Basics of Noise and Its Measurements
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Lecture – 42
Weighting

Hello, welcome to Basics of Noise and its Measurements. Today is the last day of this week. What we have discussed in this week till so far is, we started with discussing some of the important considerations for related to how we go around choosing different equipments for our noise measurement and other important considerations while we are taking these measurements. Then, we did something different and that is how to measure impedance of a material with unknown impedance.

And, we discussed this two microphone method; and, the difference between this method and the method which was discussed couple of weeks earlier was that, here these two microphones did not move. So, that is an advantage. And then, we discussed octave bands. And, at this point of time, I think now we are ready to start discussing this whole concept of weighting. So, that is what we will discuss today.

And, let me give you a basic understanding of sound as it is perceived by the human ear. And, that is why things like weighting become important. It just so happens; that is how we have designed as human beings that, even if the pressure level of sound is seen let us say for 10 Hertz, 100 Hertz and 1000 Hertz. Let us say it is 1 Pascal. So, I am playing a speaker; and, it is generating sound pressure level of 1 Pascal at 10 Hertz. And then, I am playing another sound; and, there also the sound pressure level is 100 Hertz is 1 Pascal. And, let us say the frequency is 100 Hertz. And, in the third cases, I am playing a third sound – 1000 Hertz tone and still the pressure level is 1 Pascal.

My microphone is going to measure the same value of Pascals, because it is indeed 1 Pascal. But, our ear will hear something different. To us, we will perceive that, the 1000 Hertz tone, which is at 1 Pascal; we will hear it to be the loudest. And then, the 100 Hertz tone, it will be significantly – we will perceive it even though the pressure is same. We will perceive that, this sound is significantly lesser loud. It is significantly lighter, less intense. And then; of course, the 10 Hertz tone our ears are not sensitive to it. So, we will not hear that at all. So, this is our perception. So, the way sound is perceived by an instrument, let us say a microphone; it is different than compared to our ears. A good microphone in the audible range.

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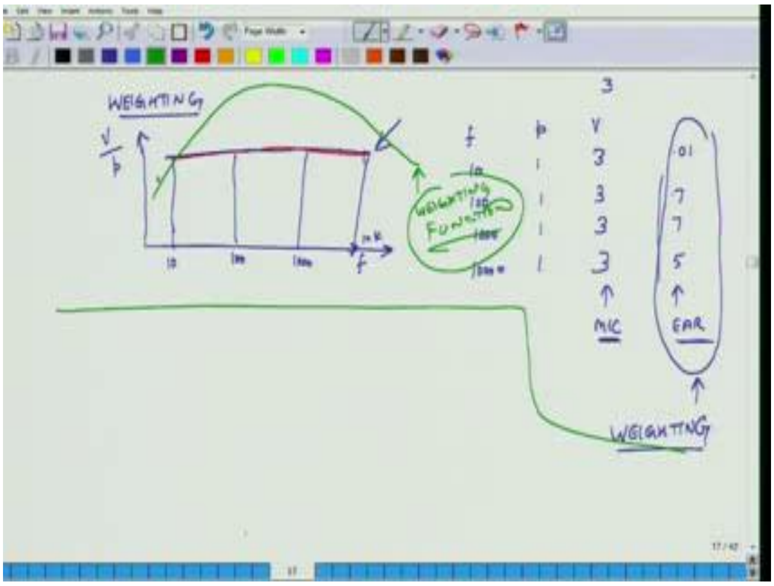

So, a good microphone in the audible range, if I am plotting pressure frequency and pressure; then, across the frequency spectrum, a good microphone has a flat frequency, flat curve. So, what does this mean? That, if I am measuring, so this is voltage over pressure let us say. So, if I am measuring sound at let us say 10 Hertz, this may be 100; this may be 1000 and this may be 10,000. So, a good microphone has a flat response curve; which means that, so let us draw a table.

