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Sound Levels and Decibels

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Summary

In this chapter, the basic characteristics of sound and sound propagation are described. Levels and decibels, which represent the magnitude of sound waves, are defined and explained.

12.1 Introduction

Sound is related to vibration, and is described as a propagating perturbation through a fluid, which is air or water in most cases. A very wide variety of noise sources exists. Each source is peculiar to its generation mechanism, which may cover a wide range of phenomena including fluid mechanics and the vibration of structures. Sound is perceived by the ear of the listener as a pressure wave superimposed upon the ambient air pressure. The *sound pressure* is the incremental variation about the ambient atmospheric pressure. Generally, it is detected by a microphone and expressed as oscillatory electric signal output from an audio measurement instrument. We shall present a mathematical description of these pressure waves that are known as sound. The field of acoustics concerns sound and vibration, and is treated in Chapter 12 to [Chapter 20](#) of this book.

12.2 Sound Wave Characteristics

The characteristics of a sound wave are described by a pressure oscillation of a pure tone. A “pure tone” is a sinusoidal pressure wave of a specific frequency and amplitude, propagating at a velocity determined by the temperature and pressure of the medium (air).

Let us consider a hypothetical sound field in a duct with constant cross-sectional area, as shown in [Figure 12.1a](#). A reciprocating piston at the left end emits the sound wave and it propagates toward the right-side end along the indicated axis. It is detected by a microphone at the right end. [Figure 12.1b](#) shows the instantaneous pressure distribution in a duct at time $t = t_0$. [Figure 12.1c](#) shows the pressure variation of the time history detected by the microphone at $x = x_0$.

The wavelength, λ , is the distance between successive two peaks in the waveform in Figure 12.1b. Wavelength is related to the frequency, f , and the velocity of wave propagation, c , by

$$\lambda = \frac{c}{f} \quad (\text{ft or m}) \quad (12.1)$$

The period, T , of the sinusoidal wave is the time interval required for one complete cycle, as depicted in Figure 12.1b. The period, T , is related to the frequency, f , by

$$T = \frac{1}{f} \quad (\text{s}) \quad (12.2)$$

12.2.1 Velocity of Sound

The velocity of sound is identical to the velocity of wave propagation, c , and in air it is given by

$$c = \sqrt{\frac{\gamma p_0}{\rho}} \quad (\text{ft/s or m/s}) \quad (12.3)$$

where γ denotes the ratio of specific heat, p_0 denotes the ambient or equilibrium pressure, and ρ denotes the ambient or equilibrium density. For air, γ is taken as 1.4. Equation 12.3 then becomes

$$c = \sqrt{\frac{1.4 p_0}{\rho}} \quad (\text{ft/s or m/s}) \quad (12.4)$$

which can be further simplified by the fact that the ratio p_0/ρ is related to the temperature of the gas. On assuming that the air behaves virtually as an ideal gas, the velocity, c , is related to the absolute temperature in degrees Kelvin (K) by

$$c = 20.05\sqrt{T} \quad (\text{m/s}) \quad (12.5)$$

where T , the temperature in degrees Kelvin, is

$$T = 273.2^\circ + (^\circ\text{C}) \text{ K} \quad (12.6)$$

Example 12.1

Calculate the velocity of sound, c , giving the temperature of 15°C .

Solution

$$T = 273.2^\circ + 15^\circ = 288.2 \text{ K, then}$$

$$c = 20.05\sqrt{288.2} = 340.4 \text{ m/s}$$

is obtained. This value means a typical velocity of sound in the air.

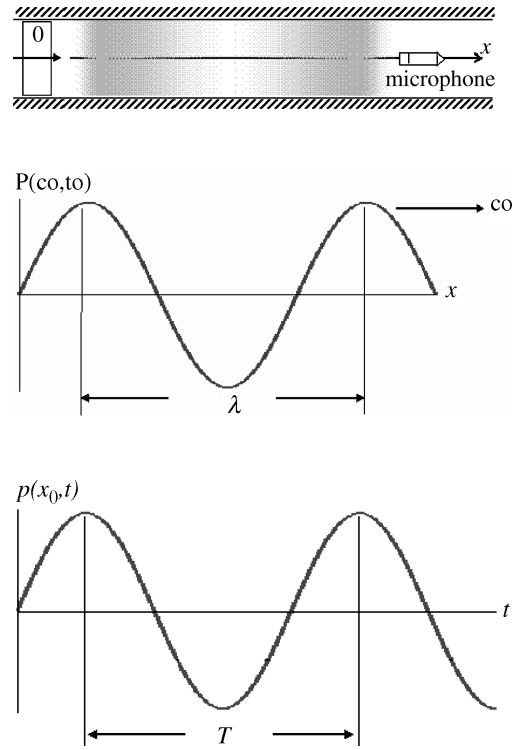


FIGURE 12.1 (a) Propagating sound wave in a duct; (b) instantaneous pressure distribution; (c) pressure variation in time history detected by a microphone at $x = x_0$.

12.3 Levels and Decibels

Sound pressure and power are commonly expressed in terms of *decibel levels*. This allows us to use a logarithmic rather than a linear scale. It provides the distinct advantage of allowing accurate computations using small numerical values, while accommodating a wide range of numerical values.

