Broadband Acoustic Reflectivity and its Application to the Characterisation of Materials

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Abstract - Underwater acoustic imaging and classification sonars are being progressively extended into broadband and interest is shifting to higher frequencies for use in shallow waters with particular emphasis on object classification for mine counter-measures. These shifts raise the opportunity to use the frequency-dependent scattering properties of different materials to characterise target composition. Many mechanisms may play a role in the total backscattered signal, including specular reflections, scattering from surface irregularities and multiple resonances (often modified by internal structures). These contain a great deal of unexploited information that can tell us a lot about the nature of the object. The acoustic backscattering properties of an object depend to a large extent on the materials used on the object surface and on its structure, yet little is documented about the broadband reflective properties of common marine materials such as rubber foams, Aluminium, Steel, etc., in open literature. In this paper, we explore the reflective properties of these materials over a range of frequencies and incident angles through direct measurement via ensonification by a broadband source in an acoustic tank. An experimental set up is described that can record the reflected energy over a several discrete angles simultaneously. Compact source pulses are used to permit multiple reflections from tank walls and the free surface to be separated out.

I. INTRODUCTION

An underwater object returns acoustic energy in a number of ways. These include specular reflections, resonant returns and scattering by surface irregularities. In a nutshell it is possible to characterise the underwater object just by looking at the acoustic echoes from them. Different materials have different reflectivity due to variations in their acoustic impedance and a general theory for characterising the target strength of materials as a function of the scattered energy is given in [1]. Acoustic characterisation of some viscoelastic materials like polyurethane mounted on an aluminium plate has been described in [2]. There, the authors have measured the reflection coefficient and the losses of acoustic energy in the material at different frequencies using a parametric sonar. Sound scattering from small rectangular submerged plates with thin acoustic coatings has been treated in [3]. A theory based on the Geometrical Theory of Diffraction (GTD) has been derived and some numerical results have been given. The experiments conducted is limited to low frequencies (max 12.5 kHz) and applied only to a rectangular steel plate. In [4] the acoustic scattering strength of submerged aluminium plates of rectangular and circular geometry has been measured for different surface roughness at a single frequency (192.3 kHz). The variation of scattering strength for different bottom types (fine sand and limestone) in an acoustic tank has also been measured.

The broadband reflectivity of submerged materials and their combinations in layers has not been treated and documented well to the best of our knowledge. We employ targets made of layers of different materials in our ambient noise imaging (ANI) experiments and it is believed that the results from these studies will be useful in interpreting the images from the ANI system. The main objective of this study is to understand how the reflected acoustic energy varies with frequency and as a function of scattering angles for different materials and their combinations. In this paper the results obtained from reflectivity experiments conducted in an acoustic tank using materials like aluminium, closed cell neoprene foam and Klegecell and their combination are discussed. An experimental set up well suited for such measurements in an acoustic tank is also described.

II EXPERIMENTAL DETAILS

Under this section the experimental set up used and the methodology adopted for the conduct of experiment are discussed. The experiment was performed in a 2m x 2m x 2m acoustic tank, with wooden lining, available in the laboratory. Due to the small dimensions of the tank a special set up had to be used to create a plane wave and also to separate direct arrivals and reflections from the test panels from among other multi-path arrivals.

A. Test set-up

The test set-up used is shown in figure 1. A parabolic reflector with a hydrophone mounted at its focus was used as the transmitter. This ensured that a focussed plane wave directed towards the reflecting panel was available. TC-4013, a miniature broadband hydrophone manufactured by Reson., Inc., was used both for the transmission and reception of acoustic signals. Four receiving hydrophones were mounted at different angles but along the same line as shown in figure 1, so that we could measure the acoustic energy scattered at different

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angles from the reflective panel and at the same time measure the direct arrivals from the transmitter. The hydrophones were mounted on a sliding rail to make their positioning easier. The data acquisition system employed a 4-channel data acquisition card namely PC-6115 from National Instruments. The system can sample the input at a rate of 1 M Samples per second per channel. This card was plugged into the PCI slot of a 2 GHz PC operating under Windows 2000. The card can be programmed to generate analog output signals on two of its output channels. A Matlab program was written for generating the signals for transmission and also for receiving and analysing the received signals. A custom 4-channel preamplifier was built to amplify the signals from the hydrophone before sending them to the input of the data acquisition card. A G.R.A.S Sound and Vibration 30AA model power amplifier was used to amplify the signals generated before sending them through the transmitting hydrophone. A photograph of the test set up is shown in figure 2.

