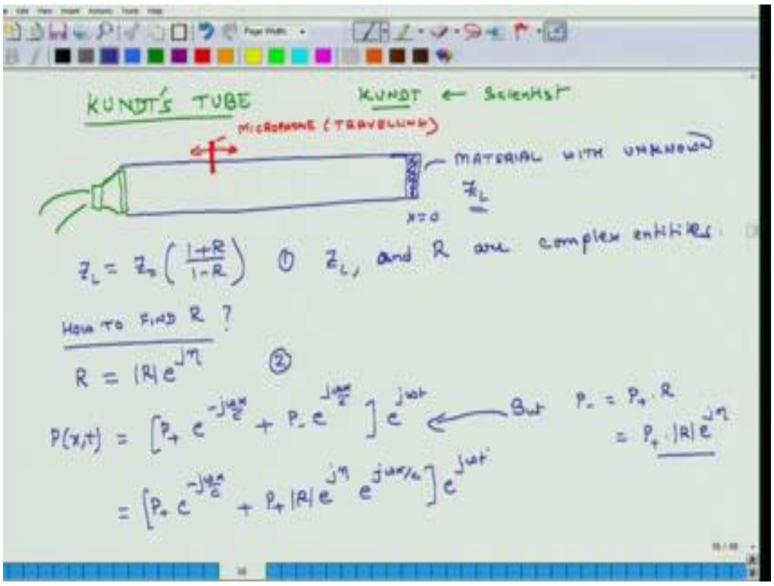
Basics of Noise and Its Measurements
Prof. Nachiketa Tiwari
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture-18
Measuring Impedance Through Kundt's Apparatus

Welcome again, to Basics of Noise and its Measurement. Today is the last day of this week, and we will complete this week's journey by actually helping you all understand as to how you can physically measure impedance of a material using a special Apparatus known as Kundt's tube.

So that is what we are going to discuss today. This whole course is about noise, we have already covered some of the important basics of noise and now we have just started sharing information as to how different parameters of noise can be effectively measured. So what we are going to learn today is how you can use this apparatus called Kundt's tube? And using this apparatus you can measure the impedance of a material. In this course we will also actually get to see several instruments and see how they operate, but the first parameter we have going to learn in terms of measurement is impedance of material.

(Refer Slide Time: 00:36)



So, what does a kundt's tube look like? So this is kundt's tube. Kundt, he was the scientist, and he studied noise and sound and he was the person who designs this methodology and apparatus so that is why it is known as kundt's tube. So essentially, in a very simple form the tube is nothing but a long hollow tube and at this end you can close it with a material with unknown impedance Z L, let us say that impedance is Z L but we do not know so we want to measure the value of that Z L. You place that material at the end, and let us say this position as x is equal to 0 and then you somehow figure out a way to measure this material impedance. There are two more things in this tube, so it is a tube; at one end you have this material and then, you have a microphone in the tube.

So, what does a microphone do, it actually measures the pressure fluctuations of due to sound. This is a microphone and the interesting thing about this microphone is that the tube is served design that it is slot installed on its top, so this microphone can move in this way travel. It is a traveling microphone. It can travel along the length of the tube that is why this apparatus is also known as a traveling microphone impedance tube. This method to measure the impedance is also known as traveling microphone method for measuring impedance. So, this is a microphone so that is a second element.

First element is the tubes, second element is the unknown material, third element is microphone, and then the fourth element is sound source. You can have speaker placed at this end of the tube, and you can exit this is speaker using some source. So that is all this apparatus is about, it is a long tube at x equal 0, they place the unknown material, material with unknown Z L. There is a traveling microphone, which measures the sound pressure level at different locations, and that sound is generated by a speaker which is at the other in the tube

