- Sound frequencies that are higher than detectable with the human ear.
- Sound waves above frequency normally detectable by the human ear, *i.e.*, above 15 to 20 kHz are referred as ultrasonic waves. In most practical applications of ultrasonics, pulse or packets, containing a number of oscillation cycles are set through the solid or liquid under investigation.
- An appreciation of useful applications of ultrasound dates back to the development of RADAR and SONAR in the late 1930's and early 1940s World War II era. One of very earliest uses was for detecting flaws in materials. Today's ultrasound is one of several effective methods used in the field of non-destructive testing (NDT) and inspection. Ultrasonic devices are also used in industrial processing applications such as cleaning, drilling, emulsifying soldering and welding. Possibly the most nature worthy of ultrasonic devices are found in the medical fields for use in diagnostics where ultrasound views with *X*-rays and other diagnostic procedures. Ultrasound is also applied in some security systems to detect inducers.
- Sound waves with frequency above 20,000 Hz are called ultrasonic waves. Because of their very small wavelengths, narrow beams of ultrasonic waves can be sent out and reflected from small objects.

- Bats can emit and detect frequency up to about 120 kHz corresponding to a wavelength of 2.8 mm, which they use to locate small prey such as moths. Ships use a device called SONAR (Sound Navigation and Ranging) to detect the outlines of submarines and other submerged objects with ultrasonic waves.
- In medicine ultrasonic waves are used for diagnostic purposes.
- To create a sonogram, ultrasonic waves are passed through the body and information about the frequency and intensity of transmitted and reflected waves is processed to construct a three dimensional picture of the body interior.

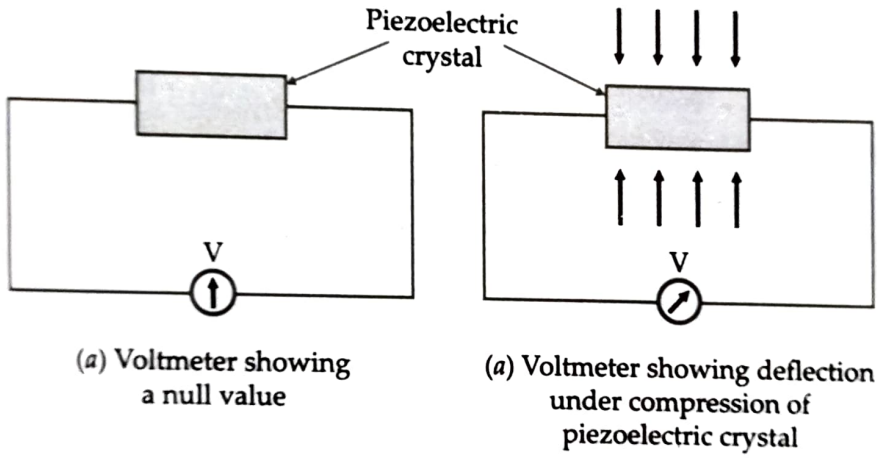
8.3 PRODUCTION OF ULTRASONIC WAVES

Ultrasonics can be generated by means of following methods :

1. Piezoelectric Generator
2. Magnetostriction Generator
3. Galton Whistle

8.3.1 Piezoelectric Crystals (Piezoelectric Effect)

In 1880, the Curie brothers (J. Curie and P. Curie) discovered that *when a crystal having one or more polar axes or lacking axis symmetry is subjected to mechanical stress an potential difference occurs* (Fig. 8.3). Consider a segment of such a crystal, in the form of a slab or a disc, that is act with its parallel surface running normal to a polar axis. When this segment undergoes a mechanical stress, equal and opposite electric charges arise on the parallel surfaces. The magnitude of the charge density (*i.e.*, dielectric polarization is directly proportional to the applied stress), provided by the applied stresses does not strain the crystal beyond its elastic limit.

