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खनि विषयक

खनि लिखनी

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#### 4. Acoustics & Ultrasonic

B.Sc. III<sup>rd</sup> year

##### Q.1 Acoustics:-

The branch of physics that deals with the process of generation, reception and propagation of sound is called Acoustics. खनि विषयक प्रसार

This branch in fact covers many fields and is closely related to various branches of engineering. Some of the important fields of acoustics are a) design of acoustical instruments b) microphones, amplifiers, loudspeakers c) music halls, recording studios in radio and television broadcasting stations.

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##### Q.2 Reverberation:-

[It is as good as persistence of vision when sound waves are produced in a big hall, they spread out, scatter & strike the surfaces of the various objects in the hall such as ceiling, walls, floor etc. some of the sound energy is reflected & some of it is absorbed and thus the distribution of sound energy in the hall continues to be affected. The reflected portions travel back into the hall & again to form echoes (sound).]

In other words when the source of sound is stopped then we hear the sound for sometime & then we feel that intensity of sound is reach to zero. This remaining (existence) of sound even after the source of sound is stopped is called Reverberation.

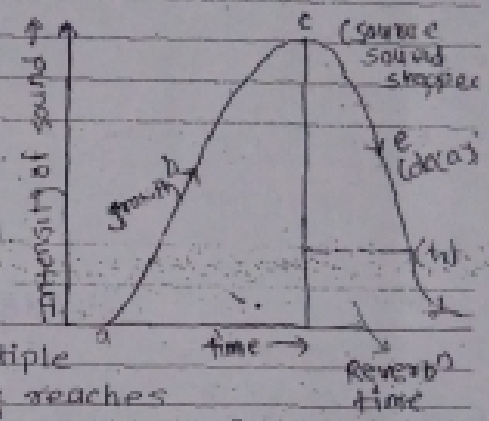
## IMP \* Reverberation time :-

{The time upto which the sound intensity remain in the hall after the source of sound is stopped is called Reverberation time.}

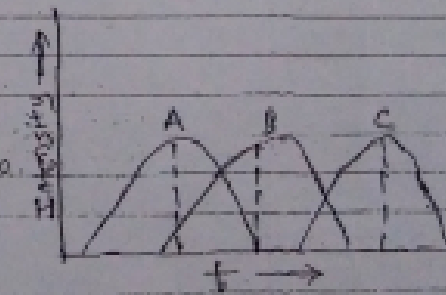
The growth and decay of sound intensity in a hall is as shown in fig. 'a' is point where source of sound started.

At 'b' & 'c' the sound intensity increases in the hall because of multiple reflection and intensity reaches maximum upto when the source of sound stopped. After the source of sound stopped intensity decreases to 'f'.

The time difference bet<sup>n</sup>  $t_1$  &  $t_2$  is called Reverberation time.



(In a good Auditorium it is necessary to keep the Reverberation time negligibly small.)  $\Rightarrow$  M.C.Q.



②

classmate  
Date \_\_\_\_\_  
Page \_\_\_\_\_

ac\* Derivation for Reverberation time :-  
(Sabine's Reverb<sup>n</sup> formula).

[Sabine and others established from theoretical considerations that the standard period of reverberation i.e. the time that the sound takes to fall in intensity by 60db or to one millionth of its original intensity after the source of sound is stopped is given by,

$$T = \frac{0.05V}{\sum a_i s_i}$$

where,

V - volume of the room

$a_i$  - ( $a_1, a_2, a_3, \dots, a_n$ ) - absorption coefficient of different materials.

$s_i$  - ( $s_1, s_2, s_3, \dots, s_n$ ) - surface area of material.

This relation is known as Sabine's law.

\* Law of Sabine's form (2)

Let I be the average intensity in the room at a given instant then the fall in intensity dI by absorption in time dt is given by,

$$dI = -\bar{a}nI dt$$

where,

$\bar{a}$  = average absorption coefficient.

n = no. of reflection

$$\frac{dI}{dt} = -\bar{a}nI \quad \text{--- (1)}$$

According to Jager's method.

$$n = \frac{sv}{4V}$$

Where,

$v$  = vel. of sound

$V$  = volume of the room

$s$  = total surface area

If  $E$  is the rate of emission of sound energy from the source per second, then rate of growth of energy per second per unit volume of room is given by,

$$\frac{dI}{dt} = \left( \frac{E}{V} - \frac{\bar{\alpha}svI}{4V} \right) \quad \text{--- (2)}$$

