MODULE :03

ACOUSTICS

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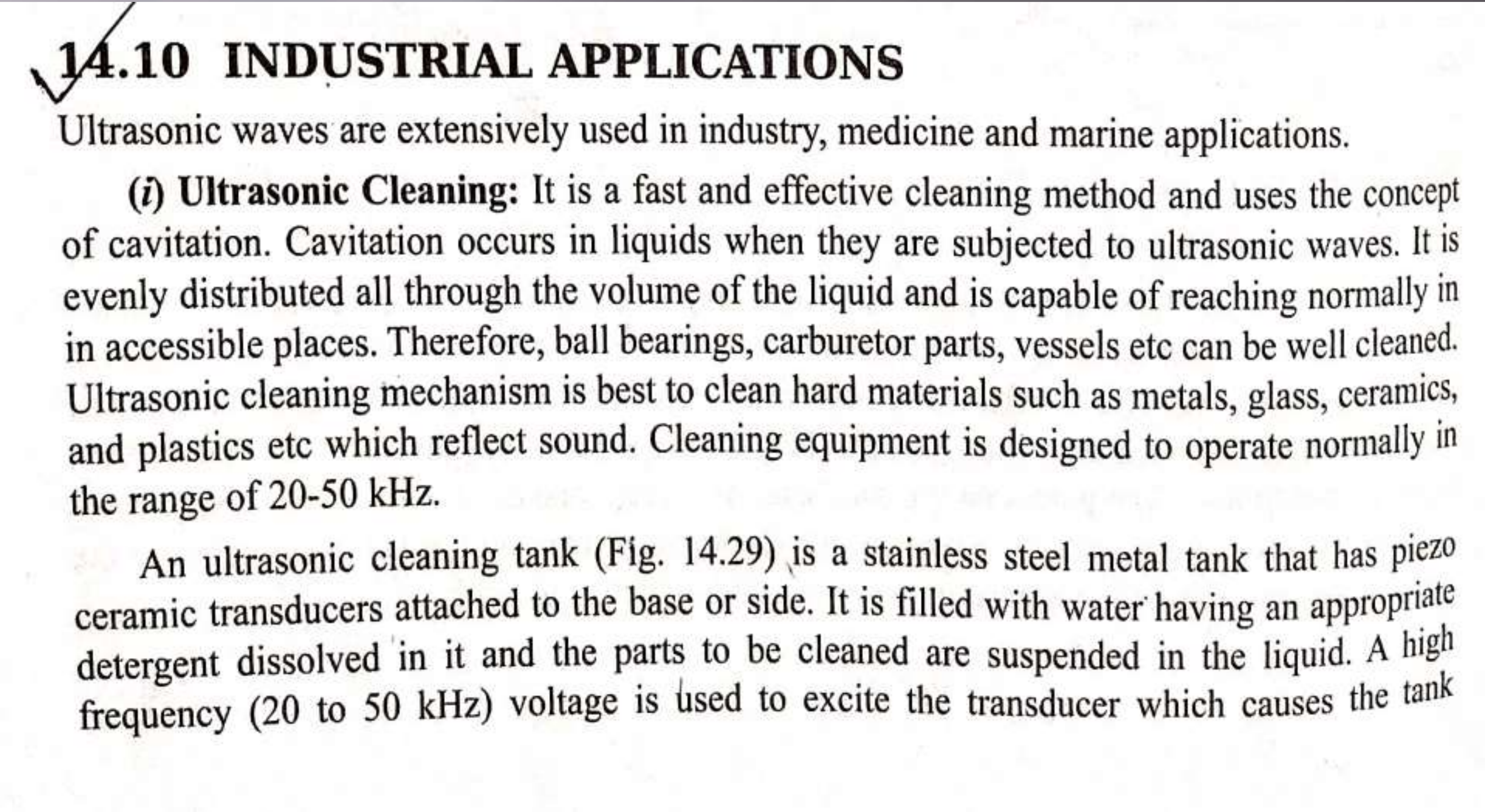
Outlines:

- Applications of Ultrasonic's waves
- Industrial applications
- Marine applications
- Medical applications

Applications of Ultrasonic's waves



14.10 INDUSTRIAL APPLICATIONS

Ultrasonic waves are extensively used in industry, medicine and marine applications.

(*i*) Ultrasonic Cleaning: It is a fast and effective cleaning method and uses the concept of cavitation. Cavitation occurs in liquids when they are subjected to ultrasonic waves. It is evenly distributed all through the volume of the liquid and is capable of reaching normally in in accessible places. Therefore, ball bearings, carburetor parts, vessels etc can be well cleaned. Ultrasonic cleaning mechanism is best to clean hard materials such as metals, glass, ceramics, and plastics etc which reflect sound. Cleaning equipment is designed to operate normally in the range of 20-50 kHz.

An ultrasonic cleaning tank (Fig. 14.29) is a stainless steel metal tank that has piezo ceramic transducers attached to the base or side. It is filled with water having an appropriate detergent dissolved in it and the parts to be cleaned are suspended in the liquid. A high frequency (20 to 50 kHz) voltage is used to excite the transducer which causes the tank bottom to move rapidly and induces compression and rarefaction waves at that ultrasonic frequency in the liquid. When cavitation happens in water near a dirty object, creates a tiny pressure wave that reaches deep into suspended items in the liquid. This tiny pressure wave dislodges and breaks up the dirt and other contaminants and gently lifts it away.

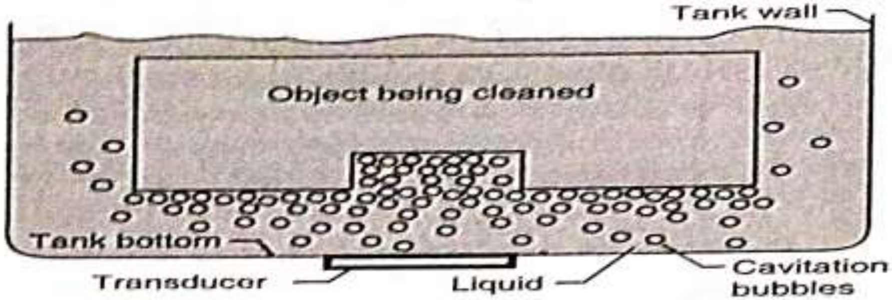


Fig. 14.29:
Ultrasonic cleaning tank.