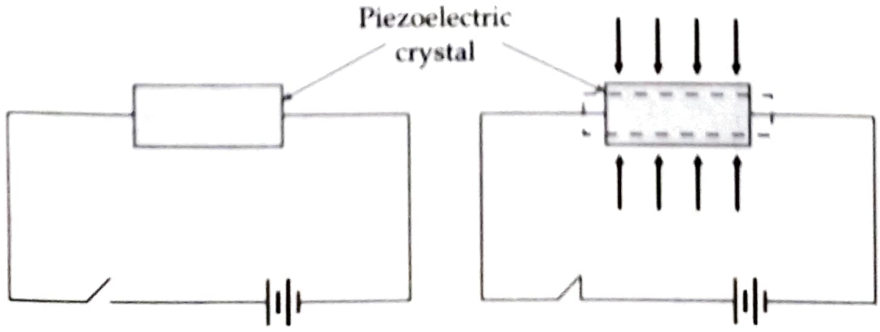


(*a*) Voltmeter showing a null value

(*a*) Voltmeter showing deflection under compression of piezoelectric crystal

Fig. 8.3 Direct piezoelectric effect.

The opposite effect, predicted by Lippmann in 1881 and verified experimentally by the Curie brothers in the same year when an electric field is applied in the direction of a polar axis, causing a mechanical strain in the crystal segment (Fig. 8.4). The amount of strain is directly proportional to the intensity of applied electric field. From the view point of the principle of conservation of energy, the piezoelectric effect and its converse may be deemed to be equal and opposite. Such effects occur in crystals such as quartz (a member of the trigonal system) as shown in Fig. 8.5 ; Rochelle salt and lithium sulphate.



(*a*) Key in open state

(*a*) Key in closed state

Fig. 8.4 Inverse piezoelectric effect.

8.3.4 Magnetostrictive Transducer (Magnetostriction Effect)

Magnetostriction occurs in ferromagnetic materials and certain non-metals which are termed as *ferrites*. *When a magnetic field is applied, a bar of ferromagnetic or ferrimagnetic material undergoes a change in length.* Conversely, *a mechanical stress applied to the bar will cause a change in intensity of magnetization.* The former effect was discovered by *Joule* in 1847 and the converse effect by *Villari* in 1868.

Magnetostriction occurs prominently in materials such as iron, nickel and cobalt. Whether there occurs an increase or decrease in length fully depends on the nature of the material as well as on the strength of the applied magnetic field. The change in length does not depend on the direction of the magnetic field. The magnitude of the strain varying as a function of the applied magnetic field is shown in Fig. 8.9 for four different materials, viz cest cobalt, permendur, nickel, and iron. Fig. 8.10 shows strain varying as a function of magnetic polarisation. The magnetostrictive effect generally decreases with a rise in temperature and disappears altogether at the Curie temperature.

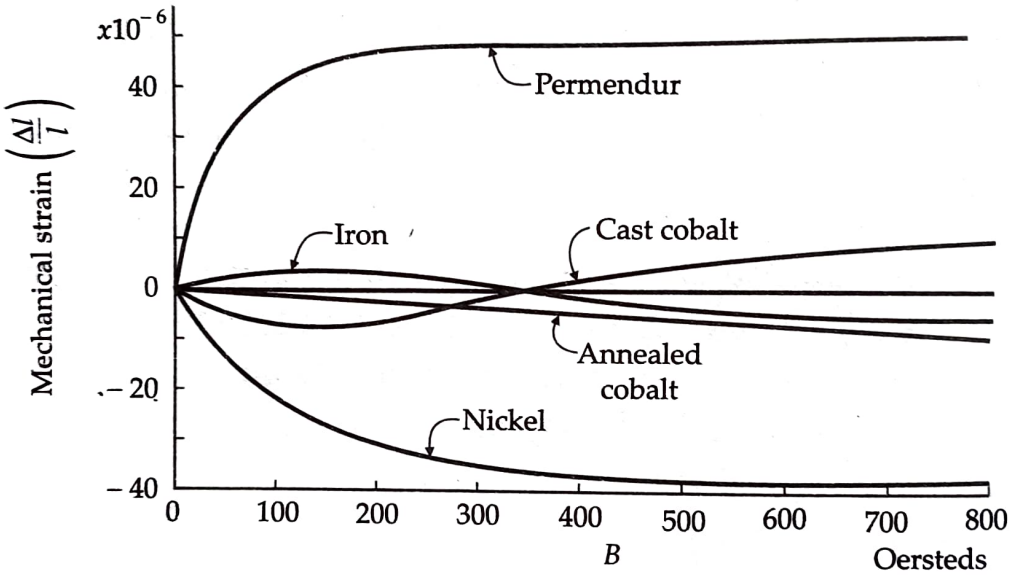


Fig. 8.9 Mechanical strain as a function of magnetic field.

