Applied Acoustics 85 (2014) 106–110

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical Note

Measurement of sound absorption by underwater acoustic material using pulse-separation method

Liang Sun [a,b,*], Hong Hou [b]

[a] Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[b] College of Marine, Northwestern Polytechnical University, Xi'an, China

ARTICLE INFO

Article history:
Received 13 November 2013
Received in revised form 23 January 2014
Accepted 10 April 2014
Available online 10 May 2014

Keywords:
Sound absorption measurement
Underwater acoustic pulse tube
Pulse separation method
Low frequency

ABSTRACT

An alternative pulse-separation method is presented for measuring the sound absorption at normal incidence of an underwater acoustic material in a water-filled impedance tube. A damped sine pulse was generated in the water-filled impedance tube with a regular waveform and a short duration time of approximately 1 ms. During the generation of the pulse, the inverse filter principle was used to compensate for the transducer response. In addition, the effects of the characteristics of the tube termination can be eliminated during the generation of the pulse to obtain a single plane pulse wave in the impedance tube, which is a necessary condition for this technique. Measurements of the sound absorption coefficient of the rubber material and the reflection coefficient from a water/air interface were used to verify the pulse-separation method.

1. Introduction

The low-frequency sound absorbing properties of an underwater anechoic coating, which is usually fabricated from rubber material, is essential for its engineering use in applications such as submarine stealth. However, there are still many difficulties associated with the measurement of its low-frequency sound absorbing properties. [1]. In general, three types of methods are used for such measurements, including pulse tubes [2,3], two-sensor transfer function techniques [4,5], and active cancellation approaches [6,7]. Recently, the two-sensor-three-calibration technique, which is capable of improving measurement accuracy and precision between 5 and 9 kHz, was adopted by Wilson et al. [8].

The low-frequency water-filled impedance tube testing facility, which is a part of the Low Frequency Facility of the Naval Undersea Warfare Center in Beijing, utilizes the traditional two-sensor transfer function method that can operate between 200 Hz and 4000 Hz. Using this impedance tube instrument, a pulse-separation method is employed here, following the work of Sun and Hou [9,10]. The majority of these studies have been performed in air. Our purpose here is to examine an alternative to the traditional underwater acoustic measuring methods.

2. Experimental setup

As shown in Fig. 1, the experimental setup includes a computer, an NI DAQ6062E data acquisition board, a BNC2029 adaptor, a power amplifier (B&K 2703), a signal conditioner (B&K 2692), and a water filled impedance tube system. A transducer (whose resonance frequency is 1350 Hz with a 3 dB bandwidth over 1200–1500 Hz) is positioned at the bottom of the tube and is utilized as the sound transmitter. Both the sound transmitter and four wall-mounted miniature hydrophones are fabricated from PVDF (poly vinylidene fluoride) sheets. The stainless steel tube is 3.8 m in length, with an inner and outer diameter of 0.208 m (responding to its first cutoff frequency 4183 Hz) and 0.42 m, respectively. The distance between hydrophone 1 and the surface of the projector is 0.1 m. Hydrophone 1, flush mounted into the tube wall, is first used to generate the plane pulse wave, and hydrophone 2 is utilized to measure the sound pressures of the incident and the reflected pulses, at a distance of 0.9 m from the surface of the test specimen. Two other hydrophones, 3 and 4, are used to measure the acoustic pressure in water when the transfer function method implemented. The distances between hydrophones 2 and 3, and between 3 and 4 are 0.35 m and 0.1 m, respectively. For the combination of hydrophones 2 and 4, the working frequency is fixed between 200–1000 Hz. The combination of hydrophones 3 and 4 corresponds to a working frequency of 1000–4000 Hz. The test sample is placed vertically at the end of the straight pipe, backed by a 25 cm stainless steel column cover. The AI and AO channels of

* Corresponding author at: Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China. Tel.: +852 23587522.
E-mail address: phsunliang@ust.hk (L. Sun).