When the source is stopped then  $E = 0$

$$\frac{dI}{dt} = -\frac{\bar{\alpha}svI}{4V} \quad \text{--- (3)}$$

$$\frac{dI}{I} = -\frac{\bar{\alpha}sv}{4V} dt \quad \text{--- (4)}$$

If  $I_0$  is steady maximum value of intensity at the instant of cutting out of the source & it is value of  $I$  at time  $t$ , integrating eq<sup>n</sup> (4)

$$\int_{I_0}^I \frac{dI}{I} = -\int_0^t \frac{\bar{\alpha}sv}{4V} dt$$

$$\log \frac{I_t}{I_0} = -\frac{\bar{\alpha}svt}{4V}$$

③

classmate  
Date  
Page

According to def<sup>n</sup> of reverberation period given above when  $I$  is equal to reverberation period

$$I_t = 10^{-6}$$

$$I_0$$

$$\log_{10} \frac{10^{-6}}{I_0} = -\frac{0.54T}{4V}$$

$$\frac{0.54T}{4V} = -6 \log_{10} 10$$

$$\frac{0.54T}{4V} = 6 \times 2.3026$$

$$T = \frac{4V}{0.54} \times 6 \times 2.3026$$

|                |     |
|----------------|-----|
| $T = 0.153V$   | (5) |
| $\Sigma 0.151$ |     |

If  $v = 1120 \text{ ft/sec}$

$$T = \frac{6 \times 2.3026 \times 4 \times V}{0.54 \times 1120}$$

|                |     |
|----------------|-----|
| $T = 0.05V$    | (6) |
| $\Sigma 0.151$ |     |

From eq<sup>n</sup> (6), the reverberation time is

i) directly proportional to the volume of the auditorium  $T \propto V$

ii) inversely proportional to the total absorption plus transmission the open surfaces

$$T \propto \frac{1}{a}$$

iii) Inversely proportional to the area of ceilings, area of walls etc.

$$T \propto \frac{1}{S}$$

[To decrease the reverberation time, the walls of the auditorium are usually covered with material having large absorption coefficient] → M.C

The absorption of sound is essentially the dissipation of sound energy into other forms of energy & ultimately into heat.

The absorption coefficient of some materials at 512 Hz frequency of source.

| Material                              | Absorption coefficient |
|---------------------------------------|------------------------|
| 1) Marble →                           | 0.01                   |
| 2) Common plaster →                   | 0.03                   |
| 3) Glass →                            | 0.027                  |
| 4) Concrete →                         | 0.17                   |
| 5) Cork →                             | 0.23                   |
| 6) Asbestos →                         | 0.26                   |
| 7) Carpet →                           | 0.30                   |
| 8) Fibre glass →                      | 0.75                   |
| 9) Perforated cellulose fibre tiles → | 0.85 //                |

★ Absorption of sound :-

Different materials absorb sound depending upon it's nature at the same time to some extent, they reflect sound also.

★ Absorption coefficient :-

[The ratio of the absorption of sound energy by the surface to that of an equal area of a perfect absorber. (such as an open window).]

★ Determination of Absorption coefficient :-

suppose the source is of frequency 512 Hz. The time of reverberation in a hall is determined using a chronograph, (i) without the absorbing materials in the hall, (ii) with the absorbing materials in the hall. Let these two times be  $t_1$  &  $t_2$  respectively. According to Sabine's formula,

$$t_1 = \frac{0.158V}{\sum a_1 S_1} \quad \& \quad t_2 = \frac{0.158V}{\sum a_1 S_1 + \sum a_2 S_2}$$

$a_2$  is the absorption coefficient of the material of Area  $A_2$ .

$$\frac{1}{t_1} = \frac{\sum a_1 S_1}{0.158V} \quad , \quad \frac{1}{t_2} = \frac{\sum a_1 S_1 + \sum a_2 S_2}{0.158V}$$

$$\frac{1}{t_2} - \frac{1}{t_1} = \frac{a_2 S_2}{0.158V}$$

$$Q_2 = \frac{0.158V}{S_2} \left[ \frac{t_1 - t_2}{t_1 + t_2} \right] \quad \text{IN M.K.S system}$$

$$Q_2 = \frac{0.05V}{S_2} \left[ \frac{t_1 - t_2}{t_1 + t_2} \right] \quad \text{IN F.P.S system}$$

Absorption coefficient of a given material is different at different frequencies.

Absorption coefficient is higher at higher frequencies.

### Q. 1\* Factors Affecting the Acoustics of Buildings :-

Reverberation is one of the important single factors that affects the acoustics of a room or a hall. Besides reverberations there are also other factors like loudness, focussing, echelon effect, extraneous noise, resonance etc.

- 1) Loudness : The speech of a person in a hall can be heard by an audience consisting of about 200 persons. However, to ensure uniform distribution of sound intensity in the hall, electrically amplified loud speakers are used. These speakers are kept at different places in the auditorium and are located generally at a height higher than the speaker's head. Amplifiers, however, make the low frequency tones more prominent and hence the amplification has to be kept low. The presence of low artificial ceilings improves the audibility in general.

- 2) Focusing :- The presence of cylindrical or spherical surfaces on the walls or the ceiling gives rise to undesirable focussing.

