Chapter 2
Basic Concepts
Basic concepts

[2.1] Sound

Sound is generated by a vibrating object. The vibrations are transmitted through pressure fluctuations (waves) in the surrounding air. If the frequency and intensity of the pressure waves are within specified ranges they produce the sensation of sound. The frequency of audible sound ranges between 20Hz to 20 KHz. Sounds of single frequency are called pure-tones and they rarely exist except under artificial conditions. Pure-tones are often used for hearing tests. When the frequency is less than the audible frequency (20Hz) the sound is not generally audible, and the vibrations, if sufficiently strong, can be felt but not heard and are said to be infrasonic. While at frequencies above 20 KHz, the vibrations are called ultrasonic.

In general, noise is defined as unwanted sound or undesirable sound by the recipient. In noise pollution, the three most important parameters characterizing sound are (a) amplitude (b) frequency range and (c) duration. The aural sensitivity of the listener, time, ambient environment, frequency spectrum and intensity of sound are important factors, which determine the degree of discomfort experienced by a person (Stephens, 1986). The measurement unit of noise is dB (decibel) which measures the intensity of sound on a logarithmic scale with respect to a reference pressure. It is not an absolute physical unit like volt, metre etc., but it is a ratio.

[2.2] Noise level descriptors

The noise may consist of wildly fluctuating levels as a function of time. Therefore, it becomes imperative to use statistically derived indices to characterise noise levels. A number of indices have been employed by various workers (e.g., Delany
Few of the most commonly employed indices are as follows:

(i) Statistical Percentiles
The percentile index, $L_{n}$, is defined as that level of noise which is exceeded n% of the time in the total data points obtained for a certain interval of time. $L_{1}$ is used as a measure of peak noise levels, $L_{10}$, as a representative of levels during periods of intense noise, $L_{50}$, as an indication of the average noise level and $L_{90}$ gives an idea of the background noise levels.

(ii) Traffic Noise Index (TNI)
In studies related to traffic noise, another index TNI is also used. This is usually expressed in terms of $L_{10}$ and $L_{90}$ (Magrab 1975) as follows:

$$TNI = 4(L_{10} - L_{90}) + L_{90} - 30$$

Where the term $L_{10} - L_{90}$ indicates the range of "noise climate" and describes the variability of noise, $L_{90}$ as mentioned above represents the background noise level and the third term 30 is introduced to give convenient numbers. It emphasizes that a significant degree of annoyance arises from the variable character of noise. (Attenborough, 1974).

(iii) Equivalent Continuous Sound Level ($L_{eq}$)
One of the most important and widely used index to characterize noise, is the Equivalent Continuous Sound Level ($L_{eq}$). This is the level of a theoretical constant noise equivalent in energy content to the actual fluctuating noise over a given period of time. Mathematically,
Where,

\[ L = \text{sound pressure level} \]

\[ T = \text{time interval of observation. If the sound levels are measured over discrete time intervals } \Delta T_i \text{s, then } L_{eq} \text{ can be given by} \]

\[
L_{eq} = 10 \log_{10} \left[ \frac{1}{T} \frac{T}{T_0} \left( \frac{P}{p_0} \right)^2 dt \right] = 10 \log_{10} \left[ \frac{1}{T} \int_0^T 10^{L_{eq}/10} dt \right]
\]

This is accepted by the International Organisation for Standardization (ISO) for measurement and rating of noise.

(iv) Noise Pollution Level (NPL)

The noise pollution level (NPL) is based on two terms, one presenting the equivalent continuous noise level and other representing the annoyance due to fluctuations of the noise level (Magrab 1975). It is determined from the expression

\[
L_{NP} = L_{eq} + k \sigma
\]

Where \( L_{eq} \) is the ‘energy mean’ of the A-weighted-noise level over a specified period, \( \sigma \) is the standard deviation of the instantaneous level, and \( k \) is a constant tentatively set equal to 2.56, since this value leads to the best fit with currently available studies of subjective response to noise.