So, I am going to have f: 10, 100, 1000 and 10,000. And, let us say the pressure of the sound in all cases is 1 Pascal. Then, if the microphone is good and if it has a flat frequency response; and, let us say that its sensitivity is 3; then, it will generate 3 Volts at 10 Hertz. It will again generate 3 Volts at 100 Hertz. It will again generate 3 Volts at 1000 Hertz; and, 3 Volts at 10,000 Hertz. So, this is for a microphone.

Our ears will also generate some signal. They may not be exactly Volts or something, but we do not have to worry about. But, if our ears are there; they will generate some signal, but this signal is not going to be same across the whole frequency spectrum. Here it may be let us say 5; I am just throwing out a number. And, how this changes, we will actually see it in graphs. For 1000, it will be actually higher – a little higher – 7. For 100, it will be significantly less.

Here it will be 0.7. I do not know; we will actually see the actual graphs. And, for 10, it will be even lesser; maybe it is 0.01. So, what our ear does in terms of responding to sound is different than what a microphone does in terms of responding to sound. So, its frequency response of our ear is significantly different and it is certainly not flat. So, we hear the same pressure at different sound levels if the frequency is changing. And, this function as a function of frequencies – these numbers as a function of frequencies; this is referred to as weighting. So, what does that mean? That the weighting function for a microphone is a flat line.

So, every point it is 1. But, if I have to transform this type of a pressure into the sensation, which my ear is perceiving; then, I have to apply some different weighting functions. I have to apply different weights at different frequencies. And, this curve may change something like this – something like this. So, this is what is weighting function.

Now, why is this important? Couple of reasons; one is that, when a microphone is perceiving, it has more or less a flat frequency response, but our own annoyance levels for sounds are different corresponding to different frequencies. I will get annoyed less easily by low frequency sounds, because whenever I perceive these low frequency sounds, I perceive them at a significantly lower level. But, may be at around 1000 Hertz, I am very sensitive to sound pressure levels. So, I am very easily annoyed by sounds at 1000 Hertz if they exceed a certain threshold. And, that threshold is significantly higher for low frequency sounds. And, that threshold is somewhat higher for frequencies more than 1000 Hertz; it peaks at around 1000 Hertz.

So, if I have to convert my engineering data, which is acquired from microphones into data, which helps reflect my; which can correlate to my annoyance levels or my levels of discomfort; then, I have to understand this weighting function clearly – the nature of this weighting function, because a significant amount of work in area of acoustics and noise is to figure out what kinds of noises are more annoying and what kinds of noises are less annoying and at what levels. So, if I have to have a good understanding of these annoyance levels corresponding to different frequencies, I have to understand how my ear is behaving; how my ear is responding and sensing these sounds; and, how my brain is interpreting all that information and giving me the cues that, oh, this is annoying, this is less annoying, this is more annoying, and so on and so forth.

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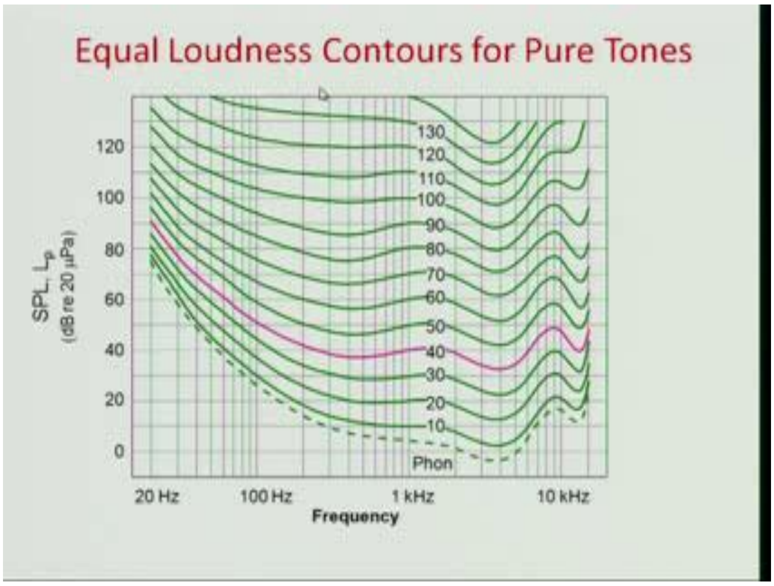

