changes are good high voltage engineering practice and should improve the transducer.

9.4. PLANS

- Examine the use of coating materials to reduce corona on foil electrodes and write report on foil electrode corona.

- Continue study of corona inception voltage effects using solid barrier insulation with various electrode shapes in three different gases.

9.5. REFERENCES

1. R.W. Timme, "Sonar Transducer Reliability Improvement Program (STRIP) FY79 First Quarter Report," NRL Memorandum Report 4014, Jan 1979.

2. R.W. Timme, "Sonar Transducer Reliability Improvement Program (STRIP) FY79 Third Quarter Progress Report," NRL Memorandum Report 4009, Jul 1979.

3. R.W. Timme, "Sonar Transducer Reliability Improvement Program (STRIP) FY79 Second Quarter Progress Report," NRL Memorandum Report 3985, Apr 1979.

4. R.W. Timme, "Sonar Transducer Reliability Improvement Program (STRIP) FY81 Third Quarter Progress Report," NRL Memorandum Report 4543, Jul 1981.

10. WORK UNIT II.B.5 ACOUSTIC EMISSION APPLICATIONS

T.J. Mapes - NUSC-New London

10.1. BACKGROUND

In the mid-seventies the U.S. Navy discovered that certain submarine sonar transducers were prone to emit undesired acoustic radiation when undergoing depth variations. As part of a program to correct these deficiencies, the technology generally known as "acoustic emission," or stress wave emission, has been applied to the problem of determining the origin of extraneous noise sources within the transducer elements. An acoustic emission laboratory has been established at the Naval Underwater Systems Center in New London, CT, (NUSC-NL) and utilized successfully in locating defects in two different element designs.

10.2. OBJECTIVE

The objective of this work unit is to determine the feasibility of applying acoustic emission techniques to the problem of localizing noise mechanisms in sonar transducers.

10.3. PROGRESS

Acoustic emission is accepted as a nondestructive test method for locating flaws in pressure vessels, aircraft components, mines, welded joints, and reinforced plastic structures. To apply this method, an empirical or analytical model of sound paths in the structure is required. High-frequency sensors are then applied to the structure in specified critical locations and the structure is mechanically loaded. Stress waves emitted by the structure are detected by the sensors and the wave characteristics are then used to estimate the source of the acoustical emission. However, application of this technique to underwater electro-acoustic transducers poses several problems. Because of the size and complexity of a typical transducer, the sound paths through the structure are difficult to define and the acoustic emission sensors required, for the most part, do not exist.

Using a longitudinal vibrator type of transducer, this effort will attempt to adapt a twelve-channel acoustic emission test system to the problem of noise source localization. Sectioned, or cut-away, transducers will be instrumented and simulated acoustic emissions used to determine the various propagation paths. Fully assembled transducers will be instrumented and subjected to both uniaxial stress in air and stress due to hydrostatic pressure. Where the required acoustic emission sensors and sources are unavailable commercially, they will be developed in-house (this has already been done to some extent). Defined acoustic emission paths and the specialized instruments will be used to develop the noise location algorithms.

The end-product of this effort will not only be a technique for application to identified problems, but also a Quality Control Procedure which would permit detection of noisy transducer elements during manufacture.

Funding for this work unit was not received until February 1982. A revised plan for FY82 reflecting the reduction in funding and available time has been prepared and submitted to the STRIP Program Manager.

A technical memorandum, "Progress in the Application of Acoustic Emission Technology to Noise Location in Longitudinal Vibrator Transducers," NUSC-NL TM No. 811147, was published during the second quarter. This document, which describes progress in this work during FY81 (before it became a STRIP task) also discusses the test equipment and capabilities of the NUSC Acoustic Emission Laboratory. A bibliography lists, among other things, previous publications issued under this program.

During FY81, a twelve-channel, micro-processor-controlled, acoustic emission test system was acquired. This system, identified by the acronym "DART" (Data Acquisition in Real Time), captures and processes transient energy bursts from sensors mounted on the specimen which is undergoing test. The processed data is then sent through a RS-232 digital interface to a general purpose host computer for additional processing, display, and storage. The host computer in used is a Hewlett-Packard 9845T system.

