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INHERENT ERRORS IN ACOUSTIC INTENSITY MEASUREMENTS FOR PISTON-TYPE SOURCES

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INTRODUCTION

This paper considers the errors arising from the use of the finite difference approximation for the pressure gradient in the two-microphone acoustic intensity measurement technique. The cross-spectral density method [1,2,3] permits the development of acoustic intensity measurements using simply two identical microphones and a two-channel FFT digital analyzer. The fundamental limitations of finite difference approximation for pressure gradients were first outlines by Fahy [2] when he presented results for the effect of Δrk on the percentage error (where Δr is the microphone separation distance, and k is the acoustic wavenumber). In 1981, Thompson and Tree [4,5,6] presented detailed error analysis based on a monopole, dipole and lateral quadrupole source model and concluded that, not only should Δrk be considered but also $\Delta r/r$ (where r is the distance between the source and the midpoint between the microphones). In this paper an attempt is made to include the source size where the error analysis is based on a baffled piston source model.

ERROR ANALYSIS FOR PISTON SOURCE

The acoustic pressure produced by a piston along its symmetrial axis is given by [7]

$$P(r,0,t) = \rho c u e^{i\omega t}\left[e^{-ikr} - e^{-ik(r^2+a^2)^{1/2}}\right] \qquad (1)$$

where a is the piston radius,
ρ is the medium density,
c is the speed of sound,
r is the radial distance in spherical coordinates,
t is the time, and
u is the normal velocity amplitude of the piston.

The exact intensity expression is then given by

$$I_{ex} = \frac{P^2}{2\rho c} = 2\rho c u^2 \sin^2 \frac{kr}{2} \left((1 + \frac{a^2}{r^2})^{1/2} - 1\right). \tag{2}$$

The measured intensity is obtained from the imaginary part of the cross-spectral density of the two closed-spaced microphones G_{12} as

$$I_m = \frac{(G_{12})_{imag}}{\Delta r \rho \omega} = \frac{\rho c u^2}{2\Delta r k} \{ \sin \frac{\alpha}{\beta} \left(\sqrt{(1 + \frac{\beta}{2})^2 + \gamma^2} - \sqrt{(1 - \frac{\beta}{2})^2 + \gamma^2}\right)$$

$$- \sin \frac{\alpha}{\beta} \left((1 + \frac{\beta}{2}) - \sqrt{(1 - \frac{\beta}{2})^2 + \gamma^2}\right)$$

$$- \sin \frac{\alpha}{\beta} \left(\sqrt{(1 + \frac{\beta}{2})^2 + \gamma^2} - (1 - \frac{\beta}{2})\right) + \sin \alpha \} \tag{3}$$

where $\alpha = \Delta rk$, $\beta = \Delta r/r$ and $\gamma = a/r$.

The intensity error level is therefore given by

$$L_e = 10 \log_{10} (\frac{I_m}{I_{ex}}) \tag{4}$$

The acoustic near pressure field along the piston axis exhibits maximum and minimum values (see figure 1) and therefore measurements along the symmetrical axis of a baffled piston type source (for example, a loadspeaker or the case of ignition piston noise transmited through engine casing) should avoid this near-field region. Hence, there is a upper limit value for $\gamma = a/r$ below which non zero pressure field exist, this value is given by

$$\frac{a}{r} \leqslant \left(\frac{4\pi}{kr} + \frac{4\pi^2}{r^2 k^2}\right) \tag{5}$$

Figure 2 shows the error level L_e given by equations (2), (3) and (4) for values of γ satisfying equation (5), using some typical recommended values for α and β [4,5,6].

CONCLUSIONS

The errors introduced by the finite difference formulation for acoustic intensity measurements depend on microphone separation, frequency range source-microphones centre and source complexity. Analysis of a piston type source shows that for an error level less than ±1.5 dB, the ratio of piston radius to its distance from the microphones centre should be less than about 2.0 for $0.05 \leqslant \Delta rk \leqslant 1.0$ and $0.1 \leqslant \Delta r/r \leqslant 1.0$.

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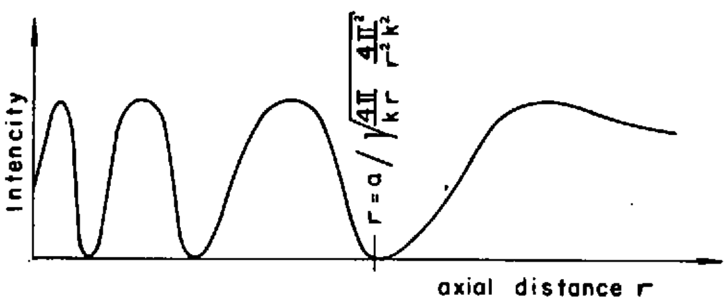

Fig.1. Sound intensity in vicinty of a baffled piston

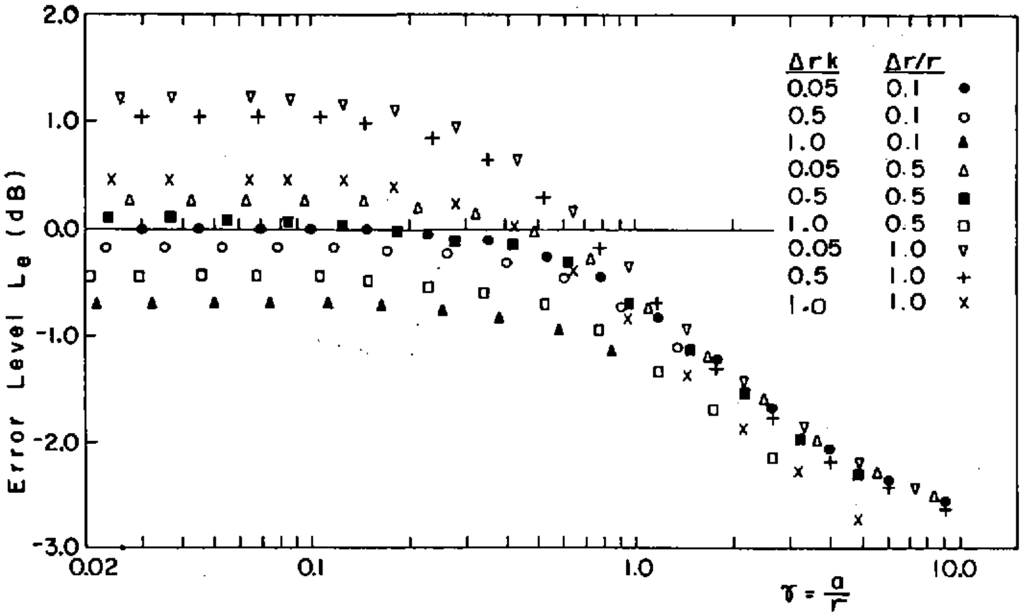

Fig.2. Finite difference approximation error level of a baffled piston source.