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SOUND POWER DETERMINATION IN HIGHLY REACTIVE ENVIRONMENTS USING SOUND INTENSITY MEASUREMENTS

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INTRODUCTION

The advent of real-time analysis using digital filtering techniques for signal processing has been a major breakthrough for the precision with which acoustic intensity measurements can be performed using the two microphone method.

One of the principal applications of sound intensity measurements is the determination of sound power radiated by sound sources [2]. Some of the advantages of using intensity rather than sound pressure measurements for determining sound power are:

1. No restriction upon the sound field which implies that the measurements can be performed in any room.
2. Measurements can be performed in the near field as well as in the far field.
3. No restriction upon the shape and size of the enclosing measurement surface.
4. The method excludes any influence from stationary, contaminating sound fields.

MEASUREMENTS

This paper deals with the limitations of point 1 mentioned above. The sound power level of a reference sound source was determined from sound intensity measurements, using the B & K Sound Intensity Analysing System Type 3360. The results were compared with the reference values for the sound source which were determined in third-octave bands from 100 Hz to 10 kHz using sound pressure levels according to ISO 3745.

An ideal intensity meter only responds to the active part of a sound field. To test the performance of a practical intensity system, the measurements were performed in the most reactive environment available, namely a reverberation room of 215 m^3 with a reverberation time of 18 s at 100 Hz, falling to 10 s at 500 Hz and 5 s at 3150 Hz. According to ISO 3741 such a room may be used for sound power determinations using sound pressure measurements from 100 Hz to 10000 Hz in third octave bands.

The relationship between pressure level L_p minus intensity level L_I, phase ϕ (between the two microphone positions), microphone spacing Δr and frequency f for the two microphone method, is shown in Fig.1. It can be seen that under free-field conditions (reactivity = 0dB), the choice of a 12 mm spacer yields a dynamic range of 11 dB at 100Hz, 21dB at 1kHz and 31dB at 10kHz for a frequency independent phasematching of 0,1° between the two measuring channels.

The phasematching of the measuring system is frequency dependent: above 250Hz it is determined mainly by the analyser whereas below 250 Hz it is determined mainly by the two microphones which constitute the microphone probe.

The dynamic range of the measuring system was determined for frequencies above 500Hz by applying electrically generated pink noise to both channels simultaneously, and for frequencies below 500Hz by applying broad band noise to a small acoustic coupler in which the probe was placed [3].

As indicated in Fig.1, the Sound Intensity Analyzer Type 3360 is in general phasematched at low frequency much better than the 0,3° maximum phase-mismatch specified in the Data Sheet [4]. The phase-matching is typically 0,05° between 30Hz and 500Hz. The lower frequency limit for the measuring system is set by the phasematching [1] between the 2 channels and it can be found from Fig.1, that the low frequency limit (± 1dB) of the intensity analyzing system for free field measurements is more likely 25Hz than 125Hz as indicated in the Data Sheet.

However, Fig.1 also shows that the lower frequency limit is shifted towards higher frequencies by a factor which is equal to the measured degree of reactivity at the measurement positions. Thus 3dB reactivity corresponds to a frequency shift by a factor of 2.

The measurements were performed using a measurement surface of hemispherical shape with a radius of 1m and 10 measurement positions distributed as described in ISO Standard 3745.

The reactivity of the sound field was found from the difference in the L_p and L_I values where each of these was the average of 10 measurements (Fig.2). L_I was measured using various microphone separations (12mm, 50mm, 100mm and 200mm) to optimise the dynamic range of the analyser at different frequencies. The reactivity (referred to in [6] as "the indicator of the validity of intensity measurements") was found to be approximately 10dB for most frequencies. For a reactivity of 10dB, the theoretical lower frequency limit of the measuring system as a functon of microphone separation is shown in Table 1.

The results of the sound power determination are shown in Figs.3 to 6 and compared with the values from the calibration table of the sound source. The lower frequency limits indicated in Table 1 could not be verified from these measurements directly as the lowest frequency on the calibration table of the sound source was 100Hz.

Therefore to test the reproducibility of the measurements, another test series was performed consisting of 40 measurements (4 sound power determinations) with a 12mm spacer over a test hemisphere of radius 1,5m. A relatively high amount of random error was observed (Table 2), which normally is not seen under free field conditions [5].

The measured intensity, $\hat{I}_r$, is related to the actual intensity I_r by $\hat{I}_r = I_r \sin(k\Delta r)/(k\Delta r)$. The measured intensity $\hat{I}_r$ becomes zero when $k\Delta r$ becomes zero. The frequency at which a zero crossing occurs, depends upon the wavenumber, k, and the spacing, Δr, and is independent of the degree of reactivity. This is clearly shown in Figs.3 to 6 where the measured zero-crossings correspond exactly to the predicted theoretical values for the plane wave approximation indicated in Table 1. Thus the upper frequency limit for intensity measurements is *not* shifted towards higher frequency as a function of increasing reactivity as suggested in [6].