When a sinusoidal varying magnetic field is applied in the direction of the axis of a bar of ferromagnetic material, the bar will oscillate at double the frequency of the applied field. Inaccordance with the associated curve in Fig. 8.10, a decrease in length occurs when a field is applied to nickel, regardless of the sense of the field. A negative strain occurs every half cycle. The waveform of the strain occurs as a rectified sine curve, with the result that unwanted harmonics may be generated. A purely sinusoidal wave corresponding to the frequency of the applied field, along with a markedly increased energy output, will be obtained if the bar is polarised. This is achieved by simultaneously applying the alternating field and a direct magnetic field of sufficiently high intensity for the value of the resultant field to remain above zero.

The maximum output for magnetostriction occurs by operating at the fundamental frequency

$$\nu_r = \frac{1}{2l}\sqrt{\frac{Y}{\rho}} \qquad ...(7)$$

where Y is the Young's modulus for the bar material, ρ is the density of the material, and l is the length of bar. The typical values for quartz are as

$$Y = 7.9 \times 10^{10}\ \mathrm{N/m^2}$$

$$\rho = 2.65 \times 10^{4}\ \mathrm{kg/m^3}$$

The term $\sqrt{Y/\rho}$ in Eq. (7) be the propagation velocity of sound in the material.

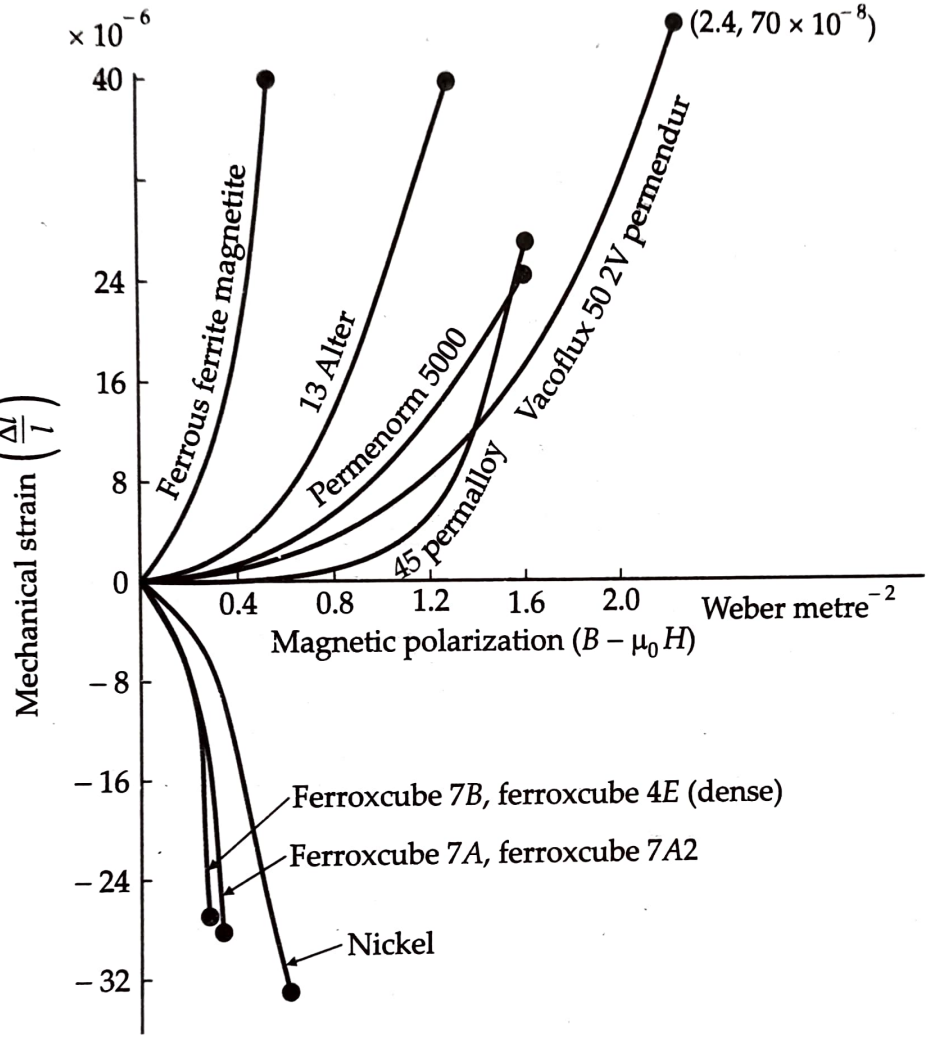


Fig. 8.10 Mechanical strain as a function of magnetic polarization.

