

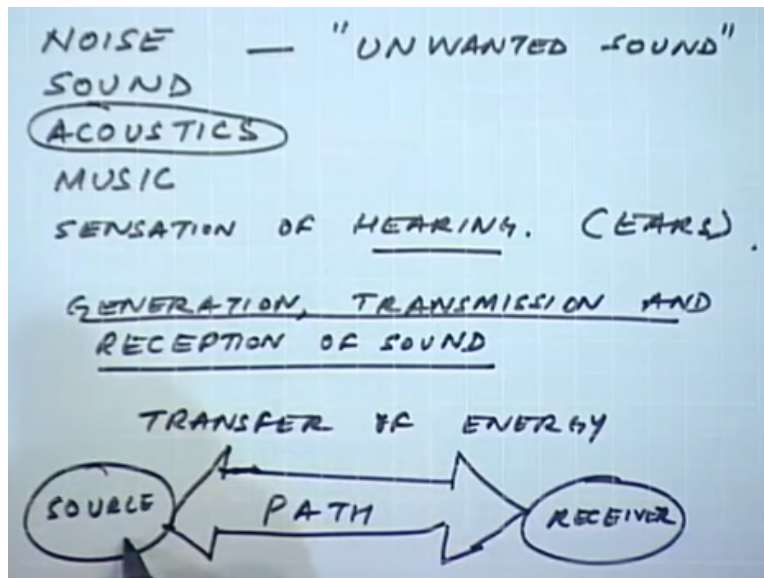
Machinery fault diagnosis and signal processing
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Module No # 05
Lecture No # 21
Basics of Noise and Noise Monitoring

In this class we are going to study about basics of noise and noise monitoring as I told you earlier in a condition based maintenance we do vibration monitoring we do motor current signature analysis oil analysis etc. Noise monitoring is a not an technique to do CBM but when a machinery develops a fault it mix abnormal noise. So noise become an indicator or an alarm to ask indicating something is abnormal with this machine.

So in that sense we will study what noise is and how noise monitoring is done towards detecting such abnormal conditioning.

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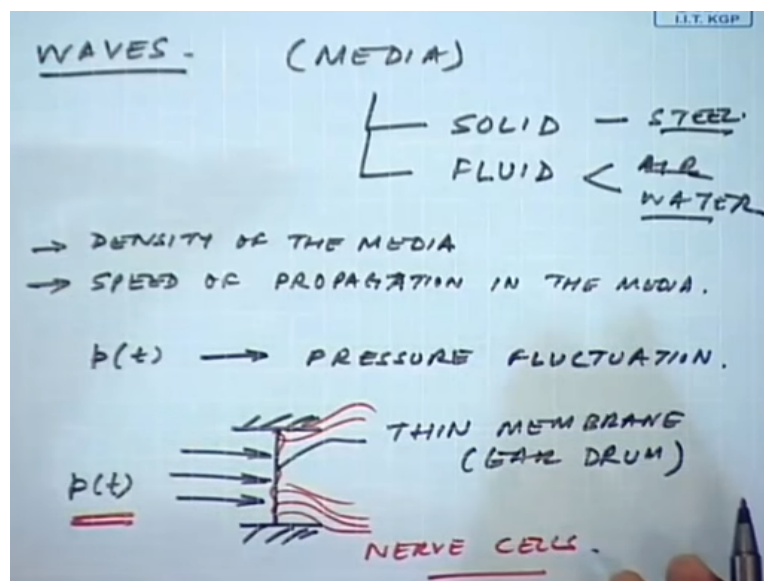
Well I have to begin with what is noise now there are very synonymy's terms in sense of noise sound, acoustics okay. If I was to define sound is some which we hear which are ears to receive we here to get the essence of hearing okay. And what is noise is very loosely you can say is unwanted sound. They say music what is music then music the sound which we initiate. Noise is

the sound which we do not appreciate okay so this is related to the sensation of hearing and this is because of god's gift to us pair of ears.

So we get the sense of hearing we hear in the sound because we have the pair of ears okay sensation of hearing because of the ears but long way between the ears and machines which we generate noise so what is this acoustics. Acoustics is a technical terms given to the field of engineering where it deals with the generation, transmission and reception of sound. This is the definition of acoustics it is science which deals with generation, transmission of reception of sound.

Now generation means basically talking about the source transmission means about the media because this sound is basically because of a transmission of energy from a source to a receiver and obviously this is a path okay. This is a path which is connecting the source and the receiver and this energy gets transferred and then what is this path as will recall from your high school physics.

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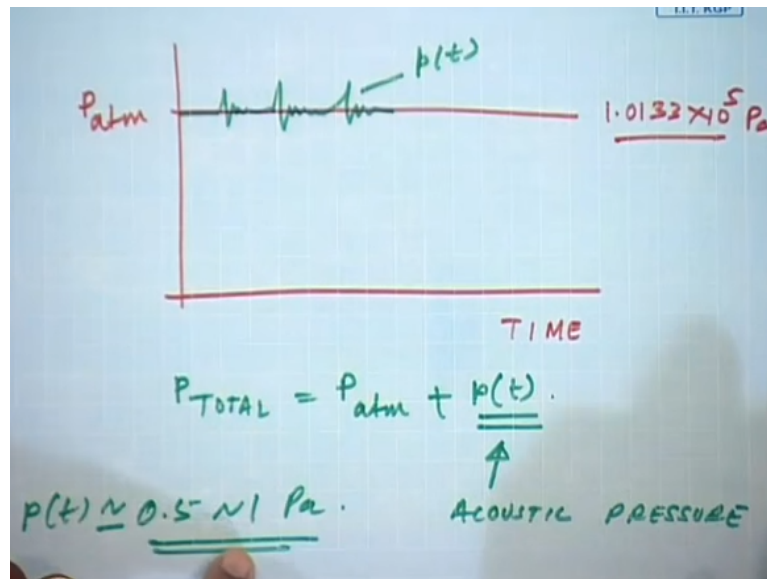


The energy is transferred as waves this waves require a medium media. This media can be solid and the fluid like him air water a steel structure everything so depending on the media depending on the density of the media. Where to parameter come into play in the propagation of the energy and transfer waves from a source core receiver to density of the media and speed of propagation in the media okay.

