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Sound intensity

Sound intensity level also known as **acoustic intensity** is defined as the power carried by sound waves per unit area in a direction perpendicular to that area. The SI unit of intensity, which includes sound intensity, is the watt per square meter (W/m^2). One application is the noise measurement of sound intensity in the air at a listener's location as a sound energy quantity.[1]

Sound intensity is not the same physical quantity as sound pressure. Hearing is directly sensitive to sound pressure which is related to sound intensity. In consumer audio electronics, the level differences are called "intensity" differences, but sound intensity is a specifically defined quantity and cannot be sensed by a simple microphone. The rate at which sound energy passes through a unit area held perpendicular to the direction of propagation of sound waves is called intensity of sound.

Sound measurements	
Characteristic	Symbols
Sound pressure	*p*, SPL, L_{PA}
Particle velocity	*v*, SVL
Particle displacement	*δ*
Sound intensity	*I*, SIL
Sound power	*P*, SWL, L_{WA}
Sound energy	*W*
Sound energy density	*w*
Sound exposure	*E*, SEL
Acoustic impedance	*Z*
Speed of sound	*c*
Audio frequency	AF
Transmission loss	TL

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Mathematical definition

Sound intensity, denoted **I**, is defined by

$$\mathbf{I} = p\mathbf{v}$$

where

- *p* is the sound pressure;
- **v** is the particle velocity.

Both **I** and **v** are vectors, which means that both have a *direction* as well as a magnitude. The direction of sound intensity is the average direction in which energy is flowing.

The average sound intensity during time *T* is given by

$$\langle \mathbf{I} \rangle = \frac{1}{T} \int_0^T p(t) \mathbf{v}(t)\, \mathrm{d}t.$$

Also,

$\mathrm{I} = 2\pi^2 \nu^2 \delta^2 \rho c$

Where,

ν is frequency of sound,

δ is the amplitude of the sound wave particle displacement,

c is speed of sound, and

ρ is density of medium in which sound is traveling

Inverse-square law

For a *spherical* sound wave, the intensity in the radial direction as a function of distance r from the centre of the sphere is given by

$$I(r) = \frac{P}{A(r)} = \frac{P}{4\pi r^2},$$

where

- P is the sound power;
- $A(r)$ is the surface area of a sphere of radius r.

Thus sound intensity decreases as $1/r^2$ from the centre of the sphere:

$$I(r) \propto \frac{1}{r^2}.$$

This relationship is an *inverse-square law*.

Sound intensity level

Sound intensity level (SIL) or **acoustic intensity level** is the level (a logarithmic quantity) of the intensity of a sound relative to a reference value.

It is denoted L_I, expressed in dB, and defined by[2]

$$L_I = \frac{1}{2} \ln\left(\frac{I}{I_0}\right) \mathrm{Np} = \log_{10}\left(\frac{I}{I_0}\right) \mathrm{B} = 10 \log_{10}\left(\frac{I}{I_0}\right) \mathrm{dB},$$

where

- I is the sound intensity;
- I_0 is the *reference sound intensity*;
- 1 Np = 1 is the neper;
- 1 B = (1/2) ln(10) is the bel;
- 1 dB = (1/20) ln(10) is the decibel.

The commonly used reference sound intensity in air is[3]

$$I_0 = 1\ \mathrm{pW/m^2}.$$

being approximately the lowest sound intensity hearable by an undamaged human ear under room conditions. The proper notations for sound intensity level using this reference are $L_{I\,/(1\ \mathrm{pW/m^2})}$ or L_I (re 1 pW/m²), but the notations dB SIL, dB(SIL), dBSIL, or $\mathrm{dB_{SIL}}$ are very common, even if they are not accepted by the SI.[4]

The reference sound intensity I_0 is defined such that a progressive plane wave has the same value of sound intensity level (SIL) and sound pressure level (SPL), since

$$I \propto p^2.$$

The equality of SIL and SPL requires that

$$\frac{I}{I_0} = \frac{p^2}{p_0^2},$$

where p_0 = 20 μPa is the reference sound pressure.

For a *progressive* spherical wave,

$$\frac{p}{c} = z_0,$$

where z_0 is the characteristic specific acoustic impedance. Thus,

$$I_0 = \frac{p_0^2 I}{p^2} = \frac{p_0^2 pc}{p^2} = \frac{p_0^2}{z_0}.$$

In air at ambient temperature, z_0 = 410 Pa·s/m, hence the reference value I_0 = 1 pW/m².[5]

In an anechoic chamber which approximates a free field (no reflection) with a single source, measurements in the far field in SPL can be considered to be equal to measurements in SIL. This fact is exploited to measure sound power in anechoic conditions.

Measurement

One method of sound intensity measurement involves the use of two microphones located close to each other, normal to the direction of sound energy flow. A signal analyser is used to compute the crosspower between the measured pressures and the sound intensity is derived from (proportional to) the imaginary part of the crosspower.

References

1. "Sound Intensity" (http://hyperphysics.phy-astr.gsu.edu/hbase/sound/intens.html). Retrieved 22 April 2015.
2. "Letter symbols to be used in electrical technology – Part 3: Logarithmic and related quantities, and their units" (http://webstore.iec.ch/webstore/webstore.nsf/artnum/028981), *IEC 60027-3 Ed. 3.0*, International Electrotechnical Commission, 19 July 2002.

3. Ross Roeser, Michael Valente, *Audiology: Diagnosis* (Thieme 2007), p. 240.
4. Thompson, A. and Taylor, B. N. sec 8.7, "Logarithmic quantities and units: level, neper, bel", *Guide for the Use of the International System of Units (SI) 2008 Edition*, NIST Special Publication 811, 2nd printing (November 2008), SP811 PDF (http://physics.nist.gov/cuu/pdf/sp811.pdf)
5. Sound Power Measurements, Hewlett Packard Application Note 1230, 1992.

External links

- How Many Decibels Is Twice as Loud? Sound Level Change and the Respective Factor of Sound Pressure or Sound Intensity (http://www.sengpielaudio.com/calculator-levelchange.htm)
- Acoustic Intensity (http://ccrma.stanford.edu/~jos/pasp/Acoustic_Intensity.html)
- Conversion: Sound Intensity Level to Sound Intensity and Vice Versa (http://www.sengpielaudio.com/calculator-soundlevel.htm)
- Ohm's Law as Acoustic Equivalent. Calculations (http://www.sengpielaudio.com/calculator-ak-ohm.htm)
- Relationships of Acoustic Quantities Associated with a Plane Progressive Acoustic Sound Wave (http://www.sengpielaudio.com/RelationshipsOfAcousticQuantities.pdf)
- Table of Sound Levels. Corresponding Sound Intensity and Sound Pressure (http://www.sengpielaudio.com/TableOfSoundPressureLevels.htm)
- What Is Sound Intensity Measurement and Analysis? (http://www.acoustical-consultants.com/noise-vibration-acoustical-related-resources/sound-intensity-noise-measurements/)