Physics of Ultrasound

First lecture

The Nature of Ultrasound

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2021- 2022

1. *Introduction*

- Ultrasonic imaging is a technique of generating images using a very high frequency sound.
- Sound is a mechanical, vibration form of energy.

How is ultrasound produced for medical imaging purposes?

- Ultrasound for medical imaging is generated in special crystalline materials which, when electrically excited, are capable of vibrating at frequencies of millions of vibrations per second.
- The devices in which ultrasound is produced, and also detected, are called transducers.
- The ultrasonic energy is suitably focused into a narrow beam, which is then directed into the tissues in selected areas of the patient.
- The beam when interacts with the tissues suffering a reduction in its intensity, or attenuation.
- Beam interacts with the tissues through various processes include reflection, refraction ,absorption, and scattering of the beam energy.

What are factors affected on the interaction processes?

- ✓ The parameters of the ultrasound beam, especially the frequency.
- ✓ The physical properties of the medium through which the beam passes such as density, elasticity, and viscosity.

2. *The sound spectrum*

- Sound is a mechanical form of energy. A vibrating source is responsible for the production of sound.

- The number of vibrations per unit time, called the **frequency** of vibrations, determines the quality of the sound produced. Frequency is expressed in units called **hertz**, abbreviated Hz.

1Hz = 1vibration per second

- The sound spectrum can be conveniently divided into three distinct parts:

1. Audible sounds are those which can be perceived by the human ear.

- In most humans, the audible frequency range is approximately 20 Hz - 20,000 Hz.

2. **Infrasound**, Sound which has a frequency below that which can be perceived by the human ear.

3. Ultrasound. Sound of frequencies higher than that of human perception.

- Ultrasound may be defined as sound energy of frequency higher than 20 kilohertz (20 kHz).

3. Propagation of ultrasound

2.1 Transfer of energy

- The propagation of ultrasonic energy requires a material medium it cannot take place in empty space.
- A source of ultrasound in contact with a medium transfers the mechanical disturbance to the medium, initiating vibrations in the "particles" of the medium.
- Through these tiny vibration movements, neighboring particles are similarly affected, setting them in motion by direct transfer of energy from one particle to another

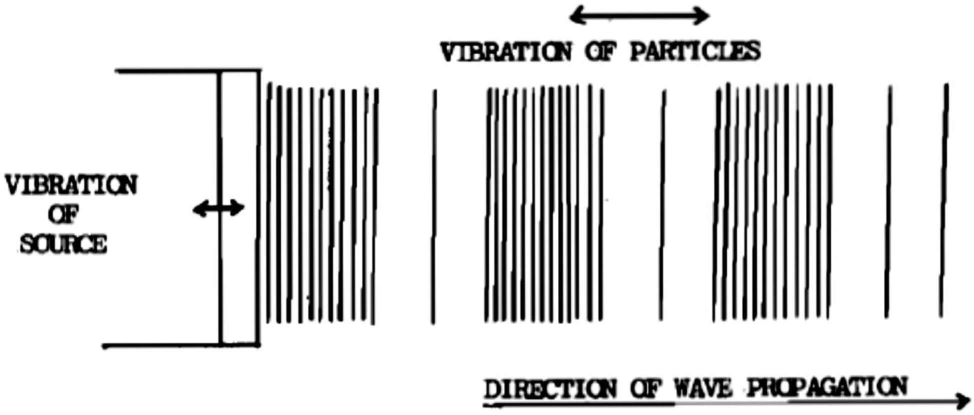
2.2 Pressure waves

- The mechanical movements of a source of ultrasound may be compared to the action of a piston moving rapidly in confined space.
- In the forward direction, the piston compresses the medium particles in front of it, increasing their concentration per unit volume, hence creating increased pressure. This is referred to as the compression phase, sometimes also called the condensation phase.
- When the piston moves in the reverse direction, the medium particles are decompressed, giving rise to a low pressure phase, known as rarefaction.
- The periodic movement of the piston therefore creates pressure waves in front of it, alternating between high and low pressure.
- The mechanical vibrations of a source of ultrasound create alternating phases of compression and rarefaction in the particles of the propagating medium with which it is in contact.
- These pressure variations are propagated through the transmitting medium.

