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PRACTICAL ASPECTS OF SOUND INTENSITY MEASUREMENT

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Introduction

The principle by which sound intensity may be measured by processing the outputs from two closely spaced microphones is now widely known. Research during recent years has led to the development of two main practical techniques for implementing this principle. In one, the two signals are subject to Fourier transformation by digital F.F.T. procedures and the cross spectral density of the two signals is computed. The sound intensity in a temporally stationary field is proportional to the imaginary part of the cross spectral density [1,2]. In the other main technique the signals are filtered by either analogue or digital filters, and combined and integrated in such a way as to produce filtered signals proportional to pressure and particle velocity. These signals are then multiplied, either directly or indirectly [3,4]. The main advantages of this latter direct technique over the current F.F.T. technique is that real time intensity information is displayed continuously, which is very valuable in source diagnostic tests.

The I.S.V.R. Analogue Intensity Meter employs completely analogue circuitry and the filters are based upon switched capacitor technology. The multiplication of the pressure and particle velocities is performed indirectly, by quarter square multiplication; the technique obviates any necessity to phase match the filters. In the following sections various applications of sound intensity measurement are described and examples of measurements made with the I.S.V.R. Intensity Meter are presented. Some problems associated with the performance of measurements and the interpretation of results are also discussed.

Microphones and Calibration

The microphones are the most critical components of a sound intensity measurement system. They must have sufficient sensitivity to measure down to about 30 dB, for example for sound insulation measurement; they must be robust, and sensitivity and phase stable over temperature and humidity ranges encountered in the field; and they must be small, in order to minimise diffraction and mutual interference effects at high frequencies (4-10 kHz). With the I.S.V.R. meter, ½" condenser pressure microphones have been used successfully in a side-by-side configuration up to about 4 kHz, but diffraction behaviour is unacceptable at higher frequencies. A face-to-face configuration has been developed which substantially increases that range, as reported elsewhere [5]. If intensity levels below 65 dB are not of interest, a 1/4" side-by-side configuration will work well up to 8 kHz.

Calibration of intensity microphones must encompass free field directivity tests over a continuous (not banded) frequency range and calibration of the entire measuring system should be made in an interference field of at least

25 dB standing wave ratio. The effects of wind should also be investigated. Whereas phase response differences between microphone channels can be automatically allowed for in the digital F.F.T. technique [6], the direct filter techniques require the use of phase matched microphones, although the use of microphone reversal considerably extends the allowable tolerances in this respect.

Applications

Source sound power determination

This is likely to become the most common application of sound intensity measurement. The advantages over the conventional techniques based upon sound pressure measurement are that corrections for the nature of the environment, and interfering noise from other sources, are unnecessary, and in-situ measurements can be made in the geometric and hydrodynamic near fields of large, complex sources. Examples of sources on which such measurements have been made with the I.S.V.R. meter include a large furnace, individual machines in production lines in a number of operating factories, an earth moving machine in a production space, an electric motor in a despatch bay and a number of automotive engines in test cells. Although sound power can be accurately determined in noisy and reflecting environments, the source directivity cannot be accurately determined because the intensity meter faithfully measures the total local intensity, and does not distinguish between sources. The outstanding question relating to the use of intensity measurement for sound power determination relates to the influence of the number, disposition and orientation of measurement stations on the uncertainty of the determination [7].

Of course, close-in sound intensity distribution measurements can be used to locate the radiation "hot spots" of a complex source, but the complexity of near fields can produce misleading interpretations.

Sound absorption measurement

In-situ measurement of the sound power absorbed by surfaces, or objects, can be made with an intensity meter. Examples of the application of the I.S.V.R. meter include special purpose absorbent panels in a room, and individual concert hall seats while in the hall. Two problems arise with this technique. First, the sound absorption coefficient in other than normally incident plane wave fields cannot be directly determined because only the nett (absorbed) intensity distribution over the surface is measured; the incident intensity is unknown and has to be estimated from sound pressure measurements, which often give unreliable results. Second, the absorbed intensity level at a surface on the boundary of a reverberant field is approximately related to the local sound pressure level on the surface by the equation $L_I \approx L_p - 9 + 10 \log_{10}\alpha$ (dB): for $\alpha = 0.25$ $L_p - L_I \approx 15$ dB. This difference imposes considerable strain on the dynamic range of a measuring instrument. In addition, the sound intensity distribution in the vicinity of partially absorbent surfaces is found to be very complex, and estimates are subject to positional and directional sampling errors. This is particularly true in the strongly diffracted fields near resonant sound absorbers.