So, let us look at this weighting function. What you see here is there are bunch of lines and these are known as equal loudness contours for pure tones. And, I will explain that, what is all these about. So, on the x axis, you have frequency plotted on a log scale. And, that is how it typically plot loudness contours. So, we start with 20 and go up to 20 kilo Hertz, which is this line. And, on the y axis, you are actually plotting the actual measured sound pressure level. So, the y axis is the sound pressure level. And, I will explain this – what is happening. So, what does this mean?

So, let us look at one curve; let us look at this pink curve, which corresponds to 40. What this means is that, if I play and this says these are loudness contours for pure tones; so, what does this mean? That let us say that, I am hearing, I am playing a sound at 1000 Hertz; let us say this is 1000 Hertz; at 1000 Hertz, I am playing a sound and its pressure level is 40 decibels. So, this is 40 decibels. And then, because my perception is different than the actual measured sound pressure level; so, sound pressure level – I call it in decibels. The measure of loudness; loudness is related to perception.

So, I say that, at 40 decibels at 1000 Hertz, the loudness is 40 Phons. Phon is a unit of loudness; it is based on perception. So, at 1000 Hertz, I am playing a sound. And, the actual value of the pressure level corresponds to 40 decibels. And, the loudness level is also 40. So, at 1000 Hertz, loudness and the actual pressure is same. I mean this is what you will see on all these lines. But, we will just right now look at only the pink line.

Now, you go down to 100 Hertz. Now, the pink line corresponds to 40 Phons; pink color line corresponds to 40 Phons. The y axis corresponds to decibels. So, what does that mean? That if I have to hear 40 Phons sound at 1000 Hertz, I have to generate 40 decibel of sound. If I have to generate 40 Phons of sound at not 1000 Hertz, but at 100 Hertz then, I have to generate 50 dB of sound.

So, I have my sound pressure level has to be higher; sound pressure level has to be higher. From 40 dB, I have gone to 50 dB, which means 10 decibels increase of energy; which means 10 times energy is more. Each time you will have to go 10 decibels up; energy goes up by a factor of 10. Then, we look at let us say this; so, this is 20 Hertz, 30 Hertz. So, you look at 30. So, at 30 Hertz, you will hear 40 Phon sound only if the decibel level is, this is 70; this is 80; this may be 77. So, that is what this curve means; that of different values of frequencies, you have to generate different values of pressure to hear the same loudness level to perceive the same loudness level. And, this pink line is just for your reference purposes. Plus you have a similar curve for 45 decibel level, 50 decibel level, 60, 70, 80, 90, and so on and so forth. And so, these are loudness contours.

If you are on this loudness contour, you are perceiving the same level of loudness. If you are on this loudness contour, you are perceiving the same level of loudness. And, what it shows is that, to perceive the same loud level of loudness, which is measured in Phons, you have to generate different decibels at different frequencies. And, typically, around 1000 Hertz, you have to generate (Refer Time: 15:20) list of amount of decibels. If you specially, you go on this side and the lower side, you have to generate more amount of decibels and so on and so forth. It does something weird here, but on the low frequency side, you have to generate more amount of decibels. So, this is what loudness contour is.

