Fundamentals of Acoustics
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Lecture – 03
Nature of Sound

Hello. Welcome to Fundamentals of Acoustics. Today is the third day of the first week of this particular MOOC. My name is Nachiketa Tiwari, and what we are going to discuss today is continuation of some of the fundamental ideas around sound. And specifically what we are going to discuss today is a little bit more about the nature of sound.

So, we had discussed in the last lecture and in the lecture before that one that sounds is essentially a wave which is propagating in an elastic medium. And that too specifically what we will be discussing in this particular course is that sound is treated as a pressure wave and it propagates in a medium. And this particular wave is specifically when we look at fluid media for instance in air or in water it propagates as a longitudinal wave.

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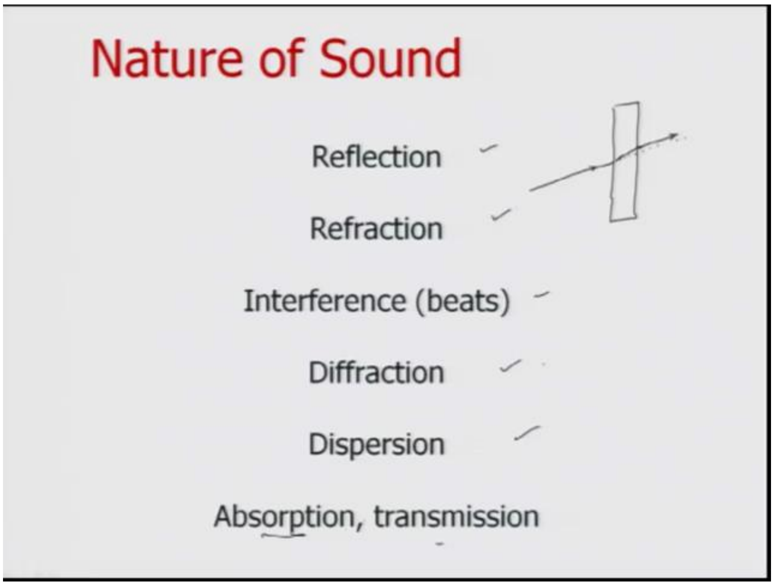

So it is essentially it is a wave, and we know that waves exhibit several important phenomena which are not observed by particles. So, there are two realities in nature when we have particles and you have waves. So, waves undergo reflection which means that if you have a wall and a wave hits it then it will get reflected, and when it gets reflected it follows the law that angle of incidence is equal to angle of reflection.

The other phenomena which waves observe are that they undergo refraction. So, essentially again if you have a transparent media that is a media through which a wave can get propagated, so it comes and hits the second media and once it does that it changes that angle direction of it is path so it gets refracted. And then when it enters the third media it again changes it is direction of path. So, that phenomena is known as refraction. So you have let say transparent media, and transparent in the sense that the way which we are talking about in this case is sound wave, so it comes at a particular angle and this would have been it is normal direction but then it changes it is direction. So, it may do this and then again it can do this. So, it is change in it is direction is known as Refraction Phenomena.

Then we know that waves can interfere with each other. So, we have two waves a three sources producing waves and they interact with each other at a point p far away from resources. And the behavior of the total wave which is perceived by the human ear or a microphone at that far point p is essentially a consequence of summation of the influence of each of these individual waves. And as a consequence of interference we have several physical phenomena and one of these phenomena is known as beats. And in case of beats what you have is that there are two wave sources and the frequency of both of these waves is fairly close to each other, and when these two interact with each other then you hear beats.

Then you have the phenomena of diffraction that is when waves hit the corners they bend around corners, then dispersion. And then as waves propagate in a media the energy of the wave progressively gets absorbed, so that is an absorptive phenomena. And of course they get transmitted in a media. So these are important characteristics of waves; reflection, refraction, interference, diffraction, dispersion, absorption, transmission, and sound waves follow; all these phenomena. So, all these phenomena can be observed in context of sound waves as well.