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In one-dimensional fields a combination of single point sound intensity and sound energy density measurements can be used to directly determine sound absorption coefficient, since

$$I = (1/\rho_o c)(\overline{(p^+)^2} - \overline{(p^-)^2})$$

and $\varepsilon = (1/\rho_o c^2)(\overline{(p^+)^2} + \overline{(p^-)^2})$: hence $\alpha = (p^-)^2/(p^+)^2$ can be found.

Sound reduction index measurements

The sound power transmitted through a partition, or part thereof, can be determined with an intensity meter: the sound power incident cannot be so determined. Even if the partition is removed, the "incident" power is not necessarily correctly estimated by measurements at its previous location: consider a partition dividing a reverberation room in two. Hence the conventional, unreliable estimate based on reverberant sound pressure measurements must be employed. However, transmitted sound intensity distributions can be used to rank under the sound reduction index of component areas of a complex partition. In field measurements the transmitted sound intensities are often very low, of the order of 30-40 dB, and very sensitive instrumentation must be used.

Determination of sound power flux in ducts

The equations on which sound intensity measurement in a non-flowing fluid is based, are not valid for a moving medium. Below $M \approx 0.1$, the corrections are generally small for a one-dimensional wave system. However, the errors associated with the application of zero flow equations to sound propagation in a flow duct are seriously in error close to the cut-off frequencies of higher order modes, and near discontinuities [8]. Consequently it is not in principle possible to use normal sound intensity measuring systems in flow, except at low Mach numbers, below the lowest cut-off frequency of a duct.

Investigation of sound sources in enclosed spaces

The use of intensity meters to investigate the flow of acoustic energy in an enclosed space is fraught with problems of interpretation, especially for tonal sound fields, and at low frequencies, where the enclosure dimensions are comparable with a wavelength. In strongly reactive standing wave fields sound energy is known to circulate in loops and the direction of local intensity vectors can not be interpreted as indicating their source of origin. In fact, there is not likely to be any simple relationship between the level of sound pressure at any point and the rate of injection of acoustic power into the space. Hence, even the location and suppression of regions of locally high sound intensity on the boundary of an enclosure may not result in a reduction of sound pressure at a crucial point in the space. This stricture applies particularly to the cabins of vehicles in which strongly tonal sound fields may be generated by periodic sources.

Conclusions

Sound intensity measurement is now a practicable possibility which offers significant advantages over conventional methods based upon sound pressure measurement for a range of problems of practical importance. However, there remains much to be learnt about the optimisation of sound field survey techniques and about the interpretation of intensity distributions so measured. Accurate calibration of measurement systems is of crucial importance, upon which rests the future credibility of the new techniques, and to which insufficient effort has so far been directed.

References

1. F.J. FAHY 1977 J.Acoust.Soc.Am. 62, 1057-1059(L). Measurement of acoustic intensity using the cross-spectral density of two microphone signals.

2. J.Y. CHUNG 1978 J.Acoust.Soc.Am. 64, 1613-1616. Cross spectral method of measuring acoustic intensity without error caused by phase mismatch.

3. F.J. FAHY 1977 Noise Control Engineering 9(3), 155-162. A technique for measuring sound intensity with a sound level meter.

4. BRUEL AND KJAER 1981 Sound intensity analysis system 3360.

5. P.S. WATKINSON and F.J. FAHY 1982 Proceedings of Acoustics '82 - Spring Conference of the Institute of Acoustics. Acoustic characteristics of a face-to-face microphone arrangement for sound intensity measurement.

6. G. KRISHNAPPA 1981 J.Acoust.Soc.Am. 69, 307-310. Cross-spectral method of measuring acoustic intensity by correcting phase and gain mismatch errors by microphone calibration.

7. S.J. ELLIOTT 1981 Proc. Internoise 81. Spatial sampling of acoustic intensity fields.

8. D.H. MUNRO and U. INGARD 1979 J.Acoust.Soc.Am. 65(6), 1402-1406. On acoustic intensity measurements in the presence of mean flow.