Work has commenced on writing software for the 9845T to operate with DART. A simple linear array of three sensors on a long, thin bar was set up for debugging and confidence tests. This arrangement has been exercised using a somewhat unsophisticated program with encouraging results. All of the acoustic emission variables quantized by DART (including pulse amplitude, duration, rise time, threshold crossing, average signal level, and counts, as well as differential times between sensors) are now being received at the 9845T.

10.4. PLANS

During the next quarter intensive effort will be directed toward developing the DART-9845 operating system. A test will be made with a sectioned TR-155F using the DART system to gain experience relevant to the actual transducer configuration. A system feasibility demonstration is planned for November 1982.

11. WORK UNIT III.B.1 MEASUREMENT METHODOLOGY

J.F. Zalesak - NRL-USRD

11.1. BACKGROUND

Many electroacoustic transducers in use by the Navy are operated in an environment where the hydrostatic pressure changes. Some of these transducers emit transient acoustic signals when subjected to changes in hydrostatic pressure. Presently, transducers are checked by measuring them for acoustic emission in small reverberant pressure tanks, and translation of the results to free-field effects are difficult and in question. Thus, a laboratory method is needed which will simulate the operational environment and which will determine the free-field transient acoustic signals which may be generated.

11.2. OBJECTIVE

The objective is to determine a method for measuring the free-field acoustic radiation emitted from electroacoustic transducers undergoing changes in hydrostatic pressure in a laboratory environment.

11.3. PROGRESS

Methods to be investigated under this task include:

- Use of a pressure vessel with acoustically transparent walls. The transducer under test is placed inside the vessel, which is then submerged in an open body of water. The pressure within the vessel is then varied and the resulting acoustic radiation is measured directly. If the body of water is large enough so that there is no interference from the boundaries (unwanted reflections) and the acoustic measurement is made at a sufficient distance from the vessel, then it is the free-field acoustic radiation which is measured.

- Use of pressure vessels with anechoic linings. A measurement of the transient acoustic radiation can be made within a pressure vessel if the vessel has an anechoic lining. The anechoic lining absorbs all the sound energy incident on it so that no interfering reflected signals will be measured. There are a number of problems associated with the use of pressure vessels. The tank itself and its ancillary equipment must not emit transient acoustic radiation when the hydrostatic pressure is changed. The sound-monitoring hydrophone must not produce transient signals with changing hydrostatic pressure. A suitable anechoic material must be found which will work at very low acoustic frequencies, which will operate at high hydrostatic pressure, which will be small enough in volume so as not to completely fill any reasonably sized tank in order to be effective, and which will not itself emit transient acoustic radiation.

- Use of signal extrapolation techniques to allow recovery of the free-field signal from the early part of the received signal which is uncontaminated by reverberations from tank walls. In this way, an anechoic lining for the pressure vessel walls is not needed. However, all the comments about the various system components emitting transient acoustic radiation still apply.

- Use of complex transfer functions to relate reverberation-contaminated signals measured in a tank to free-field signals. This technique requires a large, fast computer to implement. The computational task of determining the free-field radiation from measurements in a reverberant chamber is enormous. The comments about the various system components emitting transient acoustic radiation apply in this case also.

Effort during this fiscal year will concentrate on the first two methods.

Although funding for this task was not received until the beginning of the second quarter, some progress has been made. A preliminary investigation revealed that an attempt was made previously to use a rigid, fiberglas-reinforced tank as a transparent pressure vessel. However, it was found that the vessels produced for this purpose emit transient acoustic radiation while undergoing changes in hydrostatic pressure. It is possible that a flexible vessel might not suffer from this problem. A short length of small-diameter, aramid-reinforced hose with suitable end closures has been purchased to test this hypothesis. The hose will be tested during the next quarter to determine whether or not it emits transient acoustic radiation. This small-diameter hose will simulate the more expensive large-diameter hose which could be used as an acoustically transparent pressure vessel for testing transducers. The procurement papers for purchasing the full-sized hose are being prepared so that the hose may be ordered immediately if it is determined, from the small hose tests, that the approach warrants further investigation. There is a 210-day delivery time for the large-diameter hose so tests on it will be delayed until next fiscal year.