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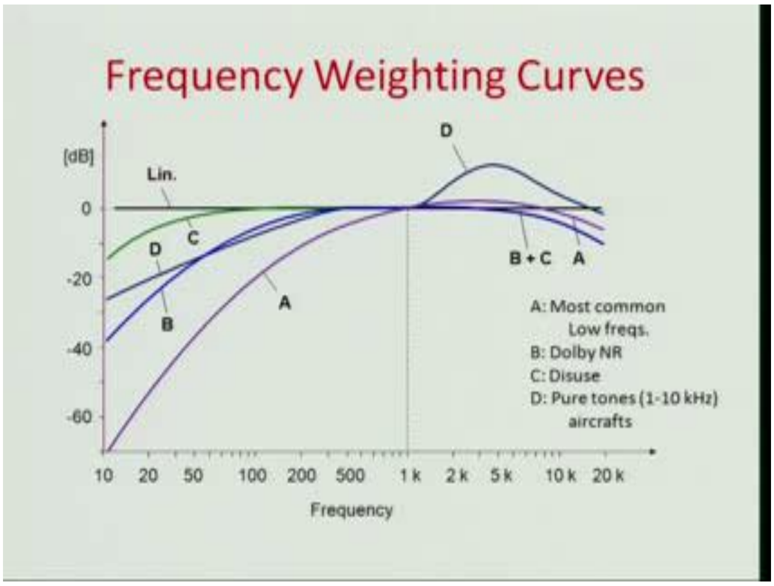

Now, let us look at frequency weighting curve. So, then the question is if I have to generate – how much is the delta? The question is how much is the difference corresponding to different frequencies? So, that is what this whole notion of weighting is about. Now, we are seeing here a lot of curves – A, B, C, D; and then, this is a linear. And for the moment, just ignore the B curve, the D curve and the C curve; just look at the A curve. And, I am explaining the meaning of that A curve.

So, if I am having a microphone and it produces 0 decibels of sound; then, at 1000 Hertz, I will hear 0 decibel of sound, because my a curve crosses this dark line, black line, linear line. So, this is the actual pressure corresponding to (Refer Time: 16:40) decibels. And, the purple line, which is the A line is the actual perceived pressure perceived soundless level, loudness level. So, at 0 at 1000 Hertz, they cross – they match.

As you go down in frequency; as you go down in frequency; even if you are playing 0 decibel sound, your loudness, which is perceived is significantly lesser – is significantly lesser. So, if you want at this frequency, let us say at 100 Hertz; at 100 Hertz, suppose you want to create a 0 decibel sound; then, what you have to this difference is maybe 20 decibels. So, then what that means is the whatever this difference is, you have to create not 0 decibel sound; you have to create 20 decibel sound. And then, because the delta will be minus 20 dB, it will be perceived as 0 decibel. So, this is the weighting curve. This is the weighting curve for A.

Now, we have different types of weighting curves for different applications. But, for most of the hearing applications, A weighting curve is used and this is shown in purple. Then, if you have pure tones; so, see in A, you have all sorts of frequencies at the same time. If you have pure tone; for instance, you are in an aircraft, lot of time more – a lot of sound you hear; there are significantly pure tones or times; something like that. So, there you use somewhat different curve, which is this D curve. Then, you have a C curve, which I was not being used nowadays.

Then, there is you have a B curve, which is being used for Dolby noise reduction methodology. But, at least in context of this course, do not worry about all these – B, C, D; there are more curves also. But, I think if you just understand A curve, you can use same concept for other weighting curves also. But, fundamental thing is that, this whole idea of weighting is related to our perception. And, this curve helps us bridge the gap between perception and actual measured sound pressure levels. Now, one way to figure out this weighting curve is – for different frequencies, you measure physically the distance on this graph and you calculate.

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$$A(f) = 2.0 + 20\log_{10}\left(R_A(f)\right)$$

$$R_A(f) = \frac{12200^2 \cdot f^4}{(f^2 + 20.6^2)\ \sqrt{(f^2 + 107.7^2)\,(f^2 + 737.9^2)}\ \ (f^2 + 12200^2)},$$

The other way is that, you use this formula. So, this is the weighting curve. A is the weighting curve. So, when you measure, after you have weighted the sound; when you – when you record sound after weighting it, you do not call it dB, you call it dB A and this is the weighting curve. So, A, which depends on frequency is 2 plus 20 log of this R a term. And, R a is given by this complicated formula. So, if you use this formula, then you can do the weighting. Last thing; and, this is extremely important, because especially if you are doing sound and noise related experiments; so, you have understood the whole concept of weighting.