8.3.6 Galton Whistle

Galton whistle works on the principle of organ pipe. It consists of a closed end air column A whose length can be adjusted with the help of a movable piston. The piston P can be moved to the desired position with the help of s screw S_1. The open end of the pipe A is

fitted with a lip L. The position of the pipe C can be adjusted with the help of the screw S_2. The gap between the ends of A and C can be adjusted with the help of the screw S_2. (see Fig. 8.12).

An air blast is blown through the nozzle N at the top. The blast of air coming out of C strikes against the lip L and the column of air in the pipe is set into vibration. By adjusting the length of the air column in A, it is brought to the resonant position. The resonant frequency will depend on the length and diameter of the pipe A. If l is the length of the air column in A, x the end correction, then the wavelength

$$\lambda = 4(l+x)$$

The frequency of sound is

$$\nu = \frac{v}{\lambda} = \frac{v}{4(l+x)} \qquad ...(8)$$

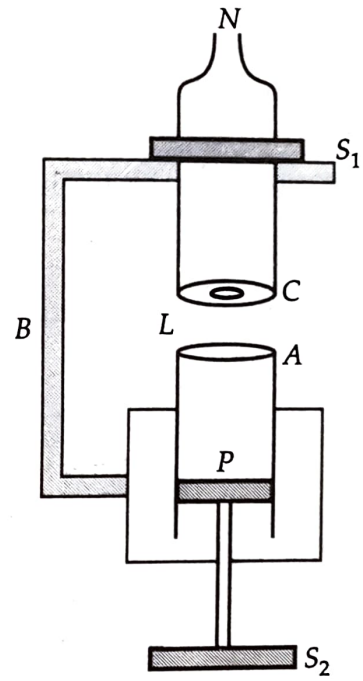


Fig. 8.12 Galton's Whistle.

With the help of this whistle, frequencies of the order of 30, 000 Hz can be produced. The micrometer screw S_1 can also be calibrated to give directly the frequency of the sound .

Example 8.2. *Galton's whistle may be regarded as a closed tube. Calculate the least length of the whistle such that the frequency of the whistle is 30,000 Hz (Assume velocity of sound be 330 ms^{-1}).*

Solution. We know that $v = \nu\lambda$

or $$\lambda = \frac{v}{\nu} = \frac{330}{30000} = 11\times10^{-3}\,\text{m}$$

Therefore the least length of the tube is $l = \frac{\lambda}{4} = 2.75\times10^{-3}$ m.

8.6 ENGINEERING APPLICATIONS OF ULTRASONIC WAVES

8.6.1 Ultrasonic Flaw Detection

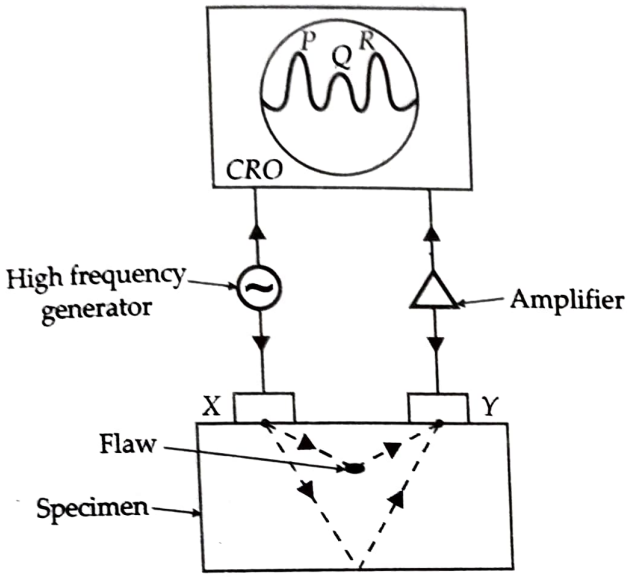
Of all the applications of industrial ultrasonic testing, flaw detection is the oldest and the most common. Since the 1940s, the laws of physics that govern the propagation of sound waves through the solid materials have been used to detect hidden cracks, voids, porosity, and other discontinuities in metals, composites, plastics and ceramics. High energy sound waves reflect from flaws in predictable way, producing distinctive echo patterns that can be displayed and recorded by portable instruments. Ultrasonic testing is completely non-destructive and safe and it is a well established test method in many basic manufacturing process and service industries, especially involving welds and structural metals.