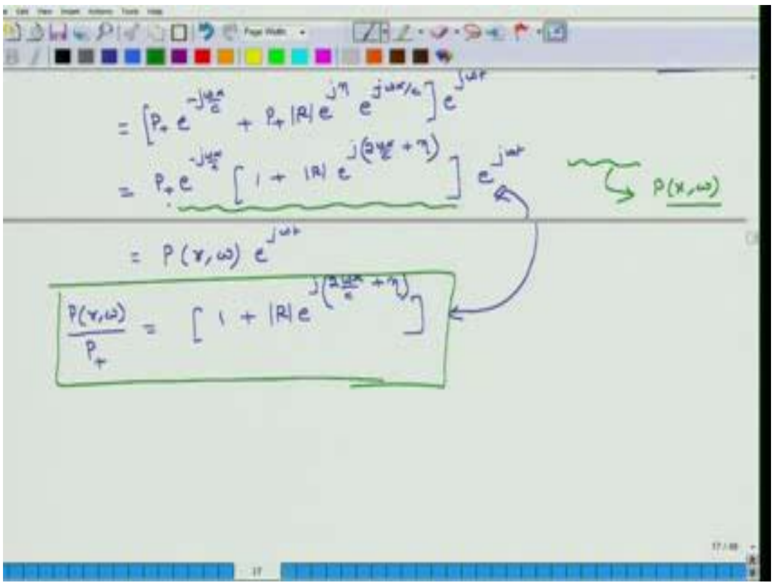
Now, let us figure out how we can, using this apparatus calculate the impedance of this material which is right now unknown. We will start with what we learnt in the last class. So, we had learnt that at x is equal to 0, Z L is the impedance then Z L can be expressed as Z naught times 1 plus R divided by 1 minus R. There something we had learnt in the last class. If I can calculate R, then I can calculate Z L. Now we try to figure out, how do we measure R? How to find R? This is the question.

Now, Z L can be a complex entity because this specific characteristics impedance we have discussed and defined that it is the ratio of complex amplitude of pressure and complex amplitude to velocity. So, whatever is the complex amplitude the pressure it x equal 0 and complex amplitude at x equal 0 of velocity, if you take the ratio we will get

Z L. What that means is that Z L and R are complex entities. They have a real part, then an imaginary part. So, we have to figure out what is R. But we know that R can be complex, so we will express R as some magnitude which is the modulus of R, and it also has a phase which can be expressed as e to the power of j times eta. Magnitude of e to the power of j times eta is one, so that does not influence the magnitude it only tells us about phase. Modulus of R is the magnitude of R. So, this is equation 1, this is equation 2.

Third thing, this is the one dimensional tube so any sound which propagates in it will follow the transmission line equation for pressure. So, the expression for complex pressure P – x, t. This is not the real pressure, but the complex pressure is nothing but P plus e minus j omega x over c plus P minus e j omega x over c e j omega t. And we know, but we know that P minus equals P plus times R and this as same as P plus times magnitude of R e to the power of j eta. We put this back into this equation, so what we get is P plus e to the power of minus j omega x over c plus, and instead of P minus we put this expression so I get P plus times magnitude of R e the power of j eta e to the power of j omega x over c e to the power of j omega t.

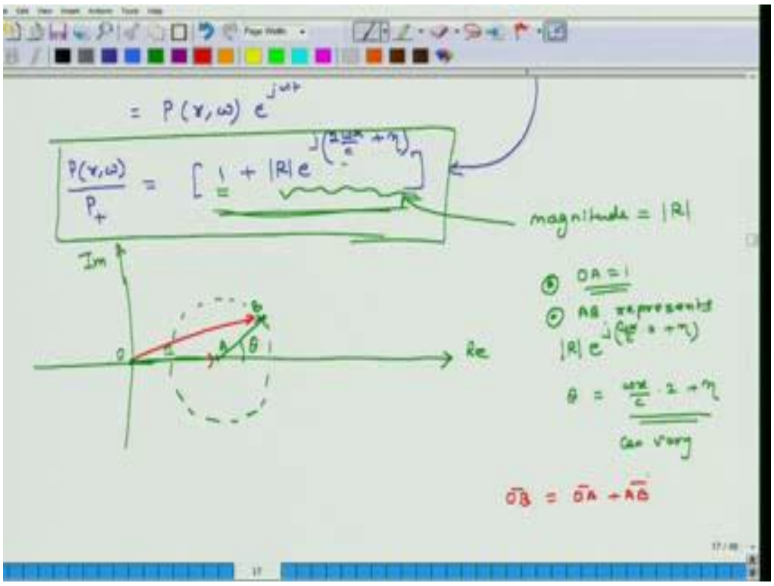
(Refer Slide Time: 09:08)



And I can simplify, not simplify; rearrange this. I can bring P plus out, so this is P and I can also take e minus j omega x out, so in the brackets I am left with 1 plus magnitude of R and then I have exponent j 2 omega x over c plus eta e j omega t. This entire term, this green term this is nothing but complex amplitude of pressure. What is complex amplitude? Complex time entity is what? It has complex amplitude this entire thing is complex amplitude times e j omega t. So, this is P of x and omega. I can rewrite this as, e j omega t. Or I can rewrite this above expression as P of x omega complex amplitude divided by p plus equals this long complicated expression, this equation coming directly from here.

