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REPORT ON SURVEY OF METHODS FOR DETERMINING THE DAMPING AND THE--ETC(U)  
SEP 66 A N SAVACCHIO, A D STUART, G GERSTEL

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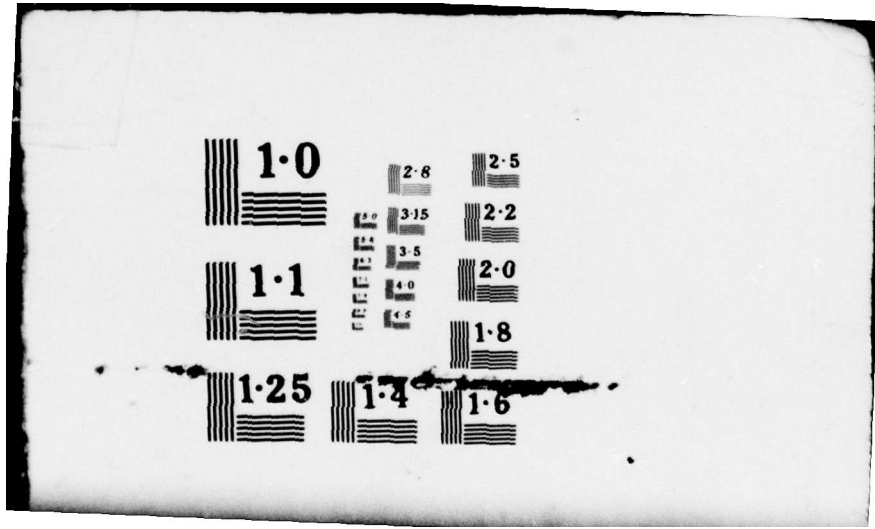
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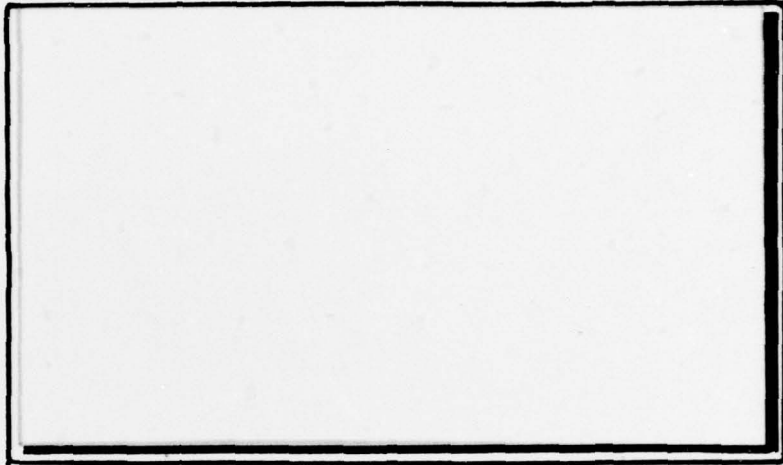
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SF 101-03-17, TASK 8213

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Lab. Project 9300-59, Technical Memorandum #1

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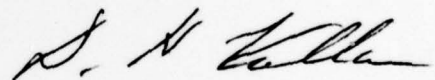
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To: Commander, Naval Ship Systems Command (Ships 2021) (3)  
Subj: Lab. Project 9300-59, Technical Memorandum #1, "Report on Methods  
for Determining the Damping and Acoustic Properties of Sonar Dome  
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Bolt, Beranek & Newman  
50 Moulton Street  
Cambridge, Mass. 02138  
Attn: Dr. J.E. Barger

