MODULE :03

ACOUSTICS

By: Mr. Birajit Basumatary
Assistant Professor (C)
Department Of Physics
BBEC, Kokrajhar

Outlines:

- Introduction
- Sound
- Sound velocity
- Sound wavelength
- Audible frequency range
- Classification of sound
- Characteristics of musical sound

13.1 INTRODUCTION

The study of sound plays a very important role in various branches of engineering and has developed to such a level that it has become an independent branch of engineering known as ***acoustic engineering*** or ***sound engineering***. The area of study of design of musical instruments is known as ***musical acoustics***, the technology of sound production and recording as *electro-acoustics*, use of sound in medical diagnosis and therapy as ***bio-acoustics***, the design of buildings, auditoriums, musical halls, lecture halls, recording rooms, etc as ***architectural acoustics***.

Architectural acoustics deals in general with the behaviour of sound waves in closed spaces and their design to give the best sound effects. The acoustic properties of buildings were not studied on a scientific basis till about 1900. Buildings designed to screen movies, to stage dramas or for music concerts often lacked the proper acoustic quality and were found unfit for such activities. The Fogg Art Museum hall in Harvard University, U.S.A. turned out to be highly defective when it was built. The lectures given in it were not intelligible to audience. Prof. Wallace C. Sabine, Professor of Physics in Harvard University was entrusted with the responsibility of eliminating the acoustical defects of the hall. Sabine undertook a systematic study of the problem and evolved conditions for a satisfactory acoustic quality of a hall. He found that quite often reverberation was the main cause for a defective quality of a hall. Addition of absorbent materials at appropriate surface enhances the quality of sound in the halls. Other precautions are to be taken about the shape of walls, ceiling and the hall in total so that acoustic defects do not arise. Thus, Prof. Sabine laid the foundations of acoustic engineering.

13.2 SOUND

A vibrating body excites mechanical waves in the surrounding medium. These mechanical waves propagate as a series of compressions and rarefactions of air molecules (Fig. 13.1). On reaching the ear, they cause the eardrum to vibrate, leading to the sensation of hearing. Sound cannot travel in a vacuum and requires the presence of an elastic medium for its propagation. Sound waves are longitudinal waves. The compressions and rarefactions caused by the vibrating body modulate the normal atmospheric pressure with small pressure changes occurring regularly above and below it. Thus, a sound wave is one complete cycle of pressure variation.

The wave motion of sound does not change the mean position of the vibrating particles (molecules) and the average maximum distance of a particle from its mean position is called ***amplitude***. Even a sound of 0.01 mm amplitude is enough to be audible, while a sound of 0.1 mm amplitude is quite a loud sound.

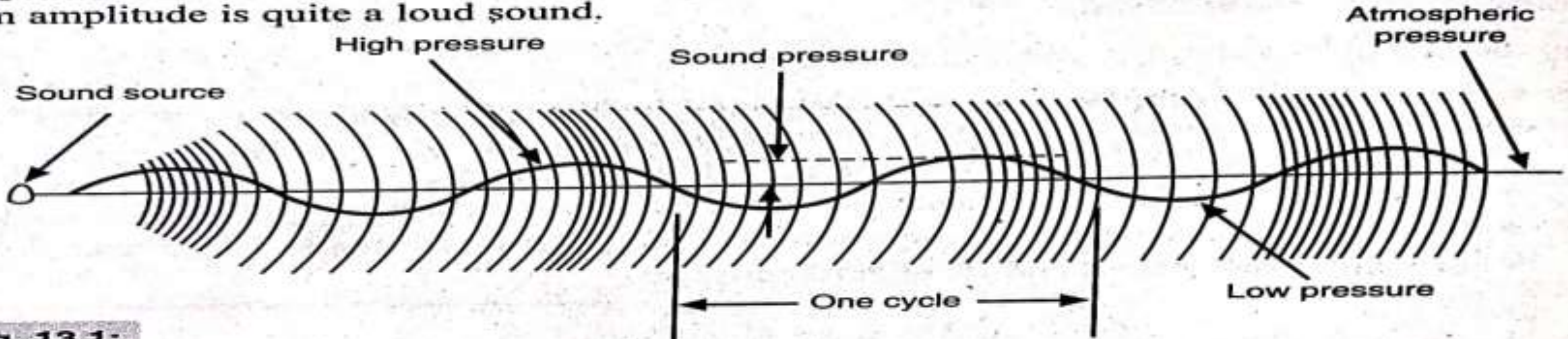

Fig. 13.1:
Compression and Rarefactions of Air Molecules.