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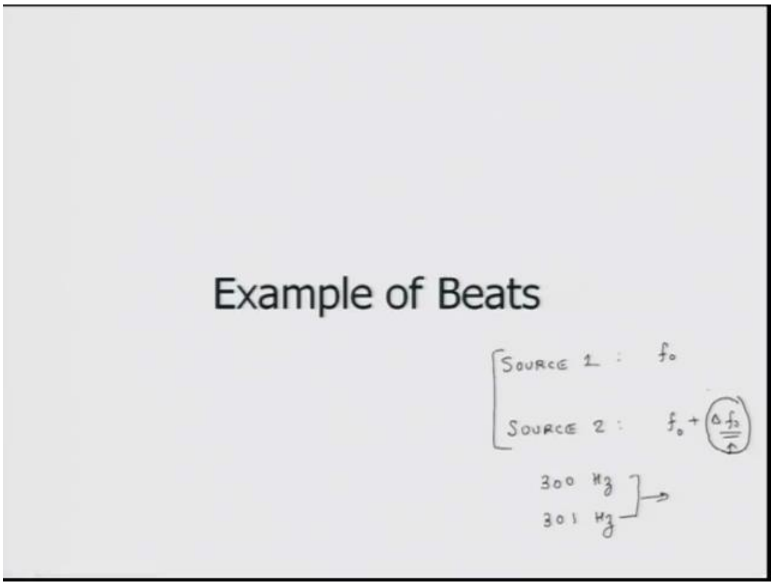

So, now what we are going to look at is an example of beats. So, what I had mentioned was that if you have source 1 and let say it is frequency is f naught; so it is a harmonic wave, monotonic wave. And then we have another source, source 2 and it is frequency may be f naught plus delta f naught. So, this delta f naught is a small change in frequency. So, when these two sources interact what the human ear perceives is as a beat. An example could be there could be a source vibrating at or producing 300 hertz wave and there could be another source which is producing 301 hertz wave sound. And when these two waves interact the net effect is that of a beat.

Let us listen to. So, the first thing I am going to play is a 300 hertz clear tone; can we play it again. So, this is the 300 hertz tone. And the next tone I am going to play is a 302 hertz tone; I am going to play it one more time. So, this is 302, this is 300. As far as the year is concerned you would have felt that there is not much difference between the natures of these two tones.

Now what I am going to do is; I am going to play these two tones together. So, I have crafted a wave signal which is an addition of these two tones, and this is what you will hear. So, one more time; I will play it one more time. So, essentially what you are hearing is that the tone is same then it is, but it is amplitude goes up and it goes down and it goes up and it goes down. And the number of times it goes up and it goes down in one second is essentially related to the difference between the frequency of the first wave and the frequency of the second wave. So, it is related to this difference in frequency that is delta f, it is related to this delta f number.

So if this delta f is large, then it will go up and down a larger number of times in one second, if this delta f is small then it will go up and down lesser number of times. So, this phenomena is known as Beats. And what we have seen just now is through demonstration that sound waves interfere and if their frequencies are very close to each other then we also see these phenomena of beats.

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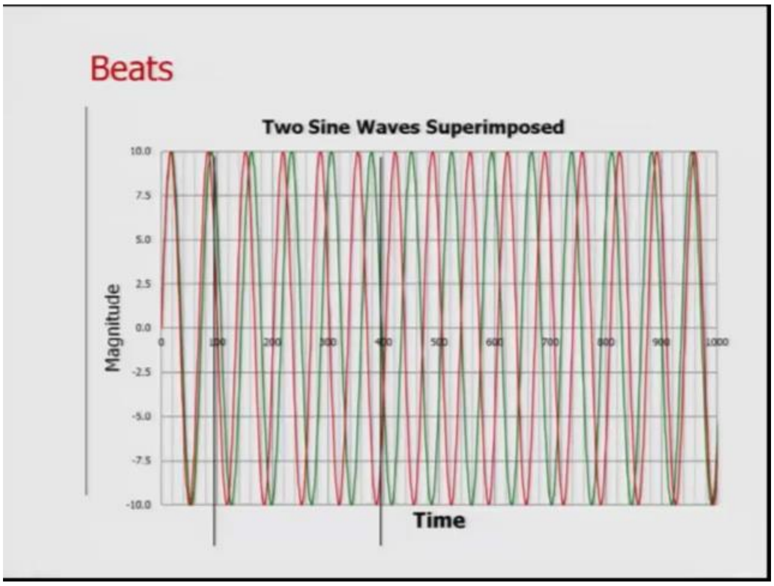