In fig. (1) the observer at O receives sound from the speaker along the direct path AC. The observer also receives the sound waves after reflection from the ceiling. Thus the intensity of sound at O is comparatively higher than other positions in the auditorium. It may also happen that the direct and the reflected

waves are in opposite phase. This results in minimum intensity of sound at 'O'. Further, the direct and the reflected waves may form a stationary wave pattern. This causes uneven distribution of sound intensity.

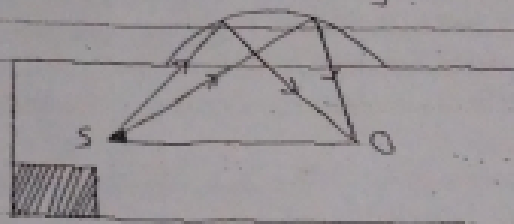


Fig. (11)

- 3) Echelon effect :- If there is regular structure similar to a flight of stairs or a set of railing railings in the hall, the sound produced in front of such a structure may produce a musical note due to regular successive echoes of sound reaching the observer. Such an effect is called echelon effect. If the frequency of this note is within the audible range, the listener will hear only this note, prominently. To avoid echelon effect, the stair cases are covered with carpets to avoid reflection of sound.
- 4) Extraneous noise :- The extraneous noise may be due to 1) Sound received from outside the room 2) the sound produced by fans etc., inside the auditorium. The external sound cannot be completely eliminated but can be minimised by using double or triple windows and doors. Proper

attention must also be paid to maximum permissible speed of fans and the rate of air circulation in the room. The air conditioning pipes should be covered with cork and insulated acoustically from the main building.

- 5) Resonance :- The acoustics of a building may also be affected by resonance. If there is resonance for any audio frequency note, the intensity of the note will be entirely different from the intensity desired. In halls of large size, the resonance frequency is much below the audible limit and harmful effects due to resonance will not be present.]//

\* Sound Distribution in an Auditorium :-

The design of an auditorium requires smooth decay and growth of sound. In an auditorium the sound must be distributed or diffused over the whole area. To ensure these factors, acoustic treatment is given viz., scattering effect of objects, irregularities on the wall surfaces, fixing absorptive material on the walls etc. In fig. (2) the first reflection of sound waves at different positions of the ceiling is shown. It is clear from the figure that the reflected sound is distributed evenly in the whole auditorium viz., the main floor and the balcony. This design enables an even distribution of sound intensity.

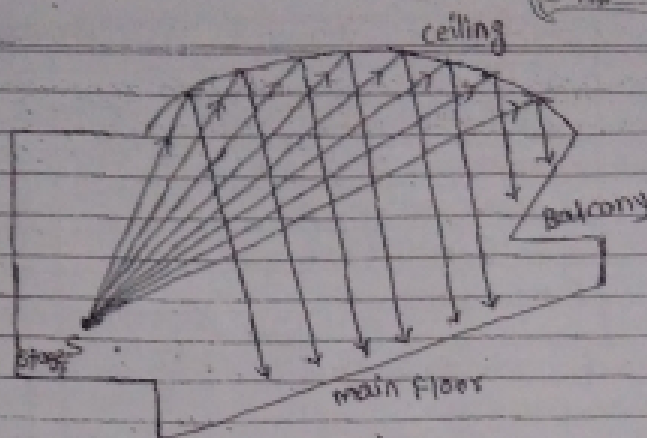


Fig. (2)

\* Requisites for good Acoustics :-

The reverberation of sound in an auditorium is due to multiple reflections taking place at various surfaces present within the auditorium. The acoustics of an auditorium can be improved by using the surfaces with high absorption coefficient. This will reduce the reverberation time below the optimum value. This can be achieved as follows -

- 1) By hanging heavy curtains.
- 2) By hanging pictures & maps.
- 3) By having a few open windows.
- 4) By having good audience. Each person is equivalent to about  $0.50 \text{ m}^2$  area of an open window.
- 5) The curved walls & corners bounded by two

①

classmate

Date

Page

two walls should be avoided. This is done to avoid (i) concentration of sound and (ii) dead spaces.

6) Upholstered seats should be provided so that the absorption is approximately the same with or without the audience.

7) The walls & the ceiling should be covered with the materials having high-absorption coefficient i.e., with perforated card board, felt, asbestos, fibre glass etc.

8) The walls should be engraved and made rough with decorative materials to increase the absorption.

★ Reverberation Time - optimum value :-

It is important that the reverberation time should be not be very much lower than the optimum value. If the time of reverberation is very small, most of the sound energy is absorbed & the average intensity of sound in the auditorium may fall below the audible limit. Due to this reason the auditorium appears dead. Thus the reverberation time should not be decreased much below the optimum limit. The optimum limit depends on the design of the auditorium and the purpose for which it has to be used.

# Absorption - शोषण

In modern halls, loud speakers are fixed at appropriate places within the hall so that the average intensity of sound is the same for all listeners.