13.2.1 Sound Velocity

The velocity of sound is not a constant and depends on the nature and temperature of the medium through which it travels. In general, the velocity of sound in a gaseous medium is governed by the relation

$$\upsilon = \sqrt{\frac{B}{\rho}} \qquad ...(13.1)$$

where B is the bulk modulus of the medium and ρ its density.

The speed of sound in air is commonly taken as 344 m/s for normal conditions. This is very less compared to the velocity of light. Table 13.1 lists the speed of sound in some materials. It may be noted that sound travels faster in liquid media than in gaseous media and much faster in solid media.

Table 13.1: *Speed of sound in some materials at 20°C*

Medium	Speed (m/s)	Medium	Speed (m/s)
Air	344	Brick	4300
Hydrogen	1305	Mild steel	5050
Pure water	1480	Aluminium	5150
Plexiglass	1800	Glass	5200
Soft wood	3350	Granite	6400
Concrete	3400	Gypsum Board	6800

13.2.2 Sound Wavelength

The velocity of the wave may be expressed as the product of frequency f and wavelength, λ. Thus,

$$\upsilon = f\lambda \qquad ...(13.2)$$

Therefore, the wavelength may be written as

$$\lambda = \frac{\upsilon}{f} \qquad ...(13.3)$$

It follows that the wavelength of sound will be larger in a medium having a higher velocity. When the medium is air, we can write

$$\lambda = \frac{344 \text{ m/s}}{f} \qquad ...(13.4)$$

13.2.3 Audible Frequency Range

The limit of the audible frequency range is generally 16 Hz to 20,000 Hz. The human hearing system is sensitive to frequencies in the range of 1000 Hz-4000 Hz. Higher the audible frequency the wider is the range (Fig. 13.2). A unit *octave* describes the interval between two frequencies having a ratio of 2:1. Fig. 13.2 illustrates some sounds in frequency domain.

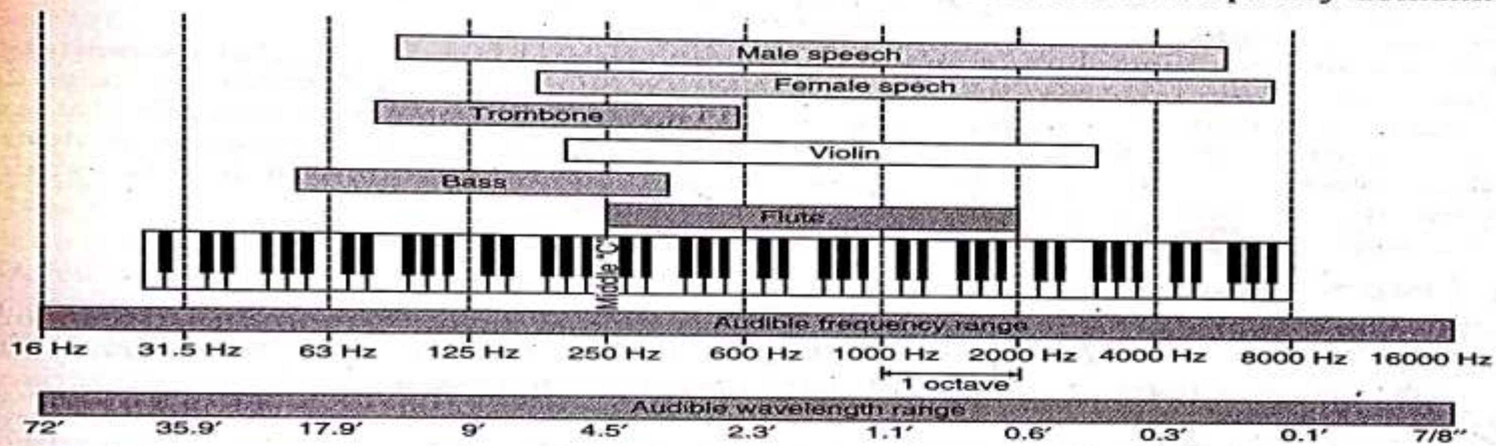

Fig. 13.2:
Audible frequency range.

13.3 CLASSIFICATION OF SOUND

Sound waves are classified based on their *frequency* into three groups, namely *sonic* (audible), *infrasonic* and *ultrasonic* waves.

(*i*) **Audible Waves:** The waves that produce a sense of sound on a human ear and lying in the range of 16 Hz to 20,000 Hz.

(*ii*) **Infrasonic Waves:** Sound waves with frequencies below 16 Hz.

(*iii*) **Ultrasonic Waves:** Sound waves with frequencies above 20 kHz.