(v) Day-Night Level (L_{dn})

The day night level, \( L_{dn} \), provides a single number measure of community noise exposure over a specified period. It was designed to improve \( L_{eq} \) by adding a
correction of 10dB for the nighttime (2200-0700 hr) sound levels to account for the increased annoyance to noise during these hours. Its main purpose is to predict the effects on a population of the average long-term exposure to the environmental noise. The $L_{dn}$ is obtained from the relation

$$L_{dn} = 10 \log_{10}[0.65 \times 10^{Ld/10} + 0.375 \times 10^{Ln/10}]$$

Where,

- $L_{eq}$ = $L_{eq}$ for the day time (0700 – 2200 hr)
- $L_{n}$ = $L_{eq}$ for the night time (2200 – 0700 hr)

**(vi) Sound Exposure Level (SEL)**

A second way of describing the sound environment is to measure the sound exposure level (abbreviated SEL), which is the total sound energy of a single sound event and takes into account both its intensity and duration. One way to understand SEL is to think of it as the sound level you would experience if all of the sound energy of a sound event occurred in one second. This normalization to duration of one second allows the direct comparison of sounds of different durations.

**[2.3] Sound Pressure**

Sound literally means the sensation caused by vibrating wave motion that is perceived by organs of hearing. It essentially propagates as a pressure perturbation through a medium and can be mathematically represented by the following equation:

$$p(t) = p_0 \sin(\omega t - \phi) \quad [N/m^2 \text{ or } Pa] \quad (2.1)$$

Where

- $p_0$ = amplitude of sound pressure $(N/m^2)$
\[ T = \text{time (s)} \]
\[ \omega = 2\pi f, \text{ angular frequency (rad/sec)} \]
\[ f = \text{frequency of oscillation} \]

[2.3.1] Sound Pressure level – The Decibel Scale

The audible sound pressure variations range from about 20 \( \mu \text{Pa} \) \((20 \times 10^{-6} \text{ Pa})\) to 100 \( \text{Pa} \). The sound pressure of 20 \( \mu \text{Pa} \) corresponds to the average person’s threshold of hearing. A sound pressure of approximately 100 \( \text{Pa} \) is so loud that it causes pain and is, therefore, called the threshold of pain. Since the range of sound pressures commonly encountered by the human ear is very wide, it has been condensed into a more manageable logarithmic scale by the acoustical scientists by devising the concept of Sound Pressure Level \( (L_p) \), given by

\[
L_p = 10\log_{10}\left(\frac{p^2}{p_{re}^2}\right) \text{ [dB]} \quad \text{or} \quad L_p = 20\log_{10}\left(\frac{p}{p_{re}}\right) \text{ [dB]} \quad (2.2)
\]

Where

\[ p_{re} = \text{international reference sound pressure of } 2 \times 10^{-5} \text{Pa which represents the average threshold of hearing for the normal healthy human ear.} \]

\[ p = \text{root mean square (rms) sound pressure (N/m}^2) \]

In terms of equation (2.1), the root mean square pressure can be given by

\[
p_{rms} = \sqrt{\lim_{T \to \infty} \frac{1}{T} \int_0^T p_0^2 \sin^2(\omega t - \phi) \, dt} \quad (2.3)
\]
It may be worthwhile here to note that Sound Pressure Level is essentially a logarithmic ratio and as such should not have any units. However, for the sake of common man to relate to Sound Pressure Level values, a unit ‘Decibel’ has been assigned to it. In the decibel scale, a sound of 0 dB (20 $\mu$ Pascal in linear scale) represents the threshold of hearing and that of 134 dB (100 Pascal in linear scale) represents the threshold of pain. Typical noise levels for various spheres of human activities are given in Table 2.1.

Table 2.1: Sound pressure levels for various types of noise sources.

<table>
<thead>
<tr>
<th>Noise sources</th>
<th>SPL(dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average threshold of hearing</td>
<td>15</td>
</tr>
<tr>
<td>Broadcast studio</td>
<td>30</td>
</tr>
<tr>
<td>Inside private business office</td>
<td>50</td>
</tr>
<tr>
<td>Normal conversation</td>
<td>62</td>
</tr>
<tr>
<td>Passenger car in city traffic</td>
<td>70</td>
</tr>
<tr>
<td>Business machines</td>
<td>80</td>
</tr>
<tr>
<td>Noisy factory</td>
<td>90</td>
</tr>
<tr>
<td>Rush hour city traffic</td>
<td>90</td>
</tr>
<tr>
<td>Heavy machine factory</td>
<td>100</td>
</tr>
<tr>
<td>Rock music band</td>
<td>113</td>
</tr>
<tr>
<td>Loud automobile horn</td>
<td>120</td>
</tr>
<tr>
<td>Jet aircraft</td>
<td>140</td>
</tr>
<tr>
<td>Threshold of physical tissue damage</td>
<td>160</td>
</tr>
<tr>
<td>Instant deafness</td>
<td>200</td>
</tr>
</tbody>
</table>

[2.3.2] Sound Power and Sound Intensity

Other physical parameters of interest in the context of sound waves are Sound Power level and Sound Intensity level. Sound Power refers to the rate at which acoustical energy is radiated from a sound source. Just as in case of sound pressure
the range of interest over which sound power varies is extremely wide therefore, to condense the range of variation, a logarithmic ratio called the Sound Power Level has been devised.