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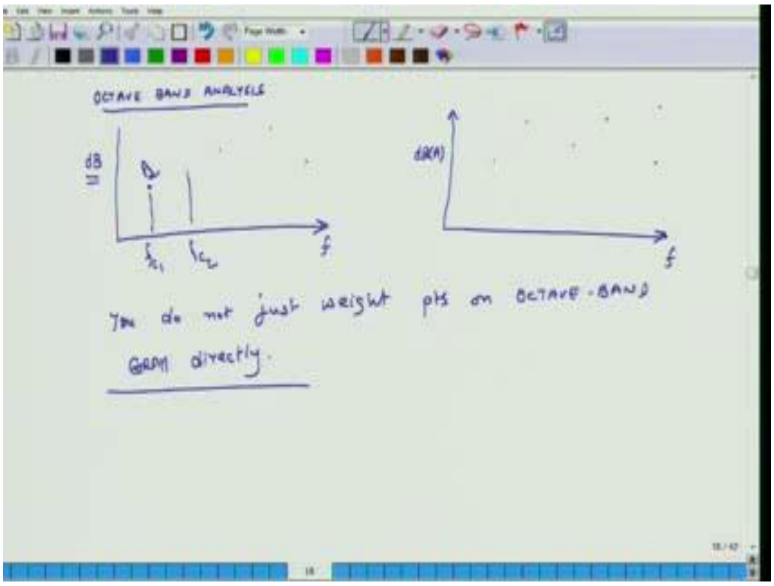

And then, a lot of times what you do is – So, we had said that, when we do octave band analysis, on the y axis – on frequency, we have center frequencies; and then, on the y axis, we are plotting it in decibels. But, if it is related to noise, people not only expect you to publish data in decibels, but also in dB A – dB A. So, this dB A – these points may not be same. There may be different points, because for each frequency, you have to weight it. Now, the – but, again suppose this point is point A and you have calculated how we figure out the value of A, you cannot; now, this corresponds to let us say f c 1. This corresponds to f c 2, and so on and so forth. For A, if you add the weight corresponding to that single frequency, which were if you use the formula, which I showed earlier; you will get a wrong result.

Why? Because this A point is not about just one single frequency; it is about that entire band; it is about that entire band. So, you do not just weight; you do not just weight points on octave. I do not know what to call this – octave band graph directly. You do not do that; rather you do something different, because if you just take care of one frequency; but, it is not one frequency; it represents a large number of frequencies in that band. So, what you do?

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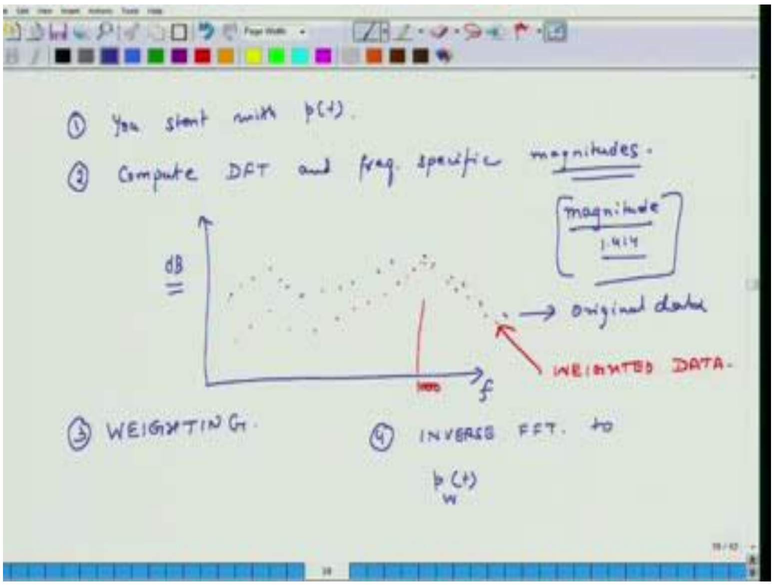