(*ii*) Ultrasonic Metal Welding: Practically, all metals and plastics can be welded using ultrasonic waves of suitable energy. The surfaces of the work pieces are cleaned and held together. They are subjected to ultrasonic oscillations at the spot where they are to be welded. The ultrasonic energy converts to heat at the contact area as a result of friction arising between the surfaces. As the temperature of surface layers exceed the recrystallization point, the layers melt and bond together to form a strong joint. The merits of this process are that it does not cause stress at the spot of welding and that the structure of the materials remain unchanged.

Ultrasonic welding (Fig. 14.30) makes use of vibration energy at the interface of the joint to create bonding. The ultrasonic energy is delivered to the interface by a *horn* that is in contact with the top part. The horn vibrates at high frequencies. The bottom of the part is held on an "anvil." The joint forms by diffusion and there is no melting at the joint. The equipment required for ultrasonic metal welding ranges from low power microbonders (40 and 60 kHz) to machines of several kilowatt output capacity (10 and 20 kHz) for welding of larger parts.

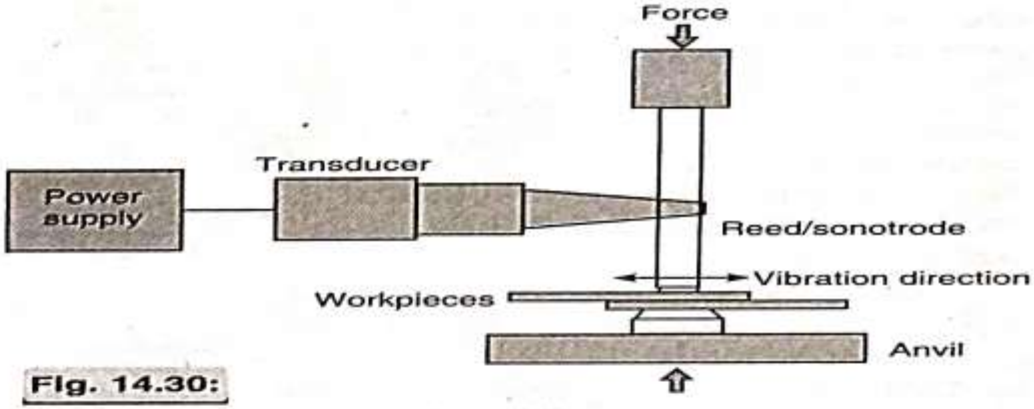


Fig. 14.30:
Schematic of ultrasonic welding setup.

Drawbacks of micro-welding:

(*a*) Mechanical contact is required on either side of the joint.
(*b*) As the horn is a consumable, inspection and replacement of it is required.
(*c*) Joint geometry is limited to lap welding only.
(*d*) The speed of the welding cycle is slow.

Applications of ultrasonic metal welding:

(*a*) As the process is relatively cold and typically below the melting temperatures of the metals it is useful for high resistance inter-metallic compounds in dissimilar metal welds.

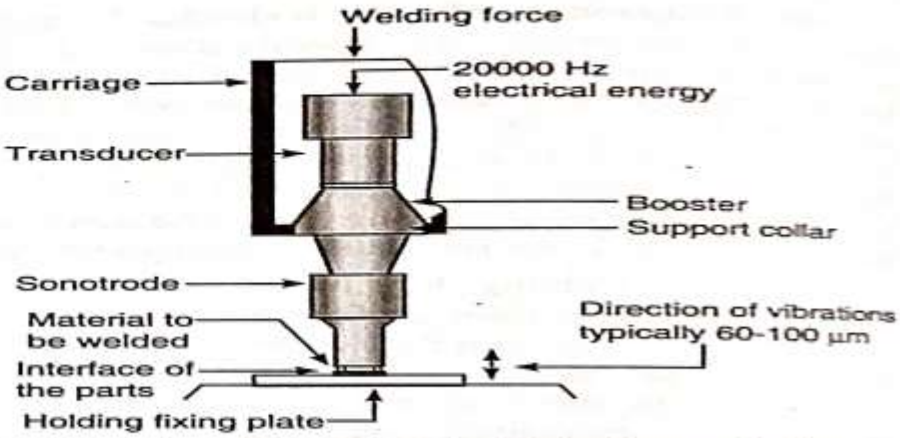
(*b*) Useful for resistance welding including the melding of high conductivity metals such as electric grade aluminum and copper also combinations of metals of different resistivities like copper and steel.

(*c*) It is useful where heat-dependent methods cannot be used such as welding of parts widely differing in heat capacity such as foil to thick sections.

(*d*) The method is essentially suitable for producing spot welds and line welds as now days copper is being replaced by aluminum.

(*e*) Besides micro-bonding it is useful in electric and electronic industries in assembly of electric motors, transformers, switches, and relays.

(*iii*) Ultrasonic Plastic Welding: This method is very useful in the automotive industry for assembly of taillights, dashboards, heater ducts, and other components. In this process welding is carried by the heat produced from high-frequency mechanical motion. High-frequency electrical energy is converted into high-frequency mechanical motion in thermoplastics (Fig. 14.31). When the temperature at the joint interface reaches the melting point, the plastic melts. The parts are allowed to fuse as the melted plastic cools and solidifies. Ultrasonic plastic welding needs higher power densities, typically hundreds of watts per square inch at the weld and operate around 20 kHz.



An ultrasonic welding system for joining thermoplastics

Fig. 14.31: Ultrasonic Plastic Welding.

Advantages:

(*a*) It is a fast, clean, efficient, and repeatable process that consumes very little energy.

(*b*) Solvents, adhesives and mechanical fasteners are not required.

(*c*) The finished assemblies are strong and clean.

(*d*) Process does not require a skilled operator.