http://dx.doi.org/10.1016/j.apacoust.2014.04.009
0003-682X/

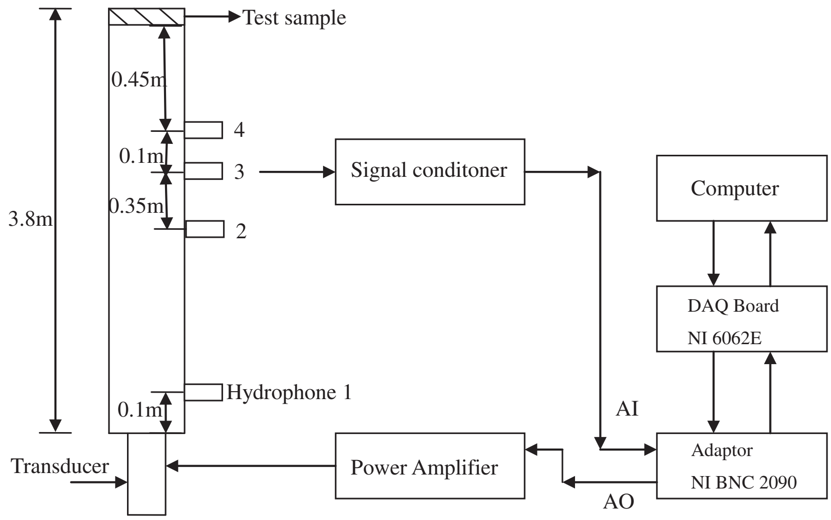

Fig. 1. The sound source configuration and the test equipment.

the NI DAQ 6062E board are programmed to be synchronized and have a sampling rate of 100 kHz.

3. Outline of the generation of the sound pulse

A sound pulse, referred to as the damped sine pulse, is generated in accordance with the requirements for the measurement of sound absorption coefficients. The principle and the process of the pulse generation are both summarized here [9,10,12]:

First, using the impulse response of a digital 5th-order Butterworth filter with approximately 1 ms duration time as the excitation signal to drive the transducer-pipe system with an open terminus, the transducer located at the bottom of the tube is used as the sound transmitter and we record the response signal at hydrophone 1. $H_e(\omega)$ and $H_r(\omega)$ denote the Fourier transforms of the excitation and the response signals, respectively. Then, the frequency response of the system is given by

$$H(\omega) = \frac{H_r(\omega)}{H_e(\omega)} \quad (1)$$

Second, the spectrum of the driving signal can be computed from the spectrum of the designed pulse $H_y(\omega)$ and the resolved frequency response $H(\omega)$.

$$H_x(\omega) = \frac{H_y(\omega)}{H(\omega)} \quad (2)$$

To avoid instabilities at the notches of $H(\omega)$, a positive constant, p, must be added to the denominator (regularization). Thus,

$$H_x(\omega) = H_y(\omega)\frac{H^*(\omega)}{|H(\omega)|^2 + p^2} \quad (3)$$

where $H^*(\omega)$stands for the conjugate of $H(\omega)$. In general, the small values of p (typically less than 5% of the transfer-function peak) are usually enough to stabilize the method [11].

By applying an inverse Fourier transform to Eq. (3), the driving signal of the transducer-tube system is obtained, after which it is fed back into the transducer and a single pulse wave is obtained at the position of hydrophone 1. In addition, it should be noted that by using this process, any deficiencies in the frequency response of the sound generation system will be compensated for, which should improve the signal–noise ratio for measurements at lower frequencies. Furthermore, any reflected waves from either end of the water-filled tube will be canceled out during the generation of the pulse [12], and this can also be regarded as an advantage of this impulse-separation technique when compared with the traditional methods.

It should be mentioned that to excite the transducer with more acoustic power in the water domain, the Butterworth filter impulse signal, with a broader frequency response spectrum, is chosen as the excitation signal. However, due to the longer duration time (transient response of the transducer) of the Butterworth filter impulse, even though the inverse filter process was used, the damped sine impulse was chosen as the designed impulse based on trial and error. The damped sine impulse has a shorter duration time, which has been confirmed by the experiments.

4. Absorption coefficient measurement

The test specimen is positioned at the tube exit, backed by a 25 cm sound-hard stainless steel column. The distance between hydrophone 2 and the specimen is 90 cm, which will ensure that the incident and reflected pulses are separated well.

The reflection coefficient of a test specimen is calculated as the ratio of the reflected sound pressure to the incident sound pressure.

$$R(\omega) = \frac{p^-(\omega)}{p^+(\omega)} \quad (4)$$

where $p^-(\omega)$ and $p^+(\omega)$ are the Fourier transforms of the reflected and incident sound pressures, respectively.

Assuming no transmission wave, the absorption coefficient can be calculated as

$$\alpha(\omega) = 1 - abs(R(\omega))^2 \quad (5)$$

Complete separation of the incident and reflected pulses and a high signal-to-noise ratio (SNR) are essential for the pulse-separation measurement. In this experiment, sufficient distance between the hydrophone and the measured specimen will ensure that the incident and the reflected pulses do separate. Time-domain averaging of the pulse reflection measurements will increase the SNR.

As addressed in Section 2, when utilizing the transfer function method, two types of hydrophone combinations are used to measure the sound absorption of the sample. These combinations are hydrophones 2 and 4 and hydrophones 3 and 4.