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ADMINISTRATIVE INFORMATION

- Ref: (a) NAVAPLSCIENLAB Program Summary of 1 May 1966, "Sonar Dome Material Development Program" SF 101-03-17, Task 8213
- (b) BUSHIPS ltr SF 101-03-17 Ser 1622-E-705 of 2 Dec 1965
- (c) USNASL Lab. Project 9300-16, Tech Memo #11 of 1 Apr 1965
- (d) Specification MIL-P-22581B (Ships) Amendment 1 (18 May 1964)  
"Plastic Sheet, Vibration Damping"
- (e) "Method for Determining the Dynamic Mechanical Behavior of Gels and Solids at Audio frequencies" by Edwin Fitzgerald and John Ferry, Journal of Colloid Science, Vol. 8 (1953)
- (f) Bruel and Kjaer Complex Modulus Apparatus, Type 3930 "Instructions and Applications"
- (g) USNUSL Technical Memorandum No. 933-54-64 of 17 Feb 1964, "Damping Characteristics of Three Untreated Steel Plates" by H. N. Phelps, Jr.
- (h) Mare Island Rubber Laboratory Report No. 133-7, Progress Report 1 of 19 Feb 1965
- (i) Hazeltine Corporation - Electro Acoustics Systems Laboratories - Test Report No. EASL-AS-5 of 5 Nov 1963
- (j) General Dynamics - Electronics Division Report No. 7-1, Acoustic Transmission Measurements" of 2 Feb 1965
- (k) U.S. Rubber Co. Final Report "Anechoic Coating Materials" of July 1965, Contract No. NOBs-88570 (FBM)
- (l) Stanford Research Institute Final Report "Prediction of Far Field Performance of Sonar Projectors from Near Field Measurements" of Nov 1961, Contract NOnr-3049(00)
- (m) USN Ordnance Laboratory Report 2257 "Pulse Tube for Acoustic Measurements" by W. S. Cramer and K. S. Bonwit of Apr 1952
- (n) Mare Island Laboratory Report No. 165-41 "Development of Super Saper Coating for Use on Submarine Pressure Hulls" of Jan 1966

- (o) General Dynamics - Electronics Division Report No. 16-1, "Acoustic Reflection Measurements" of 10 Feb 1965
- (p) Mare Island Laboratory Report 165-24 "Underwater Acoustical Decoupling Efficiency of SOUNDAMP Type RAL" of 17 Aug 1962
- (q) "Ship Acoustic Coatings" - Panel Discussion by Dale Intolubbe (DTMB) U.S.N. Journal of Underwater Acoustics Vol.13, No. 4 Oct 1963

#### INTRODUCTION

1. Materials intended for use in sonar domes are normally evaluated for damping and acoustic properties. For example, the sonar dome shell material is evaluated for damping properties; the acoustic "window" material for transmission loss; and the baffles for both anechoic and decoupling properties. Because these properties are important factors in efficient sonar performance, it is essential that the activities developing sonar dome materials have available, reliable, meaningful methods for their evaluation.
2. Preliminary investigation of test methods available to determine the damping and acoustic properties of materials revealed a lack of standardization. The methods used to study these properties were found to vary with the different investigators. As a result, it is frequently difficult and sometimes impossible to compare data obtained by the different activities engaged in this work. In view of this condition, a survey was planned in references (a) and (b) with the object of defining currently used test methods for evaluating damping and acoustic properties of sonar dome materials. The ultimate goal of this work is to develop meaningful, reliable test methods and to standardize these methods for use by laboratories evaluating sonar dome materials.

#### ACKNOWLEDGEMENT

3. Supervision for this task was provided by A. Rufolo, Head of the Coatings Branch. The program is being conducted under the guidance of Mr. D. Seganish (Program Manager - 1622E) of the Naval Ship Systems Command.

#### VISITS TO LABORATORIES

4. As part of this investigation, visits were made by NASL personnel to the following laboratories to obtain information on currently used test methods:
  - a. Naval Ordnance Laboratory, White Oaks, Maryland

- b. David Taylor Model Basin, Carderock, Maryland
- c. U.S. Navy Underwater Sound Laboratory, Fort Trumbull, New London, Conn.
- d. Mare Island Shipyard, Rubber Laboratory, Vallejo, California
- e. Marine Engineering Laboratory, Annapolis, Maryland
- f. U.S. Navy Underwater Sound Reference Laboratory, Orlando, Florida
- g. Stanford Research Institute, Menlo Park, California
- h. Celanese Corporation of America, Summit, New Jersey
- i. Lord Manufacturing Company, Erie, Pennsylvania
- j. John Hopkins University, Baltimore, Maryland
- k. General Dynamics, Electronics Division, Rochester, New York
- l. Hazeltine Corporation, Electro-Acoustics Systems Laboratory, Avon, Mass.

TEST METHODS FOR VARIOUS MATERIAL PROPERTIES

- 5. The test methods studied covered these four properties:
  - a. Vibration Damping
  - b. Acoustic Transmission Loss or Insertion Loss
  - c. Anechoic
  - d. Decoupling
- 6. This report contains a short description of the various currently used test methods together with the activities using these methods.

