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ACOUSTIC INTENSITY TECHNIQUES FOR TRANSIENT NOISE SOURCES

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1. Introduction

The two microphone method of sound intensity measurement has advanced to a stage where its documentation is quite thorough and commercial instruments are now available. The major part of this work is devoted to measurements on continuous noise sources, though recently interest has been shown in applying sound intensity techniques to transient noise sources |1,2|, particularly with respect to measurements made in-situ.

This paper comprises some of the considerations needed to be made in applying the two microphone method of sound intensity measurement to transient noise sources.

2. Instrumentation Considerations

Time domain analyses will be useful in addition to the more usual frequency domain analyses of transient events, and the former will require a much better performance from instrumentation than the latter.

The transducers must be well phase matched; real transient events will not be repeatable to enable cancellation of transducer mismatch by microphone reversal, and transducer mismatch would also produce distortion on an intensity-time history. Sensitivity mismatch is easy to compensate for in processing.

Assuming that the microphone signals will be sampled and converted to digital form, a sample rate must be chosen and measures taken to prevent aliasing. For frequency analysis, four samples per cycle of the highest frequency Fourier component is adequate but not really enough to adequately display an intensity-time history. This may mean sampling at different rates for time and frequency domain analysis; the former being of interest in the first few tens of milliseconds of an event, the latter requiring capture of the whole event. For the time domain analysis, the anti-alias filters must be precision matched and have a phase characteristic which is linear with frequency over the pass-band, to ensure minimum distortion of the signals.

It must be ensured that the two A.D.C.'s sample the microphone signals simultaneously. For, say, a microphone separation of 15 mm, an acoustic wave propagating in-line with the microphones reaches the far microphone 44 μs after passing the first. At other angles of incidence this time of flight will be less. It is surprising how many sampling systems cannot guarantee two channels to sample within, say, 0·5 μs of each other.

On the more practical side, for measurements in-situ then the equipment must be suitably portable. The pressure signals must be sampled directly and stored in digital form, analogue tape recorders are just not good enough for taking intensity measurements home.

3. Time Domain Analysis

Both intensity-time and energy flux-time histories will be useful for noise control diagnostics (energy flux being the time integral of intensity). Figure 1 shows a sample intensity-time history and Figure 2 the associated energy flux-time history. In free field conditions and away from the near field of the source, similar time histories can be deduced via $P^2/\rho c$ and its time integral. Two advantages of direct intensity measurements are a truer performance in the nearfield (where the intensity vector can, at times, be directed towards the source) and, in a reverberant environment, sound intensity from "distant" reflections will time average to zero. Reflections from nearby surfaces (e.g. the floor) will bias sound intensity results, but to a lesser extent than P^2 results.

To illustrate the nearfield intensity-time structure of a source, for a point monopole source:

$$I_r(t) = \frac{P_r^2(t)}{\rho c} + \frac{P_r(t)}{\rho r} \int_{-\infty}^{t} P_r(\tau).d\tau, \qquad (1)$$

where $I_r(t)$ = radial component of intensity at a distance r from the source, at time t

$P_r(t)$ = acoustic pressure r,t

ρ = density of air

c = velocity of sound in air.

The second term in equation (1) is proportional to 1/r and is therefore a "near field" term. This term can, at times, have both positive and negative values (cf. the first term can only be positive) and will time average to zero over a complete transient event. The second term may, at times, be more negative than the first term is positive and therefore direct the intensity vector towards the source.

For a dipole point source, the radial intensity and acoustic pressure at a field point are not exclusively related as in the case of a monopole, but the near field effects will be stronger. There will also be a tangential component of intensity which will vary with time but time average to zero over a complete transient event. This certainly shows that for complex real sources the intensity vector will not only have a time variant magnitude but also a time variant direction.

