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INTENSITY MEASUREMENT OF SOUND ABSORPTION

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1. Introduction

The evaluation of the sound absorbing properties of materials and objects is important for good and reliable design of room acoustics. However, in practice, use of absorption coefficients measured by conventional techniques often leads to disappointing results, perhaps unintelligible speech in a lecture room, or too short a reverberation time in a concert hall.

The rapidly developing techniques of sound intensity measurement offer the possibility of new methods for the measurement of sound absorption which may have advantages over conventional techniques.

2. Review of Coefficients and Measurement

The traditional meaning and measurement of sound absorption may be found in standard text books and therefore only a limited number of aspects will be discussed here. A broad discussion can be found in Beranek (1971).

Absorption coefficient (α) as a property of a surface is defined as:

$$\alpha = \frac{E_a}{E_i} \quad \text{where} \quad \begin{array}{l} E_a = \text{sound energy absorbed} \\ E_i = \text{sound energy incident.} \end{array}$$

This can also be written as:

$$\alpha = \frac{W_a}{W_i} \quad \text{where } W = \text{sound power (i.e. energy per unit time)}$$

$$\text{and} \quad \alpha = \frac{I_a}{I_i} \quad \text{where } I = \text{average sound intensity (i.e. power per unit area).}$$

Absorption coefficient will, in general, be a function of frequency, the nature of the incident sound field, and the nature of the absorber. Although the above definition is superficially simple, complications arise when it is applied to real situations, either through deviations from idealised sound fields in test chambers or unknown fields in a working environment. An example is that of a Helmholtz resonator with flow resistive material in the neck to dissipate sound energy. If placed in a diffuse sound field, at or near the resonance, the sound field in the vicinity of the absorber will be substantially modified by diffraction from the ideal diffuse model, and the magnitude and distribution of the incident sound power will not be clear.

To cope with the situation where the meaning of absorption coefficient is doubtful, the concept of "absorption cross section" is introduced, i.e. the equivalent area of perfect absorber ($\alpha = 1{\cdot}0$). For the Helmholtz resonator this will be the absorbed power divided by the assumed incident intensity which would be present if the absorbent object were not there (Kuttruff, 1979: page 139). The equivalent area of a simple absorbent surface is simply $\alpha \times A$ where A is its surface area.

For the purpose of measurement, two types of idealised sound field are of particular importance: a plane wave and a diffuse field. For a plane wave, there is a well defined absorption coefficient which will depend upon the angle of incidence $\alpha(\theta)$, where θ is the angle subtended to a normal of the surface. It is clear that from the definitions, α can only have values in the range $0{\cdot}0 \leq \alpha \leq 1{\cdot}0$, $\alpha = 0{\cdot}0$ corresponding to a perfectly reflecting surface and $\alpha = 1{\cdot}0$ corresponding to a perfectly absorbing surface.

For a diffuse field, a random incidence absorption coefficient (α_{ri}) is defined and related to $\alpha(\theta)$ by the equation (Pierce, 1981):

$$\alpha_{ri} = \int_0^{\pi/2} \alpha(\theta) \sin 2\theta \, d\theta.$$

This gives a weighted average of $\alpha(\theta)$ over the range $0 \leq \theta \leq \pi/2$ such that if $\alpha(\theta)$ = constant, then $\alpha_{ri} = \alpha(\theta)$.

α_{ri} is usually determined by reverberation time measurement for a sample of the material in a reverberation chamber. Theoretical considerations assuming a diffuse field model and uniform surface distribution of absorption have led to numerous formulae linking absorption and reverberation, the two in common use being those due to Sabine and to Norris and Eyring. The latter formula is more suitable to "short" reverberation times; i.e. high absorption and/or a small chamber.

Unfortunately, values for absorption measured in a reverberation chamber frequently exceed $1{\cdot}0$. This anomaly is common enough to be accepted in practice, and often these values are rounded down to just below $1{\cdot}0$, the justification being said to be due to "diffraction", "edge effect" or "non-diffuse fields". This type of procedure may be acceptable for, say, rank ordering of materials by absorption for a given situation, but makes true standardisation and specification most difficult. This leaves a need for a more precise technique to be developed.

3. Use of Intensity Methods for Sound Absorption Measurement

The principles and practicalities of acoustic intensity measurement by the two-microphone technique are becoming well documented (e.g. Senlis Conference, 1981) so will not be discussed here.

Virtually all evaluation applications of acoustic intensity measurement involve the determination of a sound power (power = $\int \vec{I}.d\vec{s}$); most commonly in order to determine total radiated sound power from a source in environments where sound pressure measurements can yield erroneous results, and to rank order local contributions to total radiated power of extended and multiple sources. This technique is also suitable, within limits, for the determination of sound power absorbed by some form of acoustic energy absorber, and if the sound power incident upon this absorber is known, then the absorption coefficient can be calculated. The detail of the sound intensity measurements can show the distribution of the absorbed sound power over the surface of an absorber, and hence the distribution of absorption, if the incident sound field is uniform.

