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DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER

nuwc

PRESSURE/TEMPERATURE VESSELS FOR CALIBRATING SONAR TRANSDUCERS

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May 1968

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NAVAL UNDERSEA WARFARE CENTER

An activity of the Naval Material Command

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PROBLEM

Design, develop, and construct acoustically transparent vessels that will extend the capabilities of the pressure vessel previously reported* to permit calibration of transducers under various conditions of pressure and/or temperature.

RESULTS

1. Three glass-epoxy vessels with favorable acoustical properties were built under contract.

2. They were designed to house the transducer under test.

3. Maximum operating pressures for long-term cycling are 800, 2000, and 10,000 psi.

4. Temperature range is 38° to 90°F.

5. Maximum operating frequencies are 500, 250, and 100 kHz.

6. The mounting mechanism holds the test transducer on the regular calibration column either inside or outside the vessel.

RECOMMENDATIONS

1. Consider the use at other laboratories of pressure/temperature vessels of the type described in this report.

2. Develop larger high-pressure vessels for use in calibration of larger pieces of equipment.

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*Navy Electronics Laboratory Report 1301, Pressure Vessel for Calibrating Sonar Transducers, by C. E. Green, 26 July 1965

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INTRODUCTION

Requests for calibration of sonar transducers at depths and temperatures beyond normal station capability are becoming increasingly frequent. The NUWC solution to the problem is a system for applying pressure to or changing the temperature of a transducer within an acoustically transparent vessel (fig. 1). The acoustical transparency permits the other transducers involved in the tests to be located outside the vessel in their normal environment. Three such vessels have been constructed with different maximum pressure ratings. NEL Report 1301 described the first one. This report updates NEL Report 1301 to include two additional vessels and the added capability of temperature control (fig. 2).

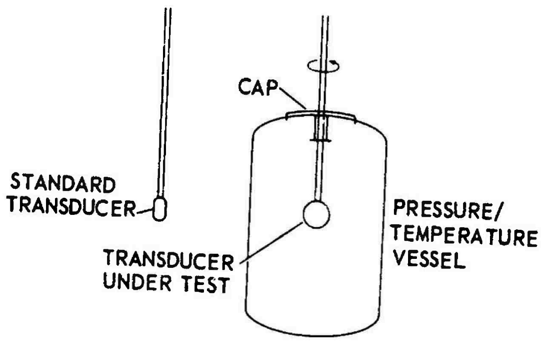

Figure 1. Test setup for calibration of a transducer under pressure and/or temperature.

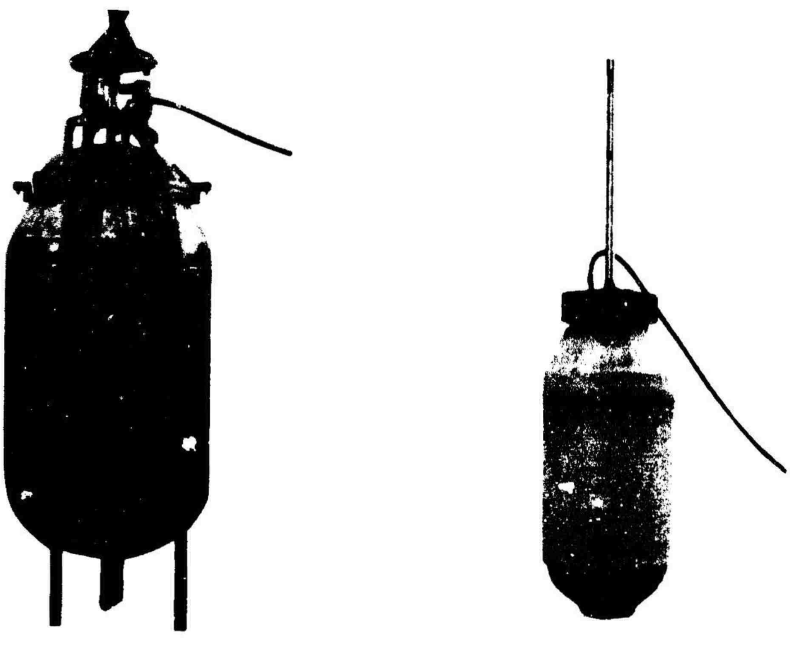

Figure 2. Pressure/temperature vessels, 800-psi (left) and 10,000-psi models.