DAMPING MATERIAL TEST METHODS

- 7. A damping material is a material which when applied to a dynamically excited structure reduces the amplitude of structure borne noise in the structure by converting some of the noise energy into heat energy.

8. The following test methods are currently used to evaluate damping materials:

a. Beam Method (reference (c))

A steel beam having dimensions of 15" x  $1\frac{1}{2}$ " x  $\frac{3}{8}$ " or 40" x 3" x  $\frac{3}{8}$ ", is coated with the damping material and set into mechanical vibration as a free-free beam by an electro-mechanical shaker. When the excitation is cut off, the rate of free decay of the system is used to measure the system damping. If the excitation is maintained, the frequency response of the system is used to measure the system damping. In both cases, the mechanical response of the system is obtained with an accelerometer. From the response data, computations are made to assess the effectiveness of the damping material on a comparative basis with other materials similarly tested. A 15" beam covers a frequency range of 300 to 7500 cps, whereas a 40" beam covers the frequency range of 40 to 2000 cps. This method is used by Applied Science Laboratory, Mare Island Rubber Laboratory, and Lord Manufacturing Co.

b. Disc Method (reference (d))

Each member of a set of discs 3" to 8" diameter,  $\frac{3}{8}$ " thick, is excited by an impulse resulting from the blow of a small hammer, and set into mechanical vibration. The method of pick-up, processing of the electrical signal, and determination of the system damping, is essentially the same as the free decay procedure of the beam method. Here again, materials are evaluated on a comparative basis in terms of the system damping. The frequency range covered varies from 1700 to 11000 cps. This method is used by Applied Science Laboratory, and Mare Island Rubber Laboratory.

c. Fitzgerald Method (reference (e))

A pair of small discs, e.g.  $\frac{1}{2}$ " diameter by  $\frac{3}{32}$ " thickness, made from the material to be tested, is subjected to a shearing stress in an apparatus known as the Fitzgerald apparatus. An electrical measuring circuit is used from which the mechanical impedance (force/velocity) and ultimately the complex shear modulus is obtained. A knowledge of the latter, constitutes a direct measurement of the material shear damping property. Data is obtained for frequencies varying from 50-5000 cps. This method is used by John Hopkins University.

d. Bruel and Kjaer (B&K) Method (reference (f))

A small beam, e.g. 12" x  $\frac{5}{16}$ " x  $\frac{1}{16}$ ", made from the damping material or more usually from a layer of damping material coated to a steel bar, is mounted in a Bruel & Kjaer (B & K) complex modulus apparatus. The specimen is excited by a magnetic transducer and the excitation picked up by a second transducer. The response of the vibrating system is determined by either the

rate of free decay or frequency response method and is ultimately recorded on a level recorder from which the complex Young's modulus may be determined. A knowledge of this modulus enables one to evaluate materials in terms of the material extensional loss factor. The B & K apparatus when installed in a suitable temperature control chamber allows measurements to be carried on from  $-150^{\circ}\text{C}$  to  $+250^{\circ}\text{C}$  and over a frequency range of approximately 30 to 3000 cps. This method is used by Celanese Corporation of America, and Lord Manufacturing Co.

e. 30" x 30" Plate Method (reference (g))

A 30" x 30" steel plate, 60 mils,  $1/8"$  or  $1/4"$  thick, is coated with the damping material being investigated. The plate is impact excited with a small hammer. The response of the plate is obtained with an accelerometer in terms of  $1/3$  octave bands. From this point on, the processing of the accelerometer signal to obtain the system damping is essentially the same as the free decay procedure of the beam method, paragraph 8a. The frequency range covered varies from 100 to 16000 cps. This method is used by Underwater Sound Laboratory and Hazeltine Corporation.

TRANSMISSION LOSS OR INSERTION LOSS TEST METHODS

9. Transmission loss of a material is a measure of the sound insulation of the material. Transmission loss is defined as the ratio (expressed in decibels) of the acoustic energy transmitted through a plate of the material under study, to the acoustic energy incident upon the plate. It is 10 times the logarithm to the base 10 of the reciprocal of the sound transmission coefficient of the material. Mathematically,

$$\text{T.L.} = 10 \log_{10} \frac{W_1}{W_2} = 10 \log_{10} \frac{1}{\tau}$$

where

$W_1$  = incident acoustic energy.

$W_2$  = transmitted acoustic energy.

$\tau = \frac{W_2}{W_1}$  transmission coefficient.