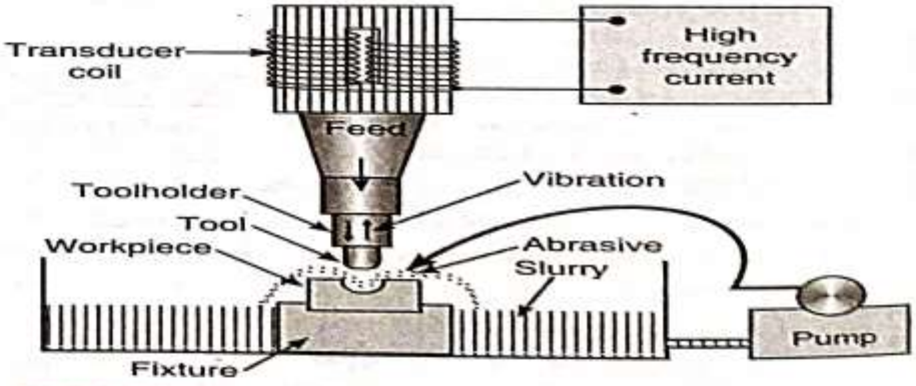


Fig. 14.32: Schematic of a typical ultrasonic drilling machine.

(*iv*) Ultrasonic Drilling: Ultrasonic machining is a vibratory process useful for the mechanical treatment of hard and brittle solids such as ceramics, glasses, precious stones, semiconductors and hard alloys. The tool motion is produced by an acoustic concentrator to which the tool holder is threaded. The acoustic concentrator consists of a needle type magnetostriction vibrator, illustrated in Fig. 14.32. The vibrator is made of thin isolated ferromagnetic plates of high magnetostriction such as nickel. A coil is wound on the needle, through which an alternating current of frequency *f* passes. The resulting magnetic field magnetizes the core and thus changes its length. The core of the vibrator vibrates at a frequency 2*f*. By choosing the frequency to be equal to half the natural vibration frequency of the vibrator, the system is held at resonance and the vibrations of the needle will be of large amplitudes. A tapered waveguide of appropriate dimensions and rigidly attached to the vibrator concentrates the vibrational energy and communicates it to the tool.

In operation, the needle vibrator is in oscillation and the tool shank is pressed against the work piece. An aqueous suspension of a solid abrasive powder is then fed through a tube to the working zone. Abrasive particles bombard the work surface at high velocity and shear off small pieces of the material. This action rapidly chips away the work piece in a pattern controlled by the tool shape and contour.

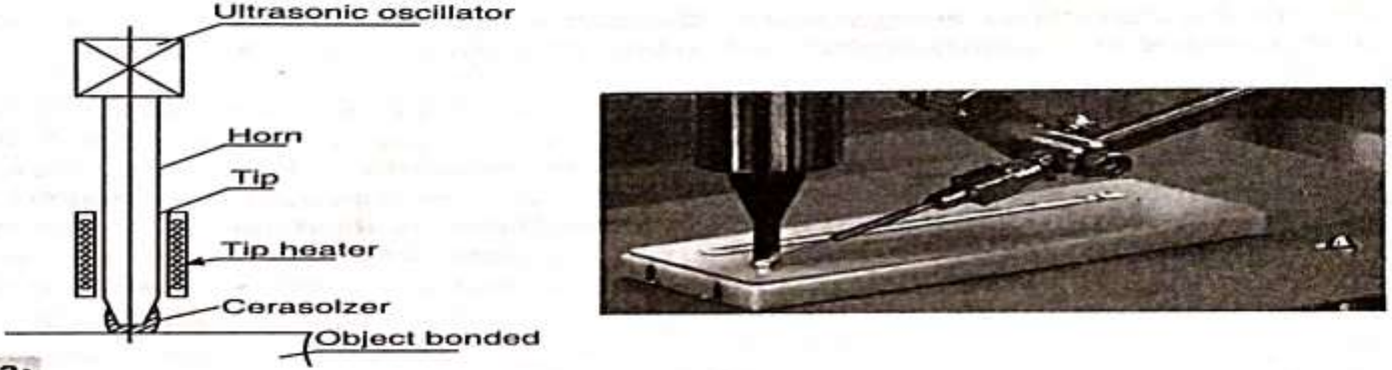


Fig. 14.33:

Ultrasonic Soldering.

(*v*) Ultrasonic Soldering: Normally, surfaces are covered with contaminants, grease and oxide films. Such films prevent formation of a good joint. Therefore, prior to soldering, the surfaces are cleaned with active fluxes. The fluxes, when heated, dissolve the oxide films and uncover the clean metal surface which readily allows the molten solder to form a firm joint. This method however is not suitable for soldering aluminium. Active metals such as aluminium can be soldered without fluxes with the help of ultrasonic waves. In this case soldering is done by a special iron that vibrates at a frequency of tens of kilo hertz.

Ultrasonic soldering is a flux free soldering method. Here surface oxide layers are cleaned by using vibrations and cavitations. During the **process**, the solder is first heated by a separate source till it melts and then vibrational energy is applied to it. The ultrasonic vibrations induce cavitation at the tip of the soldering tool which cleans the metal surfaces and subsequently the liquid solder bonds them.

Advantages:

(*a*) Solder joint is free of voids because vibrational energy pushes the liquid solder into the crevices and micro-pores in the substrate.

(*b*) Ultrasonic soldering allows for fusing dissimilar materials which is not possible with usual methods.

(c) As no flux is required, it saves time and costs of cleaning flux residues. Here corrosion is less and the durability of soldered joints is more.

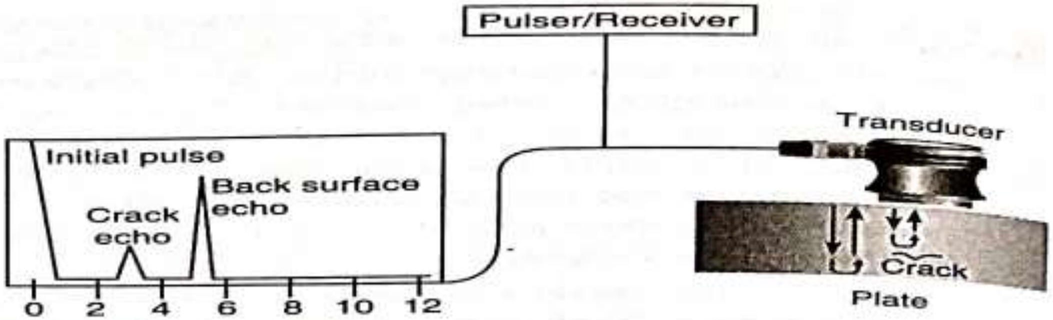


Fig. 14.34:
Block diagram of an ultrasonic testing system.

