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SOME RESULTS AND PROBLEMS OF SOUND INTENSITY MEASUREMENT

F.J. FAHY, V. SCHROTER

INSTITUTE OF SOUND AND VIBRATION RESEARCH, UNIVERSITY OF SOUTHAMPTON

1. Introduction

Two practical techniques of sound intensity measurement were described at the 1978 Spring Meeting of the Institute of Acoustics and have been reported in the literature (1,2,3). One technique employs two ½" condenser microphones, a special purpose signal processing circuit, and a portable sound level meter; the other involves digitisation of microphone outputs and subsequent processing in a computer. In this paper are presented the results of some measurements made with the analog system and also a discussion of some of the difficulties associated with the evaluation of sound intensity in the field.

2. Laboratory Measurements

2.1 Vacuum Cleaner

This test has been reported elsewhere (2) and is summarised here for completeness. An industrial vacuum cleaner was surrounded by a survey surface, shown in Figure 1, at an average distance of 70 cm from the machine surface. The room in which the measurement was made had a reverberation radius (for an omnidirectional source) of between 80 and 90 cm. Sixteen measurement points were used. The intensity components normal to the survey surfaces were measured, multiplied by the associated surface areas, and then summed to give the total radiated power. The results are summarised in Table 1. Agreement between the 'plane wave intensity', $\overline{p}^2/\rho_0 c$, and the measured values is generally better at lower than at higher frequencies. This result is attributed to the more strongly directional form of the high frequency radiation.

2.2 Radiating Panel

A 30 cm x 30 cm rectangular thin perspex panel, set in one side of an otherwise heavy, thick walled box, was excited by broad band noise from a loudspeaker inside the box. One objective was to investigate the influence on estimates of radiated sound power of variation of the measurement surface, and of the number of measurement points. The survey grids are shown in Figure 2. The room reverberation radius was about 70 cm. The results are summarised in Table 2.

Apart from the single measurement point, all survey grids showed acceptable agreement.

3. Field Measurements

3.1 Diesel Engine

In cooperation with a diesel engine company, an investigation of sound radiation from a diesel engine was performed. The engine was located in a test chamber which was lined with sound absorbent wedges except for the floor surface which was of concrete. The engine was supported with its lower surface 45 cm above the floor and a survey grid of even measurement points was chosen, as shown in Figure 3. The points were about 30 cm from the sides of the engine. For the purpose of complicating the 'task' of the intensity meter, a large number of reflecting screens were placed around the engine to produce a semi-reverberant environment. The results are summarised in Table 3 in which the sound power from the intensity measurements under semi-reverberant conditions are compared with that estimated from SPL measurements at 1m under normal test room conditions. As with the vacuum cleaner, the higher frequency agreement is less good.

3.2 Electric Motor

In cooperation with the Wolfson Unit for Noise and Vibration Control, and a manufacturer, measurements were taken as part of a qualification test on an electric motor. The motor stood on a concrete floor in the main plant. A space 5m x 5m was cleared around it and 25 mm thick plastic foam was draped over nearby surfaces (for the purpose of the standard test). A grid of seven measurement positions was chosen on a surface lying about 50 cm from the surface of the motor, as shown in Figure 4. Table 4 summarises the results. Sound powers passing through each of the five planar survey surfaces are compared with powers estimated from SPL measurements at 1m distance. The general tendency for the sound powers estimated from intensity measurements to fall somewhat below those obtained from SPL measurements, except at 4000 Hz, is consistent with the presence of a reverberant field contribution to the SPL's.

4. Some Problems Outstanding

The following is a brief summary of some of the problems encountered during the application of the current analog measurement procedure. The frequency range required for industrial noise measurements extends over the octave band frequency range 32-8000 Hz. The range of the present instrument is 125-4000 Hz. In principle, greater microphone centre separation than the 15 mm currently used, would overcome the low frequency limitation. The high frequency requirement is more difficult to meet because, although 1/8" microphones could be used at separations of less than 10 mm, the reduced sensitivity and poorer signal/noise ratios of such small microphones may not be acceptable. In principle, miniature electret microphones, placed back to back, could be employed, but these seem to have inherent problems with regard to phase match at frequencies above about 4 kHz. Also, they would naturally have to be moved apart for lower frequency accuracy.

It is impossible to establish, from first principles, a criterion for adequate, and optimum, survey grid configurations. It has been found with pure tone and narrow band noise sources that the local intensity vector is sometimes directed towards the source, and sometimes parallel to a source surface. Location of such a source within a reflective enclosure further complicates the problem since intensity vectors at adjacent points in space can be found to point in quite different directions. Hence the question of adequate coverage of a source enclosing surface for the purpose of approximating the surface integral by a surface summation is of considerable concern. There can be no completely theoretical answer, since the complete theoretical source model naturally does not exist; hence much work must be done in order to provide empirical guidance in this respect.

A similar problem exists when an attempt is made to isolate the sound power of a particular source region in the presence of other interfering sources, e.g. a diesel engine in the presence of its gear box and transmission system. In principle, measurements over a closed surface completely surrounding the engine, will exclude contributions from sources external to the enclosed volume; but what density of measurement points is necessary to ensure such exclusion ?

