In situ characterisation of materials using parametric sonar

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Introduction

Parametric sonar techniques have been intensively used in underwater acoustics since the early sixties for bottom observation: both qualitative (geometrical structure of the sub-bottom) and quantitative (impedance estimation) measurements [1 to 4]. Nevertheless, the application to airborne acoustics was envisaged more recently (in the eighties) [5], [6]. The principle consists in transmitting two primary high frequency signals at high power in order to generate a low frequency directive source. An airborne sonar system has been developed in order to characterise acoustics material in situ. As characterizing insulation panels in a factory (in the presence of noise and multipaths) is similar to the characterisation of sea sediment in situ, similar sonar approaches have been used. In particular, the parametric array principle has been used to generate low frequency chirps and gain in signal to noise by pulse compression [7]. Several results will be presented using an airborne parametric sonar for the characterisation of acoustic foam (insulation panels) in both transmission and reflection modes. The data obtained with this equipment will be compared to the results obtained with conventional methods (in a reverberation room) for a wide band of frequency in an ordinary computer room of a few square metres. The final objective is the in situ characterisation of installed materials in order to validate the installation, to detect defective panels and/or to study the aging effect.

Parametric arrays

The parametric arrays benefit from the non-linear propagation of high intensity acoustic wave that can transform, by the process of harmonic and sub-harmonic generation, a highly directive high frequency wave (primary wave) into a highly directive low frequency wave (secondary wave). The efficiency of this transformation process depends on the size of the transducer, the frequency and sound level of the primary wave and step down ratio (ratio of the high and low frequencies).

Although the non-linear physics of parametric arrays is rather complex, from a user point of view, it can be summarized in a simple manner:

- The low frequency directivity pattern is comparable to the high frequency one; i.e. a narrow angle of aperture can be obtained with a small array. Variation of directivity pattern, in low frequency range, is very small compared to a conventional (linear mode) array.

- The low frequency Q factor is much lower than the high frequency one (due to frequency shift).

- The price to pay is the low efficiency (non-linear propagation is a second order effect compared to the linear one). The efficiency is inversely proportional to the step-down ratio.

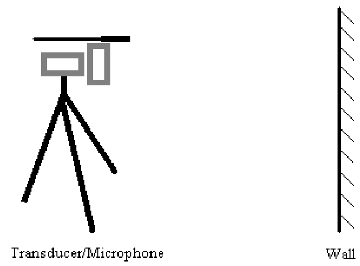
Parametric array concept has been studied for decades and used for many applications in underwater acoustics [1 to 4]. The different operating regimes have been pointed out experimentally in water and the results have been published in the open literature.

The possibility of exploitation of parametric arrays for air applications has been demonstrated and few applications came out this last decade [5], such as audio spots [6].

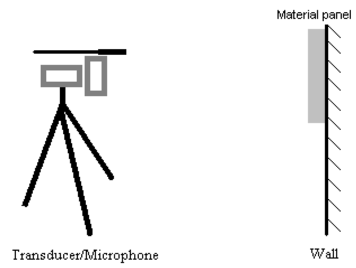
This paper considers their application to spot measurement of acoustical properties of isolation panels.

Experiment description

The experiment conducted for panel description is described in figure 1. Both transmitter and receiver are fixed on a tripod in the backscattering geometry. Prior to the analysis of a panel echo, the system was calibrated thanks to a perfect reflector (smooth wall) in order to compensate for the system transfer function.



(a)



(b)

Figure 1: Experimental configuration for measuring the reflection coefficient of a suspended panel.
(a) Recording of the reference signal: echo of a perfect reflector at 2m;
(b) Recording of the echo of the tested panel.

The experiment was conducted in a conventional computer room facility (furniture filled) of about 5 meters by 4 meters and 2.5 meters high. The background noise level was about

40 dBA. In addition, the same panels were also tested using conventional methods: reverberant room.

The experimental set-up was rather simple including an arbitrary waveform generator, a high frequency power amplifier, a power ultrasonic transducer, a receiving microphone, a band-pass filter and a digitizing system. Echoes were stored on the computer hard disk for any further processing.

A commercial transducer (Airmar©) was used for the transmission. It possesses the following characteristics: diameter of 10 cm, transmitting sensitivity: S_v= 105 dB ref 1 microPa/V @1m, central frequency: 30 kHz.

A conventional condenser microphone (1/4”) was used for reception.

The measured – 3 dB beam aperture was about 12° (for all frequencies) leading to a measurement spot of about 20 centimetres at 1 meter.

Panels’ echoes were filtered and then pulse compressed leading to an improvement of signal to noise ratio to about 25 dB and an output resolution of about 40 cm (with transmitted signals of 8 ms duration). Figure 2 shows an example of time gated echo. Spectral measurement has been averaged in 1/3 octave bandwidth to be compatible with the conventional ones (i.e. Sabine method).

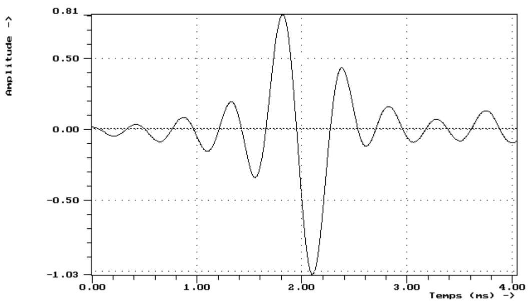


Figure 2: Example of gated a panel echo after pulse compression.

Results

Several panels were tested with various geometrical design:

- Material 1: very soft grey foam, thickness = 10 mm.

- Material 2: Multilayered panel: fibreglass, rigid foam (10 mm thick) and aluminium foil. The thickness of external layers was about 1 mm.

- Material 3: “Waffle” rigid foam with thickness varying from 30 to 50 mm.

- Material 4: multilayered panel: material 3 backed by a hard plastic foil (1 mm thick) and a 155 mm plane foam layer

The results are given in table 1 and compared to absorption obtained by conventional means (Sabine’s method).

	Material 1		Material 2		Material 3		Material 4	
f_0	a_p	a_s	a_p	a_s	a_p	a_s	a_p	a_s
1	0,77	0,41	0,86	1,05	0,84	0,83	0,93	0,96
2	0,98	0,61	0,99	1	0,99	0,93	0,99	0,94
3.15	0,88	0,75	0,99	0,96	0,98	0,99	0,97	0,98
4	0,78	0,83	0,98	1,04	1	1,02	1	1,06
5	0,94	0,95	0,98	1,2	1	1,09	1	1,1

Table 1: absorption coefficient for various central frequencies (in kHz) using parametric array (a_p) or conventional methods (a_s).

Conclusion

The experimental investigations have shown the relevance of using parametric airborne sonar for in situ characterizing of acoustic materials. The comparison between the properties obtained from in situ measurement and those obtained with conventional methods show a good agreement. Some discrepancies are mainly due to sample variability and to the fact that the sonar approach has been restricted to normal incidence. Sonar measurements have been achieved using off-shelf components. They have been run in an ordinary computer room (noise level about 40 dBA) with no specific arrangements of the furniture or absorbers on the walls.

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