Now this acoustical wave of sound wave will be many wave by which it gets transferred one is where this incidentally this sensation of hearing which you sense is because of a small pressure fluctuation. Because if you look at you ear drum you know I just draw it as a brain here a thin membrane of ear drum okay. So when the surveys are incident on the small brane this membrane is going to have a small deflection okay.

And to these membrane are attached many nerve cells okay and then this goes to the brain so because of this pressure fluctuation small pressure fluctuation this membrane will undergo formation of this place and this is sense by nerve sense attached to the ear drum and then we were sensors in a earring.

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We will just look into the pressure wave for example right now our ear drum if you plot the time history of the pressure being incident on the ear drum this is nothing but the atmospheric pressure and this is about 1.0133×10^5 Pascal this is incident on our ear drum. So this is a very high values of pressure ear drum is in subjected to on top of this pressure wave if I do a (()) (07:44) this or this energy is going transmitted because of a somebody speaking because of a machinery making noise.

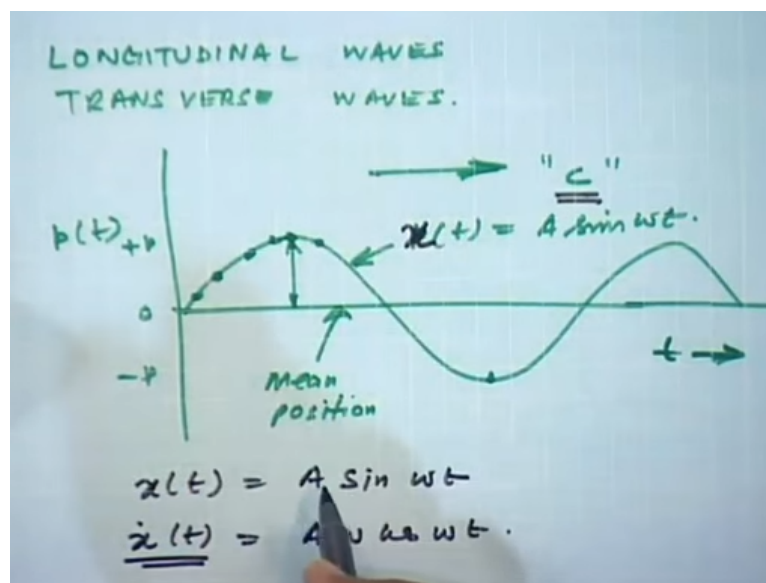
So there will be small fluctuations in some portions and this is I denote by small PT so this is the dynamic component. So the total pressure incident on our ear drum is P atmospheric + P

dynamic. And this small pressure is what is known as the acoustic pressure. This small pressure is responsible for generating the sensation of hearing. In fact I will just give you a value here right now in this room when I am speaking the atmospheric pressure is 1.0133×10^5 Pascal in the density on ear drum.

And because of my voice you may be experiencing all this about 0.5 to 1 Pascal this could be near value of PT okay. So you see the duty of ear god as made ear so sensitive over a high pressure of 1.0133×10^5 Pascal even a small fluctuation of 1 Pascal can be sense by our ear drum as disturbance as something which is incident on ear drum.

You all must have felt if you go up a high speed elevator or go up a mountain or go under the water volume or diving the swimming pool you will get a sensation of as if ear drum is popping in popping out that is because of the difference of the pressure around the ear drum. So ear drum is some sense is very sensitive to the pressure differences and on top of it on value of 1 Pascal is large enough to give sensation of ear okay.

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Now this is regarding the amplitude of the sound pressure level now if I was coming back to the waves by which the sound gets transmitted from one place to another you would have recalled in you high school physics that there are two types of longitudinal waves and transverse waves okay. If was to draw a transverse waves PT so the direction of transmission is along this direction okay.

But the particles have a maxima and minima perpendicular to the direction of propagation this is the direction of propagation and this is perpendicular it is known as the transverse flow. So this particle every particle here is oscillating about its mean position this is the mean position okay. This particles themselves do not move but they transmit the energy to the successive particle that you would have studied in the longitudinal waves.

So there is a speed of propagation of the wave front along this direction that is the speed of sound in the media but the particles themselves oscillate themselves velocity. For example if I am right down the displacement $p(t)$ as $A \sin \omega t$ I can find out if I write this as displacement some displacement extreme $A \sin \omega t$. I can find out $\dot{x}$ is nothing but $A \omega \cos \omega t$.

Mind with this is the particles velocity and which is different from the speed of sound in the media. Speed of sound means the speed at this waves front is moving and this velocity means the velocity at which the particle is oscillating which is perpendicular. Similarly in the case of the longitudinal waves we will have successive compressions and rarefactions.

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COMPRESSIONS AND RAREFACTIONS.

$p(t)$

HUMAN EAR $20 \mu Pa$
 $20 \times 10^{-6} Pa.$
 $2 Pa.$

LOGARITHMIC SCALE.

SOUND PRESSURE LEVEL

$$SPL = 20 \log_{10} \frac{p}{p_{ref}}$$

$p_{ref} = 20 \times 10^{-6} Pa.$
 (IN AIR)

So what happens because of this successive compression and rarefaction because there is increase in pressure decrease in pressure and thus the wave front is going. Here in the case of longitudinal wave the particle motion is along the direction of the propagation of the wave front.