11.4. PLANS

During the remainder of this fiscal year, the small-diameter hose will be evaluated, the large-diameter hose will be ordered, and a preliminary investigation will be initiated on anechoic linings for tank walls. This preliminary investigation will include a survey of the available acoustic absorbing materials to determine if there is a material which would render an existing pressure vessel suitably anechoic. Also, a determination of the feasibility of installing such a material will be determined.

12. WORK UNIT III.B.2. EXPERIMENTAL MEASUREMENT CORRELATION

C.I. Bohman - NOSC

12.1. BACKGROUND

Testing of transducers for extraneous noise due to changes in hydrostatic pressure is practical and cost-effective only when done in small pressure tanks. In order to successfully apply the criteria developed under STRIP work unit I.A.1 to the measurement of transducer extraneous noise in pressure tanks, it will be necessary to investigate the differences between tank measurements and operational configuration measurements and to apply some conversion factor to relate one to the other. In addition, because the tank and pressurization system itself may be a source of noise, it is important to be able to discriminate between noise that originates in the transducer and noise which is part of the pressurization system.

12.2. OBJECTIVES

To develop methods and techniques to relate the transducer extraneous noise as recorded in small pressure tanks to an equivalent characterization of that noise in an operational configuration, and to relate the noise characterization to the transducer self-noise criteria.

12.3. PROGRESS

The approach to this task will be to compare first the current transducer noise specification being used for transducer production tests with the proposed [1] *radiated noise criteria recommended* by the Naval Ocean Systems Center (NOSC). This comparison will be made by actual experimental measurements of the electrical and radiated acoustic noise of a special NRL-modified transducer in a tank while under pressure. Because the modified transducer can be excited by an independent driving signal to simulate noise and does not require the normal noise-producing mechanism through pressure cycling, the pressure will be held constant. This will eliminate the requirement of having a quiet pressure cycling system to conduct these tests.

Secondly, in order to have valid data during pressure cycling, it is imperative that "system" noise does not become mixed with transducer noise. Therefore, a technique will be developed to discriminate between system noise and transducer noise.

The third, and most important consideration, is to be able to relate the results of transducer noise testing in small pressure tanks with the criteria being developed in STRIP work unit I.A.1. The approach will be to establish reasonable bounds or limits to the transducer radiated self-noise as presently measured in pressure tanks and to convert those bounds by means of a transfer function or conversion factor to corresponding bounds or limits in the free-field and actual operational configurations.

During the first quarter, an analog tape was received from the Naval Weapons Support Center (NWSC) which was recorded during pressure tank testing of a fleet transducer. This tape is being examined with the object of being able to characterize typical transducer nose. As of yet, no transducer noise has been located on the tape.

During FY81, a portable data acquisition system was assembled with funds from a closely related NAVSEA project, of which this STRIP task is a continuation, with additional funds from two unrelated NOSC projects. This data acquisition system is microcomputer-controlled and has the capability of capturing, digitizing (12 bits), and storing on digital tape, the analog outputs of four different sensors. The system is planned for use in acquiring pressure tank test data, and possibly sea test data. After funds were received, purchase orders were written to expand its capabilities by adding a software operating system and dual floppy disk drives for program and data storage.

12.4. PLANS

- During the third quarter of FY82 a test plan will be written to conduct pressure tank tests and acquire data to compare the peak voltage method with the radiated acoustic energy method of evaluating transducer noise. Test plans will also be written on conducting tests to discriminate between system and transducer noise, and to establish a transducer function or conversion factor to relate pressure tank testing results with the criteria developed in STRIP work unit I.A.1.

- A meeting will be held with the principal investigators involved with the transducer extraneous noise investigation to discuss the overall problem, the experimental (laboratory and sea test) data that is required, the best wa· to record and transfer data between laboratories, and the cooperation that is required between the individual tasks.

- Experiments will be started to acquire data from pressure tank testing.

12 .5. REFERENCE

1. D.J. Edelblute and C.I. Bohman, "Development of a Detection Criterion for Transducer Extraneous Noise (U)," NOSC TR 328, to be published (this report is Confidential).

APPENDIX A

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7-8