Now what I do? This is my fundamental equation. What is our goal? Our goal is figure out the value of R in terms of the readings made by the microphone, because we can use the microphone and find the value is the pressure at all locations in the tube. And with that information if I am smart enough and we can figure out the value of R then I can plug that value of R in this expression, this one and I can calculate Z. So, all these things which we are doing is essentially to figure out a way as to how we can calculate R, which has magnitude modulus of R and a phase eta. That is what our aim is.

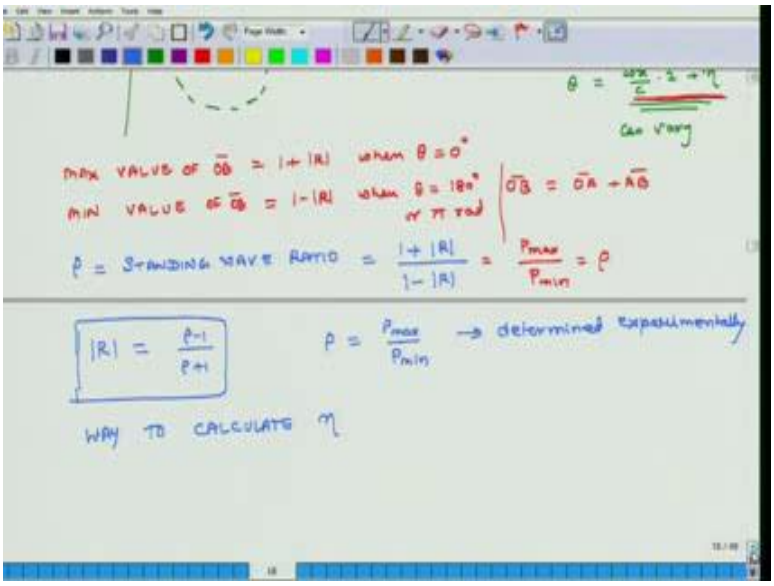
(Refer Slide Time: 12:00)



Now, let us look at this term which is there in the parenthesis. And what I am going to do is I am going to plot it, on a real n on a complex plane. This is my real axis, this is my imaginary axis, and this entire term is 1 plus modulus of R times exponent time j 2 omega x over c plus eta. So, let us say this point is O, and then there is this one, so I move 1 unit here and let us say this distance is O A, O A equals 1. Then, what about this term? The magnitude of this term is modulus of R because the magnitude of exponent j 2 omega c plus eta is 1. So, magnitude of this term is R, same as modulus of R and the phase or the angel of this is some theta. I make another that point A B, and A B represents e j omega x over c times 2 plus eta, where theta equals omega x over c times 2 plus eta. So this is there.

Now, the value of x in this kundt's tubes, it could be anything at x equal to 0 it will be 0, at x is equal to different values it will have different values. So what that means is, actually I am going to draw this line a little shorter. This is B this angle is theta. So what that means is, what I saying is that x can have all sorts of values. What this means is, that this theta can vary between 0 degrees to 90 to 80 to 170 you know so it can vary and it can go in circles like that. This vector A B can, depending on the value of x it can follow a circular path. Now again, O A represents 1 and A B represents, this whole complicated thing modules of R time e j two omega x over c plus eta, and the angle theta can be anything and it will vary with respect to x. And my total vector is, so if I use my loss of vector mechanics then O B equals O A plus A B. Now we are getting close to the thing.

(Refer Slide Time: 16:08)