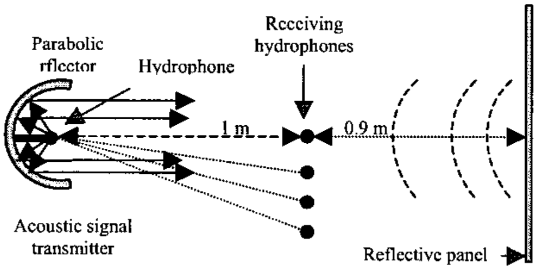

Fig.1 Experimental set up for the reflectivity measurements

B. Methodology and Procedure

A broadband m-sequence pulse of 0.4 ms was used as the transmitted signal. An m-sequence signal was selected due to its high correlation properties so that the multi-path arrivals can be discriminated by cross correlating the transmitted signal with the received signals. The signal was centered at 50 kHz and was spread in such a way that most of the signal energy was in the 30 to 80 kHz range. The on-axis receiver was placed at about 1m away from the acoustic centre of the transmitter and the reflective panels were mounted approximately 0.9m from the on-axis receiver and behind them. Other receivers were placed at angles 10, 20 and 30 degrees to the line joining the acoustic centre of the transmitter and the on-axis receiver to record specular reflections and or energy scattered from the material, if any. The signal duration and the receiver – transmitter separation were selected in such a way that the direct arrivals and the reflections from the panels arriving at the receiving hydrophones are well separated in time. Initially the signals received at the four hydrophones were recorded without any reflective panels. The experiment was then repeated for different reflective panels of 1m x 1m size, deployed at the back of the receivers. In this experiment we used four different types of panels namely, aluminium, aluminium with neoprene sponge on its reflecting face, aluminium with Klegecell on its reflecting face and aluminium with neoprene foam on one side and Klegecell on the other side. These materials and their combinations were selected as we plan to use them in an ambient noise imaging experiments and the data on their acoustic reflectivity will be useful in interpreting the images from those experiments. The different panel configurations employed and their dimensions are given table 1.

Table 1 Reflective panels-materials, dimensions and configurations

Panel material	**Configuration**	**Thickness**
Aluminium	Alone	3 mm
Aluminium and Neoprene	Neoprene glued to aluminium panel and acting as the reflecting face	Aluminium-3mm Neoprene-6mm,10mm and 15 mm
Aluminium and Klegecell	Klegecell glued to aluminium and as the reflecting face	Aluminium-3mm Klegecell-6 mm and 15 mm.
Aluminium, Klegecell and Neoprene	Neoprene glued to one face and Klegecell glued to the other face of aluminium.	Aluminium-3 mm Neoprene-6mm Klegecell-15 mm

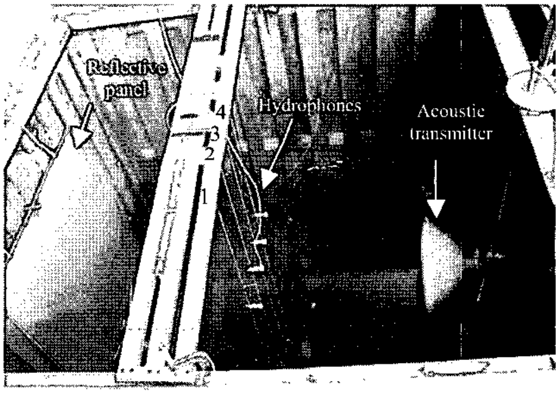

Fig 2 Photograph of the experimental set up

The first step was to ensure that the set up did produce a plane wave. We measured the time of arrival of transmitted signals at the two hydrophones in the direct beam of the transmitter and found that they arrive at the same time. We also measured the power spectral density of the direct arrivals at the four hydrophones and found that there is no appreciable energy in the third and fourth hydrophone as compared to the first two hydrophones. Thus we were able to achieve a well-focussed plane wave in the band of interest for our experiment.

III RESULTS FROM EXPERIMENTS

The main objectives of the experiment were to see how different is the reflectivity of neoprene and Klegecell as compared to aluminium and how it varies with their thicknesses. Also we wanted to see how a composite structure of Klegecell and neoprene on either side of an aluminium plate behave as we had used one such panel in an earlier imaging experiment as targets. Yet another objective was to find out whether these materials give rise to any specular reflections. In the following paragraphs we present the results obtained from the experiment and in the next section the analysis of results are presented.

A. Variation of reflectivity with material thickness

A typical time series of the signals received at the hydrophones is shown in figure 3. In this figure, the first section of the time series is the direct signal received from the transmitter followed by the reflections from the panel at the first hydrophone. The third signal is reflected signal refocused by the parabola back at the first receiver and so on. Similar recordings were observed at other hydrophones as well but with signal strength falling as we move away from the aperture of the parabola. The signals were analysed for their power spectral density (PSD) and compared with the PSD of the direct arrival at the first hydrophone. As the transmitted signal was a focussed plane wave and the attenuation over the separation between the panel and the first hydrophone is negligible, we could consider the direct arrival at the first hydrophone as equivalent to the incident power but for the spreading loss.

