NOISE CONTROL IN MECHANICAL SYSTEMS

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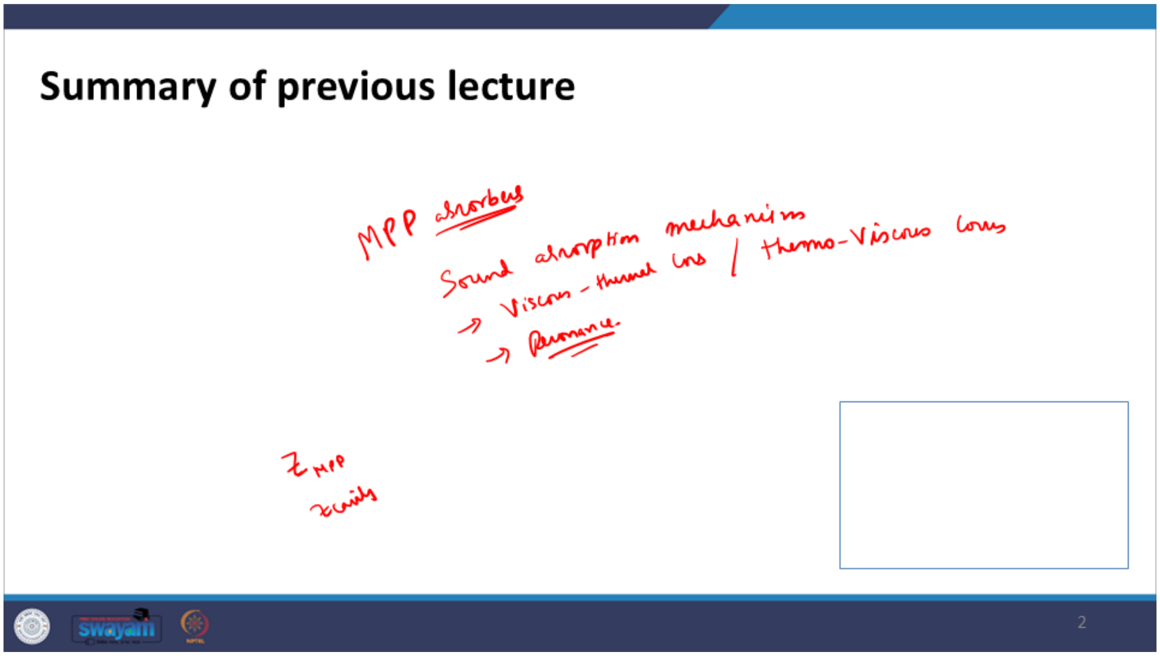
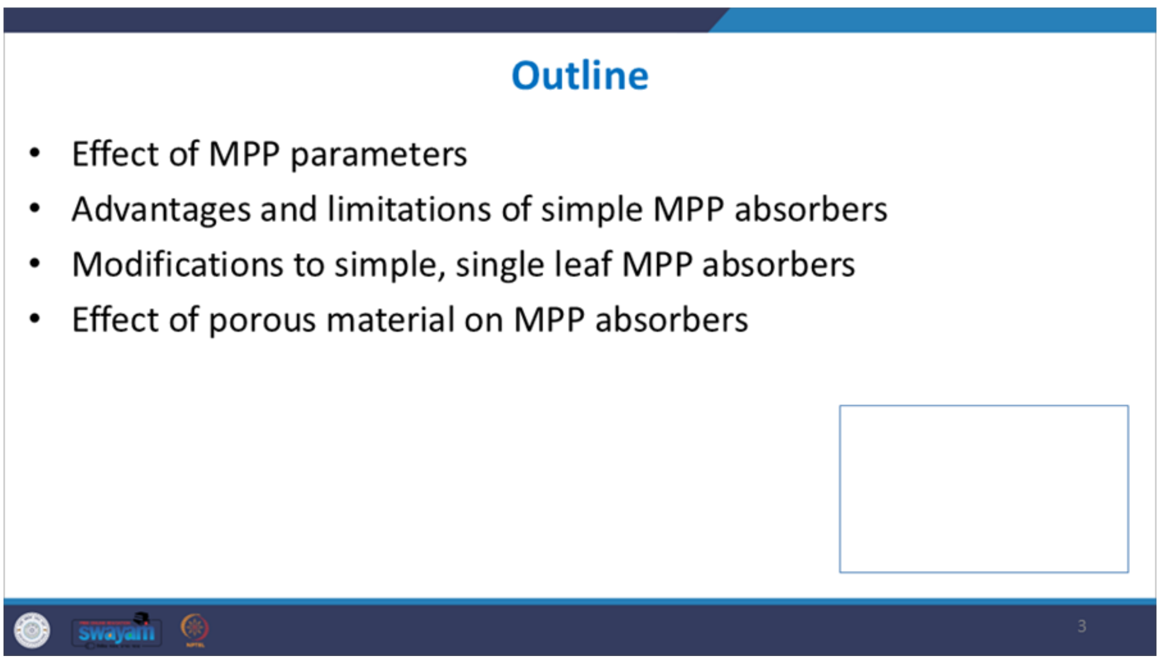
Week:9