Now coming back to this sound pressure level or pressure which we here PT now this PT is small quantity and our human ear can hear as low as 20 micro Pascal that is 20 into 10 to power 6 Pascal.

To as high as 1, 2 Pascal but if you see this scale is very large 10 to power – 6 to Pascal and that is why is felt that this sound pressure level sound pressure did not represent in linear scale but a logarithmic scale. Wherein we define something known as sound pressure level as SPL as 20 log to base 10 P is the small P reference where p reference in air is 20 into 10 to power 6 Pascal in air in water it is a different value.

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The image shows handwritten mathematical derivations for Sound Pressure Level (SPL). The first line shows the reference pressure $p = 20 \times 10^{-6} \text{ Pa}$. The second line shows the calculation for 1 Pascal: $SPL = 20 \log_{10} (1) = \underline{\underline{0 \text{ dB}}}$. The third line shows the calculation for 1 Pascal: 1 Pa followed by $SPL = \underline{94 \text{ dB}}$. The final line defines the unit: $\text{dB} \equiv \text{decibel}$.

So when $P = 20$ into 10 to the power 6 Pascal SPL would be $20 \log_{10}$ of 1 that will be 0 decibels. So I have resolved like 10 to the power – as 0 decibels and if you work out 1 Pascal could be as close to about 94 decibels. So you see by using the long scale long I have done is reduce the number from 0 to 94 decibels this is written as dB stands for decibel this capital B so small D capital B decibel .

So SPL is the magnitude of the sound pressure level is given is decibel okay now another important characteristics which will see when we have just log scale lot of properties of logarithmic addition subtraction etc., we will apply here.

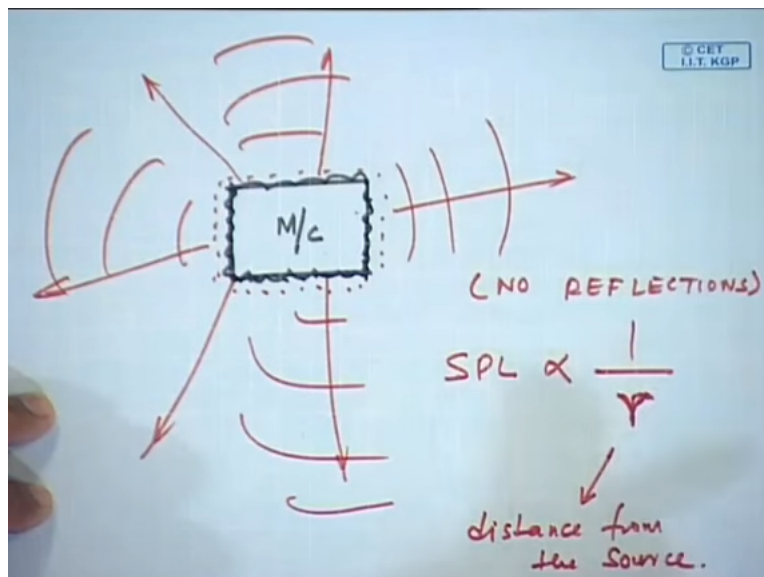
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$$\begin{array}{rcl}
 \text{Machine A} & = & 90 \text{ dB} \\
 \text{Machine B} & = & 90 \text{ dB} \\
 \hline
 \text{Both Machines operating} & = & \underline{96 \text{ dB}} \\
 \\
 \log_{10} 2 & = & 0.3010 \\
 20 \times 0.3010 & \approx & \underline{\underline{6 \text{ dB}}}
 \end{array}$$

For example suppose I have a machine A which is making a sound pressure level of 90 decibel I have another machine B which is making 90 decibel so in both the machines are there the total level will not be an arithmetic average of $90 + 90 / 2$ it will be not 90 decibels it will not 94 decibels it will be close to 96 decibels because you know log of 2 to the base 10 is 0.3010 times 20 will be close to 6 decibels.

So adding to sound level of the same sound pressure level will be the level will increase to 6 decibels okay.

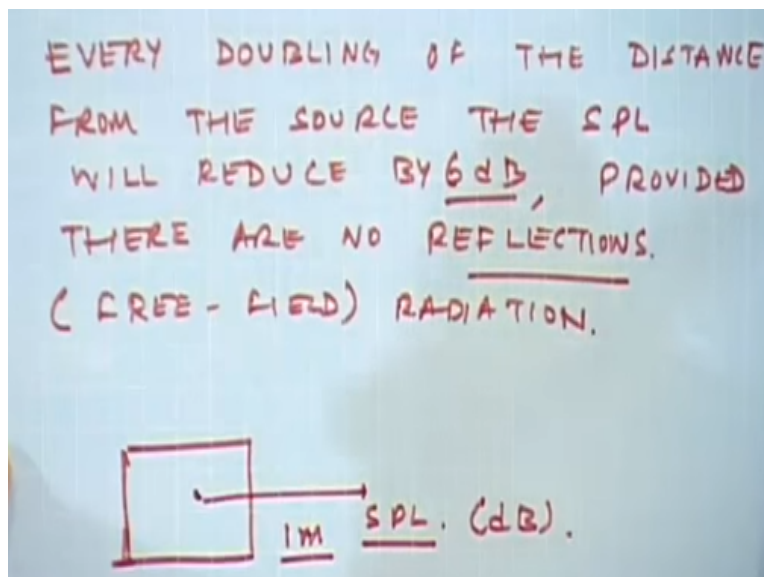
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Now this sound pressure level is suppose I have machinery here this is generating how is this sound generating? Because the machine is dynamics so these particles about the machines are going to have a vibration okay. So the air molecules next to it are going to have a particle velocity is close to this surface of course that depends on the radiation efficiency etc.

