A general description of measurement method for sound absorption and surface impedance of materials using ensemble averaging

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Abstract. Sound absorption characteristics of materials are important for acoustical researches as well as for practical designs. Various measurement methods have been proposed in this research work for sound absorption characteristics. Some of them are standardized in the International Organization for Standardization (ISO) and in the Japanese Industrial Standards (JIS). There are two well-known methods of laboratory measurement of absorption, one is the “reverberation room method” and the other is the “tube method”. However, these two methods have several drawbacks and disadvantages respectively, as they are not suitable for “in-situ” measurement. Furthermore, sufficient amount of impedance database has not yet been accumulated to meet the necessity for constructing boundary conditions of wave-based room acoustical simulations. To overcome the situation, the authors have presented a method utilizing “ensemble averaging”, namely the “EA method”. There are two types of EA methods. One uses two microphones and the other uses a pressure-velocity probe (Microflown PU-sensor). Herein, an overview of the EA method is described.

1. Introduction
Sound absorption coefficients of acoustical materials are measurable both by means of the reverberation room method and by the tube method according to ISO standards [1], [2]. The results of the sound absorption coefficient of the former in a diffused sound field are of importance for building acoustics as well as for noise control. However, this method cannot measure the surface impedance of a material which is indispensable for wave-based-room-acoustical simulations like finite element method (FEM) in constructing sound fields’ absorptive boundary conditions. The tube method can measure the surface impedance of a material and at the same time it can measure the sound absorption coefficient. Nevertheless, there are not enough amount of impedance database so far, and various alternative methods have been proposed. (Allard [3], [4], [5], Garai [6], Mommertz [7], Nocke [8]) Some of the authors also have been proposed a method using an ensemble averaging technique (EA method) [9 – 14]. In this paper, the outline of EA method is summarized in comparison with conventional methods.

2. Conventional Method
There are two well-known conventional methods. One is the “reverberation room method” and the other is the “impedance tube method”. They are standardized in the International Organization for Standardization (ISO) [1], [2] and in the Japanese Industrial Standards (JIS) also.
2.1. Reverberation room method
The Reverberation room method is widely used as a practical absorption index. However, the creation of diffuse sound field requires a large and costly reverberation room. A completely diffuse sound field can rarely be achieved. The edge effect and dependence on characteristics of reverberation room itself are not negligible [9]. Size of specimen requires approximately 10m², which is disadvantageous regarding cost and practicability. Occasionally absorption coefficient exceeds 1.0 because of edge effect. Moreover, an accurate value of complex impedance cannot be derived, which is essential for wave-based room acoustical simulations.

2.2. Impedance tube method
The Impedance Tube method can obtain both normal surface impedance and absorption coefficient at the same time. The setup system consists of two microphones, sound tube, FFT (Fast Fourier Transform) frequency analyzer. It is a rather compact and simple apparatus in comparison with the reverberation room method, and the specimen size is large enough to set it up in the sound tube ends and is somewhat smaller than the one used in the reverberation room method. On the other hand, the measurable frequency range depends on the diameter of sound tube. Consequently, one needs several sound tubes corresponding to the purpose. Furthermore, the conditions of the specimen’s cutting edge and installation status affects the results considerably.

2.3. Other method
There are some other conventional methods proposed in recent years:

- Allard anechoic room two-microphone [3], [4], [5].
- Garai MLS reflection method [6].
- Nocke Free field transfer function method [8].

These methods are categorized in reflection method. The following are disadvantages [9].

- low-frequency limitation
- inaccuracy with weakly absorbing materials
- the need for complicated equipment when used in-situ
- only one sound source can be employed
- sometimes absorption coefficient exceeds 1.0 because of edge effect and so on

3. EA method
EA signifies "Environmental Anonymous" at first, and later altered "Ensemble Average". Consistently, these naming means in-situ measurement by using ensemble average of random incidence sound source (environmental anonymous noise). Figure 1 shows the schematic diagram of EA method measurement.

![Figure 1. Schematic diagram of EA method measurement mechanism [13].](image)

3.1. Advantages and disadvantages
The main purpose of EA method is to obtain the absorption coefficient and normalized surface impedance for using the boundary condition of numerical analysis by in-situ measurement. Environmental anonymous noise works well effectively as a random incidence sound source, (but it is desirable to add sound sources (pink noise, white noise) in case signal-to-noise ratio is not enough to
measure at the measurement place.) The process of ensemble averaging is easy to be performed on an ordinary 2-ch fast-Fourier-transform instrument and it is also helpful to decrease the "edge-effects (the effect of diffracted waves from the specimen’s edge)" that is one of the most disturbing obstructions in various sound absorption measurement method [18]. The mechanism of cancelling the edge-effect is explained [10] and sample-size-independency of EA method is examined in a literature [11]. A condition of sound field is not restricted practically, if only it has relevant capacity of sound field space. Random incidence value is measurable, which nearly coincides with a normal surface incidence value. A typical disadvantage is that EA method results are not equal to other conventional values like Sabine absorption coefficient, normal impedance and so on. Nonetheless, incidence angle averaged surface normal impedance of the material can be obtained. The EA method consists of two types [Figure 2], one is the "EApp" and the other is the "EApu". The main difference between these two methods is in its setup system, the number of microphones and its characteristics. The EApp method requires that two microphones be used, and the EApu method requires that one pressure-velocity probe (Microflown PU-sensor) [Figure 3] be used.