10. Insertion loss is the reduction in the signal, in decibels, caused by the insertion of the test plate under study between the sound source (projector) and the receiver (probe hydrophone).

11. The following test methods are currently used to evaluate the transmission loss or the insertion loss of a material:

a. Reverberant Chamber Method (reference (c))

This is an insertion loss method. It employs a small 30" x 30" x 30" chamber, lined with a pressure release material and open on one side. The material to be investigated is coated to one side of a 30" x 30" x 1/16" or 1/4" thick steel plate, which is clamped to the open side of the chamber with the material facing the interior of the chamber. The chamber is filled with water and submerged in a large water tank (12'x6'x5'). A sound projector is located inside the chamber and is energized with a wide-band random noise generator. A receiving hydrophone is located at a fixed position on the opposite side of the plate, outside the chamber, where the sound pressure level is analyzed in 1/3 octave bands. The reduction in transmission caused by the coating is obtained from the difference in the sound pressure level (at the receiving hydrophone) measured for a coated plate and for an uncoated plate. This method is used by the Applied Science Laboratory.

b. Pulse Tube Method (reference (h))

This is an insertion loss method. This method employs a 3.5" inside diameter, 20 ft long vertical water-filled tube. A sample of material to be investigated is cemented to 1/2" thick sample holder which fits into the 3.5" inside diameter tube. The sample with its holder is suspended 5 ft. down from the top of the tube by a 1/4" diameter steel rod. At the top of the tube is a layer of air to provide 100% sound reflection from the water-air interface. A pulsed signal, of a given frequency, is emitted from a transducer, located at the bottom of the tube. This signal travels up the tube and past a monitoring hydrophone, located at the middle of the tube, where the signal amplitude is measured on an oscilloscope and recorded. The signal continues up the tube, through the specimen, to the water-air interface at the top of the tube where it is reflected back down the tube and it again passes through the specimen. This "reflected" signal is then monitored by the hydrophone at the center of the tube and the amplitude again measured on the oscilloscope and recorded. The difference between the amplitude of the "incident" signal and the "reflected" signal passing through the specimen is a measure of the attenuation caused by two passes of the sound through the specimen. The transmission attenuation or insertion loss of the specimen coating is one half of this difference. A correction is made for the inherent attenuation in the water-filled tube and at the water-air interface, by performing the same test without any specimen inserted. This method is used by the Mare Island Rubber Laboratory.

c. Free-Field Insertion Loss Method (references (i, j))

The acoustic material to be investigated is coated to one side of a plate whose dimensions are standardized by the measuring activity. The smallest size plate used is 30" x 30". The plate with its coating is immersed in a large body of water, such as a lake, between a sound projector and a sound receiver. The relative positions of plate, projector and receiver are fixed. The location of the projector varies from 5 ft. to 10 ft. from the material face of the plate depending on which activity is performing the evaluation. The location of the probe hydrophone is maintained at all activities as near to back face of the plate as possible without touching it. The practice is to energize the projector by a constant amplitude voltage from a sweep frequency oscillator, which is pulsed to insure separation of the directly transmitted signal through the plate and the various interference signals. The insertion loss is determined as follows. With no plate in place, the probe hydrophone reading is obtained for a given projector output. The procedure is repeated with the plate in place. The difference in reading between the hydrophone measurements, with and without the plate in place, is the insertion loss of the plate. This method is used by Underwater Sound Reference Laboratory, General Dynamics-Electronics Division, and Hazeltine Corporation.

ANECHOIC MATERIAL TEST METHODS

12. An anechoic material is a material which reflects very little of the incident sound energy that impinges upon it. It is a material with a high reflection loss or a high echo reduction. Echo reduction is defined as  $20 \log \frac{V_I}{V_R}$  where  $V_I$  is the sound pressure of the incident sound and  $V_R$  is the sound pressure of the reflected sound.