(vi) Ultrasonic Testing: This method is useful for the detecting the internal and surface defects in sound conducting materials. The wave velocity is related to the Young's Modulus of the material and is characteristic of that material. For contact testing, a probe with the oscillating crystal is used. The probe is applied to the surface of the test piece. To enable the transfer of energy across the thin air gap between the crystal and the test piece, a layer of liquid (couplant) usually oil, water or grease, is applied to the surface of the test piece.

The crystal does not oscillate continuously but in short pulses. Short pulses of ultrasound (1 MHz to 6 MHz) have less attenuation in homogeneous elastic material, such as metals. Piezo electric crystals translate electrical pulses into mechanical oscillations, and also, convert mechanical oscillations into electrical pulses. Thus, it acts as a generator of sound waves as well as a detector of reflected pulses. The crystal oscillates in short pulses, between each of which it is inactive. In the inactive state the crystal detects reflected pulses. A pulse takes a short time to travel through the material to the interface and to be reflected back to the probe. The block diagram of an ultrasonic system is shown in Fig. 14.35. It basically comprises transducer, pulser (clock), receiver/amplifier and display (screen).

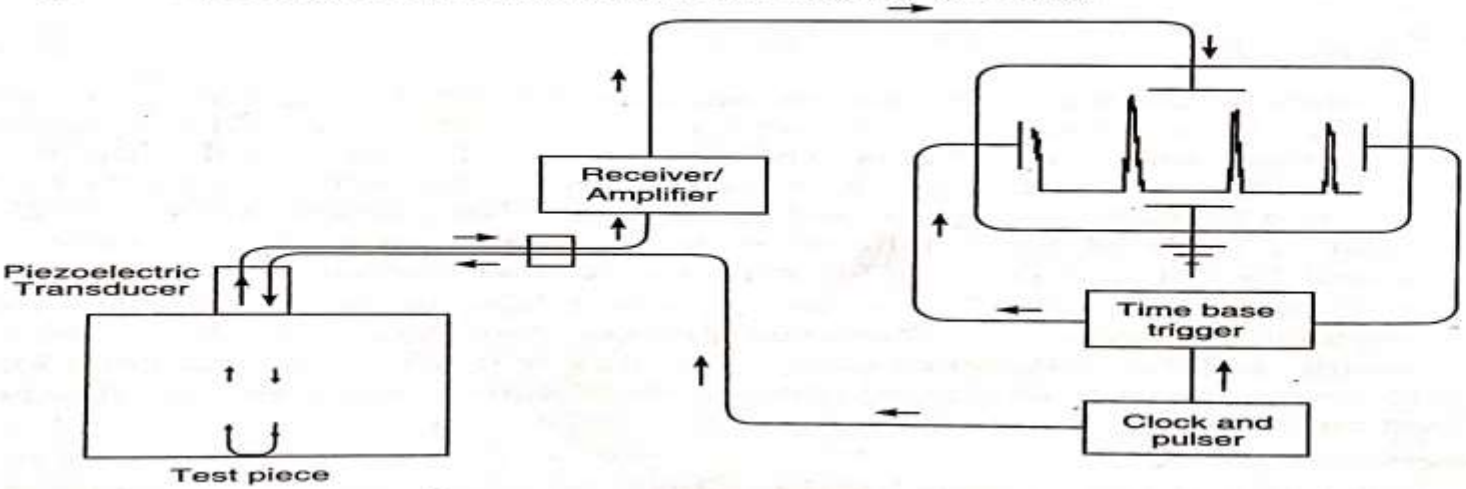


Fig. 14.35:
Block diagram of an ultrasonic tester.

The sequence of operation of the system is as follows:

(*a*) The pulser provides the short, high-voltage pulse to the transducer and at the same time it supplies voltage to the time-base trigger module. It gives the "spot" on the CRT screen.

(*b*) The voltage pulse given to transducer is converted into mechanical vibrations and these vibrations pass through the test piece. All this time, the spot is moving horizontally across the CRT.

(*c*) The energy (vibration) in the test piece now reflects off the back wall towards the transducer, where it is reconverted into a voltage. This voltage is amplified by the amplifier.

(*d*) By using the delay (or zero) control, the spot on CRT is set to start at the instant that the energy goes into the test piece.

(*e*) The spot moves horizontally across the screen. The energy gets reflected at the back wall interface and returns to be received and amplified. The amplifier sends voltage to the Y- plates. The spot moves to a later position on the time base. The spot continues its journey across the screen, and the above sequence repeats repeatedly until the energy in the test piece attenuates. The display will show multiple repeat signals.

(*f*) The clock now sends a pulse second time and the next pulse is produced. It is again repeated *n* number of times per second. The *n* number of pulses per second is referred to as the pulse repetition frequency (PRF) or the pulse repetition rate (PRR).

(*vii*) **Emulsification:** Immiscible liquids like water and oil can mix thoroughly and form stable emulsions when their mixture is subjected to strong ultrasonic waves. The ultrasonic emulsification is used in industry to mix molten metal and form alloys of uniform composition.

14.10.1 Data Presentation

Usually data can be collected and displayed in formats such as A-scan, B-scan and C-scan.

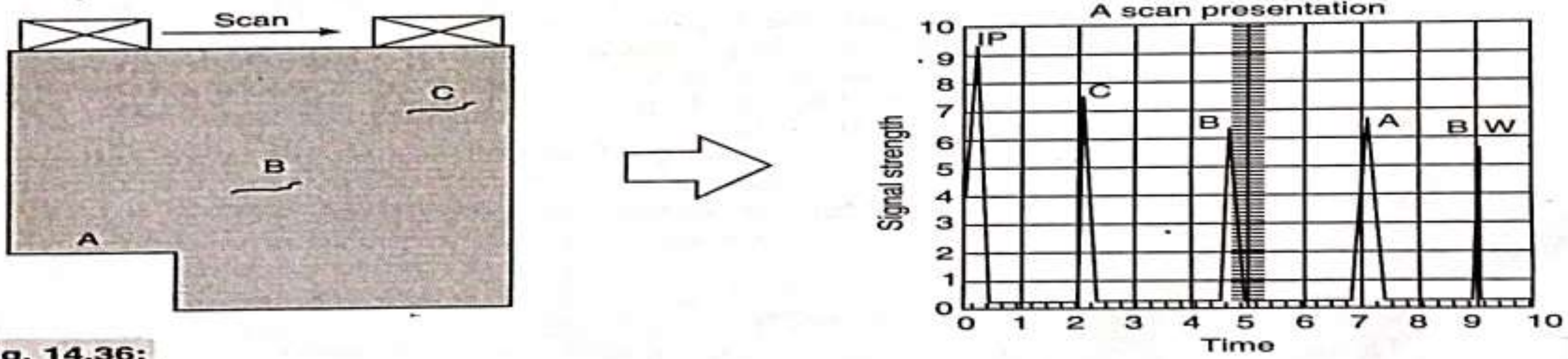


Fig. 14.36:

A-Scan presentation.