## a. 2 \* Ultrasonics :-

[Sound waves of high frequency are called ultrasonics. The frequency of ultrasonics is higher than 20,000 hertz. These frequencies are beyond the audible limit. Their wavelength are small. For a frequency of 20,000 hertz, the wavelength at room temperature is  $\frac{350}{20,000} = 0.0175$  metre.]

These waves exhibit the properties of audible sound waves & also show some new phenomena. The sound waves of frequency lower than the audible limit are called infra-sonics. Supersonics refers to the velocities higher than the velocity of sound i.e. more than 1200 km/hour.

[Ultrasonic waves have a large number of practical applications. Ultrasonic waves can be produced by the following methods

- i) Walton whistle, ii) Magnetostriction oscillator & iii) Piezo-electric oscillator.]

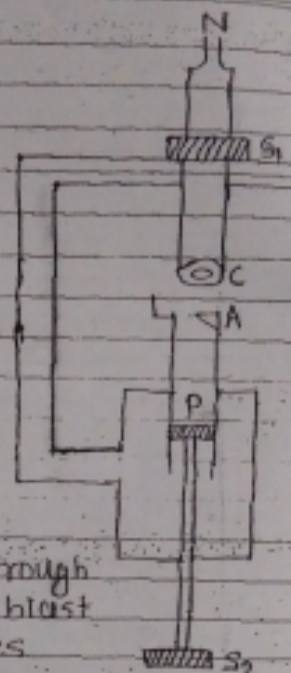
## \* Production of ultrasonic waves :-

### 1) Walton whistle :-

Walton whistle works on the principle of organ pipe. It consists of a closed end air column whose length can be adjusted with the



help of a movable piston.  
The position 'P' can be moved  
to the desired position with  
the help of a screw  $S_1$ . The  
open end of the pipe A is  
fitted with a lip 'l'. The  
position of the pipe 'c' can be  
be adjusted with the help  
of the screw  $S_2$ . The gap  
between the ends of A & c  
can be adjusted with the  
help of the screw  $S_2$ .



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

Fig (3)

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 & diameter of the pipe A. If  
' $\lambda$ ' is the length of the air column in A,  $x$   
the end correction, then the wavelength

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

The frequency of sound is,

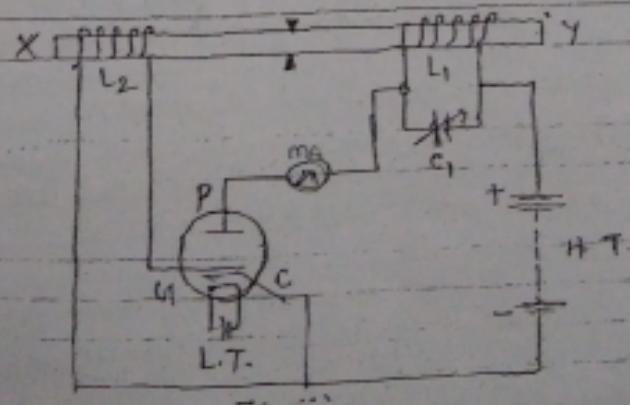
$$n = \frac{v}{\lambda}$$

$$n = \frac{v}{4(\lambda + x)}$$

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

### a.2 2) Magnetostriction oscillator :-

Ultrasonic waves can be produced by using the principle of magnetostriction. According to this principle, if a ferromagnetic material in the form of a bar (like iron or nickel), is subjected to an alternating magnetic field. The bar expands & contracts in length alternately. The frequency of contraction or expansion is twice the frequency of the alternating magnetic field. The alternating magnetic field produced with the help of an oscillatory circuit. Due to the longitudinal contraction & expansion of the bar, longitudinal compression waves are produced in the medium surrounding the bar. Frequency ranging from a few hundred hertz to about 300,000 hertz can be produced with this arrangement.



(9)

classmate

Date  
Page

The experimental arrangement is shown in fig (1). XY is a bar of ferromagnetic material say of iron or nickel. The bar is clamped in the middle.  $L_1$  &  $L_2$  are two coils surrounding the bar PQ.  $L_1$  &  $L_2$  are connected in parallel and the combination is connected in the plate circuit.  $L_2$  is connected between the grid and the cathode. The milliammeter is connected in the plate circuit. The values of  $L_1$  &  $C_1$  determine the frequency of the oscillated circuit.

Initially the bar is magnetised by passing direct current. The condenser  $C_1$  is adjusted so that the frequency of the oscillatory circuit is the same as the natural frequency of longitudinal vibrations of the bar. In this case, the oscillations are maintained by the coupling effect between the coils  $L_1$  &  $L_2$ . Any change in the plate current brings about a change in magnetisation and consequently the length of the rod changes. This gives rise to the change in flux in the coil  $L_2$  in the grid circuit. An induced e.m.f. is produced in the coil  $L_2$  & this e.m.f. is amplified by the triode valve & reacts back on the coil  $L_1$ . In this way, the oscillations are maintained and the amplitude of oscillations will be large.