First, you start with pressure as a function of time. Second, compute DFT. You calculate the DFT and frequency specific magnitudes. You can do that; you have learnt how to do this. So, we calculate DFT and frequency-specific magnitudes. So, we have to divide it by n and then multiplied to do all that stuff and then take the magnitude. So, you get magnitudes. So, what you will – So, using these frequency-specific magnitudes, you can create a graph. This is frequency and this is decibels. That you can create. So, once you divide this magnitude by 1.414, it will be the RMS value, because to calculate in decibels for each frequency, you have to calculate it in RMS. And, because each frequency is a pure sign wave; so, you can divide it by 1.414; understood? So, you get the decibel plot. So, you will get lots of points – thousands and tens or thousands of points. But, you have to do – take care of this factor 1.414, because the magnitude will be the magnitude; RMS has to be that divided by 1.414.

Then, you do the weighting. So, some frequencies you can enhance; some frequencies reduce. If they are less than 1000 Hertz, they come down based on that weighting function; understood? Based on that weighting function. So, this is the original data. And, the new data – weighted data will be something like this. Let us say this is 1000 Hertz – 1000 Hertz – they will meet something like that. So, this is weighted data. Fourth – you do inverse FFT. So, what will you get out of it?

Student: (Refer Time: 25:48)

Yeah; to get p weighted of t; it will not be p of t; it will be weighted or the weighted function.

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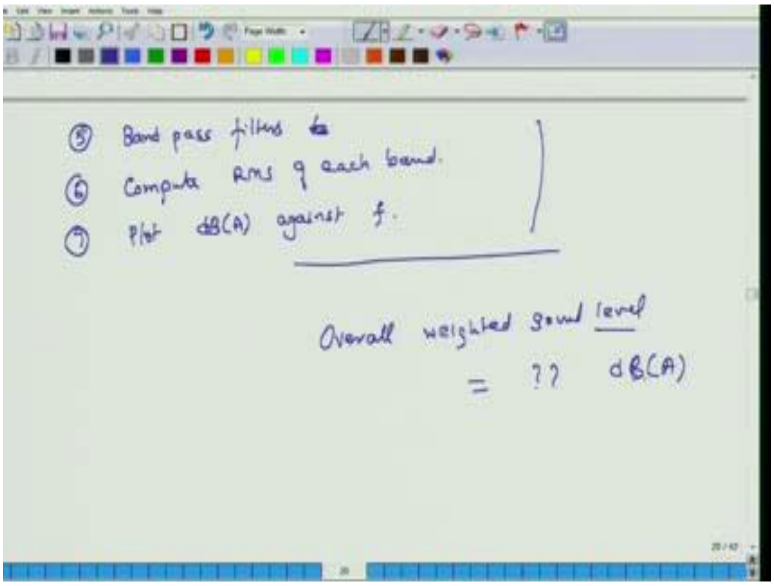

Then, fifth; this, save it. Now, what do you do? Now, you use band pass filters. Sixth – compute RMS of each band. Seventh – plot dB A against f. So, this is how you do this. Understood? So, the method is same here onwards. But, in the beginning, you have to use this FFT; do the weighting; do the inverse transform. Then, use band pass filter; and then, for different bands, you eliminate different frequencies; compute the RMS. And then, a lot times, last point a lot of times, you not only report this result dB A versus frequency, but you also represent – report one single dB value that, the overall weighted sound level is overall weighted sound level. See I did not say sound pressure level; I said sound level, is sum dB A.

Overall means what? A band is from 20 to 20,000 Hertz. So, once you have this weighted pressure data; and, if this is for 20 to 20,000 Hertz, you take the RMS of the entire thing and that will give you the overall sound pressure level; not sound pressure, overall weighted sound level. So, (Refer Time: 28:15) overall sound pressure level is you take the original data and take its RMS. And, that is your overall sound pressure level. This is overall weighted sound level in dB A. Overall sound pressure level is in dB, which is something there.

So, this concludes our topic for the day. I thank you for patiently listening to all these discussions. And, we will start our next weeks' lectures when you come here again. And thanks and have a great day. Bye.