THE USE OF A SPARSE PLANAR ARRAY SENSOR FOR MEASUREMENT OF THE ACOUSTIC PROPERTIES OF PANEL MATERIALS AT SIMULATED OCEAN CONDITIONS

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Abstract: *Characterisation of the acoustic properties of materials for underwater acoustics is often carried out by measuring the transmitted and/or reflected pressure signals after insonification of a test panel by an incident acoustic wave. For this method to be reliable, the incident and transmitted (or reflected) signals arriving at the hydrophone receiver should be well separated in time (enabling windowing techniques to be applied), and the diffracted signals from the panel edge should not contaminate the measured signal. At low kilohertz frequencies, these conditions are difficult to achieve for the size of panel and test tank commonly available. This paper describes a method for discriminating against the diffracted signals by use of a planar array of hydrophones as the receiver. The sound source used for the method is a parametric array to provide some source directivity and to provide short broadband signals for analysis. The method is demonstrated by application to the measurement of reflection loss and transmission loss for test panels at frequencies of 1 kHz to 10 kHz under simulated ocean conditions using a specialised test chamber capable of controlling the water temperature and hydrostatic pressure during measurements. A comparison is shown with results obtained with a single hydrophone, and a discussion is given of the number and position of hydrophones in the array.*

Keywords: *Reflection loss, transmission loss, simulated ocean conditions, panel measurements*

1. INTRODUCTION

A common requirement in underwater acoustics is to determine the acoustic properties of materials used as absorbers and windows, in particular in terms of reflection loss and transmission (insertion) loss [1]. Many materials of interest are viscoelastic and exhibit a variation in performance when subjected to a change in environmental conditions. It is therefore necessary to characterise the materials at the environmental conditions at which the materials will be used. The Acoustic Pressure Vessel (APV) at the National Physical Laboratory (NPL) in the UK provides the ability to conduct acoustic testing at simulated ocean conditions in a controlled laboratory environment. However, the APV will accommodate test panels of only moderate size, and with the test chamber's finite physical size and internal geometry, this introduces limitations which restrict the lowest frequency of measurement.

The characterisation of the test panel is performed by insonifying the test panel with an incident wave from a source transducer. In the case of the method described here, a parametric array is used as the acoustic source. The hydrophone receivers are positioned either in front of the test panel to determine the reflection loss, or behind to determine the transmission loss. Reference measurements without the test panel being present are then conducted (and signal subtraction performed to obtain the reflected signal in the case of reflection loss). Comparison of the relative signal changes between the "with-panel" and the corresponding reference measurements allow for the transmission loss and reflection loss to be derived. The parametric array provides some source directivity to mitigate reflected signals from the test chamber panel support structure and diffracted signals from the panel edges. However, interference from diffracted signals from the panel edge can still be observed, and are especially problematic at low kilohertz frequencies. To improve performance, a directional receiver is employed in the form of an eight element pseudo random array. This is in place of a single hydrophone that would normally be used for higher frequencies of interest (greater than 10 kHz). With this arrangement, it is possible to conduct measurements down to as low as 1 kHz (depending on panel performance). In the following section, a description is provided of the acoustic source, the single hydrophone and array receivers, the experimental set up and the test panels measured, and finally the results.

2. EXPERIMENTAL SET UP

The basic experimental set up for the work undertaken here has been described in previous scientific publications [2].

2.1 Parametric array source

A parametric array is used as the acoustic source for the work described here [3]. Such a source uses the non-linear propagation of primary wavefields to generate additional lower frequency (secondary) components that are then used to insonify the test panel. Such a source has the advantage of producing a more directional sound field than would be possible from a linear source of similar size. In the NPL arrangement, the primary transducer is driven with a short pulse of 300 kHz carrier frequency, with a raised cosine bell envelope. The low-frequency secondary waveform generated on axis can be shown to be proportional to the second derivative, with respect to time, of the square of the transmitted pulse envelope [3]. The generated waveform shape and spectrum is then easily modified by altering the envelope function. In practice, for parametric array measurements in confined spaces, it is necessary to limit the length of the interaction region of the primary beams, which is achieved by placing a panel of absorbing material, known as the acoustic filter, across the field at some distance from the source transducer to absorb the high-frequency primary beams and transmit only the low-frequency beam [3].