So once these particles are having an energy they are now going to Exide or radiate in all direction okay. But you will see that sound pressure level suppose there was no obstruction there would go down they would go in one particular direction all direction in fact and imagine this to be a spherical source they would radiate sound in all directions. But you will see this SPL is proportional to $1 / R$ distance from the source okay.

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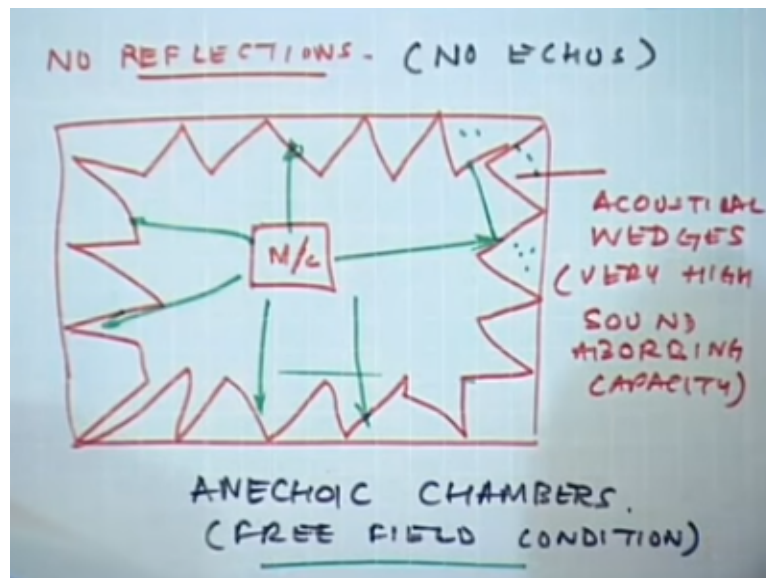


Provided there are no reflections that means with every doubling of the distance from the source the SPL will reduce by 6 decibels provided this is very important there are known reflections. And this no reflections means free field radiation okay. So if I want to find out the sound pressure level radiated by every machine I can always take them to an environment where there are no reflections and then there is rate of this distance.

Usually the standard is about 1 meter from the source you measure what is SPL less decibel the reason you will see later on in the field of acoustics is why they prefer this one meter is in a SPL in the free feel conditions whatever is the SPL and decibels you have that same will be the sound

power level you know in the radiation will be 1. I will not go into the details of sound pressure level but provided there are no reflections.

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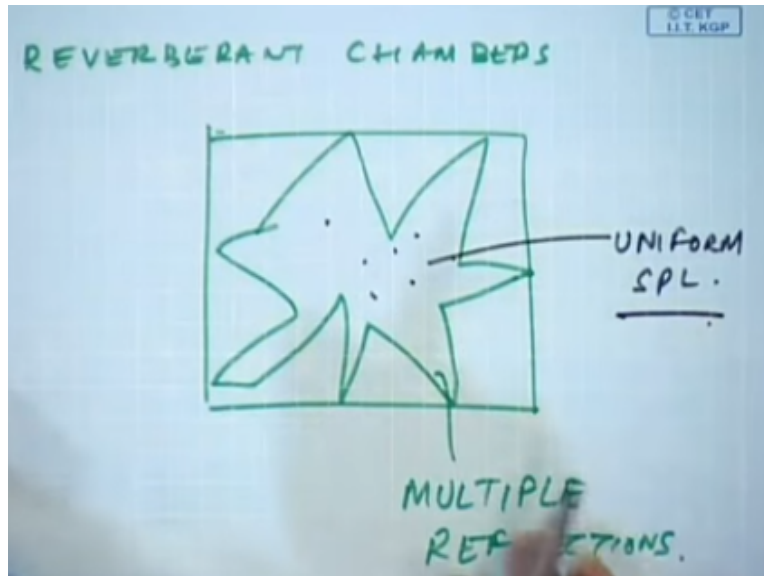


Now what do you mean by no reflections so how do you ensure that there is not reflection so we have to have certain boundary conditions suppose this is the room we research generating sound and every direction we have to ensure that there are no reflections so such rooms are no echo's or there is known as the Anechoic chambers wherein free field condition exist.

As there are special chambers wherein we like they have like wedge's all around them and this are actually acoustical wedges having a very high sound absorbing capacity what i will say right now. So any wave which goes in here gets reflected and gets trapped in the material and this is free feel condition okay. So when we do the in all labeling of product or want to find out the sound radiated by the machine we usually test them in such an Anechoic chambers okay.

In fact people test vehicles in such chambers now in fact they put a grating here and then the drive in a vehicle revert up and measure the sound pressure level radiated by in fact the same phenomena is used in a acoustical I mean the electromagnetic absorption of a radars. Such chambers also there in the radar information's chambers wherein the test antennas are there.

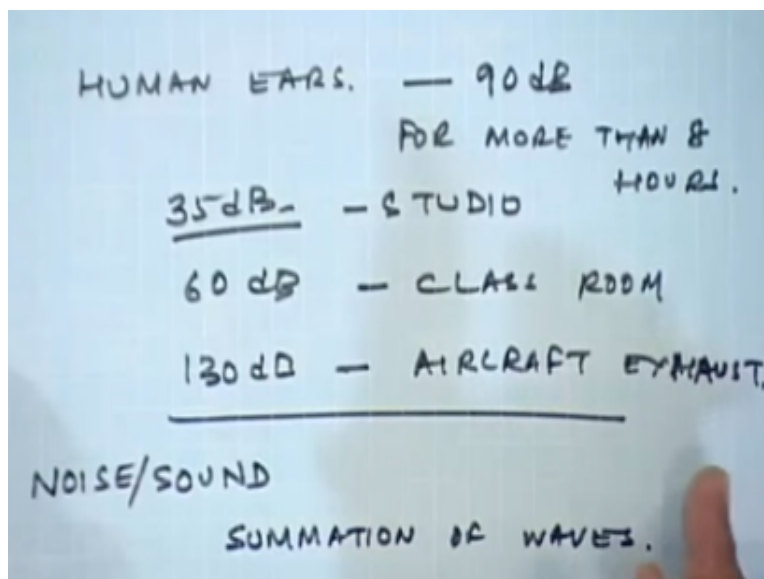
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And opposite to chamber is what is known as reverberant chamber wherein the walls are very very halls there are lot of multiple reflection I will not draw all the multiple reflections and because of multiple reflections anywhere you measure the sound reflection levels there will be uniform SPL okay and such chamber are used to acoustical testing etc. But we will not discuss them in detail this is suppose what reverberant chambers are.