Δr mm	6	12	50	100	200
f_{lower} Hz (± 1dB)	500	250	63	31,5	16
f_{upper} Hz (− 1dB)	10000	5000	1250	630	315
$f_{first\ zero\ crossing}$ Hz	28000	14000	3400	1700	850

Table 1. Theoretical limits for the accuracy of intensity measurements for a system phase-matched to $\phi = 0.05°$ in a field with a reactivity of 10 dB.

	Frequency in Hz												
	100	125	160	200	250	315	400	500	630	800	1000	1250	1600
Scatter dB	5,8	6,7	5,1	3,2	3,2	–	3,8	3,5	6,7	2,8	1,2	0,6	0,4

Table 2. Reproducibility of sound intensity measurements expressed as the difference in dB between the maximum and the minimum value of 4 sound power determinations using 10 measurements for each determination. The measurements were performed in a highly reactive sound field with a system phase-matched to $\phi = 0.05°$, with a test surface of radius of 1,5 m and a microphone separation of $\Delta r = 12$ mm

CONCLUSION

Precision sound power determinations can be performed in highly reactive environments using the two microphone intensity technique. However, the dynamic range of the analyser should be greater than the measured reactivity [7] as it is the reactivity which sets the lower frequency limit of the system, moving the limit towards higher frequency by a factor equal to the reactivity.

REFERENCES

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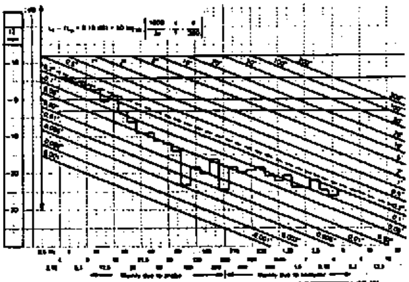

Fig.1.Phase matching of the complete system (analyser and probe) is better than 0.3° (dashed line)

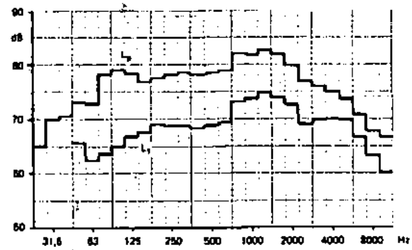

Fig.2.L_p (upper) and L_I (lower curve) averaged over 10 measurement positions. The reactivity of the sound field is the difference between the two spectra

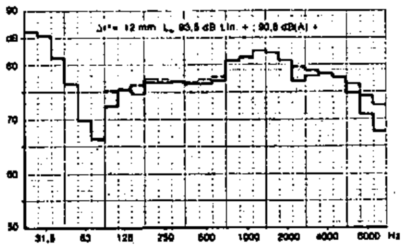

Fig.3.Sound power of a reference sound source determined from sound intensity measurements using $\Delta r = 12\,mm$. The sound power determined according to ISO 3745 is shown by the dashed line

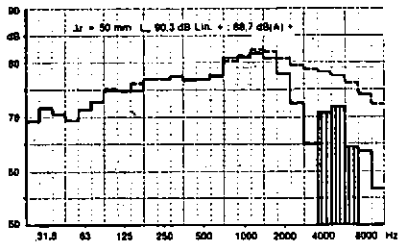

Fig.4As for Fig.3 but with $\Delta r = 50\,mm$. The "negative" intensity indicated by the hatching, which occurs just above the cut-off frequency is due to the first side lobe in the sin(x)/x function

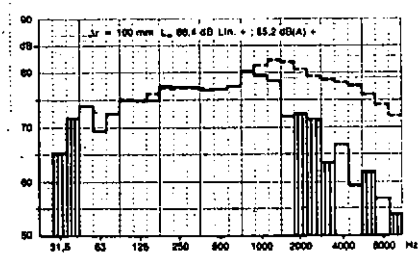

Fig.5As for Fig.3 but with $\Delta r = 100\,mm$

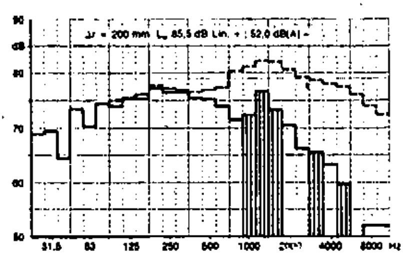

Fig.6As for Fig.3 but with $\Delta r = 200\,mm$