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Analysis of the measurement of transmission loss in rigid building materials with a standing wave tube

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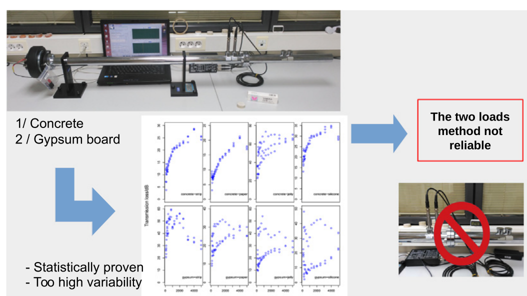
HIGHLIGHTS

- Transmission loss is tested in rigid building materials with Kund's tube.
- Two different materials (concrete and gypsum board) are tested.
- Four different sealing methods are used with both materials.
- The variability of the data obtained is very high.
- This method cannot be used in rigid building materials.

GRAPHICAL ABSTRACT



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ABSTRACT

We explore the limits of the use of the Kund's tube and the transfer matrix method for the measurement of transmission loss with common building materials. The results of several tests performed in a standing wave tube with two different building materials (concrete and gypsum board) and mounting the samples in the tube using four different sealing methods are presented.

With the analysis of the obtained data, it is proved that the "two loads" method in the Kundt's tube cannot be used to measure the transmission loss of rigid construction materials like the tested ones due to the high variability of the data.

1. Introduction

The Kundt's tube or standing wave tube is a good, albeit affordable, test device for measuring acoustic properties of materials. It is specifically well suited to measure, on the one hand, the absorption coefficient of sound absorbing materials [1], which are intended to reduce the reverberation time of a room, and, on the other hand, the transmission loss of materials intended for sound insulation in mufflers [2].

The measurement of sound absorption has two parallel methods, complementary to each other. The "room" method is described in the standard ISO 354 [3], and allows testing the absorbing properties of a complete building element [4]. In contrast, the "two-microphone" or "transfer function" method, described in the standard ASTME1050 and its counterpart ISO 10534-2 [5,6], makes use of the standing wave tube to measure the intrinsic sound absorbing property of each material, that is, its coefficient of absorption, α, which is defined [7,8] as

$$\alpha = 1 - \frac{I_r}{I_i}, \qquad (1)$$

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where I_i stands for the incident sound intensity, while I_r is the reflected sound intensity. Not surprisingly, the "room" method also allows measuring the coefficient of absorption of a sound absorbing material, and so is described in the standard ISO 354 [3], thus competing with the "two microphone" method. In this scenario, the advantages of the standing wave tube are clear: it is a simpler device, thus, much more affordable for small laboratories, it uses small samples of the material to be tested and, finally, it is not conditioned by the background noise in the laboratory surroundings. And, indeed, it is the most widespread method for measuring sound absorption and impedance of materials as these references show [9–11].

The situation regarding the measurement of sound insulation is similar. The "two rooms" method, which is described in the standard ISO 10140-2 [12], is designed to measure the sound insulation of a complete building element, such as a wall, a window, etc. Its requirements are described in the standard ISO 10140-5 [13] which specifies a test facility with two adjacent reverberating rooms with no sound transmission by indirect ways, with dimensions over 50 m^3, with no dominant standing waves, reverberating time and background noise under control and a test opening between them where the tested element is mounted [14]. The "two rooms" method can also be utilized to measure the transmission loss of a material (*TL*), that is, its intrinsic sound insulation capabilities, which is defined by the equation

