ACOUSTICS

Acoustics **deals with the production, propagation and detection of sound waves**

Classification of sound:

(i)Infrasonic<20Hz(Inaudible)

(ii)Audible20to20,000Hz(MusicandNoise)(iii)

Ultrasonic>20,000Hz(Inaudible)

Characteristics of Musicalsound:

(i) Pitch or frequency

Frequency: numberof vibrations of sound producingobject/second

Pitch:- adegreeof sensation depends on frequency

Highfrequency–shrillsound-

voiceofladies,children,mosquitoLowfrequency-gravesound-

soundbylion

(ii) Quality or Timbre

- abilityto distinguish b/w anytwo or moremusicalsound havingsame pitchand frequency

- smallestfrequencyiscalled***fundamental***andfrequenciesaccompanyingfundamentalare called ***overtones***.

(iii) Intensity or Loudness

Intensity: amount of sound energyflowingper secper unit area

$$I = Q/A \text{ watt/m}^2$$

Loudness: degree of sensation varies from one observer from other

WEBER-FECHNERLAW

- loudness is directlyproportional to thelogarithm of intensity

$$L \alpha \log I$$

$$L = K \log I$$

where k is a constant.

DECIBEL○

- Theintensitylevel*(L)*of sound is expressed in bel.
Comparativelybel is a large unit,so for convenience, one tenth of bel is called a decibel (db)
- **1bel=10decibel=10db**Inten
sitylevel $IL = 10\log_{10}(I_1/I_0)$

ACOUSTICS OFBUILDINGS

▪dealswithdesignandconstructionofhall▪hallso rroomsareacousticallypoordueto

- **distributionofintensityisnotuniform**
- **differentfrequencyofsoundinterfereatsomepointreducesthequality▪toget goodacousticalbuilding,factorstobeconsidered**

○Reverberationtime
○Focusingandinterference○E choesandEcheloneffect○Reso nanceand
○Extraneousnoise

Reverberation: persistenceor prolongation of sound in a hall even after the sound sourceis stopped

ReverberationTime:time taken bythe soundwaveto fall below the minimum audibilitylevel*i.e.,tofalltoonemillionthofitsinitialintensity*, after thesourceis stopped

$$I=10^{-6}I_o \quad \text{or} \quad I/I_o=10^{-6}$$

Sabine's Formula for Reverberation Time

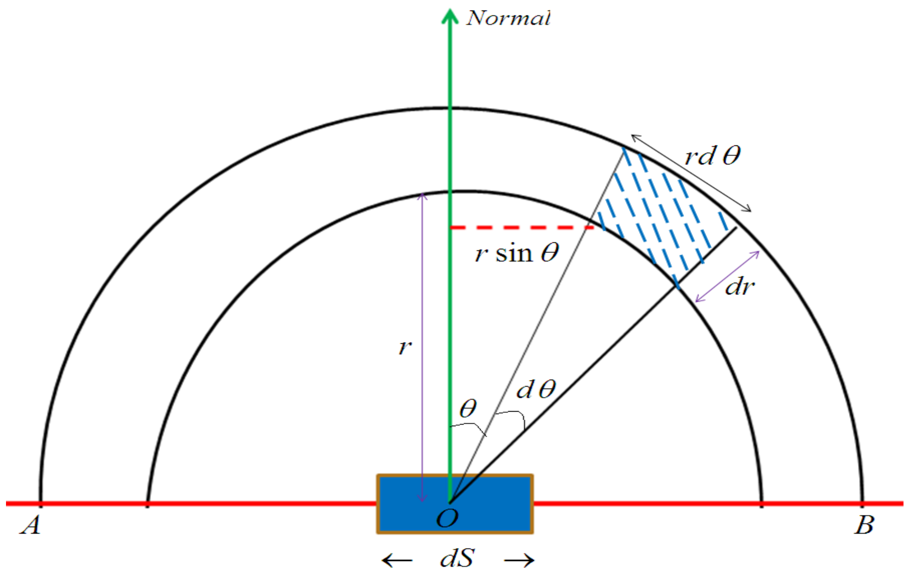
- **ProfessorWallaceC.Sabine(1868–1919) d**erived fromreverberation theorywhich explains the natureof growth and decayof sound energy.

