inter-noise 96
25th Anniversary Congress – Liverpool

INCE: 72.7.2

# THE VOLUME VELOCITY METHOD FOR MEASURING THE SPECIFIC NORMAL IMPEDANCE OF ACOUSTIC MATERIALS

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## 1. INTRODUCTION

Numerous methods for measuring the normal incidence specific acoustic impedance at the surface of acoustic materials have been used over the last century. The Kundt tube method and more recently the two microphone method have formed the basis of national standards [1]. This paper contains a description of a method based on digital signal processing of the signal from a single microphone near the surface of the material of interest and the signal from a volume velocity source at the opposite end of a short tube. This method enables accurate low frequency measurements to be made with a compact device.

## 2. THE VOLUME VELOCITY METHOD

The volume velocity method is based on measuring, with a two channel analyser, the transfer function relating the pressure sensed by the microphone close to the face of the specimen and the acceleration of the piston of the volume velocity source. The design shown in Figure 1 was used as it allowed the specimen and its holder to be transferred from the volume velocity source to a Bruel & Kjaer two-microphone tube as shown in Figure 2. Hence the impedance components and the absorption coefficient measured by the volume velocity method could be compared with those measured by the two-microphone method with the certainty that the impedance at the face of the specimen would be unchanged.

The model used for the analysis is shown in Figure 3. The positive and negative travelling plane waves in the cavity can be represented in complex form by $\mathbf{p}_+ = \mathbf{P}_+ \exp[j(\omega t - kx)]$ and $\mathbf{p}_- = \mathbf{P}_- \exp[j(\omega t + kx)]$. The complex reflection coefficient at the surface of the specimen where x = L, the complex representation of the pressure measured by the microphone at x = L-D and the complex representation of the volume velocity at x = 0 can be expressed in terms of these waves.

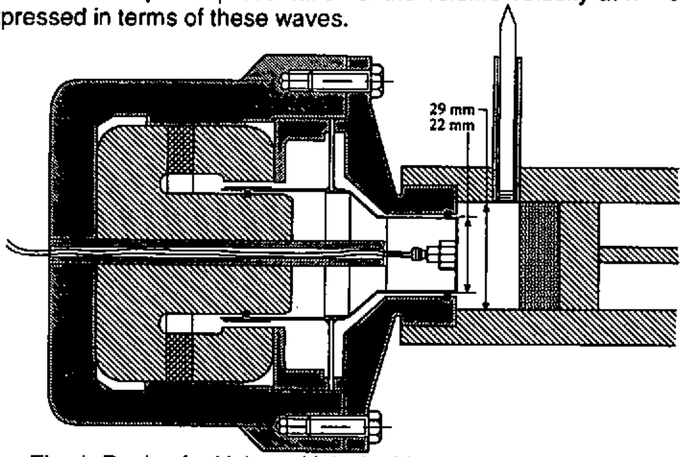


Fig. 1 Device for Volume Velocity Measurements

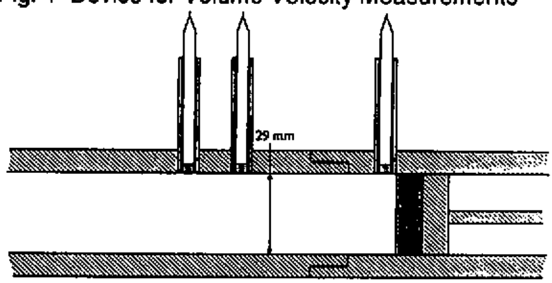


Fig. 2 Specimen Holder Fitted to Two-microphone Tube

The volume velocity produced by the piston of area, $S^*$ in terms of the complex representation of its acceleration, $\mathbf{A}$ is $S^*\mathbf{A}/j\omega$. If the transfer function which relates the pressure measured by the microphone at x = L-D to the acceleration of the piston at x = 0 is denoted $\mathbf{H}(j\omega)$, it can be shown that the complex reflection coefficient, $\mathbf{R}(j\omega)$ is given by:

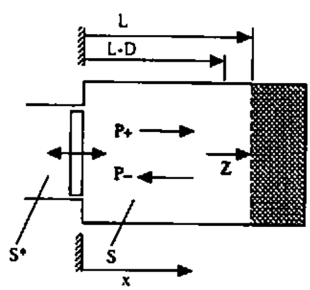


Fig. 3 Model for Analysis

$$\mathbf{R}(j\omega) = \frac{(j\omega(S/S^*)\ \mathbf{H}(j\omega)/(\rho c))\exp(+jkL) - \exp(+jkD)}{(j\omega(S/S^*)\ \mathbf{H}(j\omega)/(\rho c))\exp(-jkL) + \exp(-jkD)} \qquad (1)$$

The wave number is $k = \omega/c$, where $\omega$ is the angular frequency and $c$ is the velocity of sound. $\rho$ is the density of the air. The normal incidence specific acoustic impedance ratio at the surface of the specimen, $z/\rho c$ and the absorption coefficient, $\alpha$ can be found from $z/\rho c = (1+\mathbf{R}(j\omega))/(1-\mathbf{R}(j\omega))$ and $\alpha = 1-|\mathbf{R}(j\omega)|^2$.

