26th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
7-11 July 2019, Montreal

PRINCIPLES AT THE BASIS OF THE DENORMS ROUND ROBIN TEST ON THE LOW FREQUENCY SOUND ABSORPTION MEASUREMENTS IN REVERBERATION ROOMS AND IMPEDANCE TUBE

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In recent years low frequency measurements in building and room acoustics fields gained attention. Moreover the low frequency sound absorption coefficient (below 100 Hz) has always been difficult to determine and the results coming from different laboratories cannot always be compared. This paper describes the principles at the basis of the round robin test carried out in the framework of the DENORMS cost action (Designs for Noise Reducing Materials and Structures). The same samples have been measured in reverberation rooms and in impedance tube by the different laboratories participating to the Round Robin Test.

Keywords: reverberation room, round robin test, absorption coefficient, low frequency, impedance tube.

1. Introduction

The scientific community is growing every day and innovative researches are developed all around the world. With the aim of bringing together researchers all over the world, and in particular in Europe, the European Cooperation in Science and Technology (COST), which is a funding organization for research and innovation networks, promotes the so-called COST Actions. These actions help to connect research initiatives across Europe and beyond and enable researchers and innovators to grow their ideas in any science and technology field by sharing them with their peers.

The DENORMS (Designs for Noise Reducing Materials and Structures) - COST Action activities were launched on 9th March 2016 for 4 years.

The aim of this Action is to design multi-functional, light and compact noise reducing treatments. In order to achieve this, DENORMS brings together skills and knowledge of the complementary, but still disconnected, communities of scientists working on acoustic meta-materials, sonic crystals and conventional acoustic materials across Europe and overseas. This Action provides a framework for an efficient information exchange, helps to avoid duplication of research efforts and channel the work of groups involved in different projects towards a common goal. New approaches to the theory of sound interaction with materials and structures and standard methods of their performance characterization are being developed. In this context the work of working group (WG) 2 "Experimental techniques" is to improve and/or define new approaches for measuring the performances of the acoustic materials. The authors of this paper are part of the DENORMS WG2, and are the coordinators of the Round Robin Test (RRT) on the low frequency sound absorption measurements in reverberation rooms and impedance tube.

Since the DENORMS meeting of Rome, in January 2017, the group is working on the organization of the RRT. A financial support for the transport costs of the materials has been approved by the European Commission for the Grant period 2 and 3, starting in 2017.

The aim of this round robin is twofold. On the one hand, it is the assessment of the uncertainty in absorption measurements at low frequencies (i.e. at a few hundred hertz and lower) by means of impedance tube and reverberation room measurements and the comparison between these two methods. On the other hand, is to gain a better understanding of low frequency acoustics in reverberation rooms. In the accompanying paper [1] the description of the dedicated low-frequency analysis is presented. In another accompanying paper [2] the low frequency modal behavior of a reverberant room is modelled by means of a finite element model.

In fact, in recent years, the interest on the low frequencies has grown (e.g. [3],[4]). It is therefore necessary to assess the properties of a material also in the low frequency range, in particular for the analysis and study of the sound field in theaters and cinemas. There are different methods to measure the absorption coefficient of a material [5], in particular the impedance tube measures it easily and with relatively great accuracy. The disadvantage of this method, however, is that it is only possible to measure the absorption coefficient at normal incidence of sound. The computation of the reverberation time T of a hall, a classroom, a studio, or the reduction of the noise level in a factory, an office, etc., are issues that are frequently dealt with in a statistical way. Moreover, the sound absorption coefficient required for these calculations is then necessarily that for random incidence, because the formulas are based on the hypothesis that the sound field is diffuse. It is therefore of importance to have a method for the measurements of the sound absorption coefficient in reverberation rooms, for random incidence down to low frequencies.

2. Round Robin Test

The measurement of the absorption coefficient in reverberation rooms is standardized in ISO 354:2003. The standard method for the absorption coefficient calculation from reverberation time measurement is based on Sabine formula for a diffuse sound field. Nevertheless, the sound field in a reverberation room is not diffuse below the Schroeder frequency which is, for a volume of 200 m^3, and typical reverberation time, around 400 Hz. For example, the average reverberation time of ITC reverberation room (219 m^3) in the frequencies from 100 to 5000 Hz is 11.3 s, that leads to a Schroeder frequency of 454Hz [6].