PRINCIPLE

Sound waves are simply organised mechanical vibrations travelling through a medium which may be a solid, a liquid, or a gas. These waves will travel through a given medium at a specific speed or velocity, in a predictable direction, and when they encounter a boundary with a different medium they will be reflected or transmitted according to simple rules. This is the principle of Physics that underlies ultrasonic flaw detection.

The pulse echo method is used for flaw detection (Fig. 8.15). In the absence of any flaw (crack, cavity, bubble etc.), two peaks P and Q are observed on the screen. The peak P is of the original transmission signal

and Q is the reflected signal. If there is any flaw, the reflection of part or all of the incident wave takes place, which results in another peak R indicates to some extent the size of the flaw. When the flaw is present, the height of peak Q diminishes. It gives a better idea about the flaw, than the height of peak R. By moving the transducer probe defects in various parts of the sample can be detected.



P = incident pulse ;
Q = pulse from flaw ;
R = reflected pulse from the bottom of specimen ;
X = Transmitting transducer ;
Y = Receiving transducer.

Fig. 8.15 Flaw detection by Pulse Echo Technique.

8.6.2 Signalling

Since the frequency of the ultrasonics can be made very high so that wavelength is reduced to a small value. Therefore ultrasonics can be transmitted in the form of a narrow beam of small amplitude and large energy. The ship captain uses ultrasonics to steer its path in mist when light fails within few metres.

8.6.3 Sonar Exploration

SONAR stands for sound navigation and ranging.

Sonar is similar to RADAR in working. In radar we use microwaves, which are electromagnetic in nature, whereas in SONAR, we make use of ultrasonics. Ultrasonic waves are sent by the ultrasonic transmitter towards the target through water and are received back by the receiver lowered into the sea water from a ship as shown in Fig. 8.16. Knowing the time interval between sending and receiving of ultrasonics we can find the position of target or submarine. We can also find the direction and the velocity of the moving submarine with this apparatus. So this sonar technique is used for the detection of enemy submarine inside water during war time

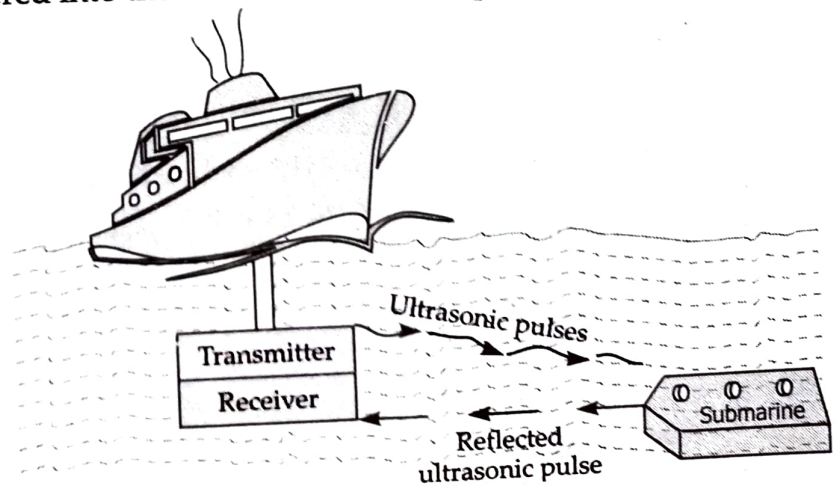


Fig. 8.16 SONAR

in a similar manner as RADAR is used trace the enemy aeroplanes in the atmosphere. During piece time, sonar is used for detecting the glaciers, icebergs, searocks and other submerged objects.