At the start, the milliammeter shows alternation when the oscillations are set up. The condenser  $C_1$  is adjusted to the position where these alternations are maximum. In this position, the vibrations are most intense.

The frequency of the ultrasonic waves produced by this method will depend on the length, density and elasticity of the material of the bar.]

### Q. 3) ~~Piezo~~ - electric Oscillator :-

[In 1880, the Curie brothers, discovered that certain asymmetric crystals exhibit Piezo-electric effect. In this effect, if one pair of opposite faces of a crystal is subjected to pressure, the other pair of opposite faces of a crystal is subjected develop opposite electric charges.] The sign of the charges changes when the faces are subjected to tension instead of pressure. The converse of Piezo-electric effect is also true. According to this, if alternating voltages are applied to one pair of faces, the corresponding changes in the dimensions of other pair of faces of the crystal are produced. These changes have been found to be more pronounced when thin slices of crystals of quartz, tourmaline & Rochelle salt are used. The direction of the cut of the crystal with reference to the optic axis is quite important.

Thus, when the two opposite faces of a quartz crystal, their faces being cut perpendicular to the optic axis, are subjected to alternating voltage, the other pair of opposite faces experiences stresses & strains. The quartz crystal will continuously contract and expand. Elastic vibrations are set up in the crystal.

When the frequency of the alternating voltage is equal to the natural frequency of

(10)

 Classmate  
 Date \_\_\_\_\_  
 Page \_\_\_\_\_

vibration of the crystal or its simple higher multiples, the crystal is thrown into resonant vibrations and the amplitude will be large. The vibrations are longitudinal in nature. The frequency of vibration is  $\gamma$

$$n = \frac{P}{2L} \sqrt{\frac{\gamma}{\rho}}$$

$$P = 1, 2, 3, \dots \text{etc.}$$

Here,

$\gamma$  is the elasticity and  $\rho$  is the density of the crystal.

The velocity of longitudinal waves in the crystal.

$$v = \sqrt{\frac{\gamma}{\rho}}$$

(2)

The value of  $v = 5.5 \times 10^3 \text{ m/s}$  for quartz.

For a crystal of length  $0.05 \text{ m}$ , the frequency of the first mode of vibration will be,

$$= \frac{1 \times 5.5 \times 10^3}{2 \times 0.05}$$

$$= 5.5 \times 10^4 \text{ hertz.}$$

The other modes of frequency are simple integral multiples of  $5.5 \times 10^4 \text{ hertz}$ .

For an experimental arrangement, the circuit diagram is as shown in fig (5).

A is a thin slice of quartz crystal cut with its opposite faces perpendicular to the optic axis. The crystal is placed between two metal plates A and B. The plates A and B are connected to the coil  $L_3$ . Coils  $L_1$ ,  $L_2$  &  $L_3$  are inductively coupled. Coil  $L_2$  is connected in the plate circuit. The tank circuit  $L_1$  &  $C_1$  is connected between the grid and the cathode.

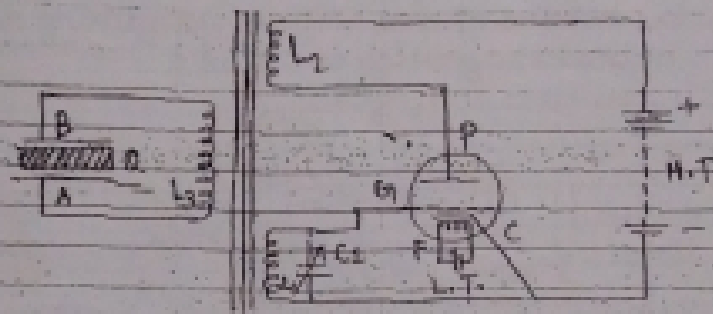


Fig. (5)

The variable condenser  $C_1$  is adjusted so that the frequency of the oscillatory circuit is equal to the natural frequency of one of the modes of vibration of the crystal. This will ensure resonant mechanical vibration in the crystal due to the linear expansion & contraction. Ultrasonic frequencies as high as  $5 \times 10^8$  hertz can be obtained with this arrangement.] //

### \* Detection of ultrasonic waves :-

Ultrasonic waves propagated through a medium can be detected in a number of ways. Some of the methods employed are as follows:

#### 1) Kundt's tube method :-

Ultrasonic waves can be detected with the help of Kundt's tube. At the nodes, lycopodium powder collects in the form of heaps. The average distance between two adjacent heaps is equal to half the wavelength. This method cannot be used if the wavelength of ultrasonic waves is very small i.e. less than a few millimeters. In the case of a liquid medium, instead of lycopodium powder, powder coke is used to detect the position of nodes.