Therefore, the sound field in reverberation rooms may not be perfectly diffuse, even at relatively high frequencies, and so it is necessary to assess a method to measure the reverberation time in the modal region [1]. On the one hand it is then of importance to have a highly absorbing material at low frequencies, on the other hand, to have a sound source that shows a flat frequency response over the one third octave bands of interest [7]. Being the true value of the measurand not known, the only way to assess the absorption coefficient of a material is a round robin [8].

Several issues are related to the measurements of random incidence sound absorption coefficient in reverberation rooms. The first RRTs on reverberation rooms were at the basis of the development of ISO 354. In the first one [9] it was found that the absorption coefficient values for random incidence were well below the values for normal incidence corrected for the random one. It is true of course that the correction is not completely satisfactory and/or trustable, nevertheless the values in reverberation rooms were so low (not only below the Schroeder frequency) that they were completely not comparable. Therefore it was suggested to use diffusers in reverberation rooms to make the sound field as diffuse as possible. On the one hand, the installation of diffusers is the only way to maintain a diffuse reverberant sound field with a highly absorbing material in the room. On the other hand, the diffusers change the mean free path (MFP) in the reverberation room. A difference between laboratories can thus be found because of the installation of diffusers of different materials, orientation and dimensions, in the rooms. [6].

Of course the sound field diffusion in a room depends on the shape [10] and dimensions [11] of rooms and of the sample surface [11]. Vercammen suggests [12] various possibilities to reduce spread between laboratories, one of them is correcting for the edge effect, as suggested by Kosten [9], but this can explain only a little part of the differences between laboratories. In fact, one of the possible reasons why physically meaningless values of sound absorption coefficient (α_s) greater than unit could be found, other than the non-diffuseness of the sound field and Sabine's formulation, is the edge diffraction [13]. That is the diffraction from the edges at low frequencies, which causes the reflected wave to no longer be planar, and so diffraction produces the edge effect whereby substantially more absorption occurs near the edges of an absorber than at its center. Of course, by sending the same material samples around for a RRT, the edge effect will be the same for all labs. It is also worth to underline the fact that usually the samples are not cased and therefore a material to cover the edges is needed and if the material used is the same in all laboratories participating in a RRT, in this case the edge effect would be the same in all labs. If, in this case some laboratories measure $\alpha_s > 1$, while some others do not, this discrepancy must be explained in a different way.

With a highly absorbing sample, it is well known that Sabine's formulation (1922) should not be applied when the mean absorption value is higher than 0.4. Instead another formulation, like the Eyring formula, should be applied. Going back to 1978, Myncke and Cops [14] stated that from the viewpoint of standardization, it is not justified to change from the Sabine to the Eyring formula. Nevertheless this is not something that can freeze the research and also Vercammen has considered this possibility [12], but finally, probably for the same reasons, he suggested the use of a reference absorber [15] to decrease the spread of results between laboratories.

This round robin test has not the goal to solve all the issues related to the measurements in reverberation rooms, but to try to understand the uncertainty of measurements at low frequencies and to find a way to measure the low frequency sound absorption coefficient as accurately as possible.

In addition the laboratories participating in the round robin were asked to perform measurements also in impedance tube [16]. Recently, the impedance tube measurement uncertainty [17] and the reproducibility of porous media [18] were analyzed. Nevertheless, a cross analysis between the uncertainty of reverberation rooms and impedance tube measurements on the same materials has not been performed before.

3. Laboratories

The laboratories participating in the RRT are 13 European laboratories (from 9 countries) and 3 Australian laboratories:

- Construction Technologies Institute of the National Research Council of Italy (ITC-CNR), Italy
- KU Leuven, Belgium

- DTU, Denmark
- Universidade de Coimbra, Portugal
- University of Technology of Compiege, France
- Centre de Transfert de Technologie du Mans, France
- Institute of Automotive and Transport Engineering, France
- University of Salford, UK
- Versuchsanstalt TGM, Austria
- University of Nis, Faculty of Electronic Engineering, Serbia
- EMPA, Switzerland
- Ferrara University, Italy
- Universitá degli Studi di Bologna - DIN, Italy
- Commonwealth Scientific and Industrial Research Organization, CSIRO, Australia
- University of Auckland, Australia
- University of Technology, Sydney, Australia

4. Samples

Thanks to the financial support from DENORMS, it was possible to have exactly the same materials sent to the different laboratories taking part in the RRT. Of course having exactly the same materials avoids the possible discrepancies that could have arisen if different samples of the nominally same material had been sent to each laboratory. Conversely, to send the exactly the same samples to the laboratories, exposes the samples themselves to possible damages during shipments.