Lecture:044

Lecture 044: Micro Perforated Panel Sound Absorbers 2

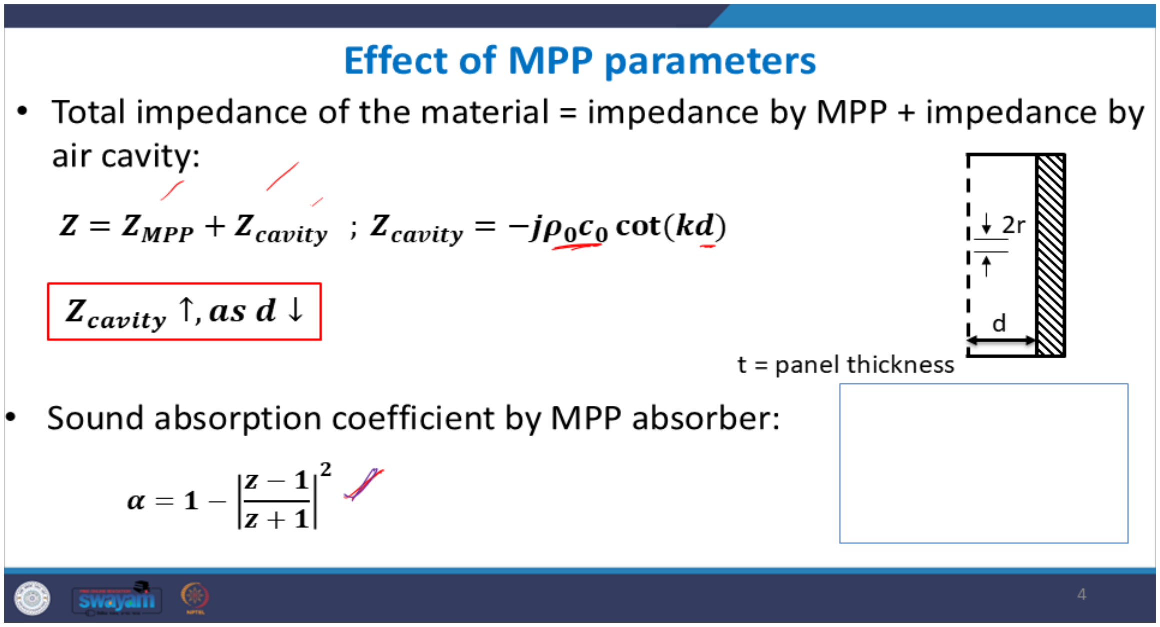
Hello and welcome to this lecture course on noise control in mechanical systems with me Professor Sneha Singh and we have been discussing about micro perforated panel sound absorbers or simply the MPP absorbers and we studied what is an MPP and what is the sound absorption mechanism behind this what leads to a much higher absorption. mechanisms such as the viscous thermal losses or thermo viscous losses and the resonance that mostly dominate and then an expression for Z of MPP was obtained and the Z of the cavity behind the MPP. today we will see what is the effect of the MPP parameters on the overall acoustic impedance and the absorption coefficient of an MPP.