(*i*) **A-scan display:** A-scan display is the most used mode of display in ultrasonic testing. In this mode of display, the relative amount of energy received is plotted along the vertical axis and the time taken by the pulse to the reflecting surface and return back to the transducer is displayed along the horizontal axis. The location of the defect is estimated by the position of the echo given by it on the horizontal axis and size of the defect from the relative amplitude of the echo. The information that is available in A-scan is one-dimensional. A typical A-scan echo pattern is shown in Fig. 14.36.

(*ii*) **B-Scan Display:** B-scan display gives a cross-sectional view of the test object and shows the position, orientation and depth of defects in the specimen. In this mode of display, Y-axis represents elapsed time while X-axis represents the position of the transducer along a line on the surface of the test object relative to the starting position of the transducer. Thus, the probe movement is displayed in x-direction while the distance of the defect is displayed in y-direction. Echo amplitude is indicated by the relative brightness of echo indications. If a storage oscilloscope is used, the whole picture will be displayed, which reveals the depth of the defect beneath the surface and its size in the lateral direction (see Fig. 14.37).

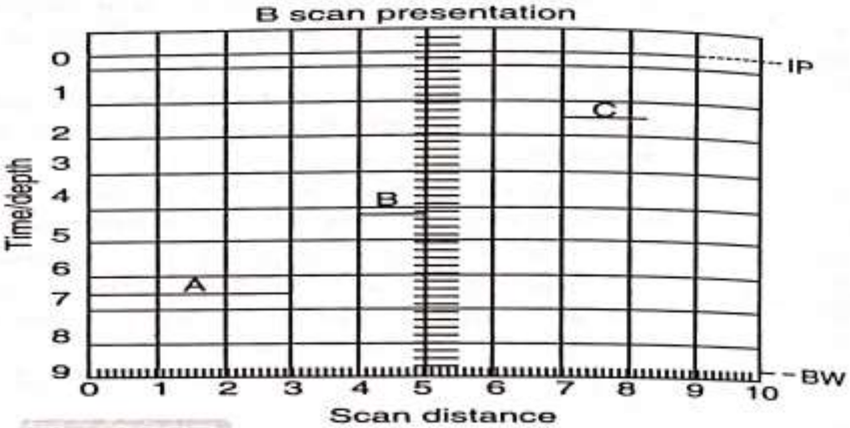


Fig. 14.37: B-scan display.

(*iii*) **C-Scan Display:** The depth of defects is not relevant in some testing problems, but information about their distribution parallel to the test surface is required. In the C-scan mode, the transducer is moved over the surface of the test piece and the echo intensity is recorded as a variation in line shading. The image shows the plan of the object as viewed from the top and is a true-to-scale reproduction of the defect in the object (Fig. 14.38). C-scan displays are produced using a computer controlled immersion scanning system.

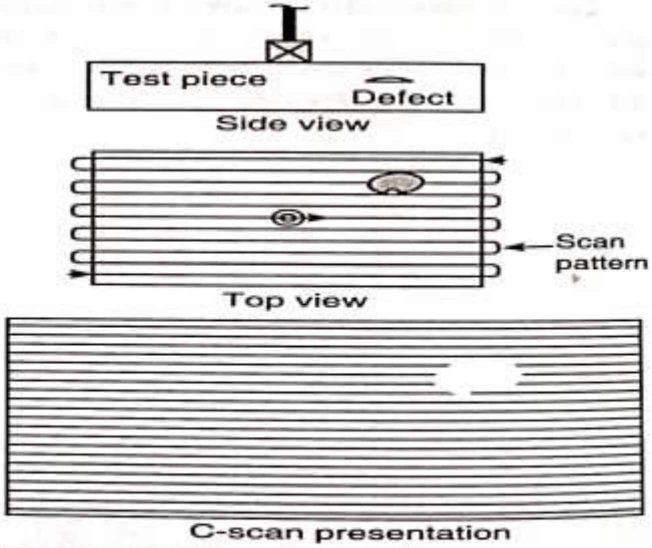


Fig. 14.38: C-Scan display.

14.11 MARINE APPLICATIONS

(*i*) **Echo Sounder:** Ultrasonic waves can be produced in the form of directed beams like beams of light. Further, ultrasonic waves can travel long distances in water. This property is utilized in measuring the depth of ocean. A ship equipped with an echo sounder sends out short pulses of ultrasonic waves towards the bed of the ocean (Fig. 14.39). These waves are reflected back from the bed and the receiver receives the reflected pulse. The time interval between the pulse sent and the pulse received is determined. Knowing the velocity of the waves through the seawater, the depth of the ocean, can be computed with the help of the following formula.

$$l = \frac{vt}{2} \qquad \text{...(14.26)}$$

where t is the time interval between the transmitted and reflected pulses.

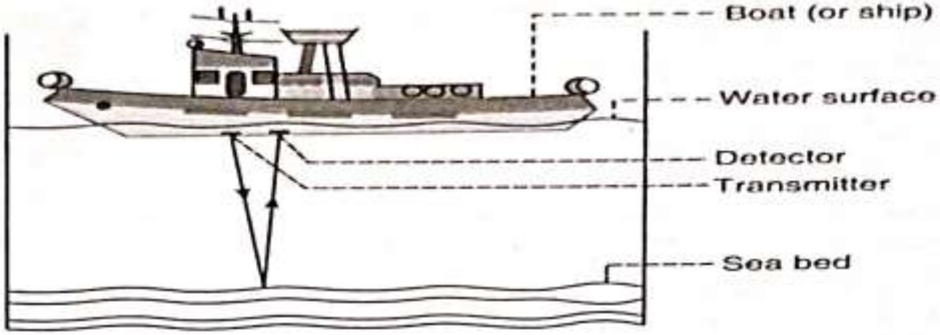


Fig. 14.39:

Depth sounding.