13. The following test methods are used to evaluate anechoic materials:

a. Standing Wave Tube Method (references (k, l))

A sound projector at one end of a water filled tube sets up a sound field of continuous plane waves. The tube is terminated with a sample of the material being investigated which is cemented to a heavy sample holder. Because of reflections from the sample, standing waves are produced in the tube. By probing the length of the tube with a moving hydrophone the maximum and minimum pressures of the standing wave are obtained, and from these data the echo reduction or anechoic property of the material can be calculated. The formulas required to compute the echo reduction are as follows:

$$\text{Standing Wave Ratio (SWR)} = \frac{\text{Maximum Pressure (Measured)}}{\text{Minimum Pressure (Measured)}}$$

$$= \frac{V_I + V_R}{V_I - V_R}$$

or 
$$\frac{V_I}{V_R} = \frac{\text{SWR} + 1}{\text{SWR} - 1}$$

Where  $V_I$  = incident sound pressure  
 $V_R$  = reflected sound pressure

since Echo Reduction =  $20 \log_{10} \frac{V_I}{V_R}$

$$\text{Echo Reduction} = 20 \log_{10} \frac{(\text{SWR}+1)}{(\text{SWR}-1)}$$

This test method is used by the U.S. Rubber Co., Mare Island Rubber Laboratory, and Stanford Research Institute.

b. Pulse Tube Method (references (m, n))

A sound projector at one end of a long water filled tube emits sound pulses of given frequencies. Each pulse travels to the other end of the tube where it impinges on a sample of the material being studied which is mounted on a heavy sample holder. The incident pulsed signal is reflected off the sample and is measured. This is repeated for the various frequencies of interest. The decrease in level of the reflected signal is a measure of the anechoic property of the material. From a knowledge of the incident and reflected sound pressures the echo reduction is computed from:

$$\text{Echo Reduction (in decibels)} = 20 \log_{10} \frac{V_I}{V_R}$$

Where  $V_I$  = incident sound pressure  
 $V_R$  = reflected sound pressure

This test method is being used by the B. F. Goodrich Rubber Co., Goodyear Rubber Co. Underwater Sound Reference Laboratory, Underwater Sound Laboratory, and Mare Island Rubber Laboratory.

c. Free-field Reflection Loss or Echo-Reduction (reference (o))

The method and electronic instrumentation used are the same as those for determining the insertion loss of a material described in paragraph 11 (c). The only difference is that the receiving probe hydrophone is located on the same side of the coated plate being investigated as the sound projector. Care is taken to gate out, with the receiving electronics, the interference due to diffraction from the edges of the plate. The location of the probe hydrophone varies from 1 foot to 10 feet from the face of the plate depending on which activity is performing the evaluation. The echo reduction is expressed in decibels and defined as  $20 \log$  to the base 10 of the ratio of the incident to the reflected sound pressures. This test method is used by the Underwater Sound Reference Laboratory, General Dynamics, Electronics Division, and Hazeltine Electronics.

DECOUPLING MATERIAL TEST METHODS

14. A decoupling material is a material which when applied to a structure reduces the radiated noise from the structure (such as a submarine hull) or which reduces the water borne sound transmission through the structure (such as a sonar dome baffle).

15. The following test methods are currently used to evaluate decoupling materials:

a. Pulse Tube Method (reference (p))

The test consists in pulsing a thick aluminum piston inside one end of a 5.5 inch diameter water-filled plastic tube and measuring the generated sound pressure by means of a hydrophone in front of the piston. A sample of the material being investigated is then cemented to the face of the aluminum piston, which is then driven at the same amplitude of vibration for each selected frequency as that used to drive the bare piston. The difference in sound pressure generated by the bare piston and by the piston covered with the sample material is used to calculate the decoupling property of the sample material. The sound radiation reduction or decoupling property in decibels is:

$$\text{Radiation Reduction (in decibels)} = 20 \log_{10} \frac{V_B}{V_C}$$

Where -

$V_B$  = hydrophone sound pressure, bare piston  
 $V_C$  = hydrophone sound pressure, covered piston.

This test method is used by the Mare Island Rubber Laboratory.

b. Buoy Test (reference (q))

This method of testing decoupling properties of decoupling coatings uses a 30 inch diameter ring stiffened steel cylinder 8 feet long. This cylinder is submerged in a free-field environment (such as a lake) to any desired depth and then excited with an internally mounted electro-magnetic shaker. The radiated noise generated by the "bare" cylinder is measured with a series of hydrophones. The procedure is repeated with the cylinder covered on the outside surfaces with the material being investigated for decoupling properties. The difference in radiated noise levels between the bare cylinder and the covered cylinder, is a measure of the decoupling property of the material. Experimentation to depths of 600 feet with this method have been made. This test method is used by David Taylor Model Basin.

FUTURE WORK

16. Work will continue on the survey of test methods for the determination of damping and acoustic properties of sonar dome materials. The next report will be submitted by December 1966. It will contain descriptions of additional test methods, technical analyses of test methods, and recommendations for standardization of test methods.