2.2 Experimental configuration

The APV consists of a cylindrical tank of external dimensions 7.6 m long by 2.5 m in diameter [2]. The tank may be pressurized to simulate increased water depth up to a maximum hydrostatic pressure of 68 bar. The facility also allows the water temperature to be controlled in the range from 2 ºC to 35 ºC. There are two access ports, the centres of which are 2.4 m apart. A diagram of the arrangement inside the vessel is shown in Fig. 1.

A mounting arrangement enables the receiving hydrophones to be positioned at any preferred distance from the panel face in the range from 0 m to 0.4 m. Typically, when using a single hydrophone receiver, the hydrophone is mounted either in front or behind the test panel (for reflection or transmission respectively) with one side of the panel measured at a time. The parametric array consists of the 300 kHz piezoelectric source transducer placed at the end of the vessel, with array truncation provided by the acoustic filter (a 35 mm thick Expancel-filled polyurethane sheet). The separation between the source transducer and the panel under test is 2.75 m and the acoustic filter is normally 1.88 m from the transducer [2].

The simplest method of capturing the energy incident upon, reflected from and transmitted by the test panel is via a single hydrophone placed on either side of the test object [2]. Spectral analysis is then performed on the time histories, from which the reflection and transmission loss can be calculated [2] from the incident, reflected and transmitted pressure waves (p_i, p_r, and p_t) by

$$R(f) = -20\log_{10}\left(\frac{p_r(f)}{p_i(f)}\right), \text{ and } T(f) = -20\log_{10}\left(\frac{p_t(f)}{p_i(f)}\right), \qquad (1, 2)$$

where R is the reflection loss, T is the transmission (insertion) loss and f is frequency.

The time history containing the reflected pressure wave also contains the incident signal. Ideally, the hydrophone would be placed in such a position that it would be possible to time resolve the incident and reflected signals; however, at the low kilohertz frequencies of interest, there is additional contamination to the reflected signal from diffracted signals from the panel edges and reflected signals from the vessel boundaries and panel mounts. It is, therefore, necessary to subtract from the reflection time history an incident signal recorded at the same point and under the same conditions without the test panel present (the latter being termed the “reference” measurement). Because the reflected signal has travelled further than the incident signal (twice the separation between the measuring hydrophone and the test panel), it is necessary to correct the reflection loss for the reduction in signal amplitude due to the extra distance travelled [2]. When measuring the transmission loss, it is not possible to capture the incident signal at the measurement point behind the test panel, and for this reason a separate measurement must be made to capture the incident signal without the test panel present.

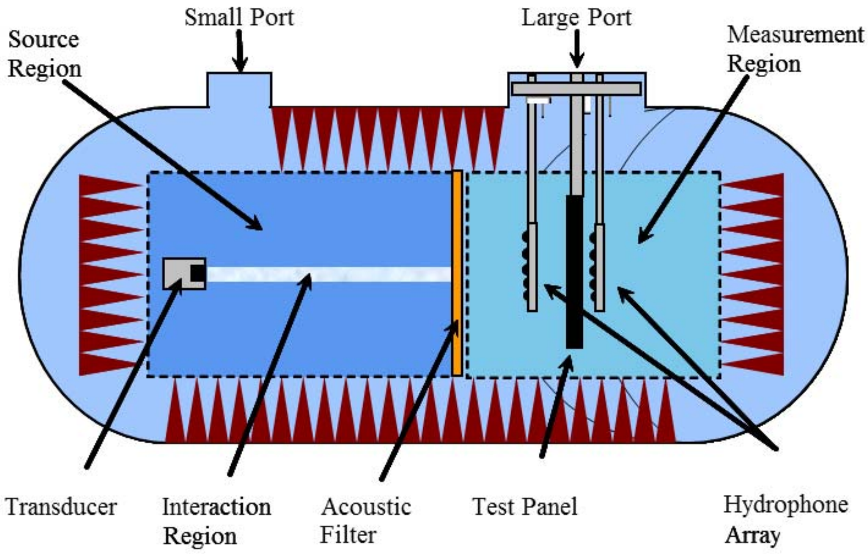

Figure 1: Schematic diagram of the measurement configuration in the APV, showing location of transducer, acoustic filter, test panel and receive array.

2.3 Test panel

Measurements were conducted on a test panel designed to have suitable performance in the frequency range 1 kHz to 15 kHz. This was 800 mm wide, 900 mm high and 125 mm thick. The test panel was designed and manufactured by QinetiQ Ltd and consists of a two layer acoustic absorber fabricated from polyurethane to which Expancel spheres had been added as a filler material.