Clearly, intensity measurements and sound power estimates, therefrom, require considerable development before they can be relied upon to complement existing techniques.

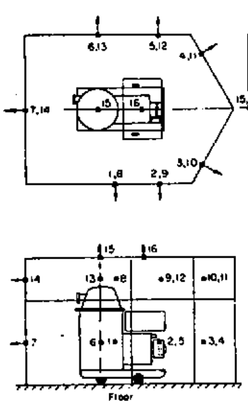

FIG. 1: The survey grid.

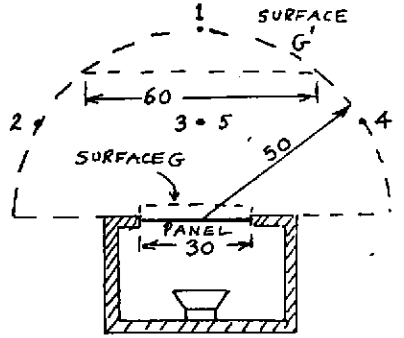

FIG. 2: Survey surfaces enclosing a panel. Surface G has 1,4 or 9 points, surface G' has 5 points.

Freq. (Hz)	Σ[I×Area]	Σ[($\bar{p}^2/\rho_o c$ × Area)]	Reverberant room power
125	62.1	61.4	59.1
250	68.5	71.2	67.9
500	77.9	81.6	79.8
1000	81.1	84.0	81.9
2000	78.7	83.1	79.2
4000	74.5	79.2	75.6
Σ(250-4000)	84.8	88.4	85.8

TABLE 1.
Octave band acoustic power estimates - (dB re 10^{-12}W)

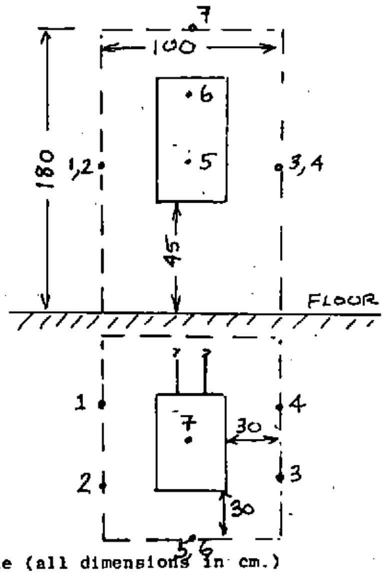

FIG. 3: Survey surface around a diesel engine (all dimensions in cm.)

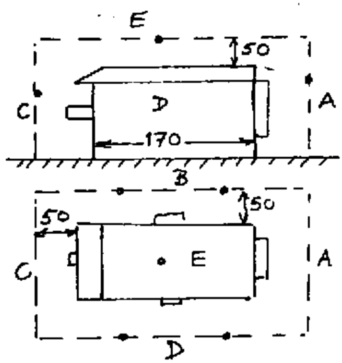

FIG. 4: Survey surface enclosing an electric motor. Measurement points shown as dots. Dimensions in cm.

Freq. (Hz)	Acoustic Power Level in dB 1	4	9	G	G'
125	54.0	56.1	57.6	57.6	58.4
250	61.6	56.5	59.5	59.5	60.2
500	62.8	57.0	56.7	56.7	58.1
1000	61.8	62.2	62.1	62.1	61.7
2000	59.3	59.0	59.6	59.6	60.0
4000	55.3	50.1	50.5	50.5	50.5

TABLE 2.

Freq. (Hz)	Radiated Acoustic Power (dB)		Difference (dB)
	Intensity Meter	Free Field	
250	93.8	94.4	0.6
500	100.0	99.2	0.8
1000	101.6	102.0	0.4
2000	101.5	101.5	0.0
4000	98.7	95.6	-3.1

TABLE 3.

Freq. (Hz)	Acoustic Power in dB Radiated from the Motor Sides										TOTAL in dB	
	Side A		Side B		Side C		Side D		Side E			
	IM	SPL	IM	SPL	IM	SPL	IM	SPL	IM	SPL	IM	SPL
125	104	101	95	101	98	100	104	104	-	98	100.7	101.2
250	91	94	90	91	93	89	89	90	86	89	90.4	90.6
500	92	94	88	92	96	95	89	92	84	89	91.6	92.8
1000	79	83	87	87	83	86	84	87	87	82	84.8	85.4
2000	77	78	84	84	81	80	83	85	75	78	81.2	82.0
4000	70	68	77	73	69	71	74	74	67	68	72.9	71.5

TABLE 4.

References

1. F.J. Fahy (1977) Noise Control Engineering 2(3), 155-162. A technique for measuring sound intensity with a sound level meter.

2. F.J. Fahy (1978) Journal of Sound and Vibration 57(3), 311-322. Measurements with an intensity meter of the acoustic power of a small machine in a room.

3. F.J. Fahy (1977) Journal of the Acoustical Society of America 62(4) 1057-1059. Measurement of acoustic intensity using cross-spectral density of two microphone signals.