ICT 1107: Physics

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Chapter 1: Waves & Oscillations

Acoustics

The branch of physics that deals with the process of generation, reception, and propagation of sound is called acoustics. Acoustics covers many fields and closely related to various branches of engineering. A few important fields of acoustics are:

1. Design of acoustical instruments
2. Electro-acoustic instruments i.e., the branch relating to the methods of sound production and recording

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Acoustics

3. Architectural acoustics dealing with the design and construction of building, operas, music halls, recording rooms in radio and TV broadcasting stations.

4. Musical acoustics dealing with the musical instruments.

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Acoustic Intensity and Intensity Level

Acoustic intensity of a sound wave is defined as the average power transmitted per unit area in the direction of the propagation of the wave.

If P is the instantaneous power and v is the velocity of sound, then the average acoustic intensity is given by

$$I = \frac{1}{T}\int_0^T Pv\,dt$$

Here

$$P = -\rho c^2 \left(\frac{dy}{dx}\right)$$

But

$$y = A\cos(\omega t - kx)$$

Hence,

$$v = \frac{dy}{dt} = -\omega A\sin(\omega t - kx)$$

and,

$$\frac{dy}{dx} = Ak\sin(\omega t - kx)$$

But $$kc = \omega$$

Hence, $$P = -\rho c A \omega sin(\omega t - kx)$$

Here c is the velocity of sound and ρ is the density of the medium.

Thus, the acoustic intensity is given by

$$P = \frac{1}{T}\int_{0}^{T} (-\rho c A \omega sin(\omega t - kx))\ (-\omega A sin(\omega t - kx))\ dt$$

$$I = \frac{\rho c \omega^2 A^2}{T} \int_0^T [\sin(\omega t - kx)]^2 dt$$

Please solve the integration. Finally you will get,

$$I = \frac{\rho c \omega^2 A^2}{T}\left(\frac{T}{2}\right) = \frac{1}{2}\rho c \omega^2 A^2 \text{............}(1)$$

Acoustic Intensity and Intensity Level

We have,

$$P_{max} = -\rho c A \omega$$

$$P_{rms} = \frac{P_{max}}{\sqrt{2}}$$

Using these in Eq. (1), we get

$$I = \frac{\rho^2 c^2 \omega^2 A^2}{2\rho c} = \frac{(P_{max})^2}{2\rho c} = \frac{(P_{rms})^2}{\rho c}$$

This is the expression for the acoustic intensity.

Acoustic Intensity Level

In acoustic measurements, logarithmic scale is used for measuring the acoustic intensity, acoustic power and acoustic pressure. The logarithmic scale is known as the decibel (dB) scale. The dB scale refers to the quantity to be measured logarithmically to some standard reference.

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Acoustic Intensity Level

Intensity of sound is a physical quantity while the loudness is merely a degree of sensation. Loudness of sound increases with the intensity of sound according to Weber-Fecher law in physiology. According to WF law, the loudness produced is proportional to the logarithm of intensity:

$$S \propto \log I$$

$$S = K log I$$

Where K is a proportionality constant.

Suppose S is the loudness at an intensity I and S_0 is that for an intensity I_0. Then the intensity level is given as,

$$IL = S - S_0 = K log_{10} I - K log_{10} I_0$$

When IL is measured in decibels (K = 10), then the acoustic intensity level is written as

$$IL = 10log_{10}\left(\frac{I}{I_0}\right)dB$$

with reference to I_0 watt/m^2.

The standard acoustic intensity reference $I_0 = 10^{-12}$ watt/m^2.

$$IL = 10log_{10}\left(\frac{I}{10^{-12}}\right)dB$$

with reference to 10^{-12} watt/m^2.

$$IL = 10[log_{10}I + log_{10}10^{12}]dB$$
$$= [10log_{10}I + 120]\mathrm{dB}$$

Acoustic Pressure Level

When the pressure level (PL) is measured in decibels (K = 10), then the acoustic pressure level is written as

$$PL = 10log_{10}\left(\frac{P}{P_0}\right)^2 dB$$

with reference to P_0 Nt/m^2.

