In Chapter 2 we saw that sound levels are measured according to a logarithmic scale of decibels and that weighting to allow for the response of the human ear gives dBA values. A decibel is defined as 10 times the logarithm to the base 10 of a ratio of two powers, thus:

$$\mathrm{dB} = 10 \log_{10} \frac{\text{Power}}{\text{Reference power}}$$

(high level indicator for this type of sound)

For sound power levels the reference power is taken as 10^{-12} watts. Therefore, if a source is 100 times more powerful than this it will measure as 20 dB, and if it is 1000 times more powerful it will measure as 30 dB.

Sound power is the power emitted by an acoustic source, say a loudspeaker in a room, and is measured in watts. The resulting loudness, or more precisely sound pressure level (Table C.1), in the room is dependent not only on the loudspeaker but on the characteristics of the room (and its furnishings).

Most noises are, of course, variable. To deal with this, sound pressure levels can be examined over time – if a high level is infrequent it is likely to be more acceptable. An L_{10} level is that value of noise exceeded 10% of the time; L_{A10} is that value when measuring in dBA. It is also possible to average the sound. $L_{A_{eq},T}$ is the equivalent steady level of a fluctuating noise measured in dBA for a time T;[1] T is chosen according to the application, so, for example, for a school it could be the occupancy period.

Table C.1 Representative sound pressure levels

Condition	*Sound pressure level (dBA)*
Threshold of hearing	10
Broadcasting studio	10–20
Living room in a quiet area at 7 a.m.	30
Typical business office	50–60
Listening to Chopin in a living room	50–65
Normal speech	55–65
Inside a train	55–70
Busy streets in urban area, e.g. Cambridge	70–75
Pop group at 20 m	100–110
Helicopter at 30 m	100–110
Threshold of pain	120

The BREEAM evaluation procedure for new offices awards one credit if noise levels in large offices are equal to or below an $L_{A_{eq},T}$ of 45 dBA.[2]

It is also very common to see sound pressure level recommendations given as noise rating (NR) values. The approximate relationship between dBA and NR is:[3]

$$\text{dBA} = \text{NR} + 6.$$

Thus, if a recommendation for an air-conditioned conference room is NR25, the dBA equivalent would be about 31.

Fairly elaborate calculations are required to determine the sound pressure level in spaces – References 4 and 5 give typical procedures. A very approximate relationship[6] is:

$$\text{Noise level inside (dBA)} = \text{Noise level outside (dBA)} - \text{Average insulation (dB)}$$

Thus, if the noise level from a road is about 65 dBA and one is trying to achieve 30 dBA inside, an average insulation value of 35 dB would suffice.

References

1. Anon. (1987) Sound insulation and noise reduction for buildings. BS 8233:1987. British Standards Institution, London.
2. Prior, J. (ed.) (1993) *BREEAM/New Offices Version 1/93*, BRE, Garston.
3. Anon. (1986) *CIBSE Guide A1: Environmental Criteria for Design*, CIBSE, London.
4. Anon. (1993) *ASHRAE Handbook – Fundamentals.* Chapter 7: Sound vibration. ASHRAE, Atlanta.
5. Anon. (1986) *CIBSE Guide B12: Sound Control*, CIBSE, London.
6. Anon. (1988) Insulation against external noise. BRE Digest 338. BRE, Garston.

Relationships Among Intensity, Pressure, and Power Levels

Substituting equation (14-15) in equation (14-18) yields

$$L_I = 10\log\frac{\Delta p_{rms}^2/\rho v}{10^{-12}} \qquad (14\text{-}20)$$

At 25°C, $\rho_{air} = 1.184$ kg/m^3, $\beta_{air} = 20.6$ psi $= 142{,}038.51$ N/m^2. Therefore $v = \sqrt{\beta/\rho} = \sqrt{142{,}038.71/1.184} = 346.4$ m/s. Substituting the values of ρ and v in equation (14-20) gives

$$L_I = 10\log\frac{\Delta p_{rms}^2}{4.1(10^{-10})} \qquad (14\text{-}21)$$

Although equation (14-21) holds at 25°C, from equation (14-19), $L_I = L_p$ approximately.

By definition, $P_w = IA$, where A is the area of air that is receiving noise normal to the direction of propagation. Therefore,

$$L_w = 10\log\frac{P_w}{10^{-12}} = 10\log\frac{IA}{10^{-12}} = 10\log\frac{I}{10^{-12}} + 10\log A = L_I + 10\log A \qquad (14\text{-}22)$$

Example 14-3

The sound power from a voice shouting is 0.001 W. What is the sound power level? What are the sound intensity, the sound intensity level, the sound pressure, and the sound pressure level at a distance 6 m from the source?