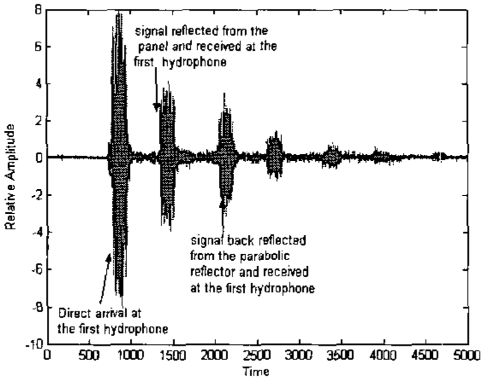

Fig 3 Time series of typical received signal chain

1) Neoprene on aluminium panel

Measurements were made using a 3mm aluminium panel with neoprene sheets of different thicknesses pasted on it. The power spectral density of the reflected signal at the first hydrophone (back reflected signals) is shown in figure 4.

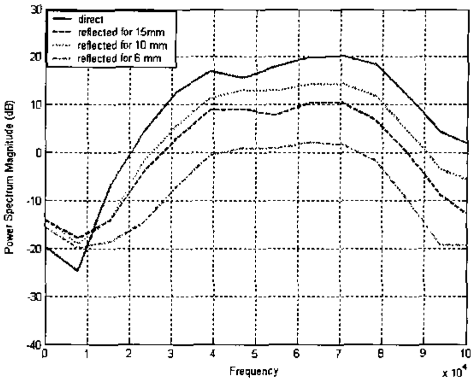

Fig 4: Variation of broadband reflectivity of neoprene with its thickness. The neoprene sheet was mounted on a 3 mm aluminium sheet. For comparison a direct arrival is also shown in the figure.

2) Klegecell on aluminium panel

Klegecell is another material which has been used as an acoustic reflector in underwater applications. We have carried out measurements on Klegecell of two thicknesses, 6 mm and 15 mm mounted on a 3 mm aluminium plate. The PSD of reflected signals and the reference signal are shown in figure 5.

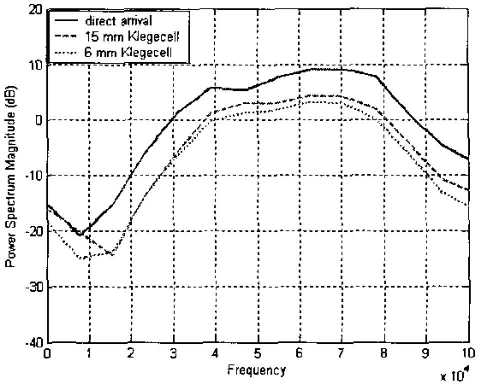

Fig 5: Variation of reflectivity for Klegecell of different thickness. The direct arrival is also shown for reference

B. Comparison of reflectivity for different materials

In this section we look at the variation in the reflectivity of different materials like aluminium, neoprene and Klegecell as a function of their thicknesses. The configurations tested include a 3 mm thick aluminium panel and 6 & 15 mm neoprene and Klegecell sheets mounted on the 3 mm aluminium panel. The results of experiments are summarised in figures 6 and 7 respectively.

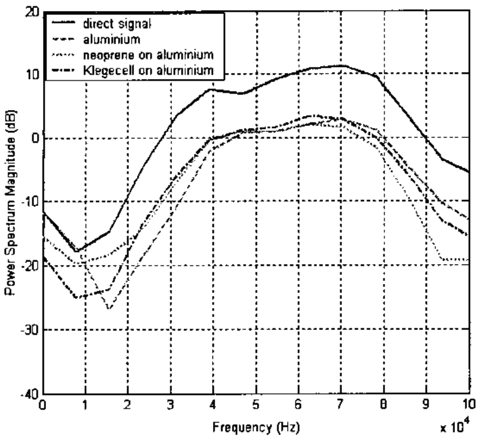

Fig 6: Variation of reflectivity for different materials. The signal received directly from the transmitter at the first hydrophone is also shown for reference.

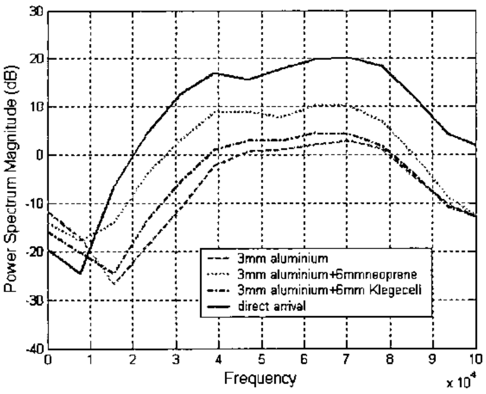

Fig 7 Variation of reflectivity for different materials. Note that both neoprene and Klegecell has more than twice the thickness than in figure 6.