Now coming back to the discussion on sound pressure level so we are just talked about the magnitude of the pressure.

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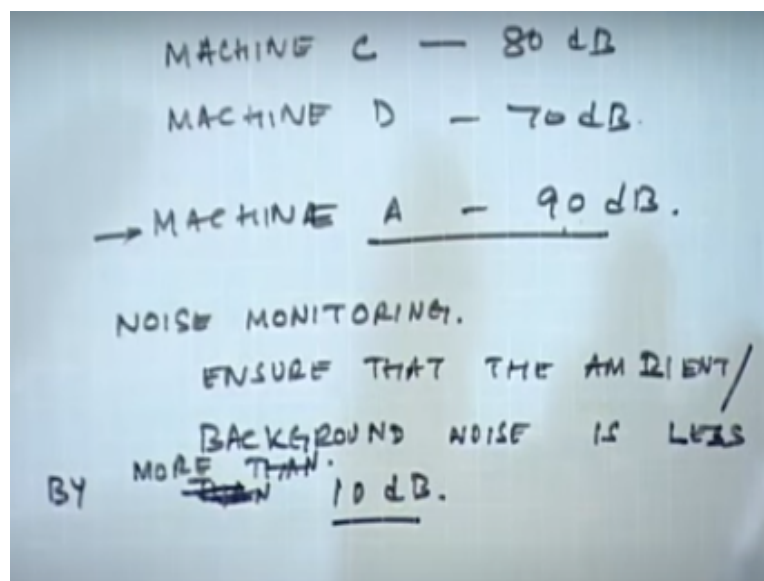


And you know human being human ears can withstand not more than 90 decibel in fact it is recommended for more than 8 hours. In fact in this room I am talking in this studio it is a very quiet studio if the studio nobody is speaking this level could be a 35 decibel in this recording studio okay. Now one somebody speaking comfortable classroom this could be about 60 DB classroom studio and the aircraft takes off this could be about 130 DB.

So you can get a feel of the noise level which we are talking about my question about you would have seen that noise or sound their waves. So at any locations this sound waves would be adding up themselves. So we will have a summation of waves like you say an example when you have a machine device in 90 decibels another machine giving 90 decibel we have the overall decibel level of 96 decibels.

For example I was to monitor the sound radiated by a machine do I need to another machine next to it is running obviously your answer would be everything I should be quiet we should be only running the machine whose noise is to be measured.

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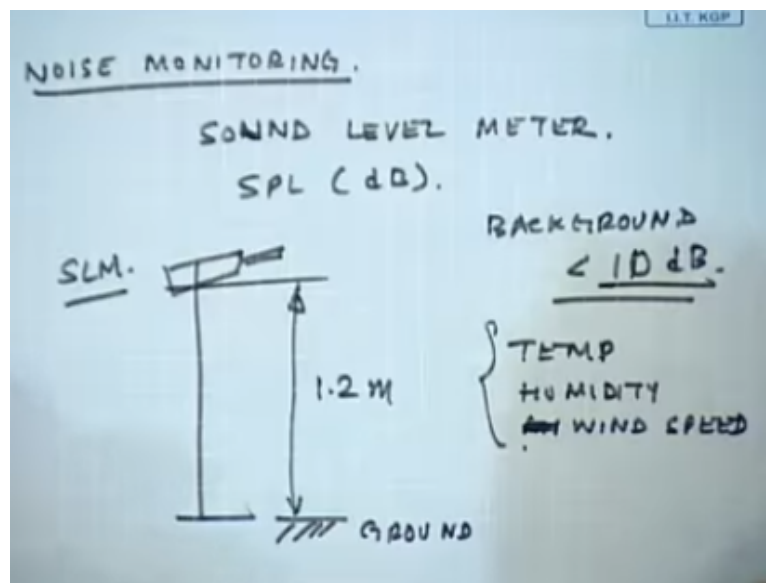


Now you would have seen from this logarithmic scale if one machine, machine C generated 80 decibel machine B generated 70 decibel and machine A generated 90 decibel. The presence of the machine is so loud because it is 90 decibel the presence of 70 would be raised about 90.0 you know some small fractions same is to about 80%. So the presence of machine with an level 10 DB less or 10 DB less or more does not affect the machine.

For example there is a 90 degree machine 80 degree presence or a 70 degree presence is not going to effect a overall value of this machine. But if there is 90 and 90 and 85 I need to be get worried so anything is less than – 70, 90 – 80, 90 – 60 need not worry so whenever we do noise monitoring of machines we have to ensure that the ambient or diagram noise is less than 10 DB. However less by more than 10 decibels okay.

So in a room if was to measure the noise radiated by a overhead projector may 40 decibel the ambience noise level is 20 decibels, 25 decibels am okay but then I can say the projector made in a 40 decibels noise but if the am mean noise is 25 decibel I will say the projector is making 50 decibel it should be around us. So it is always it is good measure the back ground noise level and back ground noise level should be less than less by more than 10 decibels okay.