Pressure variations in the propagation of ultrasound

2.3 Longitudinal propagation

- ❖ The direction of displacement of medium particles is usually the same as the direction of oscillation of the source of ultrasound.
- ❖ The ultrasound wave is propagated in the same direction as that of the disturbance causing it.
- ❖ Such waves are called longitudinal waves

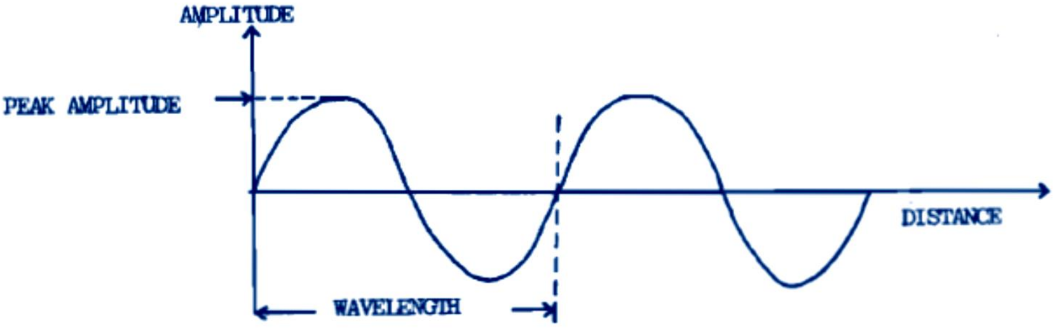


Longitudinal propagation of ultrasound

- ❖ When propagation of a wave takes place in a direction that is perpendicular to that of the disturbance causing it, then the wave is referred to as a transverse wave.
- ❖ Although ultrasound is usually propagated as longitudinal waves, it should be noted that in bones it may be propagated as transverse waves.

4. Simple wave parameters

- The periodic movements of medium particles about their mean positions, and the corresponding regular fluctuations in pressure, can be conveniently represented as a sinusoidal curve.



Variation of particle displacement in the direction of wave travel represented as a sinusoidal curve.

- The sine waveform is characterized by the wave parameters of **amplitude** and **wavelength.**
- The amplitude at a given moment is the magnitude of particle displacement from its mean position at that particular time
- The peak amplitude represents the maximum particle displacement.
- The peak amplitude corresponds to:
  - ✓ The maximum change in pressure
  - ✓ The vigor of vibrations
  - ✓ the intensity of the ultrasound beam.
- The wavelength is the distance between two consecutive corresponding positions on the sine wave.
- It represents the distance travelled by the pressure wave during one complete wave cycle.
- Each complete wave cycle is attributed to one vibration of the source.
- The number of vibrations per unit time is called the frequency of vibrations.
- The frequency also represents the number of times the wave is repeated per unit time.

- The velocity of the wave is the total distance travelled by the wave in unit time. Which is to the product of wavelength and frequency

Wavelength x frequency = wave velocity

- Ultrasound for medical imaging employs frequencies in the megahertz (MHz) range.

1 MHz = 1 million vibrations per second.

- The period of the wave would be shown as the time for one complete wave cycle.
- The wave period is equal to the reciprocal of the frequency.

5. Velocity of ultrasound

- The rate at which the ultrasound wave is propagated through a medium is called the wave velocity.
- This velocity varies from one medium to another, depending on the elastic properties of the material
- Two physical properties of the medium are crucial in this respect. These are the density and the compressibility of the medium.

- Wave velocity should be lower in materials of high density, why?

- Compressibility, stiffness or rigidity refers to the ease with which a medium can be mechanically deformed and reformed.

- What is a relationship between compressibility and density?

- Why in materials of low compressibility need a higher wave velocity?

Two other factors which affect the velocity of ultrasound:

- The variation of the velocity with beam frequency is called dispersion.
- The velocity also changes with medium temperature; the effect of temperature on velocity is negligible in clinical ultrasound.

- Velocity of ultrasound in air, bone, and soft tissue.

Material	**Velocity (m/s)**
Air (NTP)	330
Bone	3,500 - 4,800
Soft tissue	1,540 (average)

Q: in above table why the velocity of ultrasound in bone is high?