8.6.4 Thickness Gauging

For ultrasonic thickness measurement either pulse or resonance technique is used. The principle is similar to flaw detection. The time taken for travelling the dist[illegible] is shown on the digital display. In the beginning the gauge is calibrated with the standard sample. The important advantage is that access to only one surface is sufficient for the thickness measurement. The method is used for the assessment of internal corrosion of pipes, the measurement of the thickness of a ship's hull for external corrosion from inside the ship when it is at sea, the measurement of depths of fat on the bodies of live animals such as pigs and so on.

8.6.5 Depth sounding

The depth of sea or depth of water below a ship can be found out by using the echo sounding principle. Ultrasonic waves generated by a crystal transducer in the range of 40-50 kHz are dicrected towards the bottom of the sea. The time lag between the sending of ultrasonic signals and return back as an echo to the ship is recorded. Knowing the velocity and with measurement of the time lag, the depth of seawater the ship can be calculated.

$$\text{Depth of sea} = \frac{\text{Velocity of sounds in sea} \times \text{time}}{2}$$

The velocity v of sounds in seawater at $t°C$ is given by

$$v = v_0 + 1.14\,S + 4.21\,t - 0.037\,t^2 \qquad \text{...(15)}$$

where v_0 = velocity of sound in sea water at $0°C = 1510$ m/sec

S = the salinity (gm/litre), t = temperature of sea water in °C

Example 8.4. *An ultrasonic beam of 1 cm wavelength sent by the ship returns from sea bed after 2 seconds. It velocity of ultrasonic beam in sea water is 1510 m/sec at 0° C, its salinity at 30° C is 2 gm/lit, calculate the depth of sea bed at 30° C and frequency of ultrasonic beam.*

Solution. Given $S = 2$ gm/lit, $v_0 = 1510$ m/sec $t = 30°C$

$$v_t = v_0 + 1.14\,S + 4.21\,t - 0.037\,t^2$$

Then velocity of ultrasonic beam in sea water at 30° C

$$v_t = 1510 + 1.14(2) + 4.21(30) - 0.037(30)^2$$

$$= 1510 + 3.42 + 126.3 - 33.3 = 1637.20 \text{ m/sec}$$

$$\text{Depth of sea} = \frac{v_t \times \text{time}}{2} = 1637.20 \text{ m}$$

Then frequency of ultrasonic wave $= \dfrac{v}{\lambda} = 163720$ Hz $= 163.72$ kHz.

8.6.6 Cavitation

When a sound wave travels through a liquid, during the positive half cycle of wave, the liquid is compressed and during the negative half cycle, it expands. When the acoustic

pressure is, greater than the hydrostatic pressure, voids are created. These voids expand during the negative half cycle and collapse abruptly. It releases energy, giving rise to shock waves. The local temperature rises to tens, hundreds or thousands of degrees for very short periods at the frequency of wave propagation. This is called *cavitation*. The cavitation process is used in emulsification of two immiscible liquids. In the food industry, this method is used in the preparation of *dairy products, sauces* and *gravies, salad creams* and *synthetic creams*. It is used in extraction of hops in brewing industry. The steralisation of milk and tendering of meat by breaking down its fibres are some of other applications.

8.6.7 Ultrasonic Cleaning

In ultrasonic cleaning process both agitation and cavitation are involved. The cleaning of large components is carried out at low frequency range from 18 kHz to 40 kHz, here cavitation is most active. for delicate articles, higher frequency range 100 kHz to 1 MHz is used, where cavitation is almost absent. The process is used in removal of grease from engine components, oil, dust, buffering compounds etc. from printed circuit boards, jewelry and various instruments and devices.

8.6.8 Fatigue Testing, Drilling, Soldering and Welding

When high intensity ultrasonic waves pass through a solid, the strain developed finally results in fracture. The phenomenon is used in *fatigue testing*. The ultrasonic-drill is widely used for drilling materials, like glass, ceramics, germanium, tungsten carbide etc. The high intensity ultrasonic waves are used for treatment of *melts, soldering* and *welding*.

8.6.9 Motion and Fire Sensing

One of the few ultrasonic applications in open air is that of the motion and fire sensor, which is restricted to the lower kHz range, where attenuation is not very much. A magnetostrictive transducer placed at a point in a room emits pulses in all directions. The reflected signals from the walls and furniture are eventually picked up by a receiver, from which a constant indication is generated. Any variation in the sound field, caused by an intruder or a change in temperature, gives rise to a change in this indication, which triggers an alarm. One version of this device is a light switch that goes on automatically when someone enters an empty room and goes off automatically when no body is present in the room after a predetermined period of time.