#### 2) Sensitive flame method :-

A narrow sensitive flame is moved along the medium. At the position of the antinode, the flame is steady. At the position of the node the flame flickers because there is change in pressure. In this way positions of nodes & antinodes can be found in a medium. The average distance between two adjacent nodes is equal to half the wavelength. If the value of the frequency of the ultrasonic wave is known, the velocity of the ultrasonic wave through the medium can be calculated.

### 3) Thermal detectors :-

This is the most commonly used method of detection of ultrasonic waves. In this method, a fine platinum wire is used. This wire is moved through the medium. At the position of nodes, due to alternate compressions & rarefactions, adiabatic changes in temperature take place. The resistance of the platinum wire changes with respect to time. This can be detected with the help of Callendar & Griffith's bridge arrangement. At the position of the antinodes, the temperature remains constant & the resistance of the platinum wire remains constant. This will be indicated by the undisturbed balanced position of the bridge.

### 4) Quartz crystal method :-

This method is based on the principle of Piezo-electric effect. When one pair of the opposite faces of a quartz crystal is exposed to the ultrasonic waves, the other pair of opposite faces developed opposite charges. These charges are amplified & detected using an electronic circuit.

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### Acoustic Grating :-

A quartz crystal is placed between two metal plates. These two plates are connected to an audio-frequency oscillator. The frequency of the oscillator is adjusted so that the crystal vibrates in resonance. Due to the longitudinal

compression & expansion of the crystal, ultrasonic waves are produced. These waves are reflected by the reflector R. Due to the superposition of the direct & the reflected waves, longitudinal stationary waves are produced in the medium. These waves give rise to fixed positions of nodal & antinodal planes. At the nodal planes, the density is maximum and at the antinodal planes, the density is minimum. This arrangement behaves like a diffraction grating & is called acoustic grating.

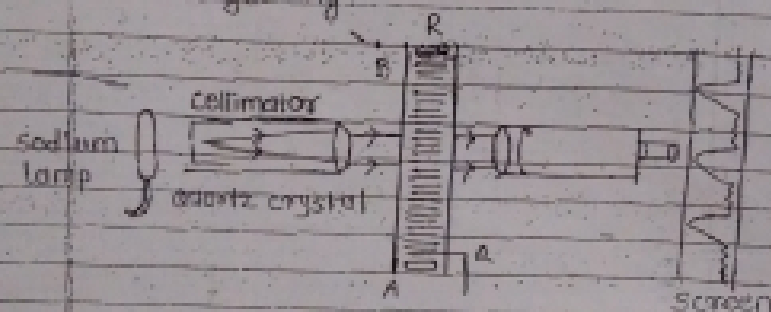


Fig. (i)

This arrangement is suitable for the measurement of wavelength and velocity of ultrasonic waves in a medium. In fig. (i), the acoustic grating is mounted on the prism table of a spectrometer. A parallel beam of sodium light from the collimator is normally incident on the acoustic grating. The diffracted beam of light is viewed through the telescope. The diffraction pattern consists of a central maximum and principal maxima on either side. The direct

of the principal maxima are given by the expression

$$d \sin \theta_n = n\lambda \quad \text{--- (1)}$$

Here  $n = 1, 2, 3$ , etc. &  $\theta_n$  is the angle of diffraction for the  $n^{\text{th}}$  order.  $\lambda$  is the wavelength of sodium light &  $d$  is the distance between two adjacent nodal or antinodal planes. knowing  $n, \theta_n$  and  $\lambda$ , the value of  $d$  can be calculated from eq<sup>n</sup> (1). If  $\lambda_a$  is the wavelength of the ultrasonic waves through the medium.

$$d = \frac{\lambda_a}{2}$$

$$\text{or } \lambda_a = 2d$$

If the resonant frequency of the piezo electric oscillator is  $N$ , the velocity of the ultrasonic waves,

$$v = N\lambda_a$$

$$v = 2Nd$$

[This method is useful in measuring the velocity of ultrasonic waves through liquids and gases at various temperatures.]

Problems :-

Q.1

An ultrasonic beam is used to determine the thickness of a steel plate. It was noticed that the difference in two adjacent harmonic frequencies is 50 kilo hertz. The velocity of sound in steel is 5000 m/s. Calculate the thickness of the steel plate.

The velocity of ultrasonic waves,

$$V = 2Nd$$

Here  $N$  is the fundamental frequency and  $d$  is the thickness.

$$N = \frac{V}{2d}$$

The harmonic frequencies are the multiples of the fundamental frequency.

$$N_n - N_{(n-1)} = N = \frac{V}{2d}$$

$$\therefore d = \frac{V}{2(N_n - N_{n-1})}$$

$$\text{Here } N_n - N_{n-1} = 50 \text{ kilo hertz} \\ = 50,000 \text{ hertz}$$

$$V = 5,000 \text{ m/s}$$

$$d = \frac{5,000}{2 \times 50,000}$$

$$d = 0.05 \text{ m.}$$

Hence the thickness of the steel plate is 0.05 meter

- Q. 2. A quartz crystal of thickness 0.001 m is vibrating at resonance. calculate the fundamental frequency given,  $\gamma$  for quartz =  $7.9 \times 10^{10}$  Newton/m<sup>2</sup> and  $\rho$  for quartz = 2650 kg/m<sup>3</sup>

