Sound intensity basics

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Sound intensity measurement is a useful technique when more information is required about the acoustic environment, or the acoustic test conditions themselves are not suitable for traditional measurement techniques. As sound intensity is a vector quantity we know its direction of travel in addition to its amplitude, so we have more information than provided by a traditional sound pressure measurement. This gives us opportunities to isolate sound sources in more complex acoustic environments and mitigate the effects of background noise and reverberation. The most common use of sound intensity is for sound power measurements in accordance with ISO 9614 series of standards. It is also useful for mapping of sound sources and for determining the performance of building elements.

Definition of intensity:
The rate at which sound energy passes through an area perpendicular to the direction of propagation of sound waves. ⇒ Sound power per area [W/m2]. When measured it is normally expressed as dB intensity, I, re 10^{-12} Wm^{-2}.

Basics of the measurement

Sound intensity measurements require the measurement of the velocity component of the sound wave. There have been several attempts to develop direct reading sound velocity measurement probes using ultrasonic waves as a carrier, or temperature gradient methods, but experience has shown that a conventional two channel analyser with two phase matched microphones provides a verifiable and reliable measurement system. These instruments are covered by International Standards and there are also Standards that specify this method in measurement procedures, covering many applications such as sound power determination and building acoustic measurements.

The microphones are orientated face-to-face as shown in Figure 1, sound travelling *along* the axis of the two microphones will arrive at one microphone before the other and hence we know the direction and velocity of the sound.

A sound wave travelling *across* the axis will arrive at both microphones at the same time and will therefore have zero velocity.

The sound pressure is determined from the average value of the two microphones. So, we have the two parameters we need to determine sound intensity; the velocity and the sound pressure.

As intensity is the product of sound pressure and sound particle velocity, I = P.V, then as the time taken for the fixed distance between the microphones gets shorter, the velocity gradient, and hence the intensity, increases. When the sound wave is across the axis the velocity gradient is zero and so is the intensity. The system therefore has a figure of eight response with zero response across its axis and can resolve +ve and -ve magnitudes and direction along its axis.

The distance between the microphones is important for the measurement as this controls the effective measurement range in terms of frequency. To measure low frequency (longer wavelengths) we need a bigger distance. This distance is controlled by spacers (three shown in image below), which typically range from 6mm to 100mm. Figure 1 also shows the typical frequency range by spacer. Note; with advances in signal processing and phase calibration, it is possible to measure a wide frequency range in a single measurement.

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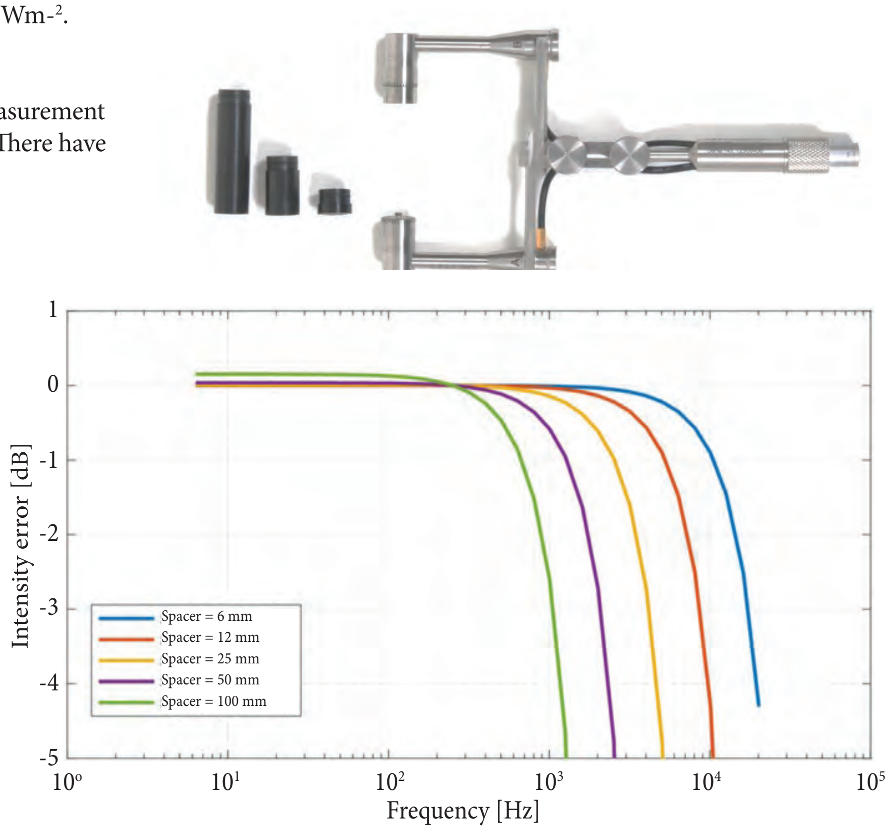