8.6.10 Acoustical Holography

The wave used in the reconstruction does not have to be the original, and this allows the use of ultrasonic waves and the subsequent reconstruction of the image using light from a laser. But size of image changes in proportion to the ratio of

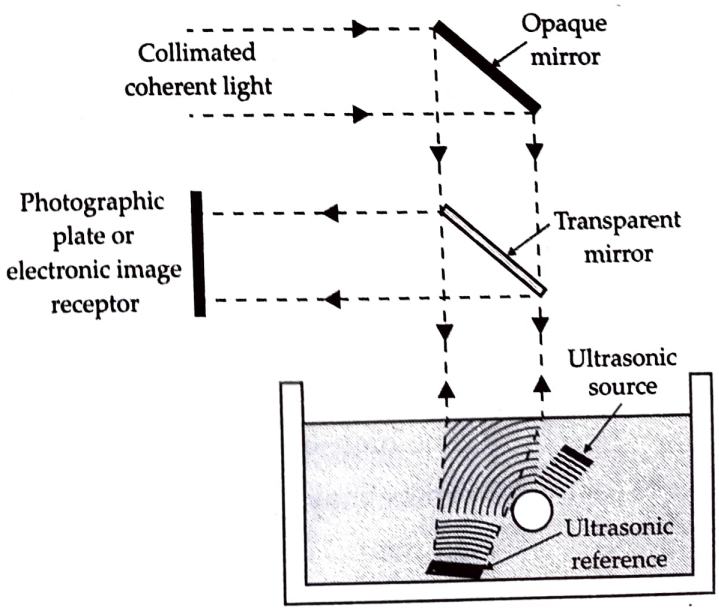


Fig. 8.17 Acoustical holography making use of liquid levitation.

the wavelength of the reconstructing wave to the wavelength of the original illuminating waves. There are a number of methods of making *acoustical holograms*. One method in Fig. 8.17 uses liquid levitation, where the acoustic waves from below the surface of liquid forms an ultrasonic image at the surface of the liquid that can be rendered visible on a photographic plate. The reference beam onto the surface or by generating a separate wave through a second transducer. The height of the bulge of the liquid surface due to the impetus of an acoustic wave is critical, it should be small as compared to the wavelength of the light.

8.6.11 Medical Diagnosis

The technique used for flaw detection is used for medical diagnosis. The characteristic impedance and absorption coefficients of different parts of human body are different *e.g.*, muscles, bones, layers of fat etc. The difference in healthy and malignant tissues can be detected for early warning of cancer etc. The frequency range used for diagnosis is 1 MHz to 10 MHz. The scanning technique is used to obtain clear pictures of the foetus at different stages of pregnancy, malignant growths, damage etc. of the various organs such as liver, brain, breast etc. The technique is known as *sonography*. The tumors in the brain, breast, abdomen and structures like gallstones, ureteric calculus, foreign bodies etc. can be located.

8.6.12 Other Applications

- Decreasing metal parts by suspending them in a liquid containing fine abrasive powder and setting up an ultrasonic beam in the liquid.
- Agglomeration of minute particles ; an ultrasonic transducer set up in a chimney causes all the soot particles to clump together and drop to the bottom, significantly reducing air pollution.
- Immiscible liquids can be emulsified by ultrasonic agitation.
- High polymers are depolymerised by ultrasonics. (For example, polystyrene in toluene molecules are reduced from 5,000 to 10,000, when exposed to ultrasonic waves for about 30 minutes.)
- Low intensity ultrasonics accelerate the rate of chemical reaction due to increased formation of free ions.
- High intensity ultrasound destroys bacteria and low intensity ultrasonic waves stimulate growth.
- Non-destructive testing (NDT) of coatings in metallurgy is an important application of ultrasonics.
- Cavitation breaks down living cells or even destroy them by means of ultrasonics.
- The high intensity ultrasonic waves are dangerous for human being.
- There may occur cellular damage or disruptive effects on chromosomes.
- In medical treatment ultrasonic waves are used to heat certain portion or kill certain tissues.
- Ultrasonic surgery is one of the emerging fields.