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So always I will check and then there are certain ground rules like when we do a noise monitoring okay. The measurement is done by a sound level meter which has a microphone which is built in circuit which is given a SPL in decibel. Now the rule is the convention is the SLM should always be at a distance of about 1.2 meter from the ground okay. And again ensure that the background will be less than 10 decibel okay. That is only one thing we have to take care.

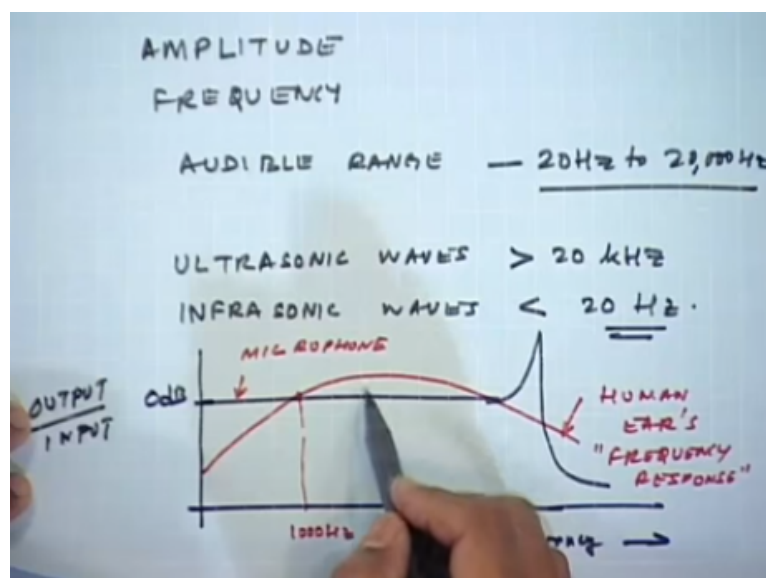
And another important parameter which we want to report is of course the temperature the humidity the wind speed because these parameters may affect the speed of sound. Because you will see the speed is dependent on the temperature of the propagation.

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$\text{At } 20^{\circ}\text{C}$
 $c = 341 \text{ m/s. in air.}$
 $\approx 1500 \text{ m/s (water)}$
 $\approx 5000 \text{ m/s (steel).}$
 $\rho_{\text{air}} = 1.2 \text{ kg/m}^3$
 $\rho_{\text{water}} = 1000 \text{ kg/m}^3$
 $\rho_{\text{steel}} = 7800 \text{ kg/m}^3.$

In fact at 20 degree Celsius the speed of sound of meter is 341 meter per second in air okay. This sound in water this is about 1500 meter per second in water in steel it is close to about 5000 with density the speed of sound is also increasing okay. Something we have to keep in mind and density of air is 1.2 KG per meter cube density of water is 1000 KG per meter cube next is steel 7800 KG per meter cube the certain value have to keep in mind.

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Now we have just discussed about the sound pressure level in terms of amplitude but again our ear has been made by god. This sound is also a wave so it has amplitude and it also has a very important point is frequency. So the human ear has an audible range which is from 20 hertz to 20,000 hertz so we can hear any sound which is in the band of 20 hertz to 20,000 hertz or 20 kilohertz.

So those which are above 20,000 hertz or 20 kilohertz are known as ultrasonic waves greater than 20 kilohertz and ultrasonic waves are less than 20 hertz okay. But again like anything linear instrument you would see the frequency response of an instrument. So this is the amplitude ratio output by input will be 1 or 1 in log scale would be 0 decibel because the log of 1 is 0. So this is typically the response of any instrument and this happens to be its mid frequencies okay.

If we think of our human ear unfortunately god has made our human ear is highly non-linear it is not affected just like this life would have been very easy to us. But the human ear's sensitivity is somewhere like this okay and this is about 1000 hertz I would say frequency response is sensitivity. Maybe wondering how I generated such a way from now these are found in the early 900 speakers' people have done experiments with human subject and this is what we found out at the subject the human ear response like this.

So we hear poor at low frequencies and so on okay and this is what is known as the so a so any instruments suppose I use this I use to measure this ground level with microphone okay. I will super impulse I will do this weighting function on this microphone measurements it is known as the human weighting okay. So and these bands these could be divided into octave bands okay.

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OCTAVE BANDS

$$f_u = 2f_l$$

$$f_c = \sqrt{2 f_u f_l}$$

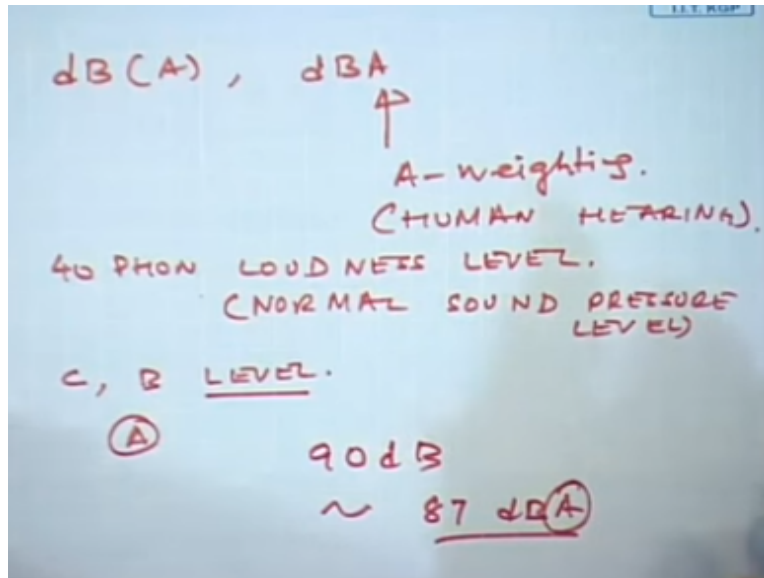
WEIGHTING CORRESPONDING TO HUMAN EAR IS APPLIED.