Some advantages and limitations we will see. Some modifications that can be done to simple single leaf MPP absorbers. What is the effect of porous material?

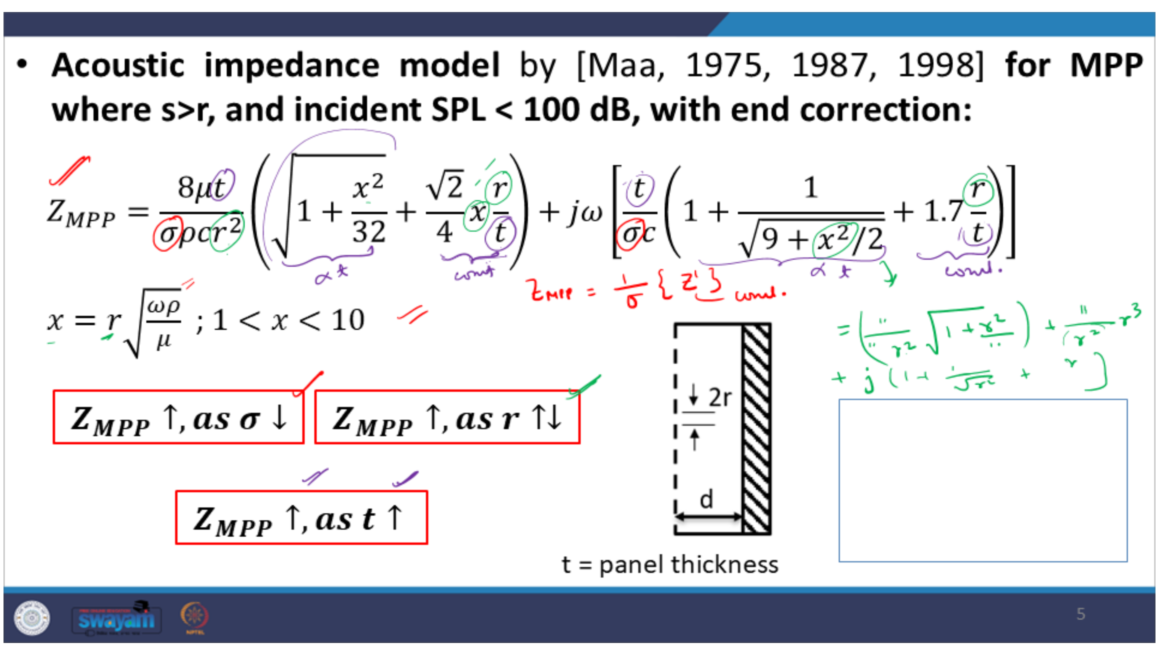
this is the equation that we had obtained. the z of MPP is given by this formulation here and the z of cavity is given by this formulation here. let us first see what is the effect of cavity depth.



First, we see that cavity depth appears in this acoustic impedance of the cavity. Here it depends on the characteristic medium obviously, and given that we are using the micro perforated panel absorbers in the air medium, this thing becomes fixed. This is like the air medium. It then only depends on the frequency and the depth of the cavity. As the depth of the cavity will reduce the acoustic impedance of the cavity is going to go up. In general, if you observe the behavior of the minus j cot function, the absorption coefficient is given by:

$$\alpha = 1 - \left|\frac{z-1}{z+1}\right|^2$$

where z is a summation of these two terms. Now, let us see how the z of MPP varies with various changes.



