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Comparison and application of the experimental methods for multi-layer prediction of acoustical properties of noise control materials in standing wave-duct systems

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Abstract

A comparison among the existing experimental methods used for measuring and predicting acoustical properties, such as absorption ratio and transmission loss, of noise control materials was accomplished in this paper. Four methods for absorption ratio and five methods for transmission loss, which can be generalized as standing wave ratio method, two-cavity method and two-load method, were performed in a special standing wave-duct with two configurations of two- and four-microphone holders and compared with the theoretical expressions in the literature. Conclusions were drawn that the standing wave ratio method with two and four-microphones was more reliable, faster, and easier to use for measuring absorption ratio and transmission loss, respectively. The two-cavity and two- load methods, which may be used to predict acoustical properties of an exceedingly thick sample or a multi-layered treatment consisting of variant materials, have different conditions of using limits. The two-cavity method, especially, can be easily conducted and is suitable for the materials with properties of symmetry and reciprocity. The two-load method, however, is more cumbersome to apply, due to the fact of its complex calibration and measurement procedure. Furthermore, some prediction examples for a set of multi-layered treatments of materials were executed by a newly proposed approach, so-called experimental hybrid multi-layer prediction. In view of applications, the works done in this paper may be directly applied in standing wave-duct systems or other noise control configurations to measure, predict and/or optimize their in situ designs.

Classification: Acoustics of porous materials; Computational acoustics; Sound absorption and insulation; Electroacoustic transducers and sound systems

Keywords: Experimental; Multi-layer; Noise control material; Standing wave-duct

1. Introduction

With the increase in public awareness and concern for noise pollution, many kinds of sound absorbing or isolating materials, such as glass wool, polymeric fibrous materials, and various types of foams, alone or with viscoelastic materials, are introduced for noise and vibration control in vehicles and industrial applications. These materials used to absorb airborne noise or to optimize the transmission loss (TL) and damping coefficient in multi-layer systems, may be found in trim lining, under carpets, in seats, cavity interior, etc. It has been of interest to be measured the acoustical properties, and moreover be able to predict the noise control impact of these materials in the design stage. Associated with the characteristic impedance and propagation constant, the absorption ratio and TL that represent sound reflection and penetrating capability of a sample material, are usually considered as the most important acoustical properties, and may be measured by a standing wave-duct system. It is essentially an impedance tube with a loudspeaker at one end, a test specimen at a certain location inside and a specifically designed terminator at the other end. Several microphones are mounted

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along the wall of the tube. Based on the one-dimensional wave equations, the measurement process may be performed by decomposing the standing wave in the tube, and frequency analysis or transfer function techniques may be applied to compute the normal incidence absorption coefficient, characteristic impedance, propagation constant, TL, and other acoustical properties of the noise control materials.

For more accurate measuring or predicting the acoustical properties of materials, a great deal of relevant research on basic theory, standing wave-duct structure design and experimental procedure was issued in the past few decades. Theoretically, based on some assumptions, acoustical materials can be modeled into three ways: i.e., rigid, elastic and limp depending on whether their bulk Young's modulus of the material's solid phase are greater, smaller, or of the same order as the fluid Bulk modulus [1]. Based on these models, the characteristics of sound propagation through single or multi-layered treatments of porous materials have been predicted by some researchers with the theoretical calculations [2–4] or numerical simulations such as FEM and BEM [5,6]. Delany and Bazley [7] stated that the complex wave propagation and characteristic impedance could be expressed in terms of the flow resistance, wave number, air density and sound frequency. This empirical expression was later confirmed through a large amount of experimental data by Qunli [8]. Note that these prediction methods are somewhat difficult to utilize in practice in that they need the mechanical and acoustical parameters of all the concerned layers, which involved in the non-acoustical experiments, such as flow resistance and structure factors, etc.

In experimental field, one of the first techniques was developed by Scott [9], who described a straightforward method for measuring the propagation constant and inferring the characteristic impedance of a porous material. Ferrero et al. [10] proposed the two-thickness method by measuring the surface acoustic impedance of two different thicknesses of the same porous material. An improved version named two-cavity method was achieved by Yaniv [11], in which tests were performed two times on the same material sample backed by a rigid wall and by a one-quarter wavelength air cavity terminated with a rigid wall, respectively. In 1977, Seybert and Ross [12] investigated a two-microphone random excitation technique, wherein the sound absorption coefficient was directly calculated by the measured transfer functions. This transfer function technique has been accepted by some standards, for instance, the ASTM E1050. For measuring TL, especially, the four-microphone method has been the preferred one and some examples of its good agreement between theoretical simulations and experimental results were widely documented [6,13]. More recently, the three-microphone method as a direct way to measure the TL of mufflers has been given more attention [14], because it can be easily derived from the fundamental wave equation, and somewhat less difficult to implement and modify than the four-microphone method. Unfortunately, for using it to measure the material in a standing wave-duct, its validity needs to be further verified. Note that the here mentioned two-, three- and four-microphone methods all use the conventional standing wave ratio method inside their calculating procedures.

In view of the prediction the acoustical properties of a complex flow acoustical system, such as noise control partitions, automotive muffler, etc., the transfer matrix method, also called four-pole approach, has been frequently mentioned in the literature [13,15,16]. To obtain the elements in a transfer matrix, accordingly, Ulsuno et al. [17] combined the two-microphone configuration with the two-cavity method so that the new method broadened the measuring range to every frequency of interest. This method has been used to calculate transfer matrix for practical purpose in engineering, although it may sometimes be inaccurate when the sample material is highly dissipative. For those referring to the in applications than its ameliorated version: the two source-location method [18], due to the latter, needs to change the sound source-location during a measurement.

Generally, the experimental methods that may be used in standing wave-duct system for absorption ratio and TL measurements or predictions were classified into standing wave ratio method (SWRM), two-cavity method (TCM) and two-load method (TLM) in this paper, and listed together with their required microphones in Table 1. During development of a standing wave-duct system, determining which of the above methods should be followed and how to broaden the measurement range are very important for developers. However, there are only a few researchers mentioned under this topic in the previous issues. This paper focuses on application purposes, studies the practicability of each mentioned method in measurement and prediction of the acoustical properties of noise control materials, and also a new concept of hybrid experimental prediction method was proposed. Some constructive conclusions based on such criteria as accuracy,

Table 1
Summary of the candidate measurement method in standing wave-duct systems (× means no corresponding method)

Microphone	Standing wave ratio method (SWRM)	Two-cavity method (TCM)	Two-load method (TLM)
2 Microphones	Absorption ratio, acoustic impedance	Absorption ratio, acoustic impedance, characteristic impedance, propagation constant, transmission loss	Absorption ratio, transmission loss
3 Microphones	Transmission loss	×	×
4 Microphones	Transmission loss	×	Absorption ratio, transmission loss