3. HYDROPHONE RECEIVE ARRAY

The acoustic pressure wave generated by the truncated parametric array can be readily acquired and time resolved by a single hydrophone under free-field conditions. However, measurements in the APV are not true free-field measurements, particularly when a test panel is present, and the benefit obtained by additional directivity from the parametric array source is substantially reduced at frequencies below 10 kHz. Since the signals of interest are plane waves travelling in directions orthogonal to the panel surface, and the contaminating signals are predominately travelling in directions across the panel at significant angles (from panel edges or vessel walls), it is possible to utilise a directional planar array to select the plane wave components of interest [4,5].

The planar array used is constructed from eight Neptune Sonar T293 spherical hydrophones of approximately 20 mm diameter, which are mounted using a mount which is acoustically transparent at frequencies below 10 kHz (a thin 0.6 mm diameter cord and a 550 mm square aluminium frame). Figure 2 shows the experimental arrangement. The configuration is a pseudo random, 2D arrangement covering an area of approximately 0.4 m^2. Measurements are performed by capturing the hydrophone signals using simultaneous capture on an etec B2008 eight channel charge amplifier and a National Instruments multifunction DAQ using bespoke LabView software. In the analysis, an average is initially calculated across the eight channels and the resulting waveforms averaged over a number of pulses. The subsequent analysis followed that of the single hydrophone pressure technique described in [2].

To examine the potential benefit of using a receive array and to determine the optimum number of elements in the array, a simulation was undertaken [6]. Synthetic array data were collected with a hydrophone scanning a square area in a plane parallel to the front and the back of a smaller test panel. This simulation was undertaken experimentally in an open tank facility fitted with an automated positioning system under computer control. A Reson TC4035 hydrophone (1.6 mm element) was scanned in front and behind a test panel consisting of a single layer of Expancel filled polyurethane sheet (thickness: 25 mm; width: 300 mm; height: 313 mm), backed with a 4 mm aluminium plate. A plane piston transducer with a centre frequency at 1 MHz was used to generate parametric signal for the measurements, the transmitted signal modulated by a single cycle of a raised cosine signal to give a centre frequency of the secondary pulse at 30 kHz. An acoustic filter was used to remove the primary signal before it reached the panel [6]. Using the scanned hydrophone data, it was possible to perform a simulation of a planar array placed before and after the panel using varying numbers of elements in varying positions (the transmission and reflection loss can be derived from these data sets with any combinations of elements). The performance of random arrays with different number of elements was then assessed with the data in terms of a normalised standard deviation for the measurements [6].

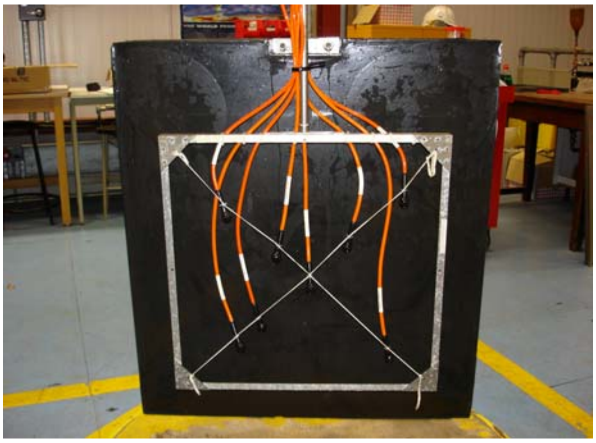

Figure 2: Hydrophone array consisting of eight hydrophones in the measurement position for the test panel (left).

4. EXPERIMENTAL RESULTS

4.1. Simulated array performance

A simulation was carried out to assess the performance of random array for use as receivers in panel measurements. Using the scanned data, the elements of the random arrays were selected randomly within a smaller area inside maximum scan ranges. Figure 3 shows the measured transmission loss with a number of planar arrays and with the centre element alone. The planar array was formed with all the elements with their signal levels in the reference signal greater than 3 dB to have a good signal to noise ratio for all the selected elements in the calculation of transmission loss. The solid lines in the figure are for the data with all the elements in the planar arrays, while the dash and dotted lines are for the centre element of the arrays. The results with the arrays are close to expected values, while spread is much more with a single element for the transmission loss.

