Basics of Acoustic Science

Vinod V. Kadam and Rajkishore Nayak

Abstract The act of hearing sound is an important communication and sensory medium with the surroundings. Sound is a wave that can be defined scientifically similar to the other mechanical waves in physics. The science of sound is acoustics that deals with the propagation of mechanical waves in various mediums such as solid, liquid and gases. As modern lifestyle includes the applications of acoustics in many fields, it is essential to understand the science of sound for people involved in acoustic applications. Various disciplines of acoustics include musical designs, vibration, noise pollution control, audiology, speech, vibration, underwater communication, audio signal processing, automotive acoustics, aeroacoustics, structural acoustics, bioacoustics, ultrasound, vibration control and environmental noise control. This chapter deals with the concept of sound waves and basic terminologies associated with acoustic science. Sound generation and propagation is covered in detail. Furthermore, sound measurement and different sound classification systems are also covered.

Keywords Sound wave · Propagation · Frequency · Absorption · Decibel

1 Introduction

The most important interactive communication in the social sense of human beings is to hear [3]. A sensation or a feeling that we hear is a sound. The science of sound is termed as acoustics. The word acoustics originated from the Greek word meaning "to hear" [4]. The American National Standard and the Acoustical Society of America have defined sound as "(a) Oscillation in pressure, stress, particle displacement, particle velocity, etc., propagated in a medium with internal forces (e.g.,

V.V. Kadam
Central Sheep and Wool Research Institute, Avikanagar, Rajasthan 304 501, India

V.V. Kadam · R. Nayak (✉)
School of Fashion and Textiles, RMIT, University, Melbourne, VIC 3056, Australia
e-mail: s3514621@student.rmit.edu.au; rajkishore.nayak@rmit.edu.au

R. Padhye and R. Nayak (eds.), *Acoustic Textiles*, Textile Science and Clothing Technology, DOI 10.1007/978-981-10-1476-5_2

elastic or viscous), or the superposition of such propagated oscillation. (b) Auditory sensation evoked by the oscillation described in (a)". Hence, acoustics is a study of sound generation and propagation in different media.

Sound originates when a material or object vibrates. These vibrations propagate in solid, liquid or gas medium in a wave form from the emitter to the receiver. Thus, a sound wave is the transfer of energy emitted by a source material or object into the medium as it travels. A sound wave is characterized by its frequency, wavelength and amplitude. The interaction of sound waves with the receiver's surface can alter the wave characteristics depending upon the surface properties of the receiver material or object. The sound wave can be absorbed, transmitted, reflected, refracted and diffracted from the surface. The change in sound characteristics due to the above phenomenon has been utilized in many scientific applications including acoustic textiles.

Acoustic textiles may be important to reduce noise pollution in modern days. It is important to understand the basics of sound in order to develop an efficient product design, say for sound insulation or so. The sound pressure levels, sound intensity and sound classification systems can help in assessing the performance of the acoustic structure. This chapter describes the concept of sound generation, sound wave propagation and the characteristic features. This also includes sound interference such as absorption, transmission, reflection, refraction and diffraction.

2 Sound Generation

Any source of vibration, which disturbs air molecules, creates sound. It pushes and pulls air molecules that convert the vibrations into acoustic signals, known as sound. Sound perceived depends on three things: vibration source to form a sound wave, wave carrier medium (such as air) and a receiver to detect the sound [5] (Fig. 1). Sound source oscillates and brings the surrounding air into motion and in the presence of a recipient, sound can be perceived [6]. Sound is a mechanical disturbance that travels through an elastic or viscous medium at a speed depending on the characteristic of that medium [7]. Sound is a wave motion in an elastic media such as air, water or a rock. While air tubulates, the mass and momentum sources of a material are ultimately sound generators [8].

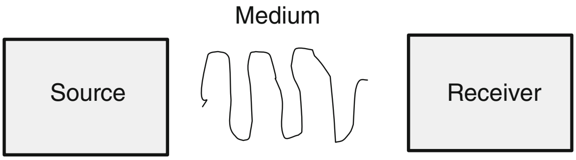

Fig. 1 Sound generation

3 Sound Wave Propagation

Sound propagation is essentially a wave phenomenon. Acoustic signals require a mechanically elastic medium for propagation and therefore cannot travel through vacuum, unlike electromagnetic light waves. Sound travels more rapidly through solids, followed by liquids, than through gases [7]. Sound, in a wave form, travels at 331.29 ms^{-1} in dry air at a temperature of 0 °C [2].

3.1 Sound Wave Concept

When vibration sound disturbs particles in the air or the other medium, then those particles displace other surrounding particles. This particle movement goes on continuously in the outward direction to form a wave pattern. The wave carries the sound energy through the medium and becomes less intense as it moves away from the source. The sound energy is also directly associated with the volume of the sound. Higher sound energy results in loud volume.

