MODULE :03

ACOUSTICS

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Outlines:

- Sound intensity level – Decibel
- Sound pressure level(SPL)
- Human Audiogram
- Unit of loudness

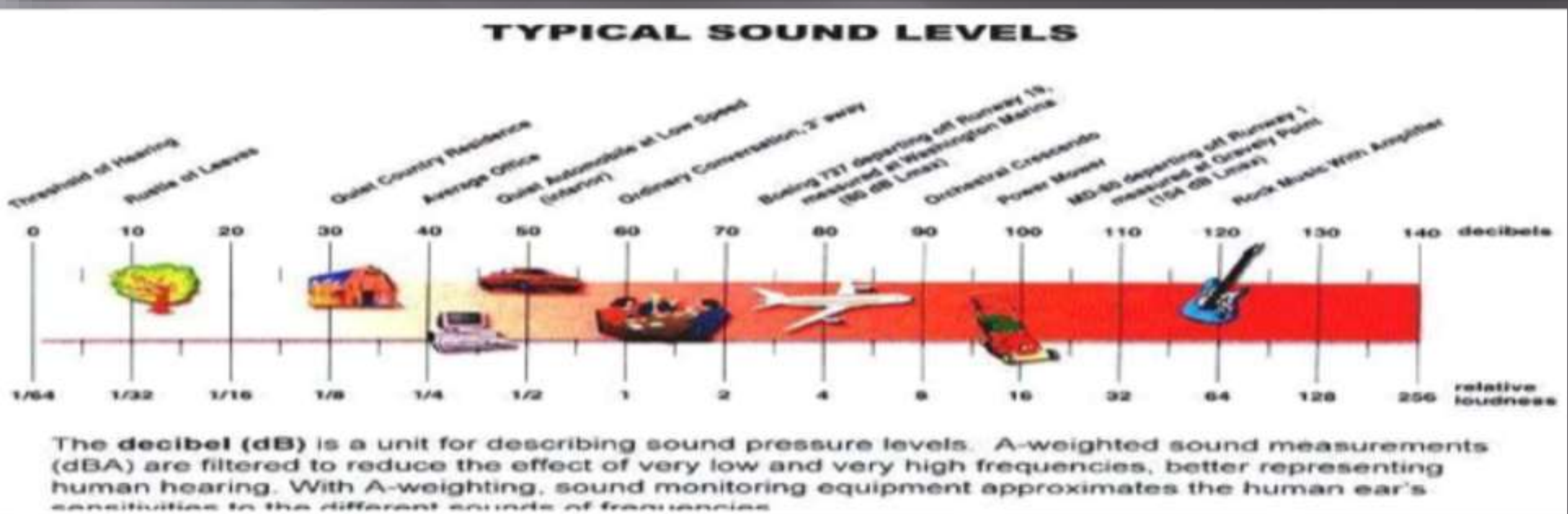
Sound intensity level – Decibel

The lowest intensity of sound at 1 kHz to which a normal human ear can respond is IO= 10-12 W/m2. This is known as threshold of hearing and the loudest sound that can be heard without pain is about 120 db. This is known as threshold of pain.

One Bel is defined as the relative intensity between two sound notes if one is 10 times more intense than the other.

1 decibel =1/10 bel

Whisper
Wind Turbine
Office
Stereo Music
Pneumatic Drill
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Falling Leaves
Bedroom
Home
Inside Car
Industrial Noise
Jet Airplane



TYPICAL SOUND LEVELS
Threshold of Hearing
Rustle of Leaves
Quiet Country Residence
Average Office
Quiet Automobile at Low Speed (interior)
Ordinary Conversation, 3' away
Boeing 737 departing off Runway 18, measured at Washington Marina (86 dB Lmax)
Orchestral Crescendo
Power Mower
MD-80 departing off Runway 1 measured at Gravelly Point (104 dB Lmax)
Rock Music With Amplifier
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
decibels
1/64
1/32
1/16
1/8
1/4
1/2
1
2
4
8
16
32
64
128
256
relative loudness
The decibel (dB) is a unit for describing sound pressure levels. A-weighted sound measurements (dBA) are filtered to reduce the effect of very low and very high frequencies, better representing human hearing. With A-weighting, sound monitoring equipment approximates the human ear's

13.5 SOUND INTENSITY LEVEL - DECIBEL

The range of variation of sound intensity is very large. The loudness of a sound as judged by the ear is proportional to the logarithm of intensity. It means that our ear is a logarithmic instrument. Therefore, the absolute intensity of sound wave is not of practical significance. Instead, the relative intensity is of more concern for us.

The lowest intensity of sound at 1 kHz to which a normal human ear can respond is $I_o = 10^{-12}$ W/m^2. This is known as the ***threshold of hearing*** and is chosen as the "zero" or "standard" intensity. Intensity of a sound is measured with reference to this standard frequency.