This is a very complex expression. just deriving and solving the typical frequencies is not possible within the scope of this lecture series. We will just see how the various parameters are affecting the impedance overall. Let us start with porosity. If you see in the first case, in the first term, the porosity is here in the denominator. Nowhere here, x is r multiplied by this quantity; the porosity is nowhere, and then it is again appearing here and nowhere else. basically, what is happening is that Z of MPP can be written as:

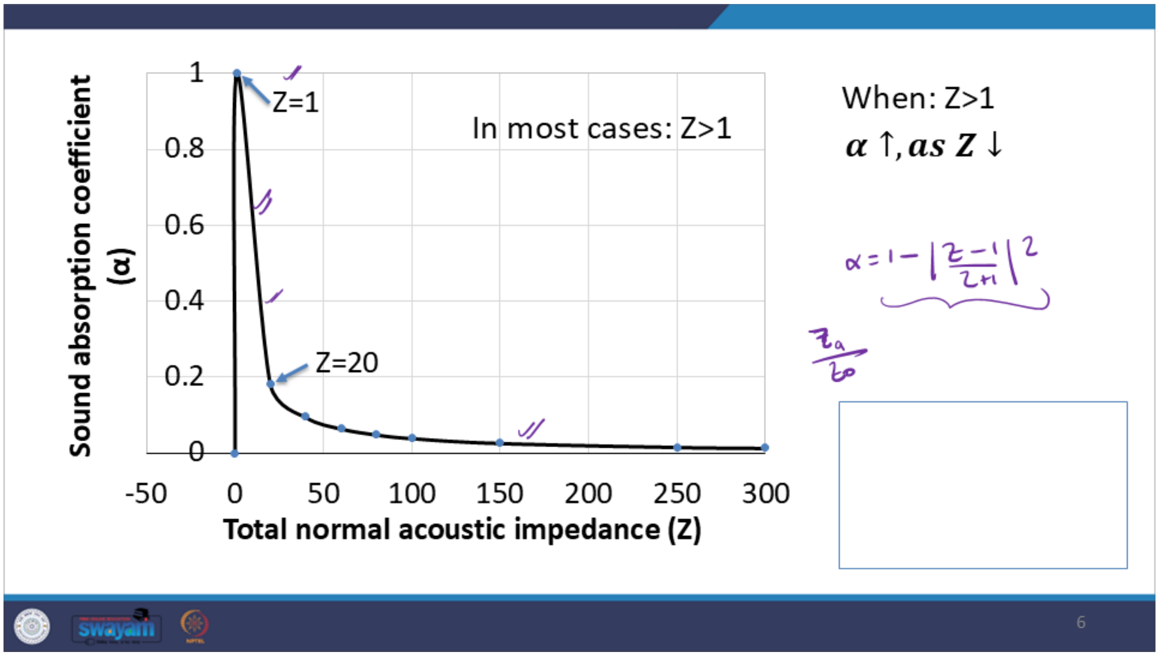
$$Z_{mpp} = \frac{1}{\sigma}\{\,Complex\ Number, independent\ of\ \sigma\}$$

As sigma reduces, the acoustic impedance is going to go up. That is a simple formulation. Now, let us study what would be the effect of Z on R. For this, let us see where R appears. Here in the first term, you can see that x directly depends on r. It is r multiplied by some factor, which is independent of r. here we will have a term which is the root of 1 plus some r squared thing, and then we have r and r squared here. Then we have r square here in the denominator, and then what we have is again an r square from here and here (refer slide 5 equation of Z_{mpp}). If you bring it down, what you will see is that let us write some constant terms. There are some constant terms and then r square here. In the first term, what we have is 1 plus some r square times things, and then again, some constant term, then r square, and then multiplied by r cube like that. here we will get an r square and r cube from this particular place here. If you solve these terms, in the j part, what you will get is some kind of root inside the root; you have an r square term and then some r here and like that.

$$= \left[\left(\frac{\#}{\#r^2}\sqrt{1+\frac{r^2}{\#}}\right)+\frac{\#}{r^2}r^2\right]+j\left(1+\frac{\#}{r^2}+r\right)$$

what you would see is that it is a very complicated relationship with r. It is not an easy function. Experimentally, what has been found is that as the r increases and then decreases, the Z of MPP rises. There is some optimum value at which you get a maximum sort of MPP, and then with the Z increase in the Z, the impedance is going to increase and decrease like that. There is a very complicated relationship that is actually found only experimentally. Now, let us see what happens when thickness is there.