The error introduced into estimations of sound pressure and particle velocity by the two microphone method can be expressed in the time domain as follows:

$$P_e(t) = P(t) + \tfrac{1}{2} \int_{t}^{t+\frac{h}{c}} P'(\tau).d\tau - \tfrac{1}{2} \int_{t-\frac{h}{c}}^{t} P'(\tau).d\tau, \qquad (2)$$

where $P_e(t)$ = estimated pressure at time t

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$P(t)$ = true pressure at time t

$P'(t)$ = time derivative of $P(t)$

$2h$ = microphone spacing.

Equation (1) simplifies to:

$$P_e(t) = \tfrac{1}{2} P(t + \tfrac{h}{c}) + \tfrac{1}{2} P(t - \tfrac{h}{c}), \tag{3}$$

which is simply the definition of $P_e(t)$. An intuitive feel for the nature of this approximation error can be obtained from considering t to coincide with a peak point of a sinusoidal waveform where $P_e(t)$ will underestimate the magnitude of $P(t)$.

For particle velocity:

$$V_e(t) = \frac{c}{2h} \int_{t-\frac{h}{c}}^{t+\frac{h}{c}} V(\tau).d\tau, \tag{4}$$

where $V_e(t)$ = estimated particle velocity at time t

$V(t)$ = true particle velocity at time t.

Intensity in the time domain will simply be the multiple of these two expressions ($I(t) = P_e(t).V_e(t)$).

Expressions of similar form can be deduced to represent the effect of, say, phase mismatch but these are quite complex and need analytic assumptions about the nature of mismatch.

4. Frequency Analysis

The time variant pressure signals from the two microphones are related to sound intensity in the frequency domain via their cross spectrum |3|. This relation can also be applied to transient events with all the assumptions necessary to apply Fourier methods to any transient signal (e.g. the complete event is captured and starts and finishes with zero acoustic pressure). Instrumentation and finite difference errors will be the same as for measurements on continuous noise sources. It must be remembered that intensity measurements are inherently band limited; by finite difference approximation at high frequency, and instrumentation at low frequency. The limiting frequencies for a particular configuration must always be known and applied to results.

References

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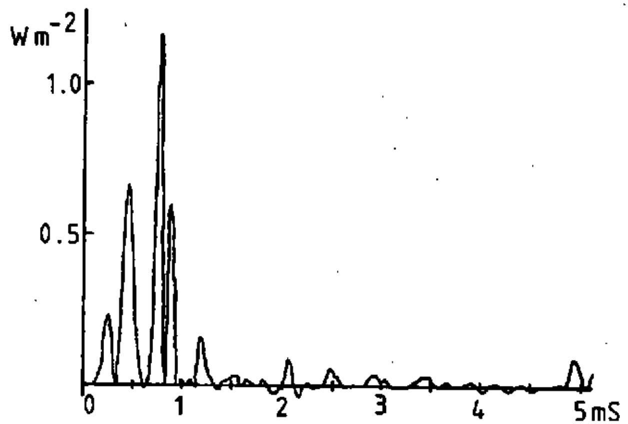

Figure 1. Intensity-time history.

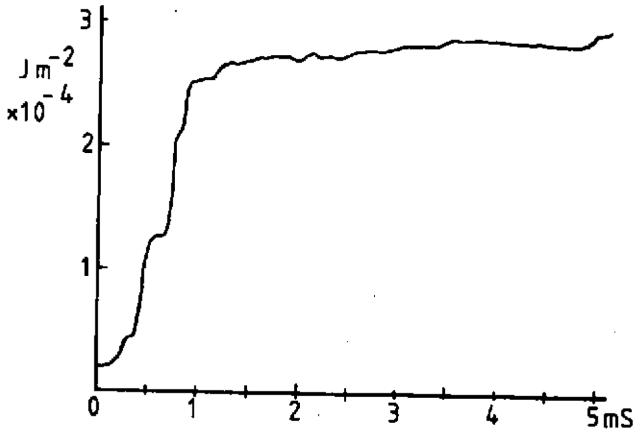

Figure 2. Energy flux-time history.