Journal of Sound and Vibration 386 (2017) 163–176

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Evaluation of free-field transfer functions in anomalous reverberant fields

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ARTICLE INFO

Article history:
Received 24 May 2016
Received in revised form
25 August 2016
Accepted 26 September 2016
Handling Editor: P. Joseph
Available online 15 October 2016

PACS:
43.30.Gy[Jx]
43.40.Yq
43.58.Bh

Keywords:
Transfer function
The principle of reciprocity
Reverberant field
Underwater measurement

ABSTRACT

The structural-acoustic transfer functions of complex structures are often measured in anomalous reverberant environments. Aiming to eliminating the influences of these reverberant fields on structural-acoustic transfer functions, an impulse-based synchronization average evaluation method is proposed. Structures are actuated according to an impulse signal, and the response signals are synchronized in time and averaged in space. This method does not require complex data processing, and the free-field transfer functions can be obtained based on the measurements in reverberant fields and the transfer characteristics of the structures are preserved. Moreover, in combination with the principle of reciprocity, the proposed method does not require the installation of impulse actuators in structures. The proposed method is verified numerically and validated in a deep lake experiment using a cylindrical model. The results show that the structural-acoustic transfer functions in the profundal zone can be effectively evaluated using the data collected in the shallow zone, and the error is less than 3 dB at most frequencies.

1. Introduction

Transfer function is a system characteristic used to describe the relationship between structural vibrations and the radiated noise. For complex structures, the computational cost of numerical methods may be high, and the accuracy of the results can hardly be guaranteed. In many cases, an in-situ test is required to obtain the structural-acoustic transfer functions of complex structures.

The structural-acoustic transfer functions measured in different sound fields are considerably different. In most case, only the transfer functions measured in free fields are needed because they can reflect the sound radiation characteristics of the structures. However, a free-field testing environment is difficult to realize because special test facilities, such as anechoic room or anechoic pool, are required. If the testing subjects are gigantic structures like ships, measurements may need to be taken on high seas.

However, constrained by the cost and feasibility, many tests are taken in normal rooms or docks instead. Obviously, in docks, it is more convenient to mount the sensors, arrange the testing personnel, and even revise the test plans, but many new problems also come up, such as the large background noise, insufficient intensity of sound sources and reverberant

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http://dx.doi.org/10.1016/j.jsv.2016.09.030
0022-460X/

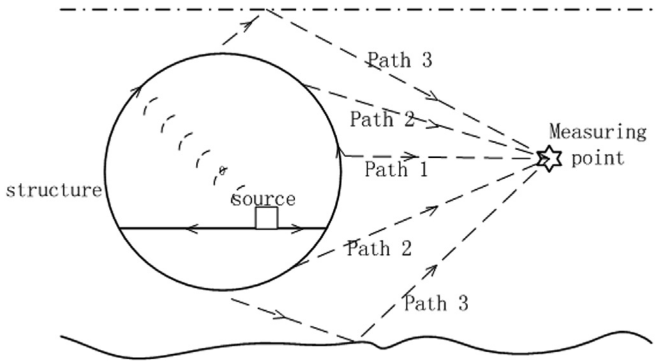

Fig. 1. The transfer paths of noise radiated by underwater structure. Path (3) is related to the surface, the bottom, and any other objects in the water.

testing environment. The influences of the background noise and insufficient intensity of sound source can be eliminated by special arrangements, such as taking the tests at night and shutting down irrelevant devices. However, the reverberant environment can not be avoided. After all, the acoustical factors were not considered in the design or construction of the docks, and the material and structure of the docks can not be changed. The other ships mooring off in the dock would not leave because of the acoustic test too. Consequently, the dock testing environment is an anomalous, reverberant sound field.

Furthermore, the influence of the reverberant field can not be totally eliminated just with an array measurement system. Most commonly used array systems can only spatially filter out the echoes which are out of the direction of the target ship. For a ship in the dock test, in view of the testing conditions such as SNR and practicability, a near-field test is often conducted and many echoes are in the direction of the ship, so the influence of these echoes can not be eliminated by the array system.

Hence, the free-field transfer functions have to be obtained based on measurements conducted in reverberant fields. The key to determining them is to separate the influences of different transfer paths in a reverberant field. Taking a structure in shallow water as an example (see Fig. 1), the influences of the reverberant system, which comprises the structure and testing environment, on the radiated noise can be divided as follows:

(1) The reverberation is not caused by the sound field environment, and is instead merely the result of the complex structure itself, namely path 2; or
(2) The reverberation is caused by the sound field environment, namely path 3.

In an ideal free-field environment, path 3 does not exist but path 2 still exists. Estimation of the free-field transfer function must therefore simultaneously maintain the influence of path 2 and eliminate the influence of path 3.

Since the 1970s, researchers have developed physical models for reverberant fields and diffuse fields, and tried to estimate the diffuse-field functions based on the results measured in reverberant fields with the method of spatial average [1–4]. Waterhouse compared the effects of discrete and continuous average methods [5], and Lubman compared the effects of different average paths [6,7]. In the application of measuring material and structural properties, the reverberant measurement methods have been proved efficient [8–10]. These models and methods helped to reduce the deviation between the reverberant measurement results and diffuse-field measurement results.

Researchers have also made great contributions in finding the connections between the results measured in reverberant fields and those measured in free fields [11,12]. Yousri and Fahy estimated the free-field noise radiation of dipole or monopole sound sources located in reverberant fields by means of temporal and spatial averaging [13]. The spectral tail energy matched-subspace algorithm proposed by (Please add Last Name) can detect signal and echo onsets and estimate their arrival times in multipath acoustic data [14]. However, this algorithm requires high signal-to-noise-ratio, which is always met in a controllable environment, such as laboratories, but not so for in-situ measurement of a complex structure. In such case, how to acquire the free-field result is still an unsolved problem.

In this paper, an impulse-based reciprocal-synchronization averaging evaluation method (IRSAE) is proposed to estimate the free-field transfer functions in reverberant environments. In Section 2, a theoretical model of impulse-based synchronization averaging is established, and the procedure of estimating the free-field transfer functions based on the data from a reverberant field is proposed. Owing to the difficulty of implementing impulse actuation on complex structures, the impulse-based synchronization averaging method is combined with the principle of reciprocity in Section 3, and the scope of application of the proposed method is expanded to meet the engineering-related demands. In Section 4, the proposed method is validated with numerical analysis. Finally, a lake experiment is introduced in Section 5 to validate the proposed method, before the final conclusion is offered.