The Sound Power level is defined as

\[
L_w = 10 \log_{10} \frac{W}{W_{re}} \quad \text{[dB]}
\]  

(2.4)

Where,

\( W = \text{acoustic power [Watts]} \)

\( W_{re} = \text{internationally accepted reference} = 10^{-12} \text{ Watts} \)

The term Sound Intensity refers to the acoustic power passing through a unit area. Symbolically,

\[
I = \frac{W}{A} \quad \text{[W/m}^2\text{]}\]

(2.5)

Where,

\( W = \text{acoustical sound power of the source (W)} \)

\( A = \text{surface area (m}^2\text{)} \)

In the far-field, the average sound intensity, that is, the average energy that flows through a unit area per unit time, is given as

\[
I = \frac{P_{rms}^2}{\rho c} \quad \text{[W/m}^2\text{]}\]

(2.6)
Where \( \rho \) is the density of the medium and \( c \) is the speed of sound in the medium. For air at 22\(^\circ\)C and 0.750 m of Hg, \( \rho c = 412 \) N·sec/m\(^3\).

[2.3.3] Sound Spectra

An average normal human ear can respond to sound waves in a frequency range of 20 Hz to 20,000 Hz. This frequency interval is called the audible range of sound frequencies. Our ear is not able to detect sounds outside the audible range. Sounds having frequencies less than 20 Hz are called the infrasonic sounds while those having frequencies greater than 20,000 Hz are called the ultrasonic sounds. Even within the audible range, our ear is not equally sensitive to all the frequencies. It is less sensitive at the extremes and more sensitive in the middle of the audible range i.e. the human ear is most sensitive to sounds in the 500 Hz to 4000 Hz frequency range and less so for sounds above and below these frequencies. This frequency interval of sensitivity (i.e. 500 Hz to 4000 Hz) corresponds to the human speech band.

[2.3.4] Loudness

The non-uniformity in the ear's response means that the threshold of audibility for sounds of different frequencies will vary. This means that sounds of equal intensity would not be perceived as equally loud by the ear if their frequencies are different. Thus, from the viewpoint of human ear's perception, it is important to characterize sound in terms of loudness level, which is measured in terms of phon. The phon is a true measure of the response of the human ear. The loudness level in phon is equal to the loudness in decibel at 1000 Hz i.e. at 1000 Hz the dB and phon values are identical. For instance, a 10 phon response is produced by definition by a 10 dB sound at 1000 Hz, but at 60 Hz it would take 40 dB to sound equally loud. The concept is best understood with the help of Equal Loudness Contours (figure 2.1)(Magrab, 1975).
It may be observed that human ear's response is fairly flat in the mid range of frequencies, but for low and high frequencies loudness drops away. However, at louder intensities the response is flatter with less variation with frequency.

[2.4] Sound Propagation in atmosphere

Sound propagation is the transmission of acoustic energy through a medium via a sound wave. There are several important factors, which affect the propagation of sound in the ambient atmosphere viz. geometric divergence, atmospheric effects, and surface effects. These are discussed briefly below:

(i) Geometric Divergence

This refers to the spreading of sound energy as a result of the expansion of the wave fronts. Geometric spreading is independent of frequency and has a major effect in almost all sound propagation situations. There are two common kinds of
geometric spreading: spherical and cylindrical spreading shown diagrammatically in figure 2.2. Sound propagation losses due to spreading are normally expressed in terms of $x$ dB per doubling of distance from the source. For example, in the case of spherical spreading from a point source, which is due to a noise source radiating sound equally in all directions, the sound level is reduced by 6 dB for each doubling of distance from the source (Inverse Square law).

A busy highway approximates to a line source, that is, equal sound power output per unit length of highway. A line source will produce cylindrical spreading, where the intensity decreases directly according to the distance from the source. This results in a sound level reduction of 3 dB per doubling of distance.

Note: Radii A and B indicate a doubling of distance.