Figure 1. Intensity probe with spacers and frequency range

Phase calibration

Sound intensity systems require the two measurement channels to be closely phase matched so that the time difference in the signals delivered from each channel are not distorted in the instrument. So, measurement microphones are carefully selected and paired for intensity systems. To verify this phase match before each measurement, an additional calibration procedure is required. For this the two microphones are placed in a phase calibration coupler as in Figure 2 below, and as the same signal is applied to both channels the complete system is checked in terms of phase.

Figure 2. Phase calibrator

Applications for sound intensity

1. Sound intensity and sound power

In situ and laboratory sound power measurements. ISO 9614. This enables us to accurately calculate sound power of equipment in situ, which is popular where equipment already installed and operating, is too large, or requires special services to operate; thus making moving to a laboratory or test area impractical for traditional sound pressure ISO 374x series tests.

The basic theory of the standard is to draw an imaginary test box encompassing the object under test. By measuring the average sound intensity for this surface and knowing the dimensions it enables sound power to be directly calculated. The assumption is that any sound entering from outside the box will decrease the sound intensity on the face it passes into, and increases the intensity on the side it leaves from. The net effect is that the total intensity, and therefore the sound power, remains unaffected. This minimises the influence of reflections and background noise. Note; background noise and the source under test should remain constant.

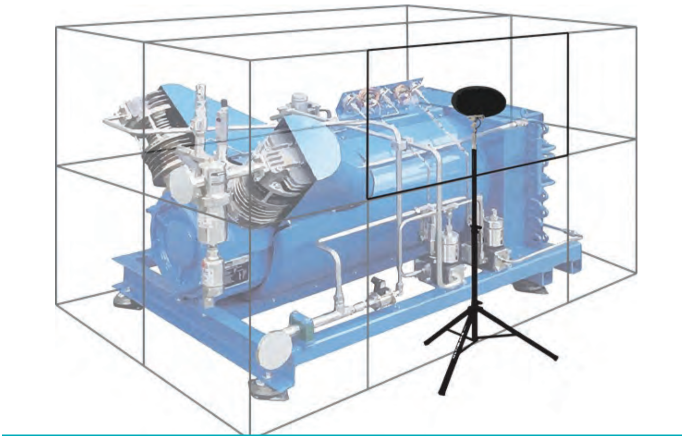

Figure 3. Part 1 – the fixed point method

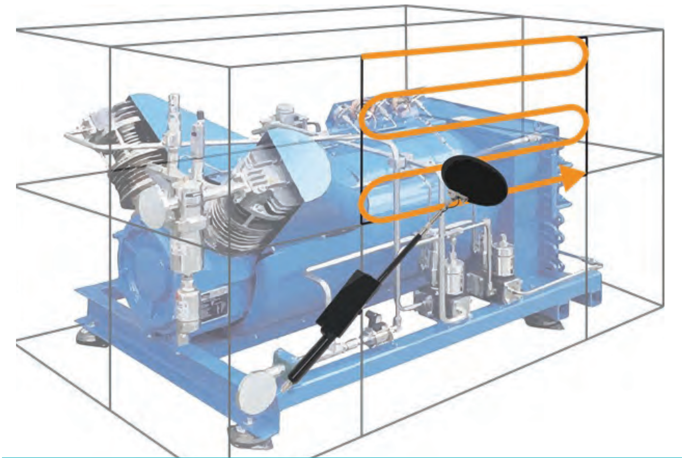

Figure 4. Part 1 – Parts 2 and 3 – scanning methods

ISO 9614 is divided into three parts:
Part 1: Measurement at discrete points (Figure 3).
Part 2: Measurement by scanning (Figure 4).
Part 3: Precision method for measurement by scanning.

Summary of ISO 9614 Parts 1, 2 and 3 can be seen in the table below. This summarises the accuracy grades associated with each measurement technique with the standard deviation and reproducibility in dB.

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Standard	Measurement method	Accuracy grade	Test room	Character of noise from the source	Standard deviation of reproducibility [dB]
ISO 9614-1	Broadband, narrow-band or discrete frequency, if stationary in time	Precision, engineering or survey	Any	Broadband, narrow band or discrete if stationary	1 1.5 4
ISO 9614-2	Broadband, narrow-band or discrete frequency, if stationary in time	Engineering survey	Any	Broadband, narrow band or discrete if stationary	1.5 4
ISO 9614-3	Broadband, narrow-band or discrete frequency, if stationary in time	Precision	Any	Broadband, narrow band or discrete if stationary	1

Troubleshooting

For measurements to be valid, certain conditions should be met. If not, you may have to report your test as a lower accuracy grade or repeat your measurement. These conditions are quantified and expressed as field indicators. They are detailed in in ISO 9614 and measurement systems will record these and indicate if they invalidate your measurement.