For longitudinal vibrations,

$$v = \sqrt{\frac{\gamma}{\rho}}$$

Here  $\gamma = 7.9 \times 10^{10}$  Newton/m<sup>2</sup>  
and  $\rho = 2650$  kg/m<sup>3</sup>

$$v = \sqrt{\frac{7.9 \times 10^{10}}{2650}}$$

$$v = 5460 \text{ m/s}$$

For the fundamental mode of vibration,

$$\text{thickness} = \frac{\lambda}{2}$$

$$\lambda = 2 \times \text{thickness}$$

$$= 2 \times 0.001$$

$$= 0.002 \text{ m}$$

Frequency,  $n = \frac{v}{\lambda}$

$$n = \frac{5460}{0.002}$$

$$= 2730,000 \text{ hertz}$$

$$= 2730 \text{ kilo-hertz}$$

- Q. 3 A quartz crystal of thickness 0.001 m radiates ultrasonic waves into water of frequency 20 kilo-hertz and intensity  $5 \times 10^4 \text{ watts/m}^2$ . calculate (i) maximum acceleration and (ii) maximum displacement. Velocity of sound in water = 1480 m/s and density of water =  $1000 \text{ kg/m}^3$ . Density of the crystal =  $2650 \text{ kg/m}^3$ .

Sound intensity,

$$I = \frac{P^2}{2\rho v} \text{ watts/m}^2$$

Here P is the sound pressure,  $\rho$  is the density and v is the velocity of sound.

$\therefore$  Sound pressure

$$P = \sqrt{2I\rho v}$$

Here,

$$I = 5 \times 10^4 \text{ watts/m}^2$$

$$\rho = 1000 \text{ kg/m}^3$$

$$v = 1480 \text{ kg/m}^3$$

$$P = \sqrt{2 \times 5 \times 10^4 \times 1000 \times 1480}$$

$$= 3.85 \times 10^5 \text{ newton/m}^2$$

Force = press  $\times$  Area = Mass  $\times$  Acceleration

$$\therefore PA \propto PA = Ma$$

M = Mass of the crystal

volume  $\times$  density =  $a \times v \times \rho$

$$PA = (AtD)a$$

i) Maximum acceleration,

$$a = \frac{P}{tD}$$

$$a = \frac{3.85 \times 10^5}{0.001 \times 2650}$$

$$a = 1.45 \times 10^5 \text{ m/s}^2$$

ii) Maximum displacement,

$$y = \frac{a}{\omega^2}$$

$$= \frac{1.45 \times 10^5}{(2\pi f)^2}$$

$$f = 20 \text{ kilo-hertz}$$

$$= 20,000 \text{ hertz}$$

$$y = \frac{1.45 \times 10^5}{(2\pi \times 20,000)^2}$$

$$= 9.4 \times 10^{-6} \text{ m}$$

Q.4. A piezo-electric X-cut quartz plate has a thickness of 1.5 mm. If the velocity of propagation of longitudinal sound waves along the X direction is 5760 m/s, calculate the fundamental frequency of the crystal.

$$\rightarrow \text{Here, thickness} = 1.5 \text{ mm} = 1.5 \times 10^{-3} \text{ m}$$

$$V = 5760 \text{ m/s}$$

(15)

Thickness,  $t = \frac{\lambda}{2}$

$$\begin{aligned}\lambda &= 2t \\ &= 2 \times 1.5 \times 10^{-3} \\ &= 3 \times 10^{-3} \text{ m}\end{aligned}$$

Frequency,  $n = \frac{v}{\lambda}$

$$\begin{aligned}&= \frac{5760}{3 \times 10^{-3}} \\ &= 1920 \times 10^3 \text{ Hz}\end{aligned}$$

$$= 1920 \text{ Kilo hertz.}$$

### Q. 5. Application of Ultrasonic waves :-

Ultrasonic waves have a large number of practical applications.

1) Depth of sea :- Ultrasonic waves of high frequency are used to determine the depth of the sea. A Piezo-electric quartz oscillator is used for this purpose. The crystal is placed between two metal plates & the plates are connected to a spark oscillator, producing damped oscillations. The frequency of the damped oscillator is tuned to be the same as the natural frequency of the quartz crystal. The quartz crystal itself acts as a transmitter and a receiver of the ultrasonic waves. The ultrasonic waves transmitted by the crystal are directed towards the bed of the sea.