3.2. EApp method

This method uses two microphones to measure transfer function between them for obtaining the values. In comparison with later-mentioned EApu, two microphones are much less costly than the PU-sensor. Furthermore, there is no need for sensitive calibrations like PU-sensor. On the other hand, the assumption of sound receiving point is geometrically not clear (distance between two microphones cannot be ignored). It takes more time and effort than EApu, because the replacement of the two microphones is indispensable in each measurement procedure.

3.3. EApu method

This method uses pressure-velocity probe. In comparison with the above-mentioned EApp method, sound receiving point is geometrically clear, because it is measured by only one PU-sensor. However, the PU-sensor is considerably expensive than the usual microphone used in EApp. Furthermore, each sensor has different characteristics, and their characteristics are fluctuated by humidity and temperature individually [14]. Therefore, calibration is necessary for each PU-sensor and in each measurement procedure.

4. Calibration of PU-sensor

This section refers to the calibration of PU-sensor (pu-sensor) [Figure 3] for EApu. PU-sensor is very sensitive and is susceptible to the surrounding environment. Calibration is one of the most important and critical procedures in EApu as mentioned earlier in this paper. Accurate and precise calibration can derive the values worthwhile. The following three techniques are adopted as our bench mark through investigation.
4.1. Standing wave tube method
The standing wave tube method is less likely to be affected by the surrounding environment because of its setup system specifications. This method consists of two types: The first one is the long tube technique [16] and the second one is the short tube technique [Figure 4] [16]. One of our purpose is in-situ measurement, so we prefer a short tube technique for easy handling. Measurable frequency range of the calibration depends on the sound tube diameter. The bandwidth is limited for high frequencies. The smaller the tube diameter is, the higher the frequency can be measured. The PU-sensor setting also significantly affects the values. At lower frequencies (f<100Hz) small leakages in the probe mountings influence the measurements. To prevent these influences, the probes must be sealed with e.g. a rubber ring [16]. Our recent research improves the calibration values for the lower frequencies by applying curve-fitting approximation [18]. In other words, the calibration of PU-sensor is the most important and difficult step to obtain the relevant values throughout the measurement procedure of EApu.

4.2. POS (piston on a sphere)
POS signifies piston on a sphere. PU-sensor calibration with POS setup [Figure 4] needs to be performed in a quiet environment with low reflections but anechoic conditions are not required [19]. The calibration process and procedure are susceptible to errors because of: probe and reference sensor allocations, reference sensor response variation, difficult assessment of the proper noise level, and lastly complicated model fitting criteria. Therefore, it is recommended that the POS calibrator be used as a checkup tool and not as an actual calibrator [19].

4.3. Manufacture’s shipping data
Microflown provides manufacture’s calibration value for each PU-sensor, but our investigation reached the conclusion that it is unacceptable, since values are fluctuated by humidity [14], [15]. Therefore, we decided to undertake research for making further refinements to the calibration by means of standing wave tube techniques was begun.
5. Example results

Figure 5 shows comparisons of sound absorption coefficients and surface normal impedance of glass wool (GW:32kg/m³) and needle felt (NF) measured by EAp method and tube method. The blue lines show the values by EAp method, and the red lines show the values by tube method. The values of the NF absorption coefficient used by these two methods have similar tendencies. The values of the GW absorption coefficient by two methods also show a similar tendency, though the certain discrepancies are observed around 200 - 400 Hz area. It can be inferred that they were caused by the noise problem from the conditions of specimen’s installation. This is one of the most serious matters of the tube method. For this reason, it demands further investigation. The values of the GW surface normalized impedance used by two methods agree well each other. On the other hand, the imaginary part of the NF surface normalized impedance deviate from each other in the lower frequency area.

6. Conclusion

This paper provides a general description of EA method by comparing with the other conventional methods. EA method can obtain the rather robust values of normal surface impedance and absorption co-efficient at the same time in m-situ measurements. EApp has advantages because it is not costly, and it has reliable setup system, and there is no need to calibrate. Nonetheless, it takes more time and effort than EAp because of its measurement procedure. On the other hand, the EAp is costly and needs calibration in each measurement procedure set. However, it is still valuable regarding its theoretical and geometrical straightforwardness. Further experiments and investigations are necessary to improve the EA method itself. Impedance database for wave-based-room-acoustical simulations is still insufficient. EA method makes a substantial contribution to the construction of materials’ impedance database.

7. References

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