Crocker et al. (1981) measured the transmission loss of panels by mounting a test specimen in the wall of a reverberation room; one side facing into the room, the other side ideally facing a free field (though this latter condition is not strict). With a noise source in the reverberation room, the transmitted sound power can be determined from sound intensity measurements over the outside surface of the specimen and the incident sound power calculated from sound pressure measurements in the reverberation room, assuming a perfectly diffuse field (i.e. intensity incident on surface = $\langle \overline{P^2} \rangle /4\rho c$). The transmission loss is simply related to these two powers. The sound intensity measurements will also show the distribution of transmitted power over the surface of the panel.

Similarly, absorbed power can be measured over the surface of an absorber placed in a diffuse field. From sound intensity measurements over the absorbing surface and pressure measurements in the room, made at points removed from the near field of the absorber, incident and absorbed powers can be estimated, and therefore an absorption coefficient can be calculated.

From the definition of random incidence absorption coefficient:

$$\alpha_{ri} = 2 \int_{o}^{\pi/2} \alpha(\theta) \cos\theta \sin\theta \, d\theta.$$

The presence of 2sinθ in the integral is due to the integration over the solid angle of 2π steradians, assuming incident intensity and α to be independent of the other angular spherical co-ordinate, and is implicit in the measurement of absorbed sound intensity. The incident intensity of a diffuse field is independent of θ, and will therefore simply scale the result of the integration. This leaves $I_a(\theta)\cos\theta$ $(\alpha(\theta) = I_a(\theta)/I_i(\theta))$, which is the vector component of an absorbed intensity in a direction normal to the measurement surface. Thus, measuring the intensity vector normal to the surface will, if the incident intensity assumption is good, directly yield the random incidence absorption coefficient.

If the absorption coefficient of the surface under test is small, the net local surface sound intensity level will be small compared to the local sound pressure level, e.g. for surfaces of low absorption coefficient $L_I \sim L_p - 9{\cdot}0 + 10 \log_{10}\alpha$ where L_I = sound intensity level and L_p = sound pressure level, which gives $L_p - L_I \sim 19$ dB for $\alpha = 0{\cdot}1$ (Fahy, 1982). A typically good two-microphone sound intensity meter will read a spurious sound intensity of $L_p - L_I = 20$ dB for a common mode pressure driving the two microphones (i.e. in a field direction having zero sound intensity) due to phase mis-match between the microphones. If measuring absorbed sound intensity on a surface of $\alpha = 0.1$, then the true and spurious intensities will add or subtract depending upon microphone orientation and result in an error of either +3 dB or $-\infty$ dB. This error can be compensated for by linearly averaging measurements with forward and reverse microphone positions. In addition to this error, the dynamic range of the instrument becomes a limiting factor, $L_p - L_I$ again being the limited parameter.

The greatest contribution to uncertainty in this style of measurement is the distribution of the incident sound field, and therefore the assumption that the incident sound intensity = $<\overline{P^2}>/4\rho c$, where P is measured outside the nearfield of the absorber and the source. In a practical reverberation chamber, the uniformity of the field will depend upon position of source and absorber; there will be a net power flow from source to absorber superimposed on the reverberant part of the field. If the source is placed facing the absorber, this flow will essentially be local and direct; normal reverberation room practice is to use multiple sources, or single sources facing room corners, to ensure an even distribution of acoustic energy throughout the room. The size and shape of the reverberation room will also affect uniformity of field, particularly at low frequency where room dimensions and wavelength are of similar order of magnitude (Bolandi and Mulholland, 1982).

Checks on field uniformity can be made by measuring the spatial variation of sound pressure level and sound intensity level (and direction) in the room, away from the source and absorber. Unfortunately there are no criteria upon which to decide whether a given situation is suitable for measurement or not. Note that it is not good enough to average many S.P.L. readings when the spatial variation is large, as "average" conditions are not necessarily prevalent in the vicinity of the absorber.

The above discussion of field applies equally to reverberation time determination of absorption coefficient. The sound intensity method may be a better method than the reverberation time method as the latter requires further assumptions about the decay rate of the field after the source has been silenced, though the reverberation time method has the advantages of maturity and "made to measure" equipment (e.g. Walker, 1982).

References

Beranek, L.L. 1971 Noise and Vibration Control, McGraw-Hill.

Crocker, M. et al. 1981 Noise Control Engineering 17(1), 6-11. Measurement of transmission loss of panels by the direct determination of transmitted acoustic intensity.

Kuttruff, H.H. 1978 Room Acoustics (2nd Edition), Applied Science Publishers.

Pierce, A.D. 1981 Acoustics, McGraw-Hill.

Senlis Conference 1981 Recent Developments in Acoustic Intensity Measurement. Secretary: Dr. M. Bockhoff, CETIM, 60304 Senlis, France.

Proceedings of the Institute of Acoustics Spring Conference 1982 Secretary: Dr. J.M. Bowsher, Physics Department, University of Surrey, Guildford, Surrey. Papers: A2.5 (A. Bolandi and K.A. Mulholland), B1.3 (F.J. Fahy) and C2.2 (R. Walker).