(*ii*) **SONAR:** The word SONAR stands for Sound Navigation and Ranging. The ultrasonic waves, which are highly directional, can be used for locating objects submerged under seawater and determining their distance. The idea of ultrasonic sonar was put forward first by the French physicist Paul Langevin and was successfully used by him during the first world war for detecting enemy submarines. The sonar acts in a way much similar to an echo sounder. In sonar, an ultrasonic beam is directed in different directions into the sea. In the absence of an obstacle, the ultrasonic pulses do not return to the ship. In the presence of an obstacle, pulses are reflected from the obstacle and are picked up by the receiver. Knowing the speed of the ultrasonic waves in seawater and time elapsed between the transmitted and reflected pulses, the distance of the object is determined. Fig. 14.40 illustrates a SONAR.

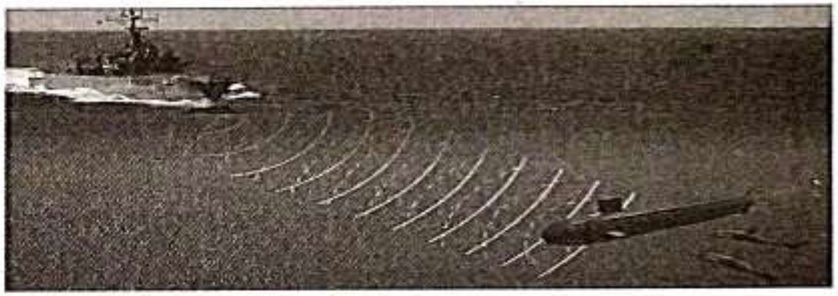


Fig. 14.40:

SONAR.

(*a*) Sonar is used to guide submarines in the seas.

(*b*) It is used to detect the presence of submerged icebergs.

(*c*) It is used for direction signaling in submarines.

(*iii*) **Fish-finder:** Ultra sound can be used to locate shoals of fish utilizing the fact that the swimming bladder of fish is filled with air that scatters ultrasonic waves. Ultrasonic sonar is used for this purpose. At present ultrasonic locators are mainly used for detecting icebergs, fish shoals and etc. Fig. 14.41 shows an illustration of Fish-finder.

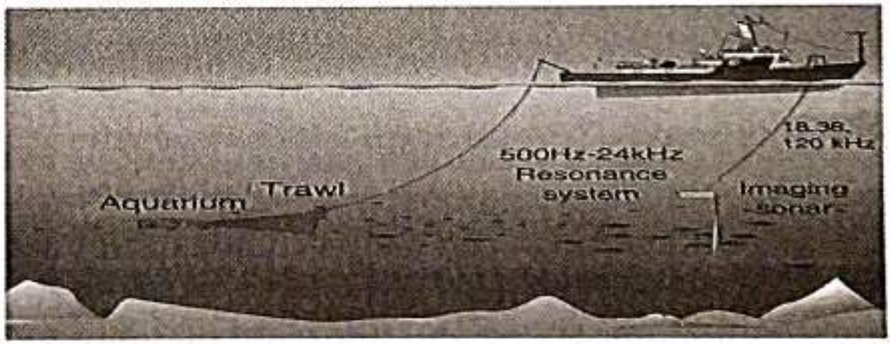


Fig. 14.41:

Illustration of Fish-finder.

Some of the sea animals such as whales and dolphins use ultrasound to locate their prey avoid collision with obstacles and even to converse with each other (Fig. 14.42). In the depths of the sea, visibility is highly restricted because of the strong absorption of light by water. It may be therefore that these animals use ultrasound that is relatively less absorbed.

Fig. 14.42:

Dolphins use ultrasound to locate their prey.

Example 14.5: *Find the depth of sea and wavelength of pulse, if ultrasonic source of 0.07 MHz launches downward a pulse which returns after 0.65 s from the seabed and the velocity of sound in seawater is 1700 m/s.*

Solution: Depth of the sea, $l = \frac{\upsilon t}{2} = \frac{(1700\text{m/s})(0.65\text{s})}{2} = \mathbf{552.5\ m.}$

Wavelength of the pulse $\lambda = \frac{\upsilon}{f} = \frac{1700\text{m/s}}{0.07\times10^{6}\text{s}^{-1}} = \mathbf{24\ mm.}$

14.12 MEDICAL APPLICATIONS

Ultrasound scanning or Sonography, ultrasound scanner, Doppler ultrasound imaging and Ultrasonic blood flow meter are a few medical applications to mention.

14.12.1 Sonogram

Ultrasound imaging is called ultrasound scanning or Sonography and is widely used in imaging of internal organs of the human body. A sonogram is a non invasive medical procedure that helps doctors diagnose and treat medical conditions. It provides valuable information regarding the size, location, and displacement of a given structure. It can show the movement of internal organs in real time. Tumors and other regions of organ that differ in density from surrounding tissues can be detected. Interfaces between solid and fluid filled spaces can be precisely observed with the help of Ultrasound technology. Therefore, doctors use ultrasound tests to examine the fetus structure and any movement of the fetus inside a woman.

Def: Sonogram is an image formed by ultrasound waves that are bounced back from tissues of differing density in the human body. The time taken by the reflected ultrasound waves to return to the machine is translated into an image of the internal organ, or of the fetus.

Principle: Sonography uses a probe containing one or more acoustic transducers to send pulses of sound into a body. Whenever a sound pulse encounters a boundary between two tissue structures, it is partly reflected from, and partially transmitted. The sound pulse reflected back to the probe is detected as an echo (Fig. 14.43). The reflection depends on the difference in acoustic impedance of the two tissues.

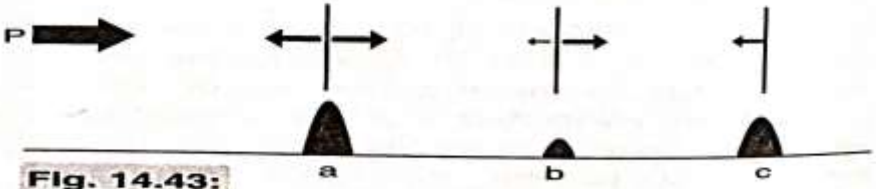


Fig. 14.43:

Sonography

The acoustic impedance of a medium

$$Z = \upsilon \times \rho \qquad ...(14.27)$$

where υ is the of speed of sound in the material and the ρ is density.