Assumptions :

- The sound energyis uniformlydistributed throughout the hall
- The absorption of soundbytheair is neglected
- The source emits the sound energyconstantly**.**

Steps involved:

1. calculatetherateofincidentenergyonthewallsandtherateofabsorptionbythewallsin terms of average energydensity*E*
2. calculate the final steadyvalue of *E* in terms ofaverage energydensity
3. calculate the final steadyvalue of *E* in terms ofrate of emission of power *P*of the source.
4. obtain an expression for therate ofgrowth and decayof sound energyin a room.
5. obtain the reverberation time.



- Consider asmall element'ds' on aplane wall AB •
  Sound energyreceived by'ds' is E
- Draw twoconcentric circles of radii 'r' and 'r+dr'from centre point 'O'
- Consider asmall shadedportion lyingbetween circles having θ and θ+dθ from normal •
  Ifradial length= dr Arclength = rdθ

Areaofshadedportion=rdθ dr **…(1)**

- Ifthewholefigureisrotatedaboutthenormalthroughanangledϕ,thenareaofshadedportion travel a distance of dx

dx=rsinθ dϕ **…(2)**

Volume traced byashaded portion dV = areaX distance

=rdθdrrsinθdϕ

=r²sinθdθdrdϕ **…(3)**

Sound energypresent in this volume **=ExdV**

=Er²sinθdθ drdϕ *Th issoundenergytravelsinallthedirectionthroughthiselement.*

Sound energypresent in this volume dV/unit solid angle=$\frac{Er^2\sin\theta d\theta dr d\phi}{4\pi}$

Solid angle subtended bythe areadS at this element of vol.dV is$\frac{dSCos\theta}{r^2}$

Sound energytravellingtowards dS from dV is

$$= \frac{Er^2\sin\theta d\theta dr d\phi dSCos\theta}{4\pi} \cdot \frac{}{r^2}$$

$$= \frac{E\sin\theta Cos\theta d\theta dr dS d\phi}{4\pi} \quad \ldots(4)$$

To find the total energy by dS in one sec, Integrate the eqn.(4) for whole volume lying within a distance of C of dS,

ϕ=**0 to 2**π

θ=**0 to** π**/2**

r=0 to C

Energy received/sec=

w.r.t. 'ϕ' $= \frac{E\sin\theta Cos\theta d\theta dr dS}{4\pi} \int_0^{2\pi} d\phi$

$= \frac{E\sin\theta Cos\theta d\theta dr dS}{4\pi} 2\pi$

$= \frac{E\sin\theta Cos\theta d\theta dr dS}{2}$

w.r.t 'θ' $= \frac{E dr dS}{2} \int_0^{\pi/2} \sin\theta Cos\theta d\theta$

X and ÷ by 2 $= \frac{E dr dS}{4} \int_0^{\pi/2} 2\sin\theta Cos\theta d\theta$

$= \frac{E dr dS}{4} \int_0^{\pi/2} \sin 2\theta d\theta$

$= \frac{E dr dS}{4}$

w.r.t. 'r' $= \frac{E dS}{4} \int_0^{c} dr$

$= \frac{EC}{4} dS \quad \ldots(5)$

Let 'a' be the absorption coefficient of wall.

Then,

Sound energy absorbed by dS in one sec $= \frac{1}{4} ECa dS$

Total energy absorbed at anytime $= \frac{1}{4} EC\Sigma a dS = \frac{1}{4} ECA \quad \ldots(6)$

If 'P' is the rate of emission of sound energy, then,

$$P = \frac{1}{4} E_{max} CA \quad \text{or} \quad \ldots(7)$$

$$E_{max} = \frac{4P}{CA}$$

Rate of Growth and Decay

Total rate of energy increase in medium:

Energy density **=E**

Total volume of the Hall **=V**

Total sound energy **=EV**

Rate of growth of sound energy = **d(EV)/ dt = V dE/dt**

W.K.T,

Rate of emission of sound energy=Rate of growth of sound energy+ Rate of absorption of sound energy

$$P = V\frac{dE}{dt} + \frac{1}{4}ECA$$

$$\frac{P}{V} = \frac{dE}{dt} + \frac{CA}{4V}E$$

Let $\frac{CA}{4V} = \alpha$ **or** $CA = V4\alpha$

$$\frac{dE}{dt} + \alpha E = \frac{4P}{CA}\alpha$$

$X^{ly}e^{\alpha t}$ on both the sides,

$$\frac{dE}{dt}e^{\alpha t} + e^{-\alpha t}\alpha E = \frac{4P}{CA}\alpha e^{\alpha t}$$

$$\frac{d}{dt}(Ee^{\alpha t}) = \frac{4P}{CA}\alpha e^{\alpha t}$$

Integrating the above eqn. we get,

$$Ee^{\alpha t} = \frac{4P}{CA}e^{\alpha t} + K \qquad \ldots(8)$$

Growth of Energy

During Growth, t = 0, E = 0

From eqn. (8) ,

$$K = -\frac{4P}{CA}$$

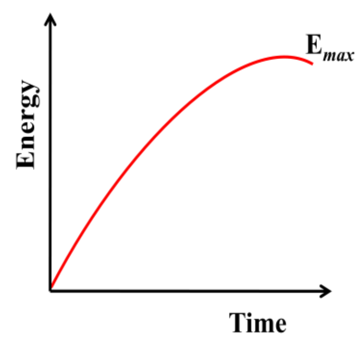
Then,

$$Ee^{\alpha t} = \frac{4P}{CA}e^{\alpha t} - \frac{4P}{CA}$$

$$Ee^{\alpha t} = \frac{4P}{CA}(e^{\alpha t} - 1)$$

$$E = E_{max}(1 - e^{-\alpha t})$$

E increases until $E = E_{max}$ and $t = \infty$



Decay of Energy

If sound energy is cut off,

rate of emission P= 0

t = 0

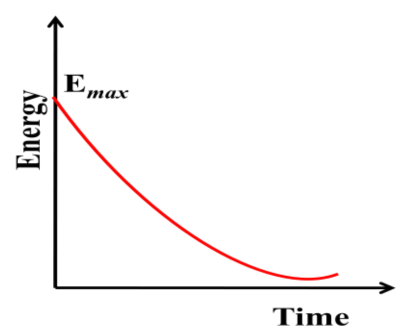
$E = E_{max}$ From eqn.(8) ,

$$K = E_{max}$$

then,

$$Ee^{\alpha t} = \frac{4P}{CA}e^{\alpha t} + E_{max}$$

Since P = 0 $Ee^{\alpha t} = E_{max}$



$\boldsymbol{E = E_{max}e^{-\alpha t}}$, even though sourceis cutoff, energydecreasesexponentially

<u>Reverberationtime</u>

Bydefinition, $E = E_{max}/10^6$

from deacyof energy, $\boldsymbol{E = E_{max}e^{-\alpha t}}$

$$\boldsymbol{E_{max}/10^6 = E_{max}e^{-\alpha t}}$$

$$\boldsymbol{10^{-6} = e^{-\alpha t}}$$

Takelogonbothsides, $\boldsymbol{\log_e 10^{-6} = -\alpha t}$

$$\boldsymbol{-6x2.3026\log_{10}10 = -\alpha t}$$

$$\boldsymbol{\alpha t = 6x2.3026} \qquad \alpha = \frac{CA}{4V} \quad \boldsymbol{t = T, then,}$$

$$\frac{CAT}{4V} = 6x2.3026$$

$$T = \frac{4Vx6x2.3026}{CA}$$

$$= \frac{0.167V}{A}$$

ABSORPTIONCOEFFICIENT

- Reciprocal of its areawhich absorbs the sameamount of sound energyabsorbed byunit areaof open window
- Absorption coeffeicient= $\frac{Soundenergyabsorbedbythesurface To}{talsoundenergyincidentonit}$
- measured in OWU or Sabine.