Solution

$$L_w = 10\log\frac{P_w}{10^{-12}} = 10\log\frac{0.001}{10^{-12}} = 90 \text{ dB} \quad \textbf{Answer}$$

Assume that the sound radiates from the source in all directions. Hence the area of propagation at 6 m distance is the surface area of a sphere $= 4\pi r^2 = 4\pi(6^2) = 452.39$ m^2. Then

$$I = \frac{0.001}{452.39} = 2.2(10^{-6}) \text{ W/m}^2 \quad \textbf{Answer}$$

$$L_I = 10\log\frac{2.2(10^{-6})}{10^{-12}} = 63.42 \text{ dB} \quad \textbf{Answer}$$

$$L_I \approx L_p \qquad L_p = 63.42 \text{ dB} \quad \textbf{Answer}$$

$$L_p = 10\log\frac{\Delta p_{rms}^2}{4.0(10^{-10})} = 63.42$$

$$\Delta p_{rms} = 0.02966 \text{ N/m}^2 \quad \textbf{Answer}$$

HOW DO WE HEAR

Figure 14-2 shows the anatomy of the ear. As shown, the ear is composed of the outer, middle, and inner ears. The pinna, auditory canal, and eardrum or tympanic membrane

Example 14-1

The maximum differential pressure Δp_m that the ear can tolerate in loud sounds is 28 N/m². What is the amplitude s_m for such a sound in air at a frequency of 1000 Hz? Assume β and ρ equal to 20.6 psi and 1.23 kg/m³ for air, respectively. What are the rms pressure and intensity?

Solution

$$14.696 \text{ psi} = 101{,}330 \text{ N/m}^2$$

$$\beta = 20.6 \text{ psi} = \frac{101{,}330}{14.696}(20.6) = 142{,}038.51 \text{ N/m}^2$$

$$v = \sqrt{\frac{\beta}{\rho}} = \sqrt{\frac{142{,}038.71}{1.23}} = 339 \text{ m/s}$$

$$s_m = \frac{\Delta p_m}{v \rho \omega} = \frac{28}{339.82(1.23)(1000)(2\pi)} = 1.07(10^{-5}) \text{ m} \quad \textbf{Answer}$$

$$\Delta p_{\text{rms}} = \frac{\Delta p_m}{\sqrt{2}} = \frac{28}{\sqrt{2}} = 19.80 \text{ N/m}^2 \quad \textbf{Answer}$$

$$I = \frac{\Delta p_{\text{rms}}^2}{\rho v} = \frac{19.80^2}{1.23(339.82)} = 0.94 \frac{\text{N}^2/\text{m}^4}{(\text{kg/m}^3)(\text{m/s})}$$

$$= 0.94 \frac{\text{N-m}}{\text{m}^2\text{-s}} = 0.94 \frac{\text{J/s}}{\text{m}^2} = 0.94 \text{ W/m}^2 \quad \textbf{Answer}$$

Example 14-2

Repeat Example 14-1 for the pressure amplitude of $2.8(10^{-5})$ Pa of the faintest audible sound at 1000 Hz.

Solution

$$\beta = 20.6 \text{ psi} = 142{,}038.51 \text{ N/m}^2$$

$$v = 339.82 \text{ m/s}$$

$$s_m = \frac{\Delta p_m}{v \rho \omega} = \frac{2.8(10^{-5})}{339.82(1.23)(1000)(2\pi)} = 1.07(10^{-11}) \text{ m} \quad \textbf{Answer}$$

$$\Delta p_{\text{rms}} = \frac{\Delta p_m}{\sqrt{2}} = \frac{2.8(10^{-5})}{\sqrt{2}} = 1.98(10^{-5}) \text{ N/m}^2 \quad \textbf{Answer}$$

$$I = \frac{\Delta p_{\text{rms}}^2}{\rho v} = \frac{[1.98(10^{-5})]^2}{1.23(339.82)} = 9.38(10^{-13}) \text{ W/m}^2 \quad \textbf{Answer}$$

MEASURES OF NOISE

Table 14-1 shows sound powers and pressures coming from various sources. Noise measurements are not normally reported, however, in terms of the units used in the table but in terms of decibels. The decibel is logarithmic.