As shown in a previous round robin [11], the higher the sound absorption coefficient of material, the higher the differences between laboratories. This is mainly caused by the lack of diffusivity of the sound field in presence of a highly absorbing material. Therefore, in order to asses the measurement uncertainty in reverberation rooms, it is necessary to have highly absorbing samples at all frequencies of interest. In particular, for the scope of the DENORMS RR, at low frequencies.

The material chosen with high absorption at high frequencies was a porous material, a glass wool. The glass wool is Ecophon Industry Modus S, 100 mm thickness, covered with glass tissue.

4.1 Box design

To avoid damages to the sample, the glass wool was inserted in protecting boxes made from MDF. Besides the protection that is obtained in this way, acoustic edge effects are prevented as well. The total sample area to be tested is 10.8 m^2, for a total of 9 MDF boxes of the following dimensions:

- 6 boxes from MDF 18mm wood, dimension 1200 x 1200 x 200, and
- 3 boxes from MDF 18mm wood, dimension 1200 x 600 x 200.

The bottom of the MDF boxes are covered with a 5.5 mm plywood panel. The glass wool was put in double layer inside the MDF boxes, with the protecting glass tissue on top and on bottom, see Fig.1.

Optionally, the boxes can be covered with two types of perforated panels to create a set of Helmholz resonators, tuned at low frequencies. These panels are from manufacturer Fantoni, a drilled one (type "4FOR") and milled one (type "4AKUSTIK"), both of 16 mm thickness.

When the boxes (without the Fantoni panels) are put up-side-down, with the 5.5 mm plywood panel facing up, the boxes behave as a panel resonator (see Section 4.2 for details).

The MDF boxes thus obtained shall be used in four configurations:

- Configuration 1: porous material (boxed, to prevent edge effects)
- Configuration 2: porous material boxed, with drilled panels on top

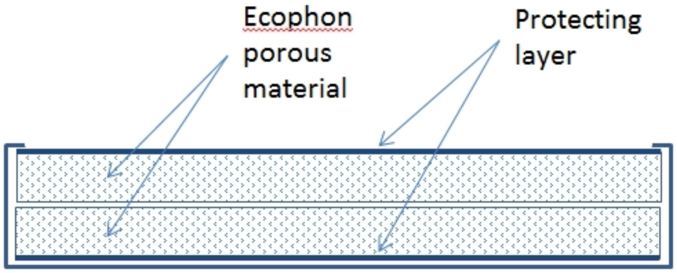


Figure 1: Box configuration

- Configuration 3: porous material boxed, with milled panels on top
- Configuration 4: panel resonator, boxes up-side-down, plywood panel up

Instructions on how to put the samples in reverberation rooms were sent to the participant laboratories. In all the cases, the boxes must be taped along the bottom perimeter of the 10.8 m^2 frame, and the inter-connections of the boxes have to be sealed too, as shown in Fig.2 for configuration number 1 (Ecophon material). It was suggested not to use paper-based tape. Preferably Tesa Utility Duct Tape or similar (usually called "American" type) should be used.

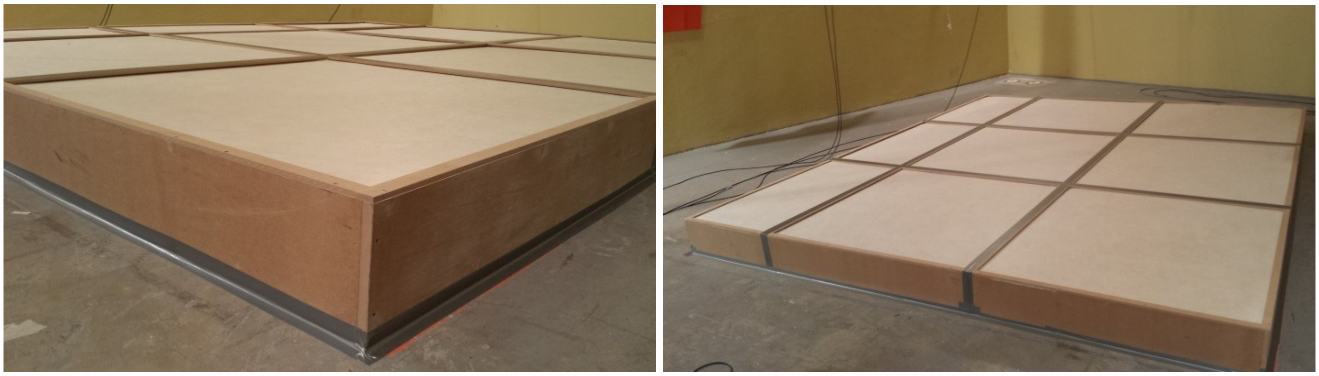

A) B)

