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APPLICATION OF AN AREA-INTEGRATING VIBRATION VELOCITY TRANSDUCER

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1. INTRODUCTION

Determination of the sound radiated by a vibrating surface usually requires a knowledge of the distribution of normal velocity of the surface. Traditionally, accelerometers are attached to the surface with a maximum spacing of half the acoustic wavelength of the highest frequency of interest; the acoustic Nyquist sampling criterion. The Green functions from each point on the surface to the point of interest in the acoustic field can then be determined analytically (for simple geometry) or by reciprocal measurement [1]. Estimates of the sound field radiated by vibration distributions sampled at points according to the above criterion can only be accurate for surfaces having vibrational wavenumbers that are lower than the acoustic wavenumber. If high vibrational wavenumber components are present, spatial aliasing of the vibration field will result and errors will be introduced into estimates of the radiated sound field. Such high wavenumber vibration components are common in thin plates and where edges and stiffeners are present. Applying the Nyquist sampling criterion to the vibration field will avoid the aliasing problem, but prior knowledge of the vibration field is necessary and the resultant number of sample points may be prohibitively large. The quantity of interest for estimating the radiated field is the volume velocity of elemental areas of the surface having dimensions determined by the acoustic Nyquist criterion, where the volume velocity is defined as the integral of the normal velocity over the element. Vibration components with wavenumbers higher than the acoustic wavenumber do not radiate sound efficiently and are averaged out by the integration. The device described below is capable of estimating the instantaneous, area-integral of the normal vibration velocity of a surface, and is thus a true volume velocity transducer.

2. DESCRIPTION OF TRANSDUCER

The transducer consists of a square-section tube which is open at one end and connected to an anechoic termination at the other. When the open tube end is brought close to a vibrating surface, a plane wave, having an amplitude which is proportional to the instantaneous integral of the normal velocity of the surface beneath the tube end, propagates along the tube towards the termination and is sensed by a miniature microphone.

The Anechoic Termination

Although the presence of the anechoic termination is not strictly essential for the operation of the transducer, it does give rise to a calibration curve which is a smooth function of frequency and reduces the sensitivity of this calibration to the distance between the tube end and the surface being measured. The anechoic termination also allows the transducer to be calibrated using a reciprocal technique [2]. The termination is required to be anechoic over as wide a range of frequencies as possible, and to be physically compact so conventional tapered absorber terminations were ruled out. A termination based upon an area expansion and a resistive sheet, first devised by Dalmont et al [3], was considered to be both effective and space efficient and was used for a prototype transducer (see [2]). This prototype termination was designed more-or-less on a trial and error basis, and proved to be reasonably effective. A mathematical model of the termination has since been developed and used to improve the design for a later prototype.

Termination Model

The termination consists of a rapid cross-section expansion terminated by a resistive layer matched to the area ratio of the expansion. In its basic form the termination is only effective at low frequencies, but past experience has shown that this performance can be extended to higher frequencies if sound absorbing treatments are applied to the cavity between the expansion and the resistive layer. The termination is modelled as two square-section ducts joined by a sudden discontinuity with the resistive sheet represented by an impedance at a plane in the larger section duct. The sound field within the small-section duct is represented by a set of modes having complex amplitudes A_{mn} propagating in the positive x direction, and a set of modes of complex amplitude B_{mn} propagating in the negative x direction; the relationships between the amplitudes A_{mn} and B_{mn} are determined by reflection from the discontinuity. The sound field within the large-section duct is similarly represented by forward and backward propagating sets of modes of amplitude C_{pq} and D_{pq} respectively, the values of which are determined by transmission through the area discontinuity and reflection from the resistive sheet. The presence of absorbent material in the larger duct can be modelled by considering the complex wavenumber (k') and complex effective density (ρ') associated with porous absorbers. By equating the total acoustic pressure and particle velocity in the two ducts at the discontinuity over the area of the small duct, and noting that the particle velocity is zero for the rest of the area of the large duct, a set of simultaneous equations can be defined which express the wave amplitudes in the small duct (A_{mn} and B_{mn}) in terms of an infinite sum of the wave amplitudes in the large duct (C_{pq} and D_{pq}). Given values for A_{mn} and the reflection coefficient of the resistive sheet, values for B_{mn} can be obtained approximately by matrix inversion after truncation of the infinite series.