If you just see what is the effect with thickness t appears here and over here and over here and over here (refer slide 5 equation of Z_{mpp}). you will see that the first term is dependent whatever the first term is it will be dependent on t the second term if you multiply it t in the numerator and the denominator, it vanishes. this will become independent. This will be directly proportional to t. This will be independent of t. This term here again would be directly proportional to t and this would be constant with t or independent of t(refer slide 5 equation of Z_{mpp}) . Basically, you will have a term with t to the power 1 both in the real part and the complex part. Again, as t increases m will increase ok.



Now, this is a graph that was just made by myself. That alpha is given by

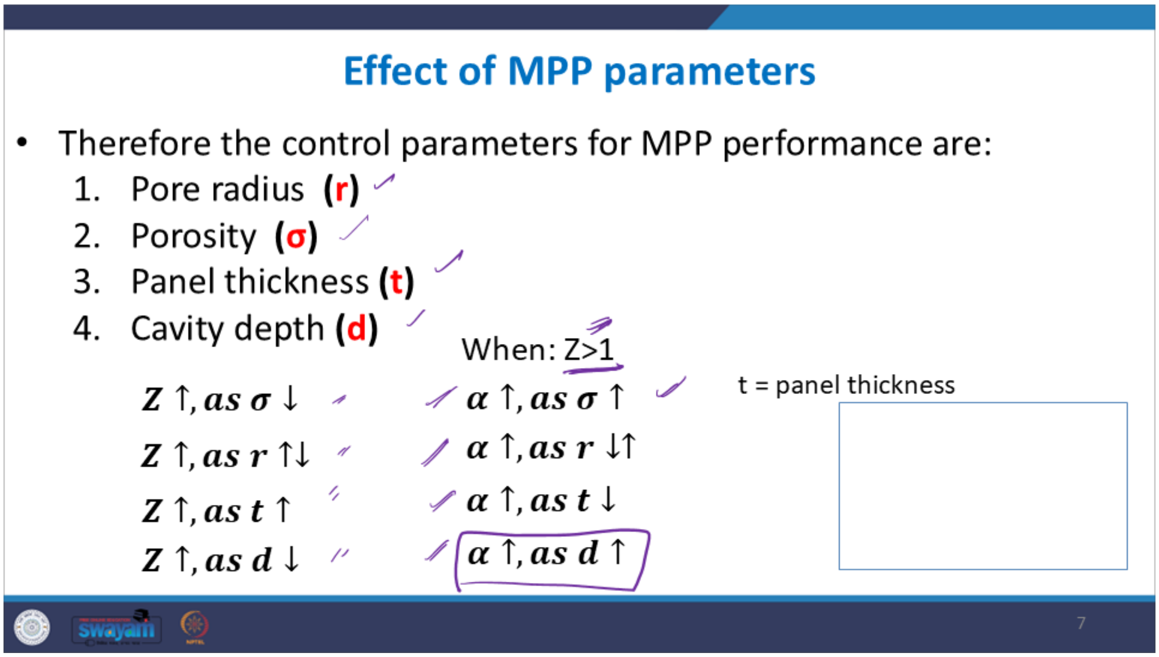
$$\boldsymbol{\alpha = 1 - \left|\frac{z-1}{z+1}\right|^2}$$

I drew a graph of how $\boldsymbol{\alpha}$ changes with a change in the overall impedance. This is the total normal acoustic impedance z and $\boldsymbol{\alpha}$ is given by 1 minus this thing here. I simply drew the graph of this to see how alpha is changing with z. What you observe is that alpha rises suddenly. With the increase in the z till z approaches 1 and post that whenever in the zone where z is greater than 1 alpha decreases with the acoustic impedance. This is the characteristics that is observed when z is greater than 1.