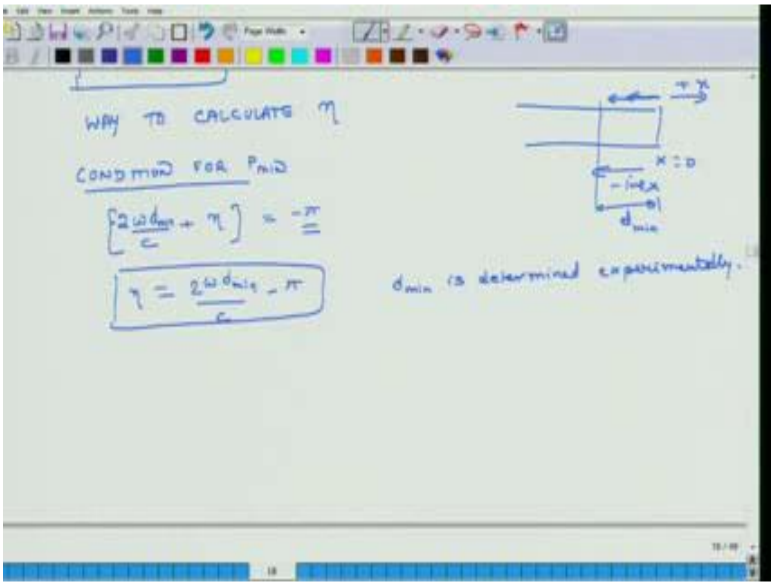
Now, what we see from this picture is that maximum value of O A will be when value of theta will be 0 degrees that does not mean that x will be 0 value of theta is this. So, when it is 0, then there will be some value of x which will correspond to the value of theta being 0. When theta is 0, then O A will be maximum and its value will be 1 plus because this magnitude this radius is R. Similarly, minimum value O A is equal to 1 minus R, when theta is equal to 180 degrees or pi radiance.

Now, we define another term and we call it standing wave ratio. This is rho is equal to standing wave ratio, and this is equal to the ratio of maximum value of O A you know and the ratio of minimum value of O A. It will be 1 plus R divided by 1 minus modulus of R. I am sorry, you are right, this should be O B. So, when theta will be 0 at some location of x and at that location of x the pressure will be maximum because, what does O B represent, it represents the ratio of P – x, w by P plus.

What that means is that, when this term is maximum, then P – x, w will also be maximum. If I am sweeping the microphone and I find the location at which pressure is maximum. Then, I record the value of that pressure. This is equal to P max that divided by P min. So, it will be P max divided by P min. At some value of x, p will be maximum, it will be maximum also at x is equal to 0, it will be maximum x is equal to 360 degrees at 720 degrees and so on and so forth. P will be minimum at some other location. So, if I am moving the microphone in my tube and I find the value of P max and let us say that P max is 5 pascals, I write it down and then I move the mic again and at some other location I find the value of P is minimum, let us say that value is 2 so then I write down that value.

So, in that way I can find the value of rho using this experimental. Once I know rho, then I can calculate the modulus of R in terms of rho using this method, using the traveling microphone method. And in this way the value of modulus of R will be rho minus 1 minus rho plus. Rho is equal to P max by P min and this is determined experimentally. Now, I figured out how to calculate modulus of R. Now the other thing which I have to figure out is how to calculate eta, because once I know eta, I will already figured out how to find the modulus of R, once I figure out how to find eta then I can know what is the value of R and then from R, I can go back and calculate the value of Z L. So that is what we will do, will figure out now how to find the value of eta. Again, how do you find out eta? What we do is that we again sweep the mic.

(Refer Slide Time: 21:31)



Now, let us again think about this. So, this P min condition for P min, what will be the condition for P min? Condition for P min will be when this entire term 2 omega x divided by c plus eta is equal to, 2 omega x by c plus eta. And because x is in negative direction see because our tube, this is x is equal to 0, this is positive x, so this is negative x. So, x is going to be negative.

When this value is equal to minus pi radiance, so suppose, I am starting my microphone from here from the phase location and then I keep on moving it and keep on moving it and till I see that P has minimized. At that location let us say that distance is d so then I replace that x by d, and I actually call it d min. So, experimentally I measure the value of d min, I already know the value of omega because I know what kind if frequency I am generating in the speaker. This value minus 2 omega d min divided by c plus eta should be equal to minus pi.

Once it is this then, I can calculate eta equal to omega d min 2 minus pi. Again here, d min is determined experimentally. So, I have determined experimentally the value of eta using d min, I have figured out how to calculate modulus of R so now I know the value of R which is nothing but modulus of R times e j to the power of eta e to the power of j times eta, and from this value of R, I can compute the value of Z L which is the impedance of the material which we are interested in. And in this way we can calculate the value of materials impedance.

This is what I wanted to talk about today, you have learnt how to calculate the value of impedance and we will continue this discussion the next week also. Now, going forward we will start actually seen actual instruments and we start learnt practical techniques related to noise measurement. Thank you very much and have a great day look forward to seeing you next week.

Thanks.