Field indicators:

- Repeatability – Too much variation in your data.
- Dynamic capability too low – You have reached the limits of your measurement system.
- Extraneous intensity – Indicates the difference between negative and absolute intensity.
- High Fpi – Indicator that sound field is too reactive.

Sound insulation measurements

ISO 15186-2:2010 Measurement of sound insulation in buildings and of building elements using sound intensity.

Part 1 covers laboratory measurements and Part 2 covers in situ measurement of sound insulation of walls, floors, doors and small building elements. Sound intensity enables us to measure the direction of the sound and localise sources. We can therefore gather information on certain parts of a partition in addition to calculating the sound reduction. ISO 15186-2 claims to have better reproducibility than ISO 140-4, -10

These measurements enable us to:

- Analyse flanking transmission.
- Compare with laboratory measurements, where flanking is suppressed.
- Rank partial contributions of building elements.
- Validate BS EN 12354-1 models.

The basic principle is to place a speaker in the 'source room' adjacent to the 'receive room', which is separated by the partition to be tested. A number of measurements are made in the source room to obtain the average sound pressure. Knowing the area of the partition of the source room, the incident sound power in the source room can be calculated. The sound power for the partition in the receiving room is calculated using the same principals as described in ISO 9614, by scanning the test area in sections. This is shown in Figure 5.

The difference in these two sound power values allows us to calculate the intensity sound reduction index.

The calculation can be seen below. The first term relates to the source room surface sound power and the second; the receive room radiated sound power.

$$R'_I = \left[L_{p1} - 6 + 10\lg\left(\frac{S}{S_0}\right)\right] - \left[\overline{L}_{I_n} + 10\lg\left(\frac{S_M}{S_0}\right)\right]$$

L_{p1} is the average sound pressure level in the source room;

S is the area of the separating building element under test or, in the case of staggered or stepped rooms, that part of the area common to both the source and receiving rooms;

S_M is the total area of the measurement surface (s);

$S_0 = 1\ m^2$

Limitations of measuring to ISO150186-2:

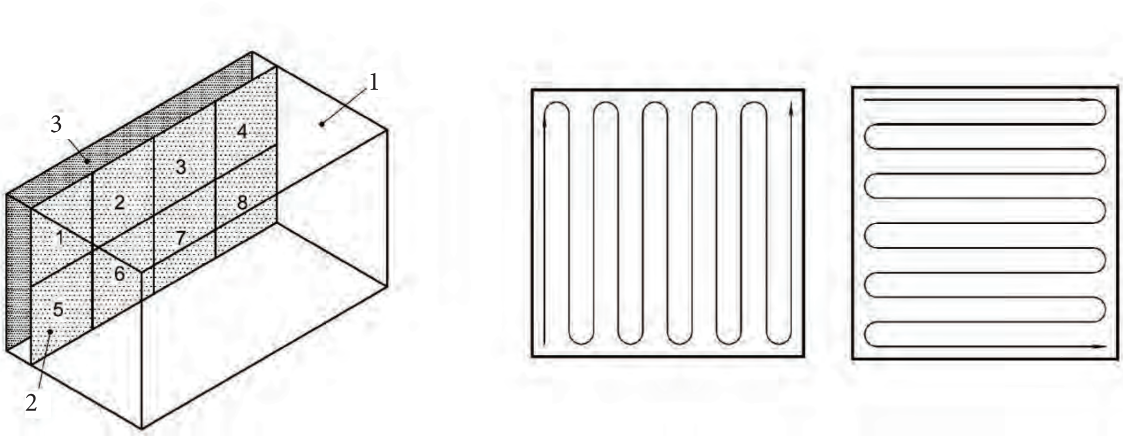
Receiving room cannot be too reactive or reverberant for measurements to be valid.

Repeatability of intensity scans can be an issue.

Conclusion

Sound intensity measurement systems have been available for many years but have tended to be complex and bulky bits of equipment to use. Advances in technology have meant small, two channel analysers can now do the job, and also guide users with an interface dedicated to the application. Intensity measurements are now far easier and provide an excellent option to the acoustic professional.

Figure 5. ISO 15186-2 sound intensity measurements



Key:
1 Receiving room
2 Measurement surface divided into eight sub-areas
3 Building element under test (dark shaded area)