The time taken by the echo to travel back to the probe is used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is.

The time lagis

$$\tau = \frac{2l}{\upsilon} \qquad ...(14.28)$$

where l is the distance between tissue transducer and υ is the ultrasonic velocity.

14.12.2 Ultrasound Scanner

Fig. 14.44 shows a block diagram of a simple ultrasound scanner. The **transmitter** supplies energy to the piezoelectric **transducer** which produces sharp pulses of ultrasound. The sound pulses travel through the body and get reflected from the organ or structure under investigation. The pulses with reduced strength are returned to the transducer probe which acts as a receiver as well. The returned echoes are amplified with the help of **swept-gain generator** and applied to the vertical deflection plates of CRO. Each time an echo reaches the probe, a vertical line appears on CRO screen. Corresponding to each reflecting surface in the body, one vertical line is produced on CRO screen. The **time base generator** supplies voltage to the horizontal deflection plates of CRO. The **rate generator** synchronizes the actions of the transmitter, time base generator and the swept-gain generator. The **CRO** displays the original pulse transmitted by the transducer into the body and the echoes received from different interfaces, as vertical lines on its screen. The CRO may be calibrated to give directly distances between the reflecting surfaces in the body. The display obtained using the above technique is known as a A-scan display and it is seen on CRO screen in Fig. 14.44. Generally, the frequencies in the range of 1 to 18 MHz. are used for medical imaging. But as the attenuation increases at higher frequencies, a lower frequency (3-5 MHz) is used.

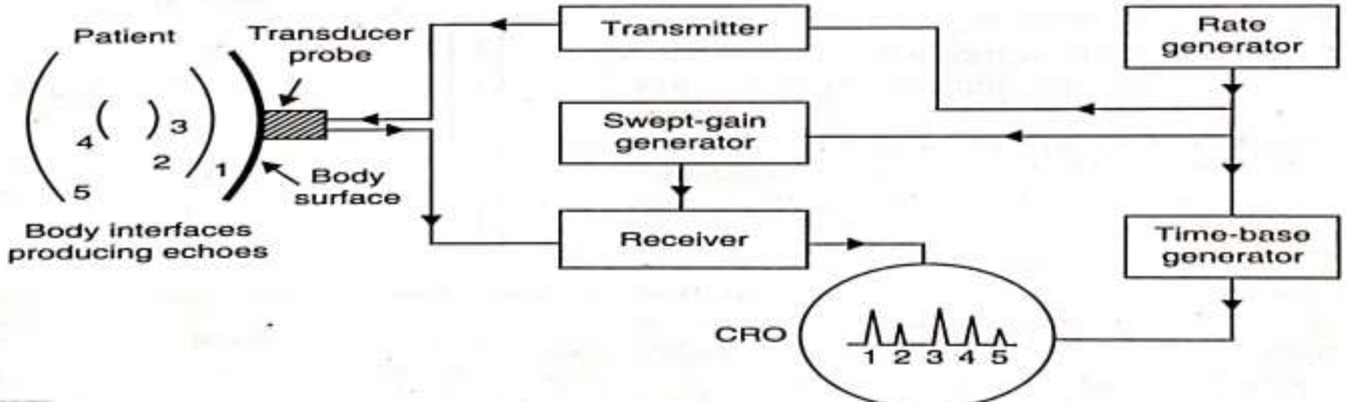


Fig. 14.44:

Block diagram of a ultrasound scanner.

Display modes: The echoes are displayed as a function of time which is proportional to the distance from the source to interface. The echo information is displayed in one of several different display modes.

(*a*) **A-mode (Amplitude mode):** A-mode is the simplest type of scan mode. It is a graphic depiction of amplitude of echo versus distance into the tissue. A high energy pulse from a pulser excites the transducer. Echoes returned from the tissue are detected by the same transducer, amplified and processed for display. The returning echoes are displayed as vertical deflections on the trace (see Fig. 14.45) which represent the amplitude of the reflected energy. In most cases, the transducer is kept stationary. Hence, the echoes are static and one dimensional. Pulses are typically a few milliseconds long and are emitted at 400 to 1000 pulses/ns. It is used in ophthalmology and encephalography.

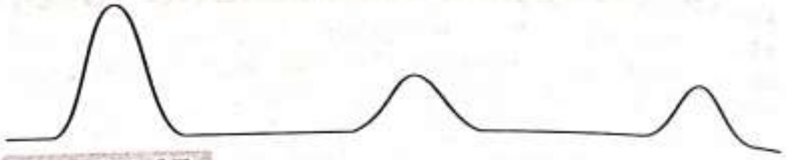


Fig. 14.45:

Typical A-scan.

(*b*) **B-mode (Brightness mode):** The amplitude can also be displayed as the brightness of the certain point representing the structure, in a B- plot. In this scan, the echo signals are not applied to the horizontal deflecting plates of CRO. Instead they are used to control the brightness of the spot on the screen. Hence the reflecting surfaces appear as spots (Fig. 14.46). The brightness of the spot is proportional to the strength of returning echo. A linear array of transducers may be made to simultaneously scan a plane through the body so that we can obtain a two-dimensional image of a stationary organ or body structure on screen. It is used in diagnostic studies of liver, breast, heart, fetus etc.

Fig. 14.46:

Typical B-scan.

(*c*) **M-mode (Motion mode):** If some of the structures are moving, the motion curve can be traced by letting the B-mode image sweep across a screen. This is called the M (Motion) –mode. It enables measure range of motion, as the organ boundaries that produce reflections move relative to the probe. In this, the probe is fixed in position so that the movement of the dots along the sweep represents movement of targets. In this scan also, the echo pulses brighten the trace as is the case in B-scan. A stationary target will trace a straight line where as a moving target will trace the pattern of its movement with respect to time (see Fig. 14.47). A typical sonogram is shown in Fig. 14.48.

