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Technical Note

Normal incidence sound transmission loss in impedance tube – Measurement and prediction methods using perforated plates

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ABSTRACT

For the determination of the transmission loss of samples in an impedance tube, two different approaches is found in the literature, one based on determining the full transfer matrix (TM method) of the acoustic element, the other based on the wavefield decomposition theory (WD method). In this paper both methods are implemented and measured results are compared using samples which includes different types of perforated plates, also combined with porous material. Measurements are conducted in a tube of square cross section with dimensions 200 × 200 mm, thereby limiting the workable frequency range upwards to approximately 850 Hz. The main purpose of the paper is, however, to compare measured results with predictions using the transfer matrix method. For a bare plate with cylindrical apertures two models are compared as well; a "classical" one and another based on modeling the perforated plate as a porous material having a rigid frame. As for these transmission loss measurements, the two measurement approaches turn out to give identical results within the numerical accuracy. The fit between measured and predicted results are reasonably good with a maximum deviation mostly within 2 dB.

1. Introduction

The literature on the determination of transmission loss in impedance tube is extensive and a thorough review of the methods used is recently given by Salissou and Panneton [1]. It is pointed out that two general methods can be found in the literature, the first one based on determining the transfer matrix (TM method) for the acoustical element, the second one based on the wavefield decomposition theory (WD method). The WD approach in effect decomposes the upstream and downstream wavefield to arrive at the incident and transmitted intensity in the tube, thereby determining the transmission loss. The main limitation to this method is the requirement of an anechoic termination of the tube, the construction of which is difficult, at least to make it effective in the low frequency range. As shown by Salissou and Panneton, this problem is solved by using a two-load method, i.e. performing the decomposition twice using two different terminations of the downstream tube.

Concerning the TM method, the general outline of the theory, also comparing measurements and predictions may be found in the paper by Song and Bolton [2]. However, the expressions for the transmission and reflection factors are given only for the case of a perfect anechoic termination. Recently, however, an ASTM measurement standard [3] has been issued where expressions for the full transfer matrix for the one-load case as well as for the two-load case is given.

Apart from comparing measurements results using these two different approaches, the WD and the TM method, the main purpose of this paper is to compare measured and predicted results using material samples being combinations of perforated plates and porous materials. Predicted results are based on the transfer matrix method combining transfer matrices for the different components of the samples. In the case of a single perforated plate with cylindrical apertures two models are compared; a fairly "classical" one and a quite recent one by Atalla and Sgard [4].

Numerous works have been devoted to predict the acoustic behavior of systems comprising perforated plates, porous materials and air cavities but mainly focusing on the absorption of such systems. Concerning transmission of perforated plates, pioneering work on the transmission through single holes and slits is found in Refs. [5–7], being a basis for predicting the transmission of perforated plates. An extension of these works to include apertures of variable transverse shapes (conical apertures and wedge-shaped) slits is given by Vigran [8], however the sound transmission aspect was not of primary concern here but the design of resonance absorbers. A number of transmission loss measurements on perforated screens under diffuse field conditions are given by Chen [9], comparing with predictions using screens of various thickness and perforation rate. The prediction model is a "classical" one, using a fixed end correction for the holes in the screen; see below.

A short outline of the expressions used for the measurements in this paper is given in the first part of Section 2, followed up in the second part by the material parameters and the acoustic quantities

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needed to predict the total transfer matrix of the tested samples. Section 3 presents the details of the measuring set-up and a description of the measurement specimens. Section 4 is devoted to the results from comparing the two measurement approaches, but mainly presenting and comparing measured and predicted results for a range of samples.

2. Theory

2.1. Measurement formulas

The general set-up used is shown in Fig. 1. The tube used in this case has a uniform square cross section with dimensions 200 mm × 200 mm. A loudspeaker is fitted in one end and as indicated, two different loads may be fitted in the opposite end. Five microphone positions are indicated with a reference microphone position near to the loudspeaker and a set of two microphone positions on both sides of the specimen having thickness d. It should be noted that the notation of the distances indicated follows Ref. [3]. Using this notation the pressure transmission factor t, the ratio between the transmitted and the incident pressure is, according to Salissou and Panneton [1], determined by the following expression:

$$t = \frac{p_t}{p_i} = H_{32}(1 - r_2 r_b e^{2jk_0 D_2}) \frac{e^{jk_0 l_1} + r_1 e^{-jk_0 l_1}}{e^{-jk_0(l_2-d)} + r_b e^{-jk_0(l_2-d)}}, \tag{1}$$

and thereby the transmission loss.

$$TL = -10 \cdot \lg(|t|^2) \quad (\text{dB}). \tag{2}$$

In Eq. (1) r_1, r_2 are the pressure reflection factor at the input and output side of the specimen, respectively, of which the latter is independent of the load condition. Furthermore, r_b is the pressure reflection factor of the termination and H_{32} the total pressure transfer function measured between microphone 3 and 2, both determined using the first load condition. Furthermore, D_2 is the distance between the backside of the sample and the termination.