MECHANICAL DESIGN

The pressure vessel is cylindrical with elliptical end sections. The walls of the vessel are made of a fiber-glass consolidated resin which provides an acoustically acceptable wall and a nonresonant body. A helical geodesic winding pattern minimizes the amount of fiber glass required. The radial strength of the vessel is increased by cylindrically-wound additional layers. The consolidated windings were vacuum cured to reduce air entrapment. The wall has a breaking strength somewhat beyond the operating pressure. Noteworthy, however, is the fact that the vessel is never checked beyond the operating pressures, since fissures develop in the resin as a result of increasing tension on the fiber glass. The intrusion of water into these fissures is prevented by use of an internal rubber lining and an external compliant coating. Experience at NUWC reveals that fissures do not extend and additional fissures do not appear after the vessel has been cycled to maximum pressure except that holding the vessel at maximum design pressure will cause slowly creeping extension of existing fissures. When a vessel is subjected to a pressure greater than the previous pressure level, new fissures and extension of old fissures may occur. *For this reason fiber-glass containers should not be checked at pressures greater than 10 percent above operating pressure.*

The life of a consolidated body of this type is dependent upon the number of cycles to full pressure and the length of time the vessel is held at the maximum design pressure. The design criteria for these vessels is based upon a minimum of 1000 cyclings to full pressure over a period of 10 years with a holding time of 15 minutes per cycle.

PRESSURE AND TEMPERATURE SYSTEMS

The greatest flexibility in the use of the acoustic vessel is achieved by means of a pressure pump located on the mounting shaft. The mount permits the pump to rotate with the vessel. A semirigid high-pressure waterline connects the pump to the vessel. The pneumatic-hydraulic pump is driven from a very flexible air line that can wind up when the shaft is rotated. Electrically operated pumps were excluded to minimize electrical hazards.

The temperature of the water in the vessel is raised or lowered by circulating it through a heat exchanger (figs. 3 and 4). Flexible heavy-wall rubber tubing connects the vessel cap to the deck-mounted refrigerator and heater. The heat exchanger consists of (1) a pump capable of circulating the water at a rate sufficient to minimize a temperature differential between the vessel and the exchanger, (2) a chiller through which the water circulates, (3) an electric heater in a small tank, (4) a sight gage for observing air trapped within the system, and (5) a flowmeter to show the rate of flow of water. A 3-ton refrigeration compressor and a 14-kW electric heater are sufficient to provide a temperature range of 38° to 90°F in a 38-cubic-foot vessel. High-pressure valves located on the vessel cap (fig. 5) are closed when pressure is applied to the vessel. This eliminates high pressure from the circulating system; no water circulates while the vessel is under pressure.

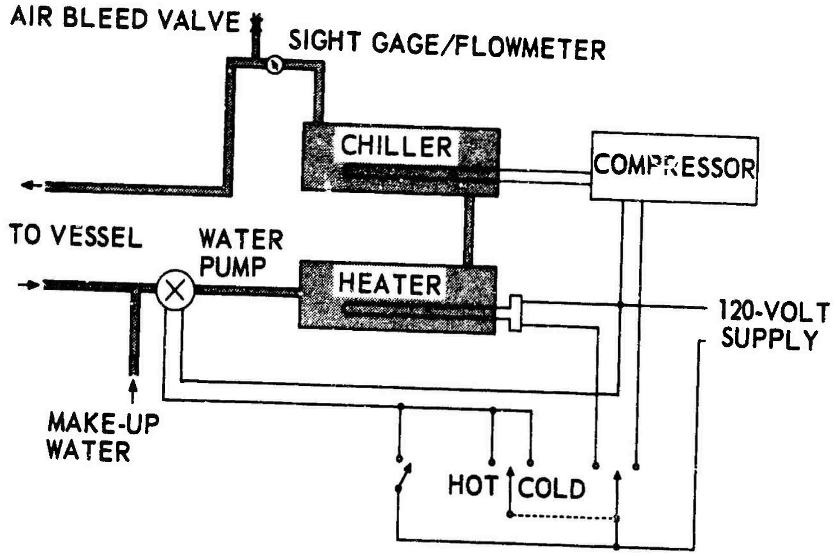

Figure 3. Heat exchanger for water supplied to vessel.