Figures 1 and 2 show predictions of the normalised acoustic impedance of a prototype termination with and without absorbent treatment respectively. The improvement in performance gained by filling the cavity with absorbent (open-cell foam) can clearly be seen. By way of verification, figures 3 and 4 show measurements of the impedance of the prototype termination taken using the two microphone position impedance tube technique [5]. The agreement between the predicted and measured results is considered sufficiently good for the model to be used for further refinement of the termination.

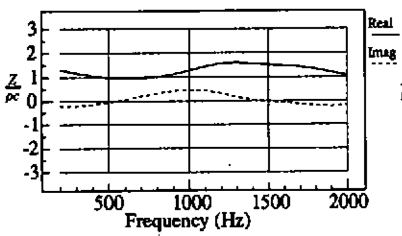

Figure 1 Predicted Impedance of Termination – With Absorbent

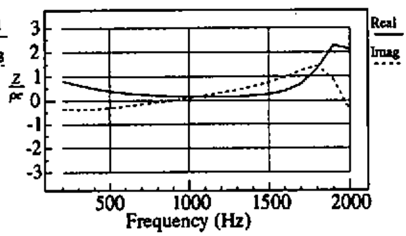

Figure 2 Predicted Impedance of Termination – No Absorbent

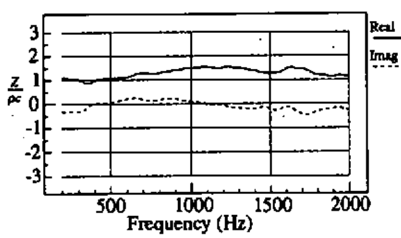

Figure 3 Measured Impedance of Termination – With Absorbent

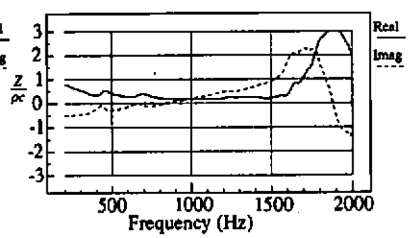

Figure 4 Measured Impedance of Termination – No Absorbent

After a thorough parametric study of termination performance, a transducer was constructed with an optimum termination and tested. Impedance measurements showed that the addition of a small inverted wedge of low resistivity open-cell foam in the small section duct yielded a further improvement in performance at high frequencies.

3. APPLICATION OF TRANSDUCER TO VEHICLE NOISE

The latest prototype transducer is currently being tested for use in the measurement of the vibration of the interior of a vehicle. The entire interior surface of the cab of a light commercial vehicle has been divided into 1600 elemental areas measuring 75mm x 75mm to match the footprint of the transducer – the size of the elements corresponds to a high frequency limit of 2kHz. All apertures within the cab, such as the area beneath the dashboard, have been covered with cardboard and sealed with modelling clay and adhesive tape to ensure that all of the noise within the cab is due to surface vibration. Engine noise is simulated by a loudspeaker placed beneath the engine.

The surface volume velocity of each element has been measured using the prototype transducer and these will be combined with a set of blocked pressure measurements to yield a prediction of the sound pressure at a point within the cab by the principle of vibro-acoustic reciprocity [1]. This prediction will then be compared with a direct measurement of the pressure. The test results will be presented at the conference.

4. REFERENCES

[1] J. M. Mason, F. J. Fahy, "Development of a Reciprocity Technique for the Prediction of Propeller Noise Transmission Through Aircraft Fuselages", Noise Control Engineering Journal, 34 (2), 1990.

[2] K. R. Holland and F. J. Fahy, "A Simple Vibrational Volume Velocity Transducer", Proceedings of Inter-noise 93, Leuven, 1993.

[3] J. P. Dalmont, J. Kergomard, X. Meynial, "Réalisation d'une Terminaison Anéchoïque pour un Tuyau Sonore aux Basses Fréquences", C. R. Acad. Sci. Paris, t. 309, Serie II, 1989.

[4] P. M. Morse & K. U. Ingard, "Theoretical Acoustics", McGraw-Hill Book Co. Inc., New York, 1968.

[5] F. J. Fahy, "Rapid Method for the Measurement of Sample Acoustic Impedance in a Standing Wave Tube", Letter to Editor, J. Sound Vib., 97(1) p168, 1984.

5. ACKNOWLEDGEMENTS

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