So, this is mathematical representation of these waves. So, what you hear see in this picture are two waves, so one wave is pictured as red and the other one is green. And their frequencies are just slightly off. So, in the beginning you have the two waves coinciding with each other, but as time progresses the difference between the green curve and the red curve becomes significant and then after that again it starts becoming less and again it starts becoming less and slowly it starts merging.

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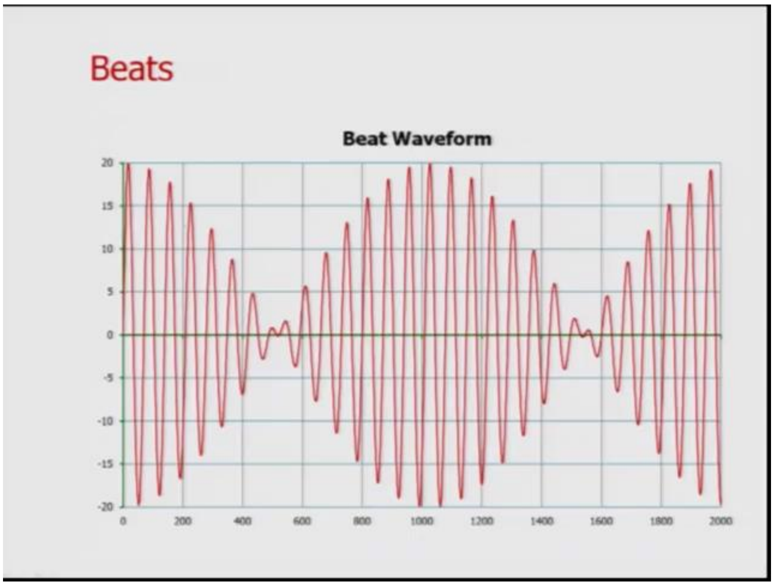

So, when I add up this red curve and the green curve this is the wave form I get. So, this is the summation of the red curve and green curve. The frequency of these two waves is fairly close to the original frequencies. So, in that case we have heard 300 and 302 hertz. So, this frequency will be 301 hertz. But then the amplitude of the wave it goes up and goes down and up and down and so on and so forth. And it is just this fact that at certain points of times two waves constrictively add, and at other times they add up in a destructive way; so the amplitude goes up and down progressively and that is why we hear the beat wave form.

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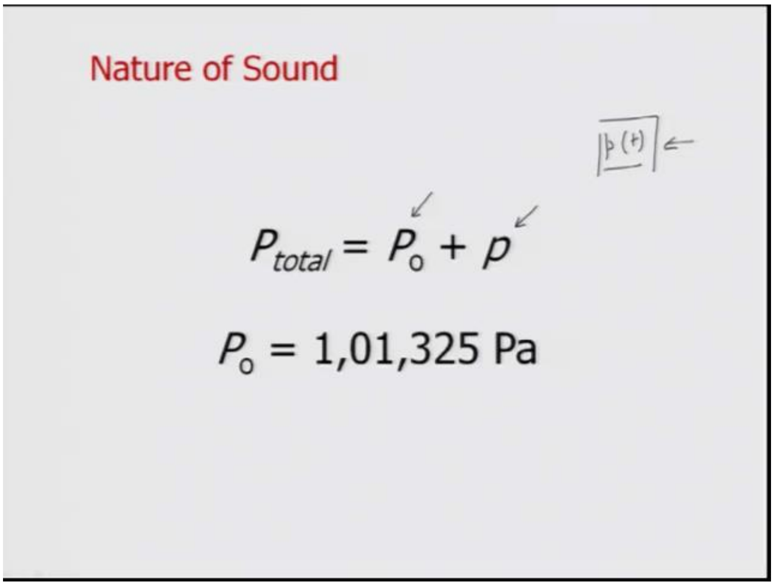