There are three aspects of a sound wave that cause different types of sounds to be produced: frequency, wavelength and amplitude. Sound waves vibrate at different rates or frequencies as they move through the medium. The wave may have a single frequency or many frequencies depending upon the vibration source.

Let us consider a sound wave of constant frequency generated by a source with displacement function on Y-axis and time function on X-axis (Fig. 2). The number of waves generated per second is the frequency of the sound and expressed in hertz (Hz). The maximum displacement of a peak is termed as amplitude while the distance from one peak to the other is the wavelength. The sinusoidal wave generates only single frequency. A variety of non-repetitive sounds produce waves of different frequencies.

Sound waves are principally longitudinal waves. It means the wave medium, for instance, air, oscillates parallel to the wave's direction. Let us consider a soft coil is stretched and fixed at one end. If the coil is quickly pushed and pulled from the other

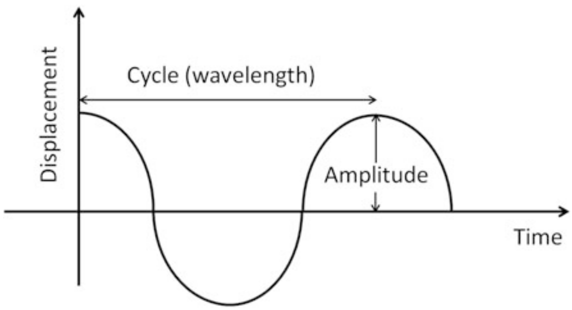

Fig. 2 Sound displacement-time diagram

end, it will compress and elongate along with the force direction. The same thing happens in longitudinal sound wave. Air particles get oscillated back and forth in the direction parallel to the sound wave movement. This create compression and rarefaction waves alternately. Longitudinal waves begin with compression followed by rarefaction. The wavelength can be determined by measuring the distance between two consecutive compressions, or rarefactions.

3.2 Sound Interference and Doppler Effect

When sound waves from two different sources either cancel or superimpose each other's effect, the phenomenon may be termed as interference [5]. The interference that cancels the waves generates no sound, whereas, noise or intermittent sound may be produced due to interference where the waves superimpose.

When a sound source is in motion, sound waves of variable lengths are generated. Wavelength become short in one direction and extends in the other. It causes change in the pitch of the sound perceived by a stationary receiver. This effect is commonly known as "Doppler effect" as per the name of Austrian Physicist Christian Doppler who discovered it [5]. In the Doppler effect, the resultant frequency reaching to the stationary receiver is not the actual output frequency of the sound source. The frequency is influenced by change in the wavelength depending on the sound source movement from the receiver. As the sound source moves towards a stationary receiver, wavelength is reduced causing an increase in the sound frequency and vice versa.

3.3 Absorption

The sound wave interact with the material or object surface and may be absorbed, transmitted, reflected, refracted or diffracted form the surface depending on type of the surface. These phenomenons are described in Fig. 3. When all the emitted sound waves are absorbed by the receiver, sound absorption occurs. It is exactly like sponge absorbing water. Sound absorption is an important phenomenon as far as sound insulation is concerned. There are different materials available for sound absorption. The sound absorbers may be porous or resonant type. Porous absorbents are classified as fibrous materials and open-celled foams. Fibrous materials convert acoustic energy into heat energy when sound waves impinge the absorber. In case of foam, sound wave displacement occurs through a narrow passage of foam and causes heat loss. Resonance absorbents are of mechanical type, where there is a solid plate with a tight air space behind. It is noteworthy that some material such as foam absorbs sound waves whereas the glass blocks it. The selection of material to be used depends on the end use application. For example, the office room in a building can be designed as sound absorbing or sound proofing.

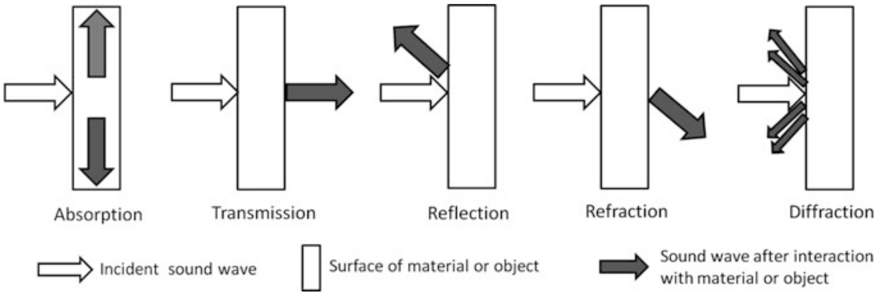

Fig. 3 Sound wave interaction with material or object surface

Sound absorption measures the amount of energy absorbed by the material and expressed as sound absorption coefficient (α). The coefficient ranges between 0 and 1 where 0 is no absorption and 1 is highest or total absorption. The higher coefficient yields lower reverberation time. The reverberation time is persistence of sound in a space after a sound source has been stopped [1]. It is the time lag, in seconds, for the sound to decay by 60 dB after a sound source has been stopped. Sound absorption is important to make the acoustic environment suitable for a specific purpose; for instance, in recording studios, lecture halls, concert rooms, lecture theatres, etc. The low frequency sound of 500 Hz is relatively difficult to absorb than high frequency sound.