The standard acoustic intensity reference P_0 =2×10^{-5} Nt/m^2.

$$PL = 20log_{10}\left(\frac{P}{2\times10^{-5}}\right) dB$$

with reference to 2×10^{-5} Nt/m^2.

$$PL = 20[log_{10}P + 94]dB$$

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Reverberation

It is observed that for a listener in a room or in an auditorium, whenever a sound pulse is produced, he receives directly compressional sound waves from the source as well as sound waves from the walls, ceiling and other materials present in the room. The waves received by the listener are :

i) direct waves and

ii) reflected waves due to multiple reflections at various surfaces.

Reverberation

The quality of note received by the listener will be the combined effect of these two sets of waves. There is also a time gap between direct wave received by the listener and the waves received by successive reflection. Due to this the sound persists for sometime even after the source has stopped. This persistence of sound is called the reverberation.

Reverberation Time

The time gap between the initial direct note and the reflected note upto the minimum audibility level is called reverberation time. The reverberation time will depend on the size of the room on the auditorium, the nature of the reflecting materials on the wall and the ceiling and the area of the reflecting surfaces.

Alternative Definition

- Sabine defined the reverberation time as the time taken by the sound intensity to fall to one millionth of its original intensity after the source stopped emitting sound.

Alternative Definition

- The time taken by the sound in a room to fall from its average intensity to inaudibility level is called the reverberation time of the room.
- Reverberation time is defined as the time during which the sound energy density falls from its steady state.

Reverberation Time

For a good auditorium it is necessary to keep the reverberation time as small as possible.

Calculation of Reverberation Time: Sabine's Reverberation Formula

Sound energy in the room depends on:

1. the power of the source
2. the volume of the room

The rate at which that energy is absorbed depends on:

1. the area of the room and
2. the absorption coefficients of all the surfaces in the room

It is found that the reverberation time is directly proportional to the volume of the room and inversely proportional to the effective surface area (total absorbing area) of the room. Mathematically,

$$T \propto V$$

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

$$T = K\frac{V}{A}$$

Here, K is the Sabine's constant or reverberation constant. Generally, large rooms have longer reverberation times than do small rooms.

For a room with solid walls, which absorb very little sound, and an open window of area A, the reverberation constant is:

$$K = 0.161 \text{ s/m} = 0.049 \text{ s/ft}$$

$$T = \frac{0.161V}{A} = \frac{0.05V}{A}$$

- We can assume an absorption coefficient, ***a***, which depends on the amount of sound power absorbed
- So any material having surface area **S** can be said to have **A = S*a***
- Total absorption of the room is found by adding up the contributions from each surface exposed to the reverberant sound

$$A = S_1 a_1 + S_2 a_2 + S_3 a_3 \ldots$$

- Sometimes absorption is expressed in sabins or metric sabins
- One sabin is the absorption of one square foot of open window

$$T = \frac{0.161V}{\sum S\alpha} = \frac{0.05V}{\sum S\alpha}$$

Where α is the absorption coefficient.

$$T = \frac{0.161V}{\sum Sa} = \frac{0.05V}{\sum Sa}$$

Sometime *a* also indicates the absorption coefficient.

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Home Work

Derive the Sabine's Reverberation Formula

(Lecture Material is Provided)

Growth and Decay of Sound

Sabine developed the formulas to express the growth and decay of sound intensity inside a room. The sound produced in a room undergoes three or four hundred reflections until the intensity become so small in audible, interference and similar effects being neglected. The main assumptions being made were:

i) The distribution of sound within the room is sufficiently uniform in all directions and is equally transmitted in all directions

ii) The rate at which the energy is emitted by the source is constant and is independent of the energy level in the enclosure

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Sample Problems
(Book: Waves and Oscillations)

1. Pages 8-20: Examples 1.1-1.11
2. Pages 101-102: Examples 2.1 & 2.2
3. Pages 155-157: Examples 4.2-4.5

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Sample Questions
(Book: Waves and Oscillations)

1. Pages 94-98
2. Pages 118-119
3. Page 159

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Questions from Waves and Oscillations

Please also see the Book

Physics for Engineers Vol. 1

"Thank You"