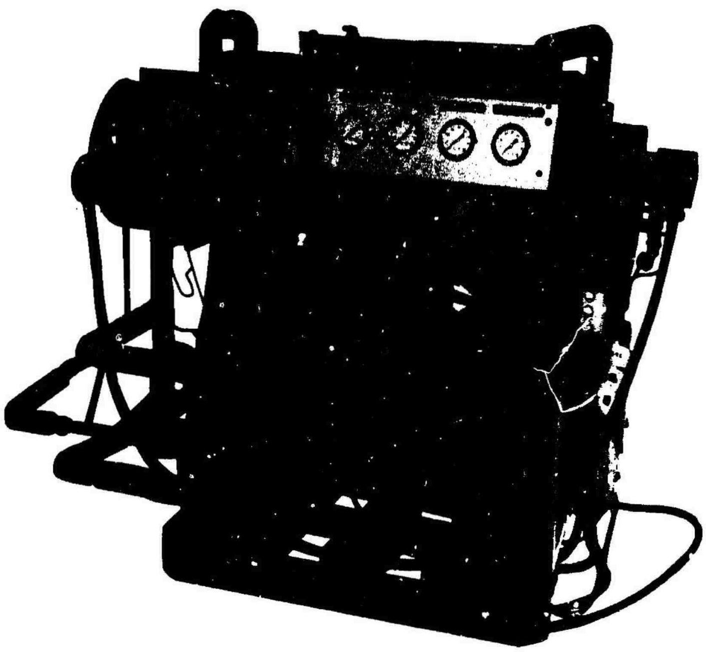

Figure 4. Heat exchanger, photograph.

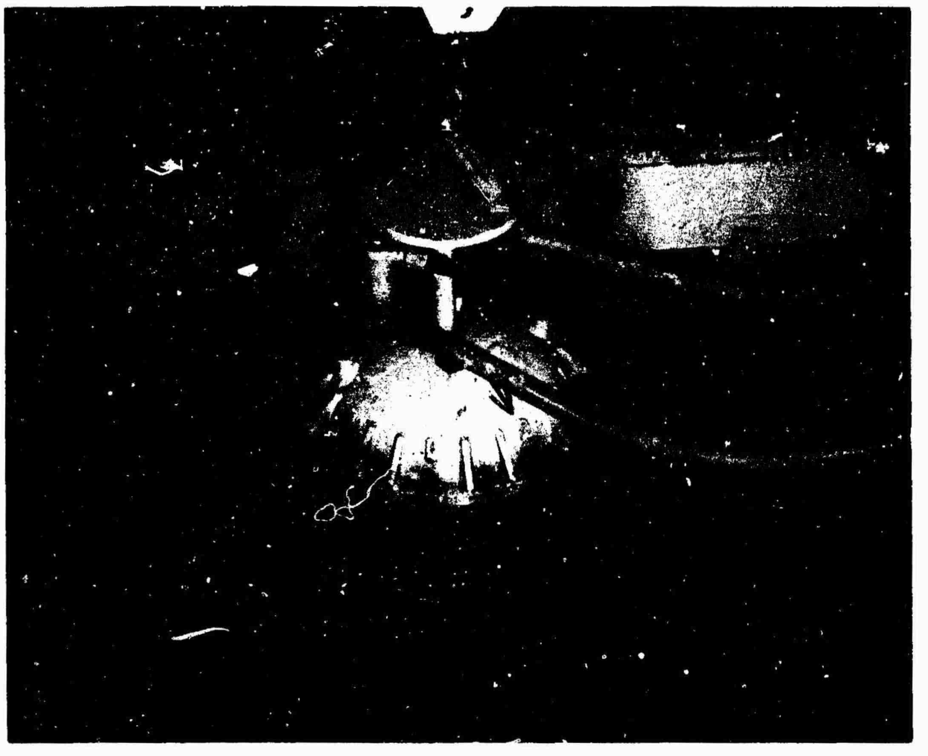

Figure 5. End cap and water hoses.

ACOUSTICAL DESIGN

Prime requisites for the acoustic vessels are (1) walls must be predictably transparent to sound, (2) mechanical Q must be low enough to dampen all resonance in water, (3) wall thickness must be uniform within close tolerances, and (4) sound reflection from the walls must be held to a minimum.