$$TL = 10\log_{10}\left(\frac{I_i}{I_t}\right), \quad (2)$$

where I_i is, again, the incident sound intensity, and I_t is the transmitted sound intensity. For instance, in previously reported [15] different techniques for measuring acoustic properties of concrete are compared, but none of them tries to measure the transmission loss with the standing wave tube. However, there is a specifically designed method for the latter property by means of the impedance tube: the "transfer matrix method" described in the standard ASTM E 2611-09 [16]. Although this method has the same advantages described above for the "transfer function" method it has not yet reached the status of a well settled method. Three are the main obstacles. First, no correlation between transmission loss measurements conducted with impedance tubes and those conducted using the traditional reverberant room method has been determined yet (notwithstanding it, ASTM E 2611-09 states: "Even though this method may not replicate the reverberant room methods for measuring the transmission loss of materials, it can provide comparison data for small specimens, something that cannot be done in the reverberant room method"). Second, ASTM E 2611-09 does not guarantee the satisfactory reproducibility which allows gaining control over the minimum and maximum variability of the results without a previous comparison by means of interlaboratory tests, as defined in the standard ISO 12999-1 [17]. And, third, the method is known to work for the so called "limp" materials such as flexible foam, soft rubber or fiber samples that are typically used as barrier materials in noise control applications.

Therefore the impedance tube method for measuring transmission loss should be used only to rank samples in a relative sense. The transmission loss obtained for a given sample will not be equal to that obtained for the same material using the room method. The most significant difference is that in the impedance tube the sound impinges on the test specimen in a perpendicular direction only, while the room method provides random incidence of the sound. Moreover, it seems not possible to compare transmission loss measurements from impedance tubes of different diameters because it is almost impossible to duplicate the specimen mounting conditions of the first tube in the other tube.

Despite of these discouraging issues, the advantages of the impedance tube makes it worth to explore all of its capabilities and, thus, this paper is focused in one of the issues still open: its use for the measurement of transmission loss in rigid building materials. To that end we have tested two common rigid building materials, concrete and gypsum board, following the standard ASTM E2611-09 [16], have analyzed the data and classified the obstacles found in the procedure and, finally answered the question: is the impedance tube well suited to measure transmission loss of rigid building materials?.

In Section 2 the method followed with each material is described in full detail, with special emphasis in the specimens preparation. The results of the tests are presented in Section 3, and in Section 4 they are discussed from a statistical point of view. This statistical analysis gives a surprising answer, enough to draw a conclusion which is accounted for in Section 5.

2. Method

We have measured the transmission loss under the conditions specified by the standard ASTM E2611-09 [16]. This test method uses a Kundt's tube and four microphones at two locations on each side of the sample. Plane waves are generated in the tube using a broadband signal from a random noise source. The resulting standing wave pattern is decomposed into forward and backward traveling components by measuring sound pressure simultaneously at the four locations and examining their relative amplitude and phase. The acoustic transfer matrix is calculated from the pressure and particle velocity of the traveling waves on either side of the sample using the two load method [18,19].

We have tested two building materials, concrete and gypsum board, for which there are reliable data on transmission loss from the two room method with the standard ISO 10140-2 [12].

2.1. Sample preparation

Sample preparation has been extremely important in our case because the specimen must fit snugly in the sample holder and this is particularly difficult to achieve with materials as hard as concrete. The standard method allows several options for the mounting of the sample in the tube: it may be rigidly mounted or clamped to the wall of the tube, freely suspended with a dense, flexible seal, or may be mounted in some other ways. We chose to make the samples with a slightly smaller diameter than the inner diameter of the Kundt's tube and seal around the circumference.

The concrete samples were made out of concrete type HA-25/B/20/IIa, commonly encountered in construction works, with Portland cement CEM II/B-L 32.5 N. The dosage, obtained from previous studies, was 1:3:2:0.45 in weight, that is, one part of cement, three of gravel, two of sand and 0.45 of water.

We needed three attempts to get suitable samples which fitted snugly in the sample holder. We firstly made six series of cylindrical samples of 150 mm × 300 mm of three samples each. We then proceeded to extract the cylindrical test samples by means of a diamond drill with a diameter 1 mm less than that of the sample holder, intended to be cut afterwards in slices of 1 cm thick. The problem showed up when the drill encountered the gravel and the sample broke apart. In a second attempt we started by slicing the sample in slices of 1 cm thick and then proceeded to cut them with the appropriate diameter, but the result was again completely useless. Finally we decided to prepare the samples in plastic molds of exactly the size we needed for the sample holder. We therefore, had to use a smaller maximum size of the gravel: size 8, retained by the sieve 6.3 of the ASTM series. We then prepared a unique