Oct Band	Weighting Factor (A)
63.5	
125	
250	
500	
1000	0

So you know about the octave bands are these frequency bands where the F upper is nothing but twice of F lower okay and this total frequency is root to of okay. So in every octave band and such weighting's corresponding to human ear is applied okay. If you go into the hand books you will see for every octave band where the weighting factor is and this is known as the A weighting factor okay. So 63.5 125, 250, 500 etc., for all these octave band you will see what the weighting factor is.

But for 1000 hertz this is about 0 so there will be subtraction so this weighting well are applied 2 to the frequency spectrum of octave from the sphere and then we can get what is known as the DBA.

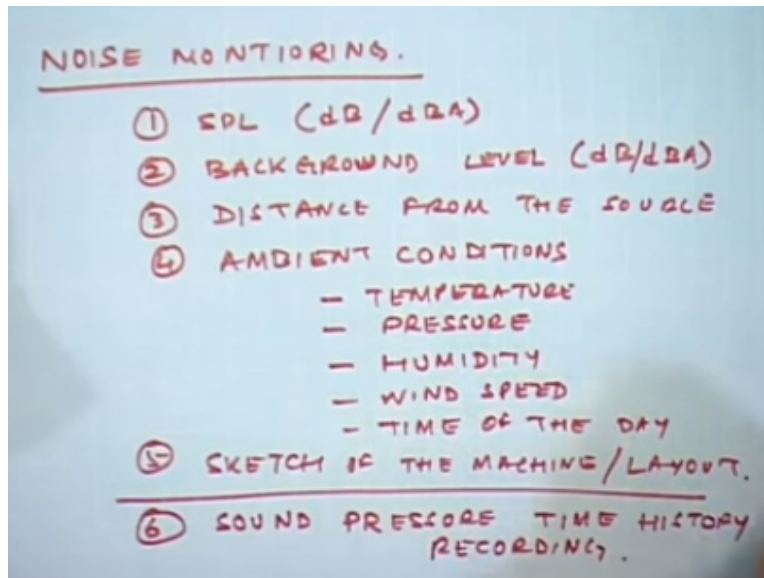
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This means the A weighting because of human hearing and this is measured at a 40 phon loudness level and that corresponds to normal sound pressure. When the levels are high for example if we are talking about aircraft take off you know very large noise level you can there also a C level in B level. But the international convention as to be used to be A weighting if all A weighting has been written same 90 decibel could be 87 decibel dBA because this means this has significant low frequency levels okay low frequencies are there.

So when ever A weighting I was given weighting it has been corrected to human hearing because if I give a measure value without the A weighting it may not related well with the sense of hearing because the dB is what microphone would have given me. But I would perceive dBA so this weighting factor as to be given so that I get the correct sense of hearing is correct sense of the sound level which I am measured okay.

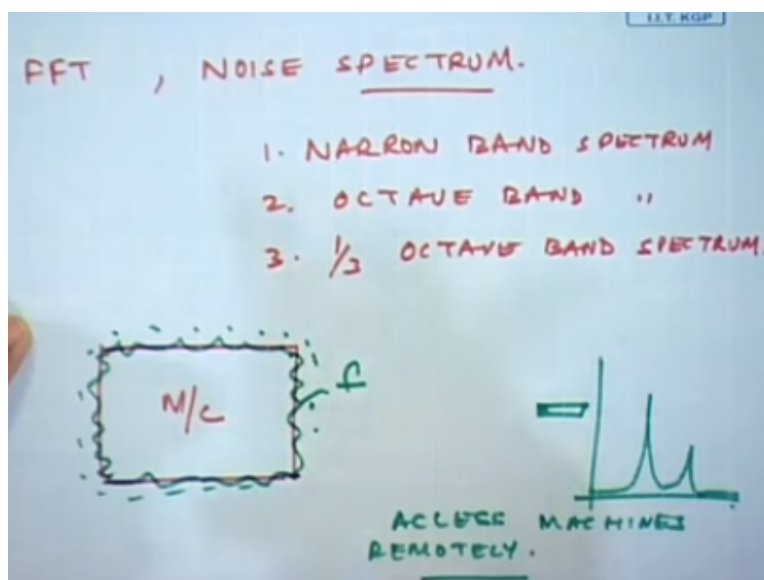
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Now let us talk about the acoustical measure for example so in if noise monitoring I have to ensure what of equipment or the machine what are the things I have to report one is the SPL level either DB or DBA next is the background level DB or DBA very important is distance from the source. Number 4 is the ambient condition that is temperature pressure humidity means speed of course time of the day.

Sketch of the machine or the layout okay so for every machine I could be doing such measurement of a machine and keep it on a record okay and later on for diagnosis sometime we may do the sound pressure time history record it and store it with us.