These waves are reflected back from the bed & the echo is detected by the crystal itself. In this case, the metal plates are automatically connected to an amplifier & a cathode ray oscillograph. The time interval bet<sup>n</sup> the emitted signal & the echo is determined with the help of the oscillograph. Knowing the velocity of sound through sea water and the time interval, the depth of the sea can be calculated. Suppose,  $t$  is the time interval between the transmission of the ultrasonic wave and receipt of the echo and  $v$  the velocity of sound waves through sea water, then depth of the sea,

$$h = \frac{v \times t}{2}$$

This method is also suitable to detect the presence and depth of submarines, rocks etc., from the surface of sea water. The instrument directly calibrated to show the depth of sea is called a fathometer or echometer.

- 2) Signalling:- Ultrasonic waves are used for directional signalling. The frequency of ultrasonic waves is higher than the audible sound waves. Therefore, the wavelength is comparatively small. Due to the small wavelength, ultrasonic waves can be sent in the form of a short beam. If a quartz crystal, taken in the form a disc of radius  $r$ , is used as a source of ultrasonic waves, the angle of the cone containing these waves is given by

$$\sin \theta = \frac{0.61 \lambda}{r}$$

For small wavelength,  $\theta$  is small. Even for a small amplitude of the vibrating crystal, large amount of energy is radiated whereas it is not possible in the case of audio frequency waves.

Recently, ultrasonic microscope has been invented. It is used to detect concealed objects. The frequency is very high so that the wavelength is of the order of the wavelength of visible light.

- 3) Heating effects :- When a beam of ultrasonic waves is passed through a substance, it gets heated. If ultrasonic waves pass through water at  $0^\circ\text{C}$ , water can be made to boil.
- 4) Mechanical effects :- Ultrasonic drills are used to bore holes in steel and other metals or their alloys. Here the drill oscillates with ultrasonic frequency and can bore any hard metal.
- 5) Cracks in metals :- Ultrasonic waves can be used to detect cracks or discontinuity in metal structure. In this case, an emitter & detector of ultrasonic waves are used. Ultrasonic waves from the emitter are directed towards the metal. The reflected beam is detected by the detector. If there is a crack or discontinuity, there will be rise in energy received by the

detector, if the emitter and the detector are on the same side. If the emitter & the detector are on the opposite sides of the metal, there will be fall in energy at the regions of cracks or discontinuity.

6) Formation of alloys :- Alloys of uniform composition are obtained by subjecting the constituents on to an ultrasonic beam. The two constituents are well mixed up by ultrasonic waves, even though the constituents differ in density.

7) Chemical effect :- Ultrasonic waves act like catalytic agents & accelerate chemical reactions. They bring about a number of chemical changes. Some of the chemical applications are as follows.

a) When potassium iodide is subjected to ultrasonic waves, it liberates iodine.

b) Water is decomposed into hydrogen and hydroxyl ions, by the action of ultrasonic waves.

c) Ultrasonic waves reduce mercuric chloride into mercurous chloride.

d) Water and oil are immiscible.

An emulsion of water and oil is obtained when the mixture is subjected to ultrasonic waves. Similarly an emulsion of water and mercury can be prepared.

e) Ultrasonic waves accelerate crystallization.

f) Ultrasonic waves explode nitrogen iodide.

8) Soldering :- Aluminium cannot be soldered by ordinary soldering method. To solder aluminium ultrasonic waves are used in addition to the electrical soldering iron. The ultrasonic waves remove the oxide film and facilitates soldering.

9) Medical applications :- Ultrasonic waves have a large number of applications in the field of medicine. Some of the important applications are as follows -

a) Neuralgic pain :- Ultrasonic waves are useful for relieving neuralgic and rheumatic pains. The affected portion of the body is exposed to ultrasonic waves. The waves produce a soothing massage action & relieves pain.

b) Arthritis :- Ultrasonic waves are used to relieve pain due to arthritis. Here a small metal head, vibrating with a frequency of more than  $10^6$  hertz is moved over the skin of the patient. These vibrations after passing through the tissues, produce a deep massage action. The patient is relieved of the pain.

c) Contracted fingers :- Ultrasonic waves are used to restore the contracted fingers. They are also used to loosen up the scar tissues in various parts of the human body.

classmate  
Date \_\_\_\_\_  
Page \_\_\_\_\_

d) Broken teeth :- Ultrasonic waves are used by dentists for the proper extraction of broken teeth.

e) Bloodless surgery :- Ultrasonic waves are used in bloodless surgery. Here the ultrasonic waves are focused on a sharp instrument & the tissues are destroyed without any loss of blood.

American doctors have used such instruments for conducting bloodless brain operations.

10) Sterilization :- Ultrasonic waves can destroy unicellular organisms. Bacteria perish under the action of ultrasonic waves. Ultrasonic waves are used in the sterilization of water and milk.

11) Energy of lower life :- When some lower animal like rats, frogs, fish, etc., are exposed to ultrasonic waves, they become lame.

Ultrasonic waves are having more and more practical applications in all fields.

Active research work is still in progress to study the effect of ultrasonic waves in mechanical, biological, chemical, physical and industrial fields. ]//