Def: *The ratio of the intensity of sound wave to the threshold intensity of hearing is defined as the* ***intensity level*** *of sound.*

If I and I_0 represent the intensities of two sounds of a particular frequency (chosen normally to be 1 kHz), L_1 and L_0 are their corresponding measures of loudness, then according to Weber-Fechner law

$$L_1 = k \log I$$

and

$$L_0 = k \log I_o$$

The difference in the loudness of the two sounds is given by

$$L = \log \frac{I}{I_o} \text{ bels} \qquad \text{...(13.8)}$$

L is called the *intensity level* and is expressed in bels, a unit named after Alexander Graham Bell, the inventor of telephone.

Def: One Bel is defined as the relative intensity between two sound notes if one is 10 times more intense than the other.

The unit of bel is large and in practice a smaller unit *decibel* is used.

$$1 \text{ decibel} = \frac{1}{10} \text{ bel}$$

Accordingly, the intensity level of a sound wave is defined as

$$L = 10 \log \frac{I}{I_o} \text{ decibels (dB)} \qquad \text{...(13.9)}$$

(*a*) Threshold of audibility: The intensity level corresponding to the intensity I_o will be 0 dB, since from Eq. (13.9), we get

$$L = 10 \log \frac{I_o}{I_o} = 10 \log 1 = 0$$

0 dB level represents the ***threshold of audibility***.

(*b*) Physical significance of a decibel: The smallest change in intensity level that the human ear can detect is 1 dB. Let us find the corresponding change in intensity or loudness. From Eq. (13.9), when $L = 1$dB,

$$1 \text{ dB} = 10 \log \frac{I}{I_o}$$

or $$\log \frac{I}{I_o} = \frac{1}{10} = 0.1$$

$\therefore$ $$\frac{I}{I_o} = 10^{0.1} = 1.26$$

or $$I = 1.26 I_o$$

It means that a change in intensity by 26% increases the intensity level by one decibel. Further,

if $I = 100\ I_o$, $L = 10 \log 10^2 = 20$ dB,

$I = 1000\ I_o$, $L = 10 \log 10^3 = 30$ dB,

$I = 10000\ I_o$, $L = 10 \log 10^4 = 40$ dB and so on.

Thus, when two sounds differ by 20 dB, the louder of them is 100 times more intense and when they differ by 40 dB, the louder one is 10,000 times more intense. The loudest sound that can be heard without pain is about 120 dB. This is known as the ***threshold of feeling*** or ***pain threshold***. Some of the typical sound levels are shown in Table 13.2

Table 13.2: *Some typical sound levels*

Source	Sound level (dB)
Rustling of tree leaves	0 - 20
Quiet living room	20 - 40
Average office	40 - 60
Average street noise	60 - 80
Train sound	80 - 100
Thunder	100 - 120
Aeroplane noise at a distance of 3 m	120-130 (painful)

13.6 SOUND PRESSURE LEVEL (SPL)

In acoustical problems, sound levels are generally dealt in terms of pressure rather than intensity. In fact, sound measuring devices respond to pressure exerted by sound. Eq. (13.5) shows that the sound intensity is proportional to the square of its pressure.

Using Eq. (13.5) into Eq. (13.9), an expression for the SPL may be obtained as follows.

$$\text{SPL} = 10 \log \frac{I}{I_o} = 10 \log \left(\frac{P}{P_o}\right)^2 = 20 \log \frac{P}{P_o} \quad \text{decibels} \qquad ...(13.10)$$

The reference pressure P_o is usually taken as $P_o = 2 \times 10^{-5}$ N/m².

The reference level P_o is approximately the lowest sound pressure that is audible to normal human ear. The *SPL* can be directly measured on a sound level meter.

13.7 HUMAN AUDIOGRAM

The human ear exhibits basically a nonlinear response. Human audiogram is shown in Fig. 13.3. The threshold of hearing represents the weakest sounds that can be heard while the upper curve shows the loudest sounds that can be heard without harmful effects. Further, heard the sensitivity of the ear varies with frequency. Thus, threshold of hearing of sound depends upon both the intensity and frequency of sound. A sound is audible above a certain minimum intensity and a certain minimum frequency. For a person with normal hearing, the threshold of audibility at 1 kHz is 0 dB; at 200 Hz and 15 kHz it is about 20 dB and at 50 Hz and at 18 kHz it is about 50 dB. Ordinary speech sounds lie between the frequencies of 100 and 8000 Hz, but musical sounds cover a greater range. When the intensity of sound exceeds a maximum limit, it produces a sensation of pain on the ear. The tolerable intensity limit is 120 decibels.