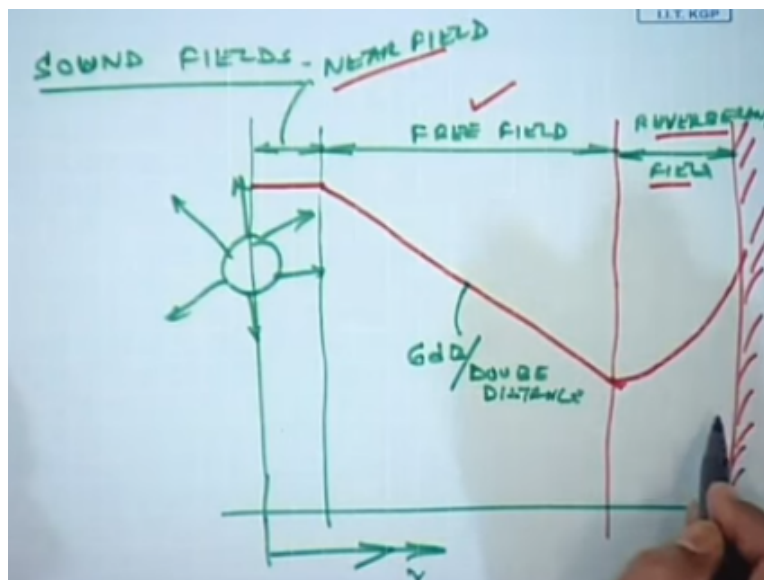
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For example we can still apply the techniques of FFT to get what is known as the noise spectrum. Now this spectrum could be a NARROW band spectrum or it could be an octave band spectrum or a one third octave band spectrum okay. Now this helps us diagnose the problem for example if you recall I was talking about the machine if this machine vibrates this will be vibration at frequency F and the particles next to it also vibration at the same frequencies.

So sometimes it may not be possible for us to diagnosis to even go near the machine may not be accessible but at a remote location I could be just putting an microphone and then doing the NARROW band spectrum and then maybe I will find out the running speeds of the machines. So noise monitoring also gives helps us act remotely okay.

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Now let us talk about the noise fields or sound fields I had talked about the machine which is radiating in all directions. So at draw with a distance very near the machine the $1/R$ law may not be followed and this is about the half or this distance is what is known as the near field and then the sound level may be a constant but this red line and then what happen with distance this is going to come down by 6 decibels and then towards the if this is a boundary.

Now this level has happen so there are three distinct level so this is the near field and this is the free field and this is the reverent field here you will be drop by 6 DB and double the fields and this is the distance R okay. And so always a good area to measure at the as I was telling you in the free field measurements so in this noise monitoring will also like when you say distance from

the force when you also say whether it is an free field or far field near field and always of about reverent field.

So in a shop floor you can move here sound level meter of microphone away from the source and see from the 6 DB decrease is there in this and whenever they try to increase you know they are close to the walls the river bands reverent field. Like would have seen if you go to the corner of the classroom and speak because of the reflections in the wall the sound pressure level will increase okay and this is what we need to measure in.

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SOUND POWER LEVEL (SWL)
SOUND INTENSITY LEVEL (SIL).
$$\underline{SWL} = \underline{SIL} \cdot (\text{NORMAL AREA})$$

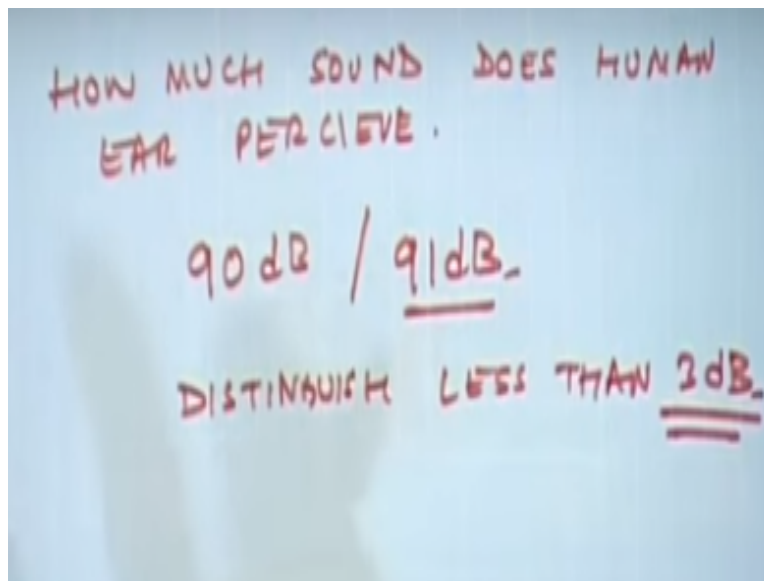
SWL WILL NOT CHANGE WITH
THE ENVIRONMENT (FIELD).

There are few other terms associated with the sound pressure level or in noise monitoring one is the sound power level denote by SWL sound intensity level SIL okay. And the sound power level I nothing but the sound intensity level times the normal area okay there are instruments to measure sound level intensity level and then knowing the area you can found out the sound power level.

The advantage of using sound power level is sound power level of machinery is not going to change with the environment. SWL will not change with the environment or field so when I label a product to certain sound power level it is going to be same it is an location A, location B, location C so it is very easy to characterize the machinery in terms of this sound power level. If something is wrong with the machine it sound power level will change.

Well the measure sound power level it is a very involve process so I may be not be very easy to measure the sound power level in-SITU at a location but never the less there are methods lot of sound intensity level by which we can measure the sound power level but the sound pressure level if you measure to monitor the health of a machine we have to tell the field condition the distance condition source and then ensure the background is less than the more less by more than 10 decibels okay.

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Now how much sound does human ear can perceive if a human ear was to sense 95 90 decibel and 91 decibel it will not be able to do that a human ear cannot distinguish less than 3 decibels that something we have to keep in mind you would have done an noise control and brought down to 90 to 95 decibels 92 to 90 decibels we may perceive okay. To make a significant difference it has to be more than 5 decibels okay.

So when we talk about alarm you know sometimes you know mere difference of 2, 3 decibels will not be noticed by an human ear okay. So we have to keep in mind so sometimes during noise monitoring there are machineries are there are online analyzers we will tell you the exact sound pressure level okay sometime this numbers may be guide us to give us the better feel of the machine condition.

So to summarize in noise as that right in the beginning is not used as a parameter perceive to do condition monitoring of machine but for the fact that the give us indication that is something

abnormal machine we need to study noise and mean to know how the background machinery is noise level can be measured and the important of A waiting why the numbers of A waiting are there and what is there frequency okay thank you.