Now, we know that here we are taking this Z as the

$$Z = \frac{Z_a}{Z_0}$$

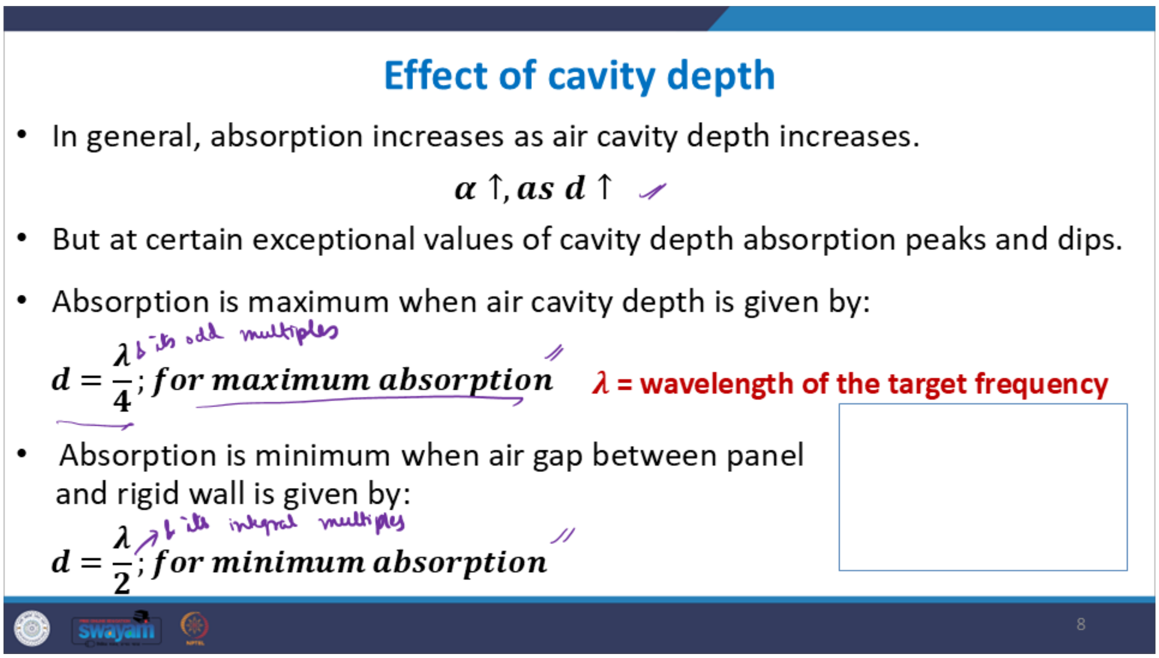
This is the relative normal acoustic impedance. In most cases, our medium is going to be the air medium, and any additional material we are adding is going to have an impedance higher than the air medium. In most cases, Z is actually going to be greater than 1. That is going to be the usual case.



We have an air medium, and then in the air medium, we are suddenly putting some kind of material which will have an impedance higher than air. Usually, for most cases in noise control engineering, we operate when the relative specific impedance is greater than 1, and hence in that case, the behavior observed is that alpha decreases with the increase in Z in this particular fashion. We already saw from the equation that this is how the overall Z is sort of increasing or decreasing with respect to the various control parameters, which are the pore radius, the porosity, the panel thickness, and the cavity depth. These are the four control parameters which are affecting the acoustic impedance of Z.

And in this zone, because $\boldsymbol{\alpha}$ decreases with the increase in Z, the reverse relationship should be there. Which means that see over here. The reverse relationship should be there because if Z is increasing, then $\boldsymbol{\alpha}$ should be decreasing. If you see here, when porosity was decreasing because porosity was in the reverse, so Z was increasing, and when thickness was increasing, Z was increasing.