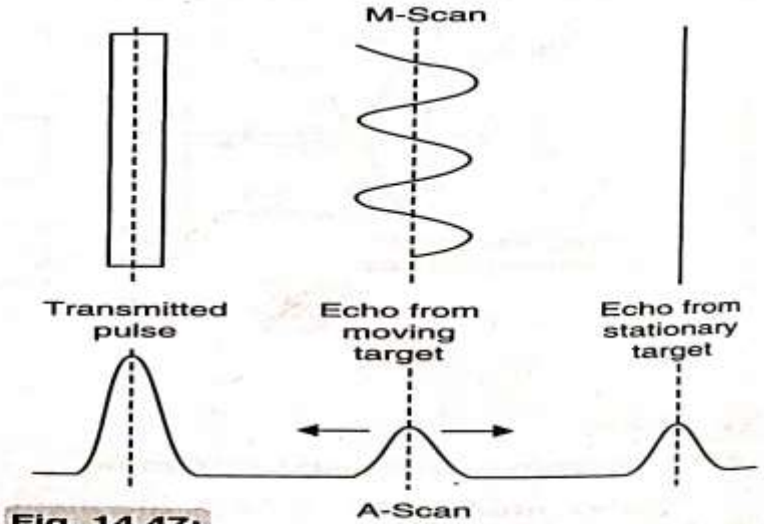


Fig. 14.47:

Typical M-scan.

14.12.3 Doppler Ultrasound Imaging

The concept of Doppler Effect is used in Doppler ultrasound imaging. When a moving object reflects the ultrasound waves, the frequency of the echoes gets changed. If it is moving toward the probe a higher frequency is generated and if it is moving away from the probe a lower frequency is produced. The change in frequency depends on speed of the object. Doppler mode enables to measure the change in frequency of the echoes to calculate how fast an object is moving. Doppler ultrasound imaging is useful to measure the rate of blood flow through the heart and major arteries.

Fig. 14.48:

A primary use of ultrasound is to monitor the progress of a pregnancy. The above sonogram shows the 27 weeks stage.

Advantages of Doppler ultrasound imaging

(*i*) It is noninvasive and uses no ionizing radiation.

(*ii*) As it causes no health problems, it can be repeatedly used.

(*iii*) It is painless, easy-to-use and less expensive.

(*iv*) It gives a better picture of soft tissues than x-ray images.

(*v*) It can be safely used for the diagnosis and monitoring of pregnant women and their unborn babies.

Limitations

(*i*) Ultrasound is not best imaging technique for the bowel (intestine) or organs covered by the bowel since ultrasound waves are disrupted by air or gas. Deeper structures such as the pancreas and aorta cannot be properly visualized because of the intestinal gas.

(*ii*) Ultrasound cannot show the internal structure of bones as it cannot penetrate the bone.

14.12.4 Ultrasonic Blood Flow Meter

The ultrasonic blood flow meter uses the concept of Doppler shift to measure the velocity of blood in veins and arteries. The speed of blood flow is measured by transmitting and receiving elements that are placed directly on the skin, as in Fig. 14.49. The transmitter emits a continuous sound of about 5 MHz. The frequency of ultrasound changes when it is reflected from the red blood cells. The electronic counter of the receiving element measures its frequency and from

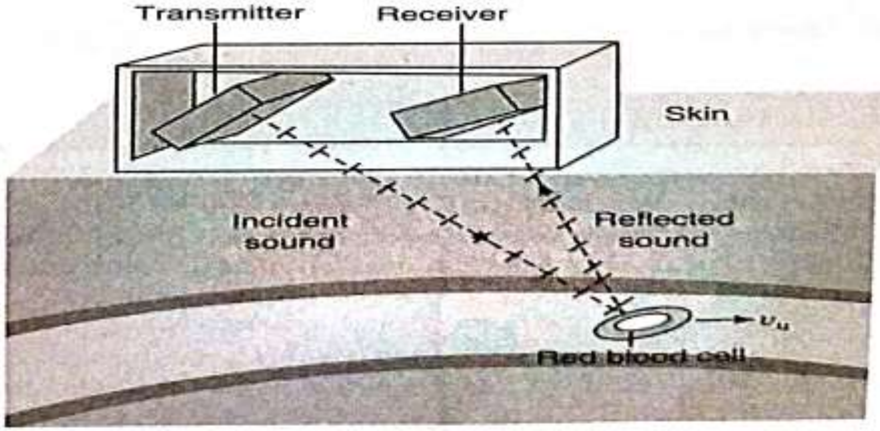


Fig. 14.49:

Doppler flow meter.

which the speed of the blood flow can be known. Usually, the frequency varies of about 600 Hz for flow speeds of about 0.1 m/s.

The Doppler flow meter can be used to find regions where blood vessels have narrowed. According to the equation of continuity, greater flow speeds takes place in the narrowed regions.

Ultrasound of frequency of about 5 to 10 MHz is directed at an angle to the blood stream. The particles of blood reflect the beam. The sound waves undergo a frequency.

The Doppler shift

$$\Delta f = \frac{2 f\, \upsilon \cos\theta}{\upsilon_u}$$

where υ_u is the velocity of ultrasonic waves in blood,

υ is the velocity of the blood with respect to the blood vessel,

θ is the angle at which ultrasonic waves strike the blood stream and

f is the initial frequency.

$$\therefore \qquad \upsilon = \frac{\Delta f\, \upsilon_u}{2 f \cos\theta} \qquad ...(14.29)$$

14.12.4 Other Medical Applications

(*i*) Ultrasonic therapy is used in treatment of rheumatic pains. Ultrasonic wave produce massaging action and relieves pain.

(*ii*) The waves are useful for dental cutting and they make the cutting painless.

(*iii*) Ultrasonic waves destroy bacteria and therefore they are used in sterilization of water and milk.

Example 14.6: *In an ultrasonic Doppler flow meter the direction of blood flow is along the direction of ultrasonic beam. The frequency of ultrasonic waves is 2 MHz and the velocity of waves in blood is 1500 m/s. If the Doppler shift in frequency is 267 Hz, calculate the velocity of blood flow.*

Solution: Velocity of blood flow, $\upsilon = \frac{\Delta f\, \upsilon_u}{2 f \cos\theta} = \frac{267\text{Hz}\times 1500\text{m/s}}{2\times 2\times 10^6\,\text{Hz}\times 1} = \mathbf{0.1\ m/s.}$

Thanks