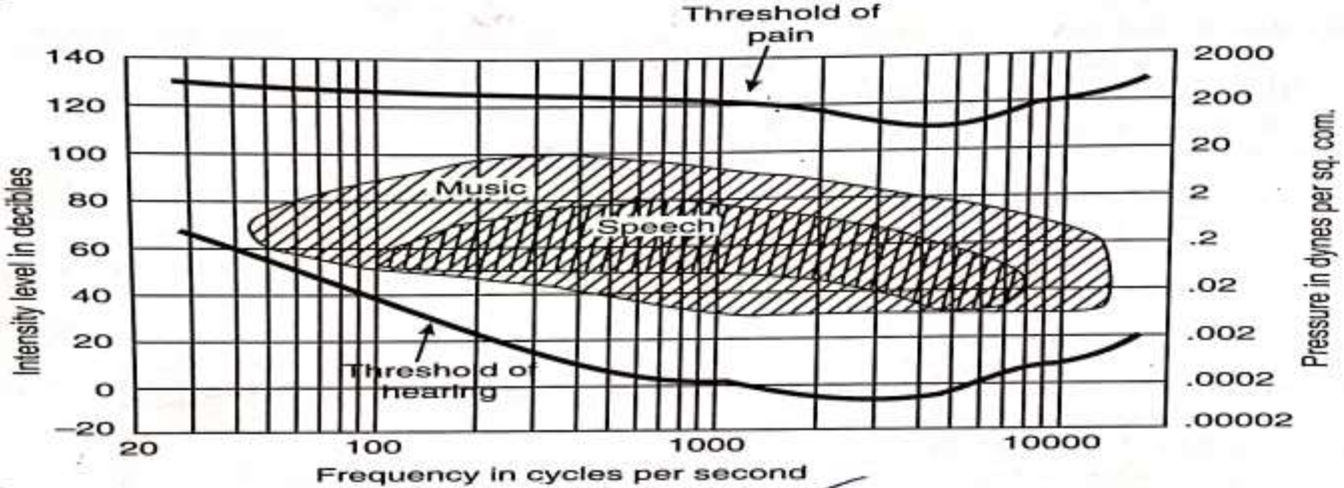


Fig. 13.3:
Human Audiogram.

Similarly, there is a maximum frequency limit beyond which the sound is not heard. Thus, the maximum audible intensity of sound also depends upon both the intensity and frequency of sound. In Fig. 13.3, the two curves, the threshold of hearing and the threshold of pain enclose an area called **auditory area**. A sound, whose frequency and intensity are not within the limits set by this area, is not heard by humans.

13.8 UNITS OF LOUDNESS

Loudness is considered a subjective measurement which is influenced not only by sound pressure, but the length of the sound. ***There are two units used to measure the loudness of sound, phon and sone.***

13.8.1 Phon

The loudness of a sound depends on the frequency of the sound and the sensitivity of the ear. Generally, two different 60-decibel sounds will not have the same loudness. The loudness cannot be measured directly with a meter.

Def: The phon is a measure of loudness and it is equal to the loudness of an equally loud 1 kHz frequency note expressed in decibels.

A sound of known intensity level is produced at the frequency 1 kHz (1 kHz being taken as the standard frequency) and then a sound at some other frequency of interest is generated. The intensity of the second sound is varied in intensity till the volunteers judge it to be of the same loudness as that of 1 kHz sound. If the intensity level of both sounds is N decibels, then the equivalent loudness is said to be N phons. In simple terms 60 phons means "as loud as a 60 dB, 1000 Hz tone." At 1 kHz, readings in phons and dB are the same.

So, for a 1 kHz note, loudness in phons

$$= 10 \log(I/I_0) \quad \text{...(13.11)}$$

$$= 10 \log I + 10 \log (1/I_0)$$

$$= 10 \log I + 10 \log 10^{12}$$

or

$$LP = 10 \log I + 120 \quad \text{...(13.12)}$$

$\therefore$

$$\log L = 0.033(10 \log I + 120 - 40)$$

$$= 0.33 \log I + 2.64$$

which reduces to $\quad L = 445 I^{0.33}$

that is, $\quad L \propto I^{1/3} \quad$ ...(13.13)

for a 1 kHz tone.

The phon unit is not an SI unit in metrology and is used by the American National Standards Institute.

13.8.2 Sone

Def: A *sone* is defined to be equal to 40 phons. A sone is the loudness of a 1 kHz tone of 40-db intensity level.

Experimentally it was found that a 10 dB increase in sound level corresponds approximately to a perceived doubling of loudness. So that approximation is used in the definition of the phon as

0.5 sone = 30 phon, 1 sone = 40 phon, 2 sone = 50 phon, 4 sone = 60 phon, etc.

Thanks