Over here, what should happen is that because Z increases with the decrease in porosity, $\boldsymbol{\alpha}$ should increase with the increase in porosity. A direct relationship should be there. In the same way, as Z is increasing, a direct relationship exists between Z and T, and so the opposite relationship should be there. as T decreases, only then will $\boldsymbol{\alpha}$ rise, and when ddecreases, Z is increasing. When d should increase, $\boldsymbol{\alpha}$ should increase. And a complicated relationship will follow with ‘r’, which means that when the radius decreases, alpha will rise, but beyond a certain point, alpha will decrease—some kind of complicated relationship. This is just a gist of roughly how the various control parameters of an MPP affect the absorption coefficient of the MPP. A higher cavity depth, a smaller panel thickness, and higher porosity would definitely be more encouraged to increase $\boldsymbol{\alpha}$.



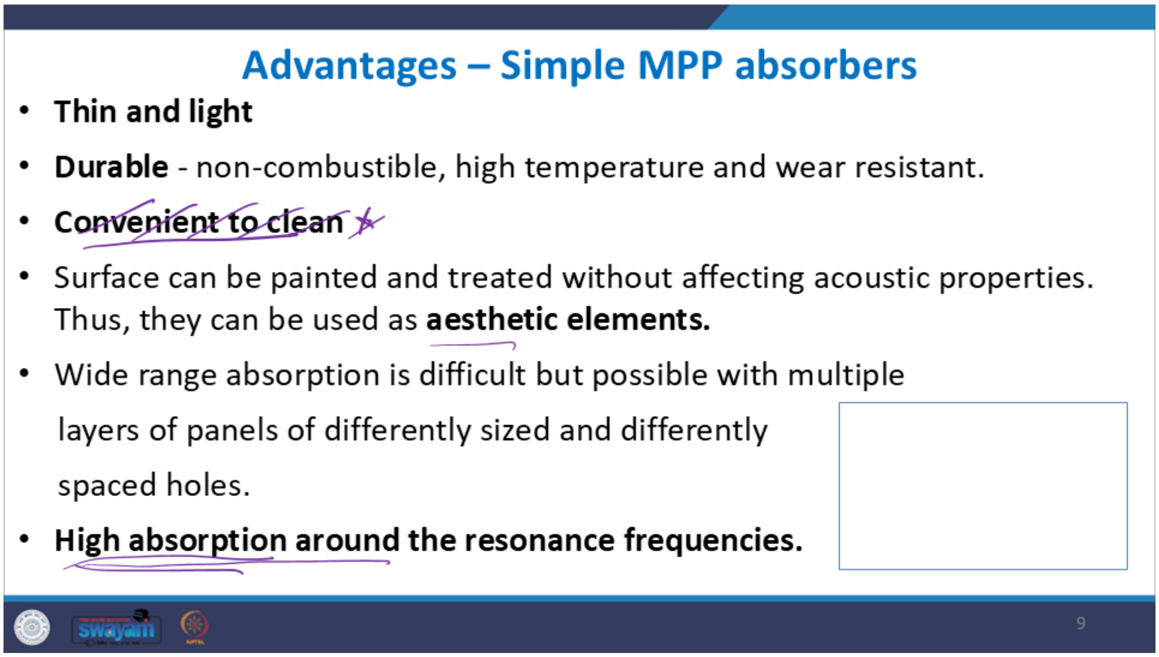
We know that, in general, what we see is that as the cavity depth rises, $\boldsymbol{\alpha}$ rises, but just like in the case of panel absorbers and perforated panel absorbers. Similarly, there are some typical values where suddenly the absorption will reach a maximum or a minimum, which is at,

$$d = \frac{\lambda}{4}; for\ maximum\ absorption$$

where we will have maximum absorption. And its odd multiples.