So, now we will discuss another concept and that is again is very specific to sound waves. So, we have explained earlier that if I am in a room and if there is no sound then the pressure in the room is P naught and when there is a sound source then the total pressure in the room it changes by an amount p where this small case or lower case p is a function of time it changes with respect to time. So, this pressure fluctuation is associated with sound propagation.

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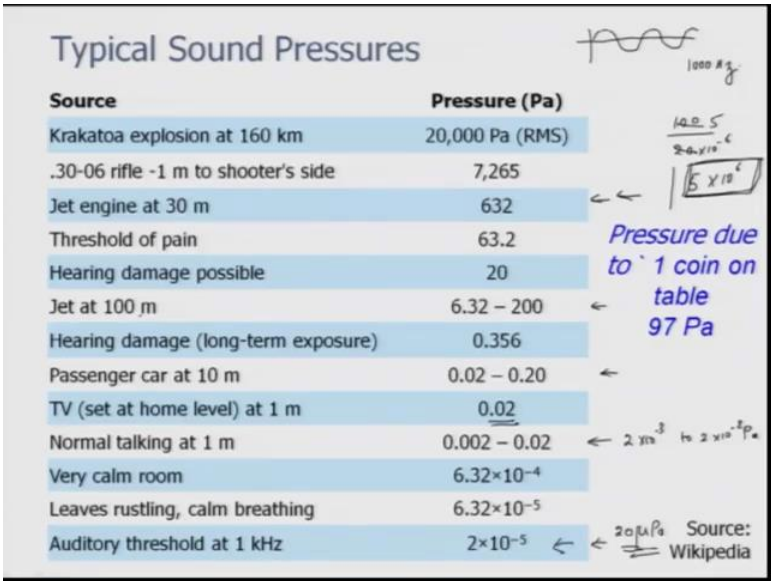

Typical Sound Pressures

Source	Pressure (Pa)
Krakatoa explosion at 160 km	20,000 Pa (RMS)
.30-06 rifle -1 m to shooter's side	7,265
Jet engine at 30 m	632
Threshold of pain	63.2
Hearing damage possible	20
Jet at 100 m	6.32 – 200
Hearing damage (long-term exposure)	0.356
Passenger car at 10 m	0.02 – 0.20
TV (set at home level) at 1 m	0.02
Normal talking at 1 m	0.002 – 0.02
Very calm room	6.32×10⁻⁴
Leaves rustling, calm breathing	6.32×10⁻⁵
Auditory threshold at 1 kHz	2×10⁻⁵

Now, we will look at some of the values of P. So, what this chart shows are they are typical sound pressure levels associated with different types of sounds. So, imagine a room where there is no sound at all and then we generate a very sound source; we generate a very small amount of sound which our ears are barely able to listen. So, initially there is no sound in the room and then we generate a very same tem sound which our ears can barely listen to; just listen to it.

Typically, the pressure fluctuation associated with this type of sound which our ears can barely listen to and it is about 2 into 10 to the power of minus 5 pascals. So, what is this pressure? The pressure is; so what I am saying is that initially there is no sound in the room so the value of lower case p is 0. And then I produce a sound wave let say it is harmonic and it is frequency is 1000 hertz. And the amplitude of this wave is such that the RMS value of this one 1000 hertz tone is 2 into 10 to power of minus 5 pascals.