Figure 2.2: Spherical and cylindrical divergence of sound waves

(ii) Atmospheric Effects

(a) Air Absorption: There are two mechanisms by which acoustic energy is absorbed by the atmosphere. These are molecular relaxation and viscosity effects. By far the most important of these is molecular relaxation. High frequencies are absorbed more than low. The amount of absorption depends on the temperature and humidity of the atmosphere. Figures 2.2-a and 2.2-b show the variation of the absorption with temperature and relative humidity.
Precipitation, rain, snow and fog, have an insignificant effect on sound levels although the presence of precipitation will obviously affect the humidity and may also affect wind and temperature gradients. Under normal circumstances, atmospheric absorption can be neglected except where long distances or very high frequencies are involved.

(b) Wind and Temperature Gradients: The speed at which sound propagates in a gas depends on the temperature of the gas. Higher temperatures produce higher speeds of sound. Since the temperature of the atmosphere is not uniform there are local variations in the sound speed. For example, under normal conditions the atmosphere is cooler at higher altitudes. This results in sound waves being 'bent' upwards. This will result in the formation of a shadow zone, which is a region in which sound does not penetrate. In reality some sound will enter this zone due to scattering. Scattering occurs when sound waves are propagating through the atmosphere and meet a region of inhomogeneity (a local variation in sound speed or air density) and some of their energy is re-directed into many other directions. In environmental noise situations, scattering is caused by air turbulence, rough surfaces, and obstacles such as trees. The scattering of sound by rain, snow or fog at ordinary frequencies is insignificant. Under conditions of a temperature
inversion (temperature increasing with increasing height), the sound waves will be refracted downwards, and therefore may be heard over larger distances. This frequently occurs in winter and at sunset.

When a wind is blowing, there will always be a wind gradient. This is due to the layer of air next to the ground being stationary. Wind gradient results in sound waves propagating upwind being 'bent' upwards and those propagating downwind being 'bent' downwards.

Temperature and wind gradients can result in measured sound levels being very different to those predicted from geometrical spreading and atmospheric absorption considerations alone. These effects are particularly important where sound is propagating over distances greater than a few hundred meters. Temperature inversions and winds can also result in the effectiveness of a barrier being dramatically reduced.

(iii) Surface Effects

*Ground Absorption:* If sound is propagating over ground, attenuation will occur due to acoustic energy losses on reflection. These losses will depend on the surface. Smooth, hard surfaces will produce little absorption whereas thick grass may result in sound levels being reduced by up to about 10 dB per 100 meters at 2000 Hz.

Reflection from the ground can result in another mechanism by which sound levels are reduced. When the source and receiver are both close to the ground, the sound wave reflected from the ground may interfere destructively with the direct wave, shown in figure 2.3. This effect (called the ground effect) is normally noticed over distances of several meters and more, and in the frequency range of 200-600 Hz.
[2.5] Frequency Weighting Networks

In order to compare different complex sounds, we have to measure their entire spectrum. Most often measurements are taken for each octave or 1/3 octave, starting at 125 Hz or sometimes as low as 63 Hz. Using the phon, it is possible to calculate a single figure that refers to the loudness of a complex sound. This can be done by deriving a weighting for the level measured in each band using the equal loudness contours. In other words, as the ear's response varies with both frequency and level, a system of sound frequency weighting curves is used (figure 2.4).
Chapter -2

[2.6] Prescribed Standards of Noise Pollution in India (also recommended by WHO)

The following table 2.2 shows the list of the ambient noise pollution standards and acoustical figures prescribed by CPCB in India and the World Health Organization. The figures are the maximum recommended.(WHO, 1999)

Table 2.2: Prescribed Standards of Noise Pollution in India

<table>
<thead>
<tr>
<th>Area Code</th>
<th>Category of Areas</th>
<th>Day Time $L_{eq}$ Levels</th>
<th>Night Time $L_{eq}$ Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Industrial Area</td>
<td>75 dB</td>
<td>70 dB</td>
</tr>
<tr>
<td>B</td>
<td>Commercial Area</td>
<td>65 dB</td>
<td>55 dB</td>
</tr>
<tr>
<td>C</td>
<td>Residential Area</td>
<td>55 dB</td>
<td>45 dB</td>
</tr>
<tr>
<td>D</td>
<td>Silence Zone</td>
<td>50 dB</td>
<td>40 dB</td>
</tr>
</tbody>
</table>

In the above table, the day time refers to 6.00 a.m. to 9.00 p.m. while the night time means 9.00 p.m. to 6.00 a.m. Silence zone includes the areas up to 100 meters around certain premises like hospitals, educational institutions and courts. Honking of vehicle horns, use of loudspeakers, bursting of crackers etc. are banned in these zones (silence).