Figure 2: Sealing of the sample along the bottom perimeter and the inter-connections of the boxes.

4.2 Panel resonator design

An accelerance transfer function measurement was performed on the MDF box being configured as a panel resonator (boxes put up-side-down, with the 5 mm plywood panels up). Figure 3 shows the test set-up for the 1200 x 600 MDF box panel resonator. A Polytec laser Doppler vibrometer comprising a OFV-505 head and a OFV-5000 controller was used to measure the velocity of the plywood panel, while hitting the panel with a modal hammer from Endevco, model 2302-50. The transfer function between the hammer force and the panel velocity was measured by means of a 2-channel Bruel &Kjaer data acquisition system type 2144. The results are converted in an accelerance transfer function, as shown in Fig. 5. The accelerances were measured for the following configurations:

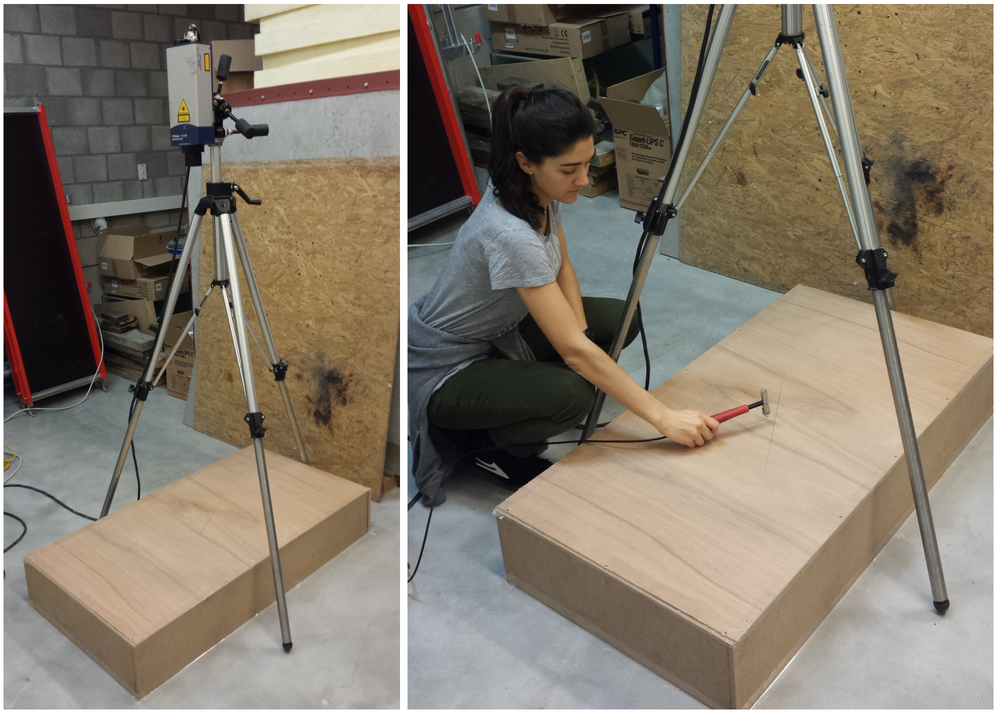
- for the 1200 x 600 MDF box and the 1200 x 1200 MDF box;
- with and without 200mm Ecophon material inside;
- with and without sealing the edges between the MDF box and the floor, as illustrated in Fig. 5 A.

The results shown in Fig.5 show some remarkable things. The first resonance frequency corresponds to a mode in which the plywood panel deforms in its '1-1'-mode. The peak is higher when the edges are sealed, and lower when the edges are not sealed. This is considered to be logical, because when the edges are not sealed air can escape from small slits between the MDF box and the concrete floor, which introduces dissipative effects which will reduce the resonance peaks.