C. Specular reflections

To check how specular the reflections are we plotted the PSD of various signals arriving at different hydrophones (placed at different angles with respect to the normal). These results are summarised in figures 8, 9 and 10 for materials aluminium, neoprene and Klegecell respectively.

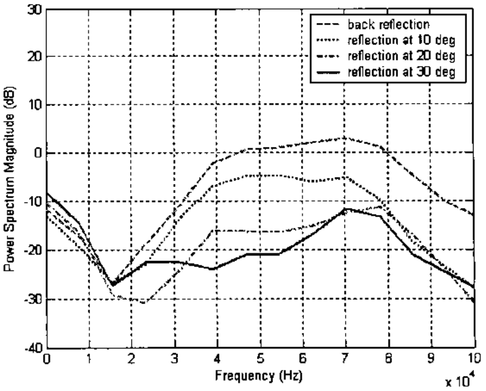

Fig 8 Variation of reflectivity of aluminium for different reflected angles.

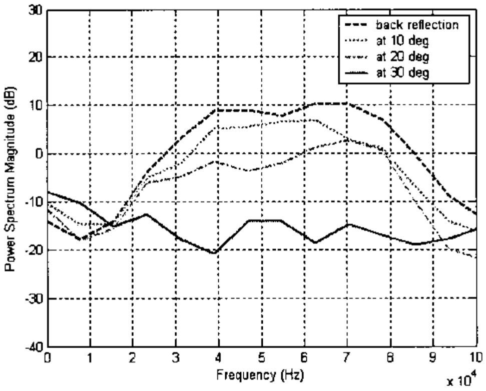

Fig 9 Variation of reflectivity of neoprene for different reflected angles

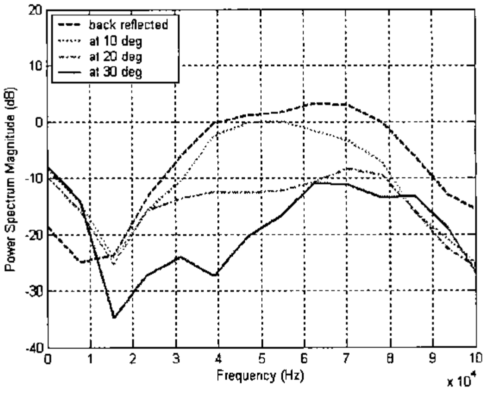

Fig 10 Variation of reflectivity of Klegecell for different reflected angles

IV DISCUSSION OF RESULTS

It is observed that the reflectivity has increased with material thickness both for neoprene and Klegecell (see figures 4 & 5). However the increase is marginal for Klegecell material as compared to the neoprene. It is also seen that the reflectivity increases by 10 dB when the material thickness is increased from 6 mm to 10 mm while another increase of 5mm in thickness had resulted only an improvement of about 5 dB (see figure 4). So we draw the conclusion that neoprene will be a better reflector compared to Klegecell and there is an optimum thickness for neoprene beyond which the reflectivity does not increase. Figure 7 also shows similar results. By comparing with the direct arrival (or incident reference signal) we can also see that there is no frequency dependence on the reflectivity for these cases.

Yet another observation is that the reflectivity does not improve for small material thickness as compared to the mounting aluminium panel itself (see fig 6). Here a 3mm aluminium panel shows almost the same sensitivity as a 6mm neoprene or Klegecell mounted on a 3mm aluminium panel.

Comparing the results shown in figures 8, 9 and 10 we see that for both neoprene and Klegecell there is appreciable energy (almost the same as that at the first hydrophone) reaching the second hydrophone, which is 10 deg away from the normal. The second hydrophone also receives some part of the back reflected energy since it is not far away from the beam. Nevertheless in comparison with the aluminium panel, Neoprene and Klegecell reflecting surfaces mounted on the aluminium plate scatters more energy in directions other than the specular angle. An interesting thing that can be said about the neoprene is that the scattered energy at the specular angle is independent of the frequency whereas for aluminium and Klegecell we see that the scattered energy falls off as the frequency goes up.

V CONCLUSIONS

In this paper we have described an experimental technique, which can be used in small tanks for reflectivity measurements. The measurements showed that we achieved a reasonable plane and focussed wave from the transmitter. The signal design and the set up had taken care of multi-path problems that otherwise would have prevented the conduct of this experiment in the tank. Results obtained from some measurements on different materials like aluminium, Neoprene and Klegecell have been given and some conclusions on the broadband reflectivity of these materials have been arrived at. More experiments are planned with varying material thicknesses and for different angles of incidence to learn about the reflectivity changes. A model that would explain the behaviour the material is also under development.

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