<u>Determination of Absorption Coefficient:</u>

- without sound absorbing material

$$T_1 = \frac{0.167V}{\Sigma as}$$

- with sound absorbingmaterial

$$T_2 = \frac{0.167V}{\Sigma as + a_m s_m}$$

- from $T_2 - T_1$,

$$a = \frac{0.167V}{s_m} \cdot \frac{T_1 - T_2}{T_1 T_2}$$

Materials and their Absorption coefficient

Brick wall	0.02		Carpet	0.24
Wooden floor	0.057		Cushion	0.45
Chair	0.25		Rubber floor	0.05
Glass	0.02		Human	0.4

FACTORSAFFECTINGGOODACOUSTICALBUILDINGANDTHEIRREMEDIES

FACTORS	DEFINITION	REMEDIES
ReverberationTime	- Time taken bythe soundwaveto fall below the minimum audibilitylevel after thesourceis stopped - *ReverberationTimeistoohigh*: overlappingof successive sound - *ReverberationTimeistoolow*: produced sound willdisappear - forthegood audibility, reverberation time should be kept at an optimum value.	byinstallingsoundabsorbing materials like ▪providingwindows and openings ▪arrangingfull capacityofaudience ▪completelycoveringthefloorwith carpets ▪heavycurtains with folds ▪decoratingthewallswithdrawing boards, pictureboards
Loudness	- degreeof sensation produced in the ear. - uniform distribution of loudness must be maintained - duetohighabsorptionorlowreflectingsurfacesnearthe sound source	***Ifloudnessislow:*** ▪speakersmaybeplacedatregular distances ▪lowering the ceiling and placing reflectingsurfaces at necessaryplaces. ***Ifloudnessishigh:*** ▪soundabsorbentscanbeplacedatnoisy places
Echo	- Ifthetimeintervalbetweenthedirectsoundandthe reflected soundislessthan1/15ofasecond,the reflected sound reaches the audiencelaterthanthe direct sound.	▪properly coveringthelongdistancewalls, high ceilings with suitable sound absorbingmaterials.
EchelonEffect	- new sound produced by*repetitiveechoes* - regularreflectingsurfacelikestaircasemaycreatethis effect.	▪Coversuchregularreflectingsurfaces properly.
Focusing	- Reflected sound bythe ceiling and wall is focusedat a particular areaof thehall. - **Planesurface**: reflect and distribute the sound evenly.	▪cover the curved surfaceswith proper sound absorbingmaterials ▪radius of curvatureof concave ceiling

	- **Curvedsurface** :focuses the sound in the front portion only.	should be two times the height of the building.
InterferenceEffect	- Caused byinterference of direct andreflected wave **constructiveinterference**: max. sound intensityoccurs **destructiveinterferenc**e:min.sound intensityoccurs	▪Bythe usage of uniformpaintingand absorbent it maybe avoided.
Resonance	- Ifwindowpanelsoranyotherwoodensectionsarenot coveredproperly,theoriginalsoundmayvibratewiththe natural frequencyof them.	▪Vibratingmaterialsshouldbemountedon non-vibrating and sound absorbing materials. ▪Panels must be fitted properly. ▪eliminatedthroughproperventilationorby Air-Conditioning
Noise	- Unwanted sound produced externally/internally gives an irritatingexperience to theears.	
	Air-BorneNoise - outsidenoisewhichreachestheaudiencethroughwindow, door and ventilator	▪Thehallshouldbeawayfromthickly populated area, factoriesand railwaytracks. ▪byairconditioningandbydoubledoor system it can be reduced.
	Structure-BorneNoise - noisereachestheaudiencethroughthestructuraldefectof the building - duetothemovementoffurniture,footstepsandthe operation of heavymachinerylikegenerators.	▪Usedoublewalleddoors,anti-vibration mounts, carpets etc.,
	InsideNoise - noise produced inside the hall like cryingkids, thesound generated bytype writers, fan, A/C, Refrigerators,*etc*.,	▪equipments must be serviced properly ▪equipment should be placed on sound absorbingmount ▪Floor, wall andceilingmust be covered

		with suitable sound absorbing materials.