[2.7] Sound Measurement

[2.7.1] Sound Level Meter (SLM)

The instrument used for measuring the sound field at a given point is the sound level meter (SLM). IEC 651 standard has categorized four types of SLM viz., Type 0, Type 1, Type 2 and Type 3. The highest specification instrument, which is designed as a laboratory reference standard, is Type 0. Type 1 is usually employed for field use as well as laboratory uses. Type 2 is generally availed for industrial and field work. Amongst all Type 3 is the lowest grade meter used for field survey. The above mentioned meters basically differ in frequency response,
performance stability and sensitivity changes in context to the precision of weighting networks, direction of incident sound and tolerance in level range controls.

The principal components of a typical sound level meter are shown in the schematic diagram of figure 2.5. The microphone senses a sound pressure signal and converts it to an analog electrical signal. The preamplifier is used for impedance matching. Different frequency weighting networks (figure 2.4) namely, A, B, C are used to modify the frequency response characteristics of the measuring instrument. This is done to improve the correlation between sound sensation and instrument reading in accordance with the sensitivity of human ear in the audible range. The selection of the appropriate frequency weighting network is dependent upon the type of measurements being made. For most common steady noises A-weighting network is considered to be the most appropriate. The root mean square detector shown in figure (2.5) is the most common detector used in sound level meters. It provides the running time average of the square of the sound pressure signal (Bell and Bell, 1994). Finally, display is the component where the results of the measurements are displayed. The display may be digital or analog in nature.

Figure 2.5: Block Diagram showing the major component of a Sound Level Meter

A simple sound level meter, however, is not able to provide information about the frequency components of a sound field. Such information is collected with the help of spectrum analyzers.
(2.8) CNG

In response to high fuel prices and environmental concerns, compressed natural gas (CNG) is starting to be used in light-duty passenger vehicles and pickup trucks, medium-duty delivery trucks and in transit and school buses.

CNG has grown into one of the major sources of fuel used in automobile engines in India, New Zealand, Australia, Germany, Argentina, Brazil, and Bolivia. Argentina and Brazil of Latin America are the two countries with the largest fleets of CNG vehicles. Conversion has been facilitated by a substantial price differential with liquid fuels, locally-produced conversion equipment and a growing CNG-delivery infrastructure.

In India, the use of CNG is mandated for the public transport system of Delhi, India's capital city as well as mega city, Ahmedabad in the state of Gujarat. The Delhi Transport Corporation operates the world's largest fleet of CNG Buses.

[2.8.1] Composition of CNG

CNG is an abbreviation of Compressed Natural Gas. The CNG has less energy density as compared to Liquid Fuel and is compressed under high pressure to over 200 Kg/cm² (g) to make it CNG usable for automobiles.

The typical composition of CNG is as follows:

- Methane : 88%
- Ethane : 5%
- Propane : 1%
- Carbon dioxide : 5%
- Other gases : 1%
- Total : 100%
[2.8.2] Physical Properties

In its natural form, it is colourless, odourless, non-toxic and non-carcinogenic.

**Non-toxic** – Natural gas being lead/sulphur free, its use substantially reduces harmful engine emissions. When natural gas burns completely, it gives out carbon dioxide and water vapour - the very components we give out while breathing.

**Lighter than air** – Natural gas being lighter than air, will rise above ground level and disperse in the atmosphere, in the case of a leakage.

**Colourless** – Natural Gas is available in the gaseous state, and is colourless.

**Odourless** – The gas in its natural form is odourless, however, ethyl mercaptan is later added as odorant so as to detect its leakage.

[2.8.3] CNG – as a fuel

CNG is a substitute for gasoline (petrol) or diesel fuel. It is considered to be an environmentally "clean" alternative to those fuels. It is extracted from natural gas. It is stored and distributed in hard containers, usually cylinders.

CNG is a safe fuel. Being lighter than air, it disperses easily into the atmosphere and does not form a sufficiently rich mixture for combustion to take place. CNG has 130 octane, which is considerably higher than 93 octane for petrol consequently, CNG vehicle is more energy efficient. Higher octane rating allows higher compression ratios and improved thermal efficiency 4, reducing carbon dioxide emissions. CNG allows the use of catalytic converter more efficiently than diesel. Compared to petrol or diesel, CNG vehicles emit 40% less of nitrous oxide (a toxic gas that creates smog), 90% less of hydrocarbons (which carry carcinogens), 80% less of carbon monoxide (a poisonous pollutant), and 25% less of carbon dioxide (a major greenhouse gas). Further, noise level of CNG engine is much lower than that of diesel driven vehicles.