So, this sound pressure level is the minimum sound which most of the human ears can perceive. Some called human ears may be able to perceive a little lower levels, some a little higher levels, but on an average. This is the bare minimum level on an average which human beings can perceive and that pressure fluctuation the RMS value is 2 times 10 to the power of minus 5 pascals or 20 micro pascals. So, that is the lowest level of sound which human ears can perceive.

Another example: if there is silent room no noise sources and let say I am talking in this room and I am not shouting or I am not talking at too lower level then the pressure fluctuation associated in an RMS sense root mean square sense is about 0.002 to with 0.02 pascals. So, the minimum pressure is 20 micro pascal here we are talking about 2 into 10 to the power of minus 3 pascals to 2 into 10 to the power of minus 2 pascals.

If I have a room and I am playing TV at some normal level and let say I am 1 meter away from the television, the pressure fluctuation it is RMS value is about 0.02 pascals. If there is a passenger car I am on a road highway and there is a passenger car driving at some normal speed and I am 10 meters away from the road then the pressure fluctuation is 0.2 pascals to 0.02 pascals.

An extremely loud noise, let say associated with let say associated with jet engine could be 6.32 to 200 pascals. And if I get closer to jet by a factor of three, so here I am 100 meters away now I am only 30 meters away. The same jet because I am closer the pressure fluctuations near my ear will be higher there will be something like 632 pascals. So, the point what I am trying to make is that the range of sound pressure levels can be as low as 20 micro pascals and in most of the cases they can go as high as a few hundred pascals. So, upper limit let say is 100 pascals and the lower limit is 20 into 10 to the power of minus 6 pascals; so that means, that the overall pressure range is something like 5 into 10 to the power of 6 the ratio.

Now, if I have to plot on a graph paper this large pressure range where the lowest pressure is 20 micro pascals and the highest pressure is a few hundred pascals. And if the scale is a linear scale then the graph will become extremely large, because I have to cover a range of 5 times 10 to the power of 6 the ratio of minimum pressure to the ratio of maximum pressure. So, graph is going to be physically very large. I mean even if 20 micro pascals is 1 centimeter it will be several kilometers long in length.

So, physically to represent sound and it is entire scale on one piece of paper or one laptops monitor using a linear scale is not possible; it is not possible or it is not practical.

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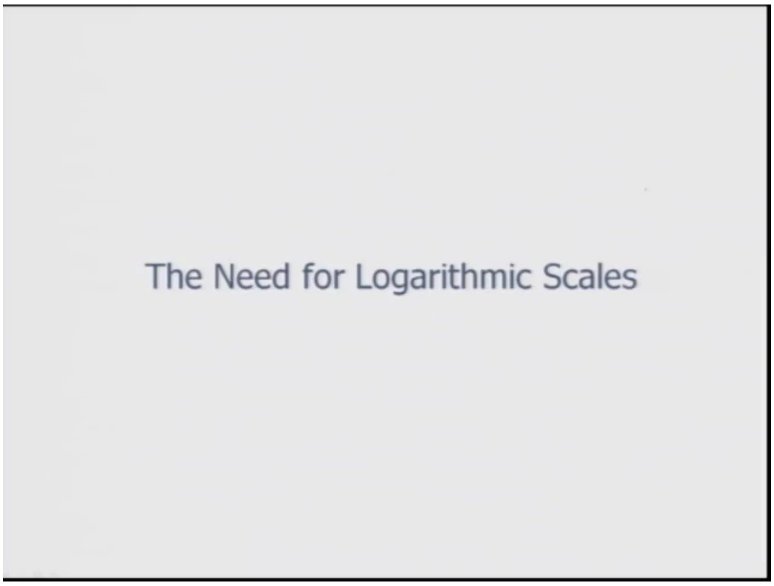

So, for that reason we use a logarithmic scale to plot pressures. So, whenever we plot pressures for sound we plot it on a log scale. And what that log scale is we will discuss that later, but at this point of time it is sufficient to understand that the fact that we have to handle a very large range of pressures as low as 20 micro pascals to as high as 100 pascals to handle such a large range of pressures we need a log scale so that we can manageably handle these this large range.