The first resonance peak of the 1200 x 600 mm panel has a frequency of 66 Hz and 61 Hz for non-sealed and sealed edges, respectively. For the 1200 x 1200 mm panel the resonance frequencies are 50 Hz and 45 Hz, respectively. The shift in resonance frequency due to the sealing of the edges is not fully understood. When the edges are sealed, the air inside the box cannot escape from small slits between the MDF box and the concrete floor, which is expected to cause an increase of the stiffness. However, from the results it can be seen that the eigenfrequency of the panel drops when the edges are sealed (for both the 1200x600 panel test and the 1200x1200 panel test). A good explanation is still missing.

Obviously, when putting Ecophon material inside the MDF box, the peaks are strongly damped (see Fig. 5). And again, when the edges are sealed, the first resonance frequency slightly drops.

In conclusion, the 1200 x 1200 mm panel resonator is designed to have its first resonance frequency in the 50 Hz 1/3rd octave band , whilst the 1200 x 600 mm panel resonator is designed to have its first resonance frequency in the 63 Hz 1/3rd octave band [1].



A) B)

Figure 3: MDF box 1200 x 600 used as panel resonator. A): laser Doppler positioned above panel resonator. B): panel resonator being excited by a modal hammer.

5. Repeatability

For each sample, and for each type of measurements, the measurements shall be repeated two times, which is the minimum number of repetitions needed to calculate the within- and between- laboratory

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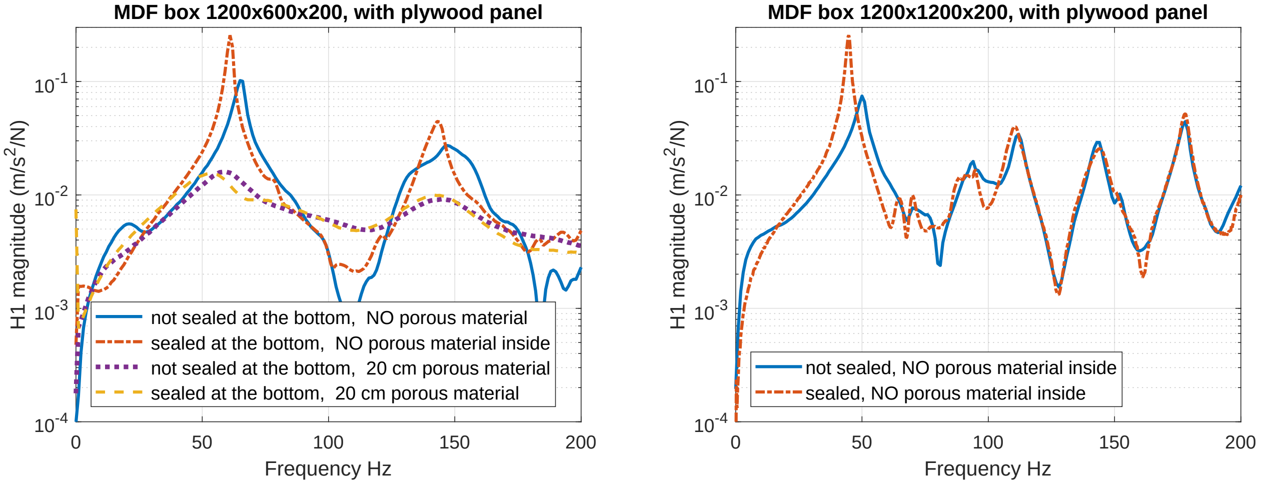
[1] The 50 Hz 1/3rd octave band starts at 45 Hz and ends at 56 Hz; the 63 Hz 1/3rd octave band starts at 56 Hz and ends at 71 Hz.

Figure 4: RRT sample box used as panel resonator; sealing detail



A) B)

Figure 5: Accelerance response function of MDF box. A): 1200 x 600 panel resonator. B): 1200 x 1200 panel resonator.

standard deviation and in order to obtain an estimate of the repeatability and reproducibility of the RRT measurements.

For impedance tube measurements, for each type of configuration at least 3 samples taken from the absorbing material have to be tested.

6. Acknowledgments

This article is based upon work from COST Action DENORMS CA15125, supported by COST (European Cooperation in Science and Technology). Anna Tira is acknowledged for her help in performing the measurements. The authors would like to thank Ecophon Sweden and Fantoni S.p.A. for providing the materials to test.

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