(*iv*) **Hypersonic Waves:** Elastic waves ,with frequencies of 10^{10} Hz and higher and correspond to thermal waves in liquids or solids.

Audible sound waves can be further classified according to their frequency *spectrum* as **Musical sounds** and **Noise**.

(a) Musical sounds produce a pleasing sensation on the ear. They have the following characteristics.

(*i*) Musical sound has a line spectrum containing multiple frequencies.

(*ii*) Musical sounds are *periodic vibrations*.

(*iii*) Sudden changes in amplitude do not occur.

(b) Noise causes irritation and strain to our ears. If very loud, noise may cause permanent or temporary deafness. Noise has the following characteristics.

(*i*) Noise is a jumble of irregularly timed, *non-periodic vibrations*.

(*ii*) It consists of a complex spectrum of frequencies.

(*iii*) It undergoes erratic changes in amplitude and frequency.

13.4 CHARACTERISTICS OF MUSICAL SOUND

Tone is a sound wave, which has a single well-defined frequency. Sound and noise usually are not pure tones. Normally, a *musical note* consists of several tones or a series of harmonic waves of different frequencies of varying intensity. The *pitch* of that note corresponds to the lowest tone it contains.

The lowest-pitch tone of frequency, f is the loudest and is called the **fundamental** tone. This frequency is dominant and defines the pitch of a note. The additional frequencies $2f$, $3f$, $4f$ ... accompanying the fundamental tone are called **overtones** or **harmonics**. The intensities of overtones diminish with increase of their frequencies. Each source (musical instrument) produces different overtones and the overtones so present are characteristic of that source.

Musical sound has the following three characteristics:

(*i*) Pitch or Frequency (*ii*) Timbre or Quality (*iii*) Loudness or Intensity

13.4.1 Pitch or Frequency

The first characteristic of a musical sound is its pitch. It enables us to classify a musical note as high or low and to distinguish a shrill sound from a flat sound of the same intensity sounded on the same musical instrument. Highness or lowness of a sound is characterized by the frequency producing it.

Def: Pitch is a subjective sensation perceived when a tone of a given frequency is sounded. The pitch of a note depends on the frequency of the source of the sound. Greater is the frequency of a musical note, higher is the pitch and vice versa.

The frequency and pitch are two different characteristics. The frequency is a *physical quantity* and can be measured accurately, while pitch of a note is a *physiological quantity* which is merely a sensation experienced by a listener. The change in pitch with loudness is most pronounced at a frequency of about 100 Hz. In the 100 Hz range the pitch increases with increasing loudness. For frequencies between 1 kHz and 5 kHz which is the range for which the ear is most sensitive, the pitch of a tone is relatively independent of its loudness. In general, the pitch varies in a parabolic manner with frequency in the range 20 Hz to 10 kHz.

13.4.2 Timbre or Quality

The second characteristic of a musical sound is its timbre or quality. Timbre is the name given to subjective sensation, which enables us to distinguish the same note played on different instruments or sung by different singers. Memory of the timbre helps us identify different sounds such as the instrument being played or the person who is speaking or singing.

✓ ***Def:*** Timbre gives distinguishable nature of a tone. The difference between the notes of the same pitch of two different musical instruments defines the quality of the note produced by an instrument. Quality distinguishes the note produced one instrument from that of the other instrument.

If two musical notes have the same fundamental pitch (frequency) but differ in overtones, they are said to differ in ***quality***. The frequencies and amplitudes of the overtones present in the musical notes can be analyzed with the help of Fourier analysis. The analysis showed that the quality of a note depends upon the presence or absence of particular overtones and their relative intensities.

13.4.3 Loudness or Intensity

Loudness signifies how far and to what extent, sound is audible. Loudness of sound is a subjective perception. Because of the varying sensitivity of the ear, different people perceive the same sound differently. What is loud to one person may be soft for another. An objective measure of loudness is sound *intensity*, which is applicable equally to everyone. Loudness is found to vary with frequency also. Intensity of sound is a physical quantity and does not depend on the listener.

✓***Def:*** *The intensity of the sound wave is the rate of flow of sound energy through a unit area normal to the direction of propagation. Since the rate of flow of energy is power, the intensity of sound wave is measured in units of power per unit area, i.e., in W/m².*

The sound intensity is proportional to the square of the wave amplitude.

Thus,

$$I \propto P^2 \quad ...(13.5)$$

where P is the pressure amplitude.

The intensity of the faintest sound wave that can be heard is about 10^{-12} W/m^2. The range of intensity of sound that an ear can hear ranges from 10^{-12} W/m^2 to about 1 W/m. Sounds of same intensity but of different frequencies may differ in loudness.

Thanks