The second thing is that a large number of plots, whenever we plot sound pressure level on one axis we plot pressure and on the other axis we plot frequency. So, frequency also spans a very large range. For the human ear the lowest possible frequency which typical human ear can sense is something like 20 hertz. And at the high end if you have really good ears we will be able to sense as high as 20,000 hertz.

So, again it is a very large range. So, 20 hertz to 20,000 hertz it is again the range is three orders of magnitude. So, once again putting all these frequencies on one piece of paper using a linear scale becomes impractical. So, that is why again whenever we plot frequencies in a large number of cases especially if we are plotting the entire range we use a log scale. So, that is the reason that whenever we plot frequencies we typically plot them on a log scale, whenever we plot pressures we once again plot them on a log scale.

The third thing, the last point I wanted to make in this particular lecture is we can measure sound using three parameters.

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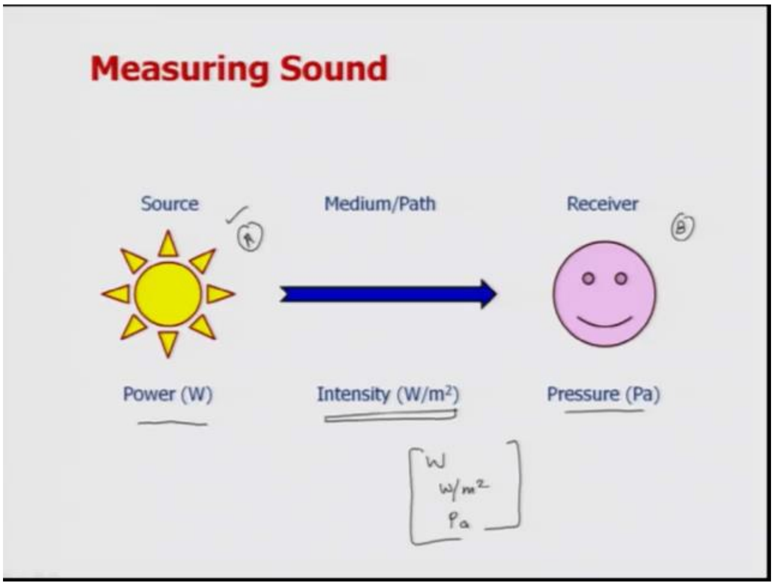

So, when sound is propagated actually three things are happening it gets generated at a source which is indicated here. Then it travels in a medium which would be air or water or steel. So, there is a source which is point A and then there is a receiver which is point B, so sound is travelling from point A to point B. And then at the receiver end it gets listened to or recorded either by a human person or an animal or a microphone or some device.

So we have a source, we have a medium and a path through which sound gets propagated and then there is a receiver. And based on this there are three ways or in three ways we can measure sound. The first one relates to how much power is being generated when sound is being produced. So, we can measure sound in terms of power. The other parameter is we can measure sound in terms of intensity. So, what does that mean? That when sound is getting propagated across a particular area. How much power is flowing out of that area? So, that is known as intensity. And the units are watts per square meter.

And finally, there is a receiver and at the receiver end typically people are interested in how much pressure is generated either at the location of the microphone or at the location of ear. So, the unit of measurement is pascals. So, we can measure it in watts or watts per square meter or in pascals. So, these are three important parameters. And once again when we measure sound we initially measure it in watts, but then we later somehow converted into logarithmic units. The same is true for intensity as well as for pressure.

So, this brings us to the closure of today's lecture and we will continue this discussion tomorrow. Have a great day and I look forward to seeing you tomorrow.

Thank you.