3.4 Transmission

Sound waves from the source propagate through the medium and receiver without being absorbed or reflected and pass through the receiver without any frequency loss, which is known as sound transmission.

3.5 Reflection

When sound waves impinge on hard or smooth surface they may reflect back with their full energy without altering their characteristics. The reflection angle of sound wave from the reflecting surface is equal to the angle of incidence. The angles are defined between a normal to the reflecting plane and the incident and reflected waves. The reflected sound waves, thus, follow Huygen's geometry where both the incidence and reflection angles are equal [7].

The reflection phenomenon of sound waves finds many applications. For example, a reflected sound wave is used to measure the depth of water from sea level with the help of echo produced from the reflective surface. The geological composition at the bottom of the ocean and inside the earth crust is also identified using the reflection of sound wave [7]. Echo is a simple example of sound reflection phenomenon. Echo can be heard when the sound wave, perpendicular to the sound source, hits a flat and smooth surface.

3.6 Refraction

Refraction occurs when sound waves transmit through the surface and bent away from the straight line of travel. Sound refraction depends on factors such as the speed of sound, angle between sound propagation direction and wind direction and atmospheric conditions such as temperature and relative humidity [9].

3.7 Diffraction

Diffraction involves a change in the direction of sound waves as it strikes through a surface. Sound waves when impact on a partial barrier, some of them get reflected, some propagate without any disturbance and some bent or diffract over the top of the barrier. As sound source moves closer to the barrier, less sound diffraction is obtained. The sound at lower frequencies tends to diffract more easily than sound at higher frequencies [7].

4 Octave and 1/3 Octave Band

In acoustics, the sound frequencies are divided into ten standard octave bands. Each octave band has a centre frequency (f_c) and each centre frequency doubles the previous one (Table 1). The geometric mean of upper band limit (f_u) and lower

Table 1 Octave bands

Lower band limit (f_L) (Hz)	Centre frequency (f_c) (Hz)	Upper band limit (f_u) (Hz)
22.4 Hz	31.5 Hz	45 Hz
45	63	90
90	125	180
180	250	355
355	500	710
710	1 kHz	1.4 kHz
1.4 kHz	2	2.8
2.8	4	5.6
5.6	8	11.2
11.2	16	22.4

Source Raichel [7]

Table 2 Sound frequency categories

Sound	Frequency
Infrasound	<20 Hz
Audible sound	20 Hz–20 kHz
Ultrasound	>20 kHz
Hypersound	>1 GHz

Source Raichel [7]

band limit (f_L) denotes the centre frequency (f_c). The band width is the difference between the upper and lower band limits.

Each octave band is divided into three sub-bands to obtain one-third octave band. Each successive frequency is higher by a cube root of 2 than the previous one. The centre frequency for one-third octave band ranges from 20 Hz to 20 kHz.

5 Sound Attributes

There are two attributes of sound: loudness and tone [6]. The physical amount of loudness is sound pressure, whereas the tone is the sound frequency which is expressed in Hertz (Hz). The tone may also be termed as pitch of the sound. The pitch is also expressed as a wavelength which is the sound velocity per unit of sound frequency [5].

Human ear is not sensitive to all the sound frequencies. The sound may or may not be audible to the human ear, depending on its frequency and intensity. The human voice lies within 500–4000 Hz and it is most receptive to sounds within that range [10]. The audible sound for humans is in the range of 20 Hz–20 kHz [7]. Based on the frequency, sound is categorized as infrasound, audible sound, ultrasound and hypersound (Table 2).

6 Sound Pressure Level

Sound pressure level is a measure of volume (loudness) of the sound in terms of the sound pressure. The level can be determined by measuring the sound pressure disturbance from the equilibrium pressure value. The pressure disturbance is the difference between the instantaneous pressure and the static pressure [10]. The mean pressure deviation from the equilibrium is always zero, since the mean compression waves are equal to mean rarefaction waves. These positive and negative effects are converted into positive using the root mean square (RMS) value of sound pressure (P_{rms}) over a period of time. However, RMS value of sound pressure is not convenient to use as it varies over a wide range of magnitudes. The

Table 3 Sound pressure levels of different activities

Source	Sound pressure level (dB)
Aeroplane take off	140
Firecrackers	120
Rock concert	110
Factories	90
Traffic	80
Business places	60
Living room and kitchen	40
Bedroom	20
Natural places	10

Source Ziaran [11]; Department of Environment and Heritage, Queensland, Australia [12]

decibel (dB) is the easiest and a more convenient way to measure the volume (loudness) of the sound in terms of the sound pressure.

$$\mathrm{dB} = 20\log\left(\frac{p_{\mathrm{rms}}}{p_{\mathrm{o}}}\right)$$

dB Sound pressure level
rms Root mean square value
p_{o} Reference pressure.