It might look strange that variables measured under the second load condition does not appear but these are contained in the expression for r_2, where transfer functions between the total pressure at microphone positions 1 and 2, 3 and 4, as well as 2 and 3 at both load conditions appear. For these expressions we shall refer to the full set of equations given in Ref. [1]. It should be mentioned, however, that if one is just interested, either, as here, in the transmission loss of the sample or the absorption factor of the specimen or the two loads, all dimensions, except for the microphone separations s_1 and s_2, cancel out. Finally, as the basic wavenumber k_0 is used in the expression, no energy losses in either the upstream or downstream duct itself is accounted for.

As for the TM method the task is, using the two-load method, to determine the two matrices relating the sound pressure p and the particle velocity u on the input side to the ones at the output side of the specimen, e.g. for the loads represented by the letters a and b we get quoting Ref. [3]

$$\begin{bmatrix} p_a \\ u_a \end{bmatrix}_{x=0} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \cdot \begin{bmatrix} p_a \\ u_a \end{bmatrix}_{x=d}, \tag{3}$$

and

$$\begin{bmatrix} p_b \\ u_b \end{bmatrix}_{x=0} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \cdot \begin{bmatrix} p_b \\ u_b \end{bmatrix}_{x=d}. \tag{4}$$

These pressure and particle velocity components are found, similar to the procedure used in Ref. [1], by decomposing the wavefield inside the tube into forward and backward traveling waves on either side of the specimen. The final transfer matrix components for the specimen is then given by

$$\begin{aligned} T_{11} &= \frac{p_{0a} \cdot u_{db} - p_{0b} \cdot u_{da}}{p_{da} \cdot u_{db} - p_{db} \cdot u_{da}} \\ T_{12} &= \frac{p_{0b} \cdot p_{da} - p_{0a} \cdot p_{db}}{p_{da} \cdot u_{db} - p_{db} \cdot u_{da}} \\ T_{21} &= \frac{u_{0a} \cdot u_{db} - u_{0b} \cdot u_{da}}{p_{da} \cdot u_{db} - p_{db} \cdot u_{da}} \\ T_{22} &= \frac{p_{da} \cdot u_{0b} - p_{db} \cdot u_{0a}}{p_{da} \cdot u_{db} - p_{db} \cdot u_{da}}, \end{aligned} \tag{5}$$

where the indices 0 and d indicate the input and output side of the specimen, respectively. The analog expression to Eq. (1) for this case is then

$$t = \frac{2 \cdot e^{jk_0 d}}{T_{11} + \frac{T_{12}}{Z_0} + Z_0 T_{21} + T_{22}}, \tag{6}$$

where Z_0 is the characteristic impedance of the air in the tube.

2.2. Transmission through perforated plates

As stated in the introduction, one objective of this paper is testing the above measurement procedures using combinations of perforated plates, also combined with samples of porous materials. Two types of plates were used; one perforated having cylindrical apertures and the other with conical apertures, in both cases the apertures was placed in a regular square pattern. Generally, the

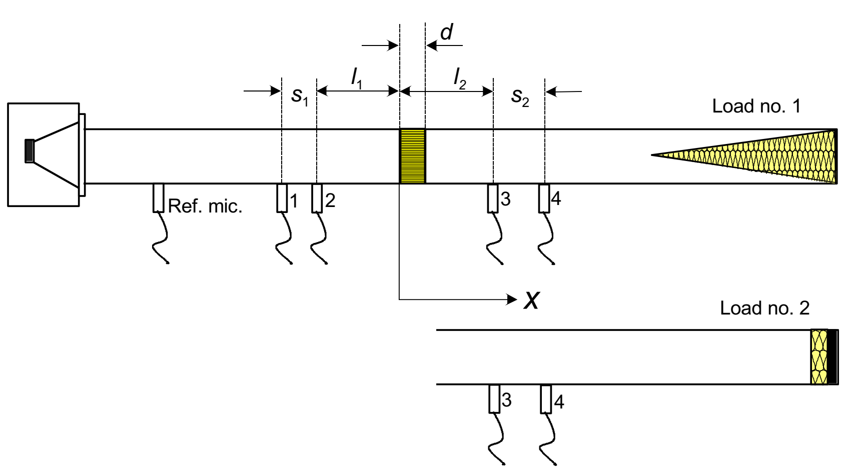

Fig. 1. Sketch of the measurement set-up with a loudspeaker, a reference microphone position and positions for microphones in the upstream and downstream tubes. The latter tube may be terminated by two different loads.