12.3.1 Sound Power Level

Sound power level describes the acoustical power radiated by a given source with respect to the international reference of 10^{-12} W. The sound power level, L_W , is defined as

$$L_W = 10 \log\left(\frac{W}{W_{\text{re}}}\right) \text{ (dB)} \quad (12.7)$$

where W denotes sound power in question and $W_{\text{re}} = 10^{-12}$ W (reference).

Example 12.2

Determine the sound power level of a small ventilation fan that generates 10 W of sound power.

Solution

$$L_W = 10 \log\left(\frac{W}{W_{\text{re}}}\right) = 10 \log\left(\frac{10}{10^{-12}}\right) = 130 \text{ dB}$$

12.3.2 Sound Pressure Level

Sound pressure levels are expressed in decibels, as are sound power levels. The sound pressure level, L_p , is defined as

$$L_p = 10 \log\left(\frac{\bar{p}^2}{p_{\text{re}}^2}\right) = 20 \log\left(\frac{\bar{p}}{p_{\text{re}}}\right) \text{ (dB)} \quad (12.8)$$

where $\bar{p}$ denotes root-mean-square (RMS) sound pressure in question Pa or N/m² and $p_{\text{re}} = 20 \times 10^{-6}$ Pa = 0.0002 μ bar. The pressure of 20×10^{-6} Pa has been chosen as a reference because it has been found that the average young adult can perceive a 10^3 Hz tone at this pressure. This reference is often referred to as the threshold of hearing at 10^3 Hz.

Example 12.3

Giving $L_p = 50$ dB for the Aeolian tone of 200 Hz, determine the RMS pressure of the tone.

Solution

Given L_p as 50 dB, then $\bar{p}$ is determined by using Equation 12.8.

$$50 = 20 \log\left(\frac{\bar{p}}{p_{\text{re}}}\right)$$

then

$$\begin{aligned} \bar{p} &= 10^{50/20} p_{\text{re}} = 316.2 p_{\text{re}} \\ \bar{p} &= 6.32 \times 10^{-3} \text{ Pa} = 0.0632 \mu\text{bar} \end{aligned}$$

Note that this value is very small, contradicting the magnitude of the sensory impression of the human ear.

12.3.3 Overall Sound Pressure Level

The sound pressure level is defined assuming “pure tone” sound. However, practically any real sound contains various components of pure tone sound. Let us consider a set of n components of pure tone, denoted by

$$\begin{cases} p_1(t) = a_1 \sin(2\pi f_1 t + \phi_1) \\ \vdots \\ p_n(t) = a_n \sin(2\pi f_n t + \phi_n) \end{cases} \quad (12.9)$$

$$p(t) = p_1(t) + \cdots + p_n(t) \quad (12.10)$$

If L_p of $p(t)$ is evaluated in RMS pressure, $\bar{p}$, we have

$$\bar{p} = \left[\lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T p^2(t) dt \right]^{1/2} = \left[\lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T (p_1(t) + \cdots + p_n(t))^2 dt \right]^{1/2} \quad (12.11)$$

Since

$$\lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T p_i(t) p_j(t) dt = 0, \quad i \neq j$$

is valid, $\bar{p}$ is obtained as

$$\bar{p} = \left[\overline{p_1^2} + \cdots + \overline{p_n^2} \right]^{1/2} = \left[\bar{p}_1^2 + \cdots + \bar{p}_n^2 \right]^{1/2} \quad (12.12)$$

where

$$\bar{p}_i^2 \equiv \overline{p_i^2} \equiv \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T p_i^2(t) dt = \frac{1}{2} a_i^2 \quad (12.13)$$

Let us define $L_{pi} \equiv 10 \log(\bar{p}_i^2/p_{re}^2)$ ($i = 1, 2, \dots, n$). Then the overall sound pressure level, L_p , of $p(t)$ is expressed by

$$L_p \equiv 20 \log \frac{\bar{p}}{p_{re}} = 10 \log \frac{1}{p_{re}^2} (\bar{p}_1^2 + \cdots + \bar{p}_n^2)$$

or L_p is expressed by L_{pi} ($i = 1, 2, \dots, n$) as follows:

$$L_p = 10 \log(10^{L_{p1}/10} + 10^{L_{p2}/10} + \cdots + 10^{L_{pn}/10}) \quad (12.14)$$

Example 12.4

Determine the overall sound pressure level of the combination of three pure tones, the sound pressure levels of which are expressed by

$$L_{p1} = 60 \text{ dB } (f_1 = 250 \text{ Hz}), \quad L_{p2} = 65 \text{ dB } (f_2 = 500 \text{ Hz}), \quad L_{p3} = 55 \text{ dB } (f_3 = 1000 \text{ Hz})$$

Solution

We have $10^{L_{p1}/10} = 10^6$, $10^{L_{p2}/10} = 10^{6.5}$, and $10^{L_{p3}/10} = 10^{5.5}$. Then the overall level, L_p , is determined by using Equation 12.14 as follows:

$$\begin{aligned} L_p &= 10 \log(10^6 + 10^{0.5} \times 10^6 + 10^{-0.5} \times 10^6) \\ &= 10 \log 10^6 (1 + 10^{0.5} + 10^{-0.5}) = 60 + 10 \log 4.479 = 66.5 \text{ dB} \end{aligned}$$

Note that the sum of 65, 60 and 55 dB is just 66.5 dB.