A planar array is very costly in practice, so a random sparse planar array may be a good alternative if the performance is close to a planar array while the number of elements is significantly fewer. A reasonably large ensemble of 50 random arrays was formed to provide reliable results. The standard deviations of the measured reflection and transmission loss were normalised with averaged reflection and transmission loss, and plotted as function of the element numbers in a random array in Figure 3. The spread of results decreases quickly with increase of number of elements initially, and then approach a constant as the number exceeds 10. Considering the cost effectiveness and practicalities of the technique, an optimum number of eight elements is a reasonable choice where the residuals variation is low but the number of elements in the array is reasonably small.

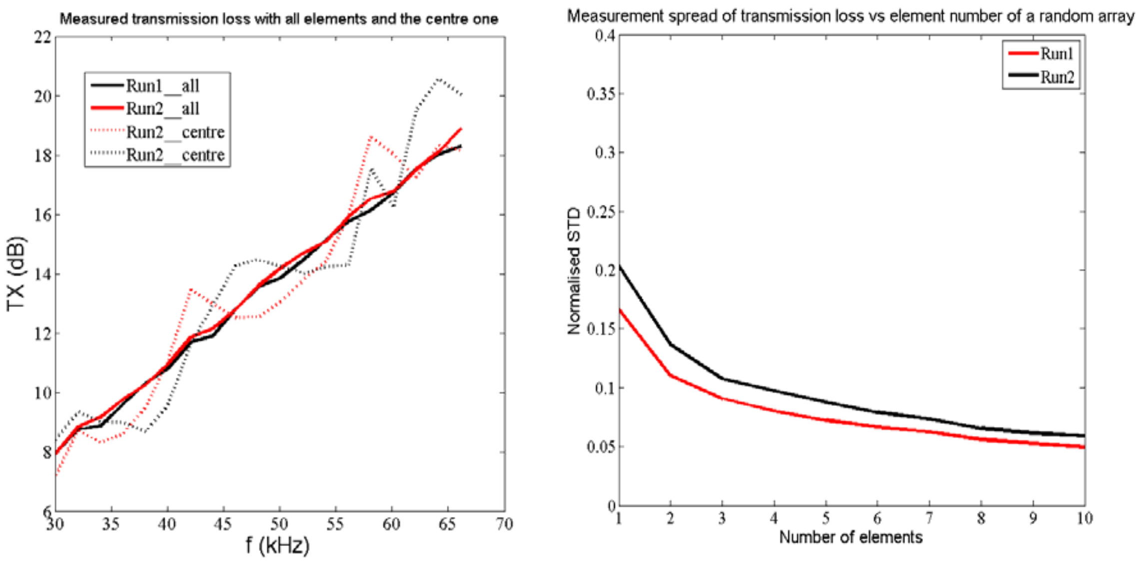

Figure 3. Measured transmission loss with all array elements and the centre element (left) and measurement spreads for transmission loss with different number of elements.

4.2. Test panel results

Figure 4 shows the results obtained from the test panel for reflection loss in the range 1 kHz to 12 kHz at water temperatures of 8 °C and 20 °C. Also shown are results for 0.1 MPa (1 bar; atmospheric pressure), absolute hydrostatic pressures of 0.7 MPa (7 bar; approximately equivalent to 60 m water depth), and 1.4 MPa (14 bar; approximately 130 m water depth) and for a temperature of 20 °C. As can be seen, an overall level of reflection loss at higher frequencies of approximately 10 dB is observed, with some dependence on hydrostatic pressure and temperature.

The results also show several peaks in the response, due to thickness-mode resonances of the panel. The peaks change as pressure is applied to the panel, reducing in amplitude and changing in frequency, and do so in a predictable manner (from knowledge of the behaviour of the material properties with temperature and pressure) [7].

When compared to the use of a single hydrophone receiver, the array offers additional discrimination against unwanted signals arriving from high angles (e.g. diffraction from panel edges, scattering from mounts). When using a single hydrophone it is not possible to so clearly observe the peaks in the structure of the reflection loss at low kilohertz frequencies.

The array offers additional rejection of diffracted and parasitic reflected signals, but requires greater processing (using eight hydrophone channels). It must also be noted that there is insufficient frequency resolution to accurately define the low frequency peaks.