## 3. PRACTICAL ASPECTS

Magnitude and phase errors in the voltages produced by the accelerometer and the microphone will result in the "measured" transfer function, $\mathbf{H}_m(j\omega)$ being different from the "true" transfer function, $\mathbf{H}(j\omega)$. The effect of these errors can be minimised by the following procedure. These transfer functions can be related by equation (2).

$$\mathbf{H}(j\omega) = \alpha(j\omega)\mathbf{H}_m(j\omega) \qquad (2)$$

$\alpha(j\omega)$, the correction term which should be applied to the" measured" transfer function to obtain the "true" transfer function, can be obtained by measurements made when a hard surface for which $\mathbf{R}(j\omega) = 1$ replaces the surface of the specimen. Suppose that the calibration transfer function measured for this condition is denoted $\mathbf{H}_{mc}(j\omega)$. Equation (1) then leads to the following result.

$$\alpha(j\omega) = \frac{\exp(+jkD) + \exp(-jkD)}{(j\omega(S/S^*)\mathbf{H}_{mc}(j\omega)/(\rho c))[\exp(+jkL) - \exp(-jkL)]} \qquad (3)$$

This expression can be used in equation (2) which then can be used in equation (1) to give equation (4) which is expressed in terms of an "equalized" transfer function $\mathbf{H}^*(j\omega)$ given by equation (5).

$$\mathbf{R}(j\omega) = \frac{+\mathbf{H}^*(j\omega)(1 - j\cot kL) - (1 + j\tan kD)}{-\mathbf{H}^*(j\omega)(1 + j\cot kL) + (1 - j\tan kD)} \qquad (4)$$

$$\mathbf{H}^*(j\omega) = \mathbf{H}_m(j\omega)/\mathbf{H}_{mc}(j\omega) \qquad (5)$$

It is evident that the two key features of the technique are the measurement of an "equalized" transfer function which allows the effect of the amplitude and phase errors in the transducers to be minimised and the use of this "equalized" transfer function in equation (4).

The internal diameter of the cavity and the specimen holder, being 29mm as shown on Figure 1, results in cross modes in the cavity not being encountered until a frequency of about 6kHz is reached. Thus the transfer function $\mathbf{H}(j\omega)$ was measured over a frequency range of 0 to 6.4kHz and the data was plotted over a range 0 to 5kHz. The axis of the microphone was 7mm from the face of the piston of the volume velocity source and the specimen was 10mm from the face of the piston.

The two microphones used with the ASTM two-microphone procedure were 20mm apart and the axis of the closest microphone was 43mm from the face of the specimen. The usual procedure of switching the microphones to minimise phase errors was followed.

## 4. SAMPLE RESULTS AND CONCLUDING COMMENTS

The components of the specific normal acoustic impedance ratio and the absorption coefficient determined by the volume velocity method and the two-microphone method for a 50mm thick fibreglass specimen are plotted in Figure 4 in two sets of graphs. One covers a frequency range of 0 to 500 Hz while the other is for a frequency range of 0 to 5000 Hz. The absorption coefficients are not plotted on the 0 to 500 Hz diagrams as they are small over much of the range. The values determined by the volume velocity method are shown by lines while the values determined by the ASTM two-microphone method are plotted as points. The lack of agreement at low frequencies is probably due to the close spacing of the two microphones in the ASTM method while at high frequencies the lack of agreement is probably due to the sound pressure not being uniform close to the specimen face due to its lack of uniformity.

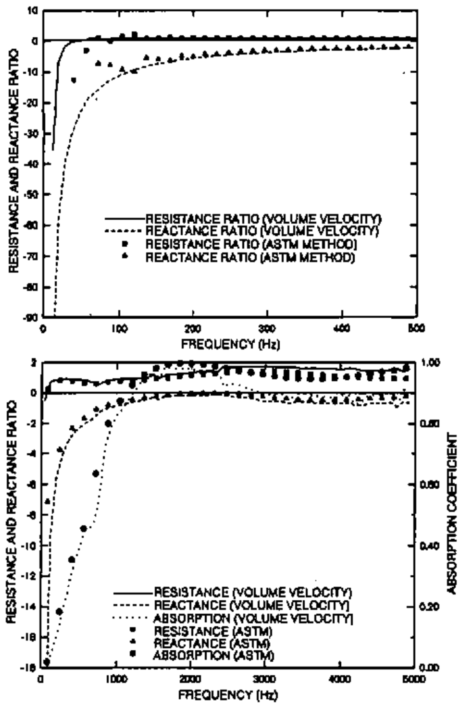


Fig. 4 Components of Impedance Ratio and Absorption Coefficient for 50mm Thick Fibreglass.

### References

1. ASTM E1050-86 "Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System".