Wall thickness must be held to a minimum compatible with the pressure requirement, all air must be excluded from the fiber-glass resin complex, and uniformity in winding must be maintained so that these requirements can be met.

The steel cap is lined with neoprene rubber and/or sound-absorbent rubber in order to reduce acoustic reflection and thermally isolate the water inside the vessel from the water outside.

EVALUATION

The vessels were evaluated acoustically to determine (1) the circular uniformity of the capsule walls, (2) the loss in transmission due to reflection and absorption as a function of frequency, and (3) the effect on the acoustic signal of temperature and pressure changes.

CAPSULE-WALL UNIFORMITY

Uniform wall thickness of the cylindrical section of the capsule permits transducers to be mounted in random orientations with respect to the walls. Uniformity is checked by mounting a small cylindrical transducer in the center of the vessel, insonifying this transducer from a single source outside the vessel in the far field, and rotating the vessel so that sound traverses the wall at all radii. The vessel is acoustically uniform if signal variation is less than 0.1 dB at a frequency where wall thickness in inches times frequency in kHz equals 25.

ATTENUATION THROUGH THE WALL

A change in acoustical transmission as a function of frequency was expected, since the frequency spectrum of interest encompasses the range from a fraction of a cycle to several cycles within the wall thickness of the plastic. The velocity of sound within the glass-epoxy consolidate is about 3.1×10^5 cm/sec, so a maximum loss of signal due to both reflection and attenuation will occur at a wall thickness of a quarter of a wavelength. This thickness occurs at 100 kHz in the 800-psi vessel (.35-in. wall), at 60 kHz in the 2000-psi vessel (.57-in. wall), and at 35 kHz in the 10,000-psi vessel (1-in. wall) (fig. 6).

The frequency-response curves for these vessels show the attenuation measured over a wide frequency range. They are quite uniform, and predictable up to where the wall is 1 wavelength in thickness.

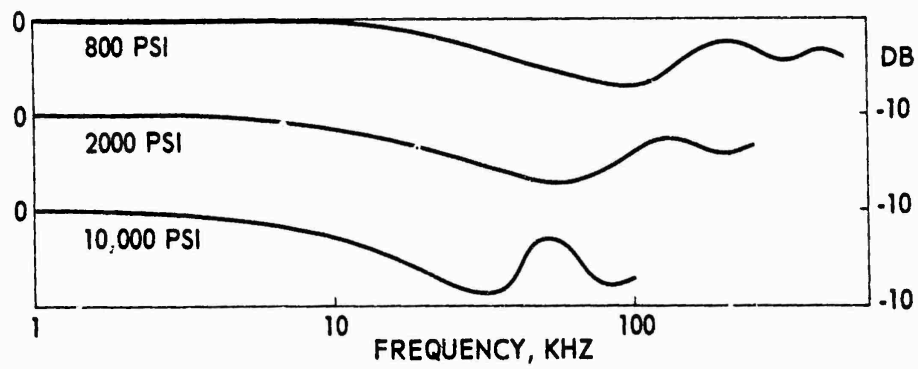

Figure 6. Response measurements – attenuation as a function of frequency.

TEMPERATURE / PRESSURE EFFECTS

The effect of signal distortion in the vessel could be a problem. An analytical look at this particular application is in order. Horton* states that $c = 4422 + 11.25\,T - .045\,T^2 + .018\,D + 4.3(S{-}34)$

where c = velocity in ft/sec
T = temperature in degrees Fahrenheit
D = depth below the surface in feet
S = salinity in parts/1000

	Outside Water	Water Inside Vessel		
		At Low T (Case I)	At High D (Case II)	At High D and Low T (Case III)
T (°F)	60	35	60	35
D (ft)	20	20	4600	4600
c (ft/sec)	4789	4615	4873	4699

Distortion will occur where the signal enters the vessel at angles other than normal. A cross section of the vessel shows the maximum angle of entrance for a plane wave (fig. 7). This limit is established by the size of the largest transducer that can be placed in the vessel. The angle θ formed at the surface of the 2000-psi vessel is 25°, and the deviation from this on the interior surface contributes to signal deformation.

Since $\sin\theta/\sin\theta_1 = c/c_1$, the values of refraction can be calculated. For Case I, $\theta_1 = 24°$, for Case II, $\theta_2 = 25.5°$, and for Case III, $\theta_3 = 24.5°$.

A maximum possible 1° refraction can occur that will bend the end ray inward toward the center of the transducer. This would cause the longest possible plane-faced transducer to appear 0.1 inch shorter than its actual length of 20 inches. This would indicate no pattern or response deterioration.

The vessels were tested with an F30 standard transducer for change in acoustical behavior due to pressure and temperature, both independently and concurrently. The transducer showed no change in level or pattern when the pressure was elevated from 0 to 2000 psi, or when the temperature was changed from 40° to 90°F (fig. 8).

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*Horton, J. W., Fundamentals of Sonar, United States Naval Institute, 1957

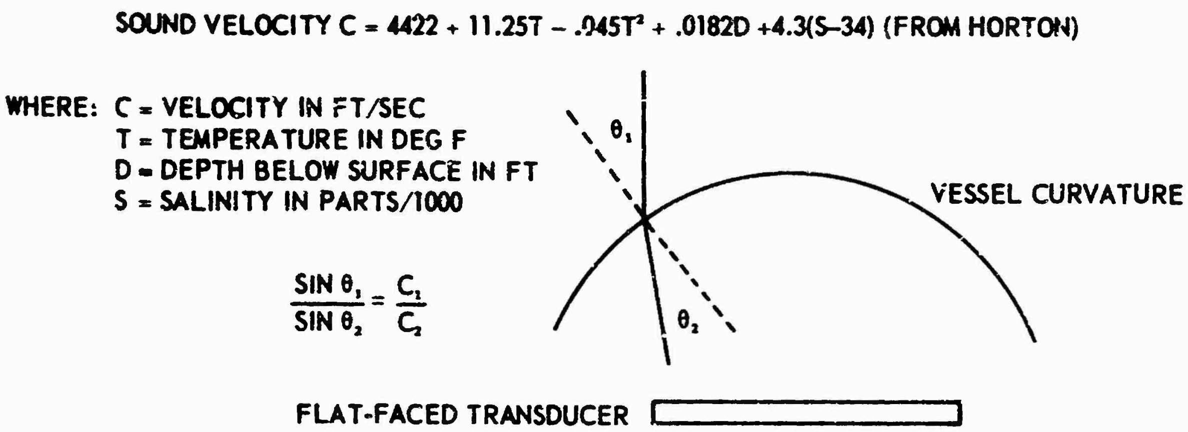

Figure 7. Maximum angle of entrance into vessel for a plane wave.

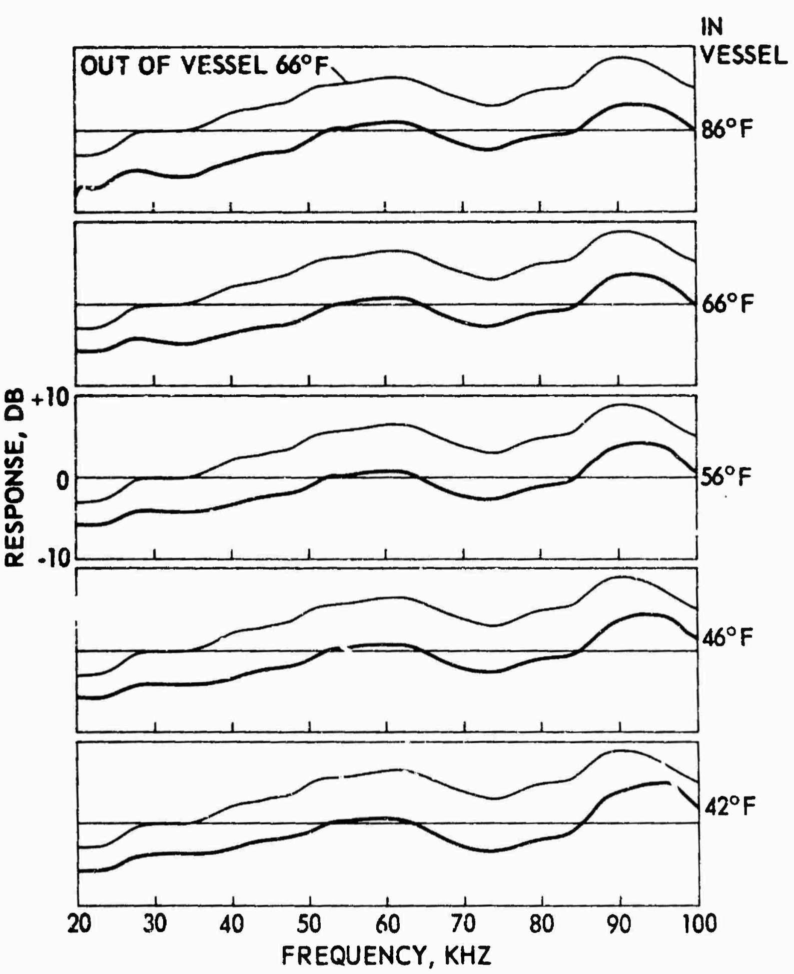

Figure 8. Transducer response at various temperatures.

MEASUREMENT TECHNIQUES

For frequencies above $f_{kHz} = 4/t_{wall}$, the signal should be pulsed (fig. 9). This technique permits the incident signal to be gated, thereby rejecting internal reflection. This is also the frequency spectrum where increased attenuation occurs. At lower frequencies the wall attenuation is less; hence, the reflections are minor. Also, the wavelength is too long at lower frequencies for effective use of the pulse method.

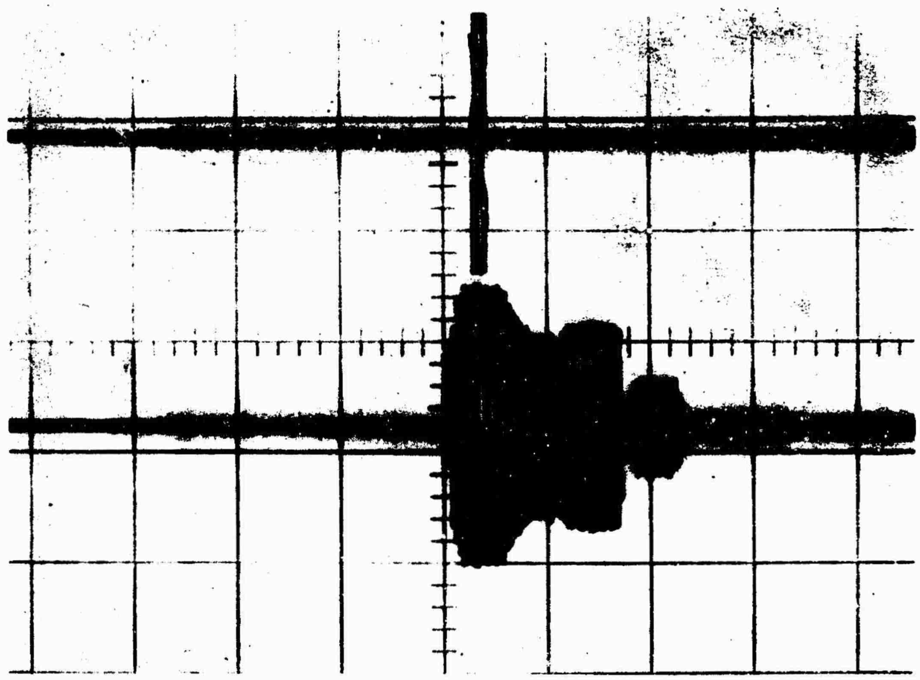

Figure 9. Pulsed signal. Bottom portion of figure is ungated received signal within the capsule showing effect of reflection. Top portion is the gated portion of the signal, which shows true transducer response.

Acoustic measurements are obtained by following three steps. (1) Make the desired measurements on the transducer when it is mounted to the vessel cap and in position on the main column; (2) repeat the measurements with the vessel in position around the transducer (no pressure differential); and (3) again repeat the measurements at the desired pressure, temperature, or both (fig. 10).

The difference between the measurements of steps (1) and (2) provides information on the effect of the presence of the vessel around the transducer under test. The difference between the measurements of steps (2) and (3) is the effect of pressure/temperature. When the measurements of step (1) are corrected by the difference between the measurements of steps (2) and (3), the true effect of pressure/temperature on the absolute response or polar pattern of a transducer is obtained.

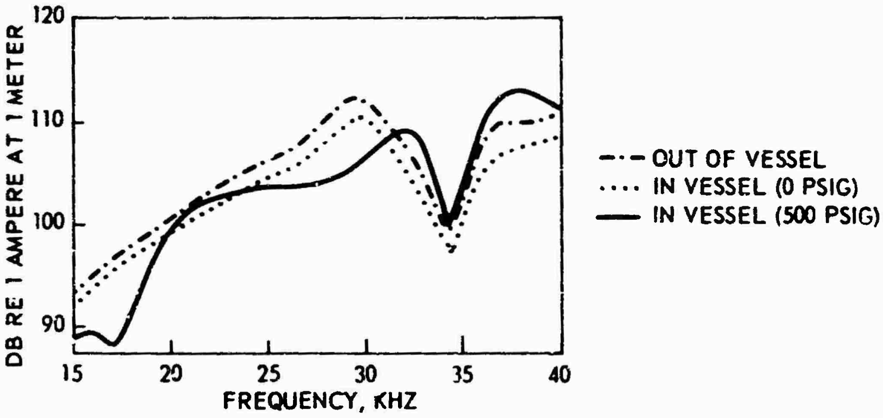

Figure 10. Transmitting response, B24FA transducer.

The complex impedance of a transducer in the vessel can be obtained by making a pulsed impedance measurement (fig. 11). An electronic system capable of making these measurements is in operation at NUWC Transdec.

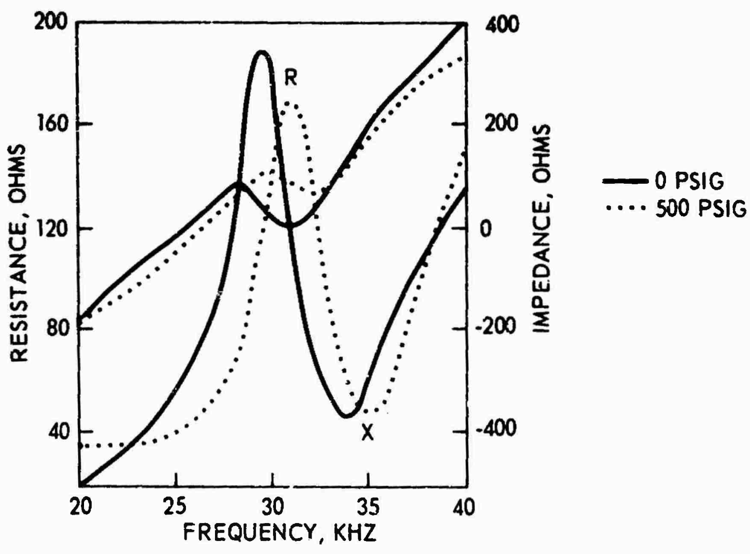

Figure 11. Complex impedance, B24FA transducer.

CONCLUSIONS

The acoustic pressure vessels can be used on the regular calibration column for testing frequency response, directivity, and impedance of transducers. Water pressure and temperature can be controlled for the period of time that is required for measurement. The effect of the presence of the vessels is negligible for low frequencies and predictable for higher frequencies. Calibration can be accomplished by cw or pulse techniques at lower frequencies. Pulse techniques must be used where the signal loss at the transducer under test is greater than 1 dB.

APPENDIX: PRESSURE-VESSEL SPECIFICATIONS

OPERATING PRESSURE, PSI	800	2000	10,000
FREQUENCY RANGE, KHZ	.02 - 500	.02 - 250	.02 - 100
ACCESS DIAMETER, INCHES	20	20	6
VESSEL DIAMETER, INCHES	30	36	18
CYLINDER LENGTH, INCHES	36	60	36
HANDLING WEIGHT, TON	1	1	½
WATER PUMP, SPRAGUE	S-216-C-10	S-216-C-60	S-216-C-150
STEEL		4340	
GLASS FIBER		Corning S99-4	
RESIN		Union Carbide ERL-2772	
DRAIN VALVE		Atkomatic EWPCV	
ELECTRICAL CONNECTIONS		Marsh Marine XSK 3 PML	

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13. ABSTRACT

Three glass-epoxy vessels with favorable acoustical properties designed to house transducers under test provide maximum operating pressures for long-term cycling of 800, 2000, and 10,000 psi. Temperature range is 38° to 90°F. Maximum operating frequencies of the three vessels are 500, 250, and 100 kHz.

Tests of the B24FA transducer, reported in NEL report 1301, indicate marked difference in transmitting response at depth.

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