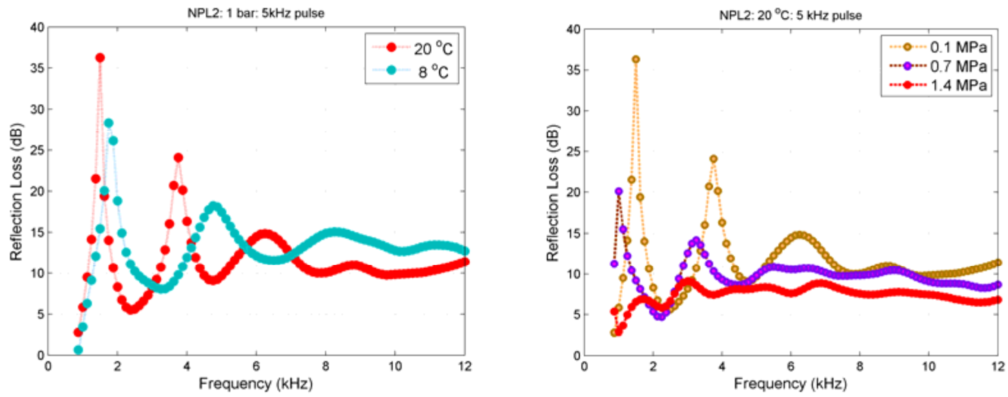

Figure 4. Results for the test panel using the receive array for reflection loss for water temperatures of 8 °C and 20 °C at atmospheric pressure (left), and for hydrostatic pressures of 0.1 MPa, 0.7 MPa, and 1.4 MPa at a temperature of 20 °C.

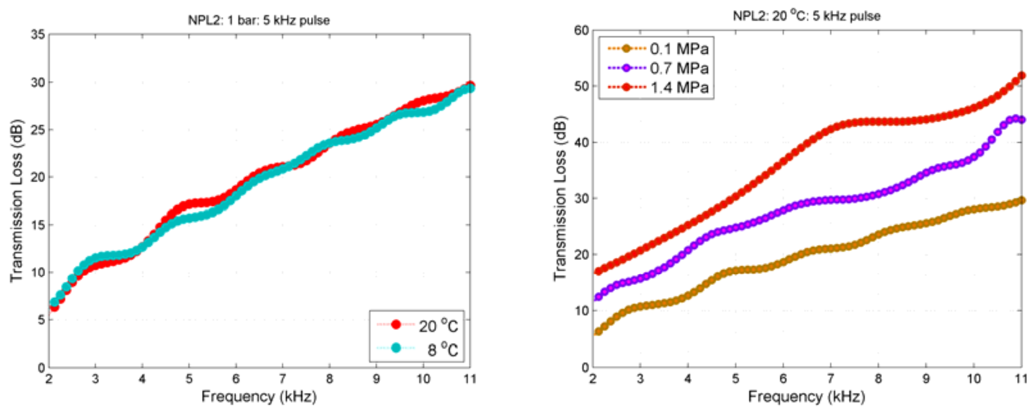

Figure 5. Results for the test panel using the receive array for transmission loss for water temperatures of 8 °C and 20 °C at atmospheric pressure (left), and for hydrostatic pressures of 0.1 MPa, 0.7 MPa, and 1.4 MPa at a temperature of 20 °C.

Figure 5 shows the results obtained from the test panel for transmission loss in the range 2 kHz to 11 kHz at water temperatures of 8 °C and 20 °C. Also shown are results for 0.1 MPa (1 bar; atmospheric pressure), and hydrostatic pressures of 0.7 MPa (7 bar; approximately equivalent to 60 m water depth), and 1.4 MPa (14 bar; approximately 130 m water depth) and for a temperature of 20 °C. As can be seen, the transmission loss is frequency dependent rising from about 6 dB at 2 kHz to 30 dB at 11 kHz (at atmospheric pressure). Increased transmission loss is observed at elevated hydrostatic pressure. This response change is predicted from knowledge of the behaviour of the material properties with hydrostatic pressure [7]. Some fluctuations are still observable in the transmission loss curves, and this is possibly the results of the influence of residual diffracted signals from the panel edges (the fluctuations being much greater for a single hydrophone receiver).

5. CONCLUSIONS

The method described in this paper has been shown to be capable of determining the reflection and insertion coefficients of panel materials at low kilohertz frequencies. By using both a directional source and receiver it is possible to provide some discrimination against unwanted signals that are diffracted from the panel edges and reflected from the tank boundaries. This enables panels of modest size to be measured at frequencies as low as a few kilohertz. The results presented here demonstrate their successful use to assess the properties of a test panel exhibiting transmission loss of up to 18 dB at 2 kHz and reflection loss containing specific peaks in the range 1.5 kHz to 4 kHz.

6. ACKNOWLEDGEMENTS

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