Decibel is a value on a logarithmic scale and it is based on the capacity of humans to sense sound pressure. Sound perception by humans is subjective in nature. Different exposure times of the same sound pressure may have different effects on hearing [10]. In general, it is recommended that sound pressure levels should not exceed 30 and 40 dB in resting room and kitchen, respectively (ISO 25267:2004/T1:2009). The sound pressure level beyond 90 dB may be harmful for human hearing, especially when the exposure time is high. The sound pressure levels of day-to-day activities are shown in Table 3.

7 Sound Intensity

The sound intensity refers to the transfer of the sound wave energy that is a product of sound pressure and particle velocity

$$I = p \cdot u,$$

where I = sound intensity; p = sound pressure; u = particle velocity.

The sound intensity is associated with the sound power and surface area surrounding the source.

Table 4 Sound absorption class and absorption coefficient

Sound absorption class	Sound absorption coefficient
A	0.90; 0.95; 1.00
B	0.80; 0.85
C	0.60; 0.65; 0.70; 0.75;
D	0.30; 0.35; 0.40; 0.50; 0.55
E	0.15; 0.20; 0.25
F	0.00; 0.05; 0.10

Source ISO 11654:1997

8 Sound Insulation

Sound insulation is soundproofing of an enclosed space. It is apparent that when all the sound waves absorbed by the receiver, the enclosed space is said to be sound insulated. In acoustic science, sound insulation has become important particularly in modern days to prevent noise pollution. Sound insulation material is inserted in the place where sound insulation is required; for instance, in residential and business places. The insulating material such as fibre glass, foam, etc. can be imparted in ceiling, walls and bottom of the floor. The efficacy of the different sound absorbing materials can be evaluated using a grade scale. This is referred as sound classification system.

9 Sound Classification

In sound classification, as mentioned earlier, sound absorption by different sound insulation materials are represented by a common value, say, sound absorption coefficient. Based on the coefficient value, various sound absorption classes are developed. ISO 11654:1997 have standardized those classes as A–F where A is the best sound class with the highest sound absorption coefficient and F is the lowest sound absorption coefficient (Table 4).

10 Conclusion

Sound is a wave similar to other mechanical waves in physics. The science of sound that deals with the propagation of mechanical waves in various mediums such as solid, liquid and gaseous is known as acoustics. Sound originates when a material or an object vibrates. These vibrations propagate in solid, liquid or gas medium in a wave form from emitter to receiver. Thus, a sound wave is the transfer of energy emitted by a source material or an object into the medium as it travels. This chapter has discussed on the fundamentals of sound and its attributes, which will enable understanding of the other chapters of this book.

References

1. Reverberation time (2009). Oxford University Press
2. Speed of sound (2016). Britannica Academic
3. Blauert J (2005) Analysis and synthesis of auditory scenes. In: Communication acoustics. Springer
4. Blauert J, Xiang N (2009) Acoustics for engineers: troy lectures. Springer Science & Business Media
5. Hollar S (2013) Sound. Britannica Educational Publishing, Chicago
6. Möser M (2009) Engineering acoustics: an introduction to noise control. Springer Science & Business Media
7. Raichel DR (2006). The science and applications of acoustics. Springer Science & Business Media
8. Williams JF, Hawkings DL (1969) Sound generation by turbulence and surfaces in arbitrary motion. Philos Trans R Soc Lond A Math Phys Eng Sci 264:321–342
9. Wilson DK (2003) The sound-speed gradient and refraction in the near-ground atmosphere. J Acoust Soc Am 113:750–757
10. Wintzell L (2014) Acoustic textiles-the case of wall panels in home environment
11. Ziaran S (2005) Acoustics and acoustic measurements. Physical Methods, Instruments and Measurements. Vol- II, [Ed. Tsipenyuk YM], in Encyclopedia of Life Support Systems
12. Noise measurement manual (2013) Department of Environment and Heritage, The State of Queensland, Australia

Springer

http://www.springer.com/978-981-10-1474-1

Acoustic Textiles
Padhye, R.; Nayak, R. (Eds.)
2016, VII, 242 p. 69 illus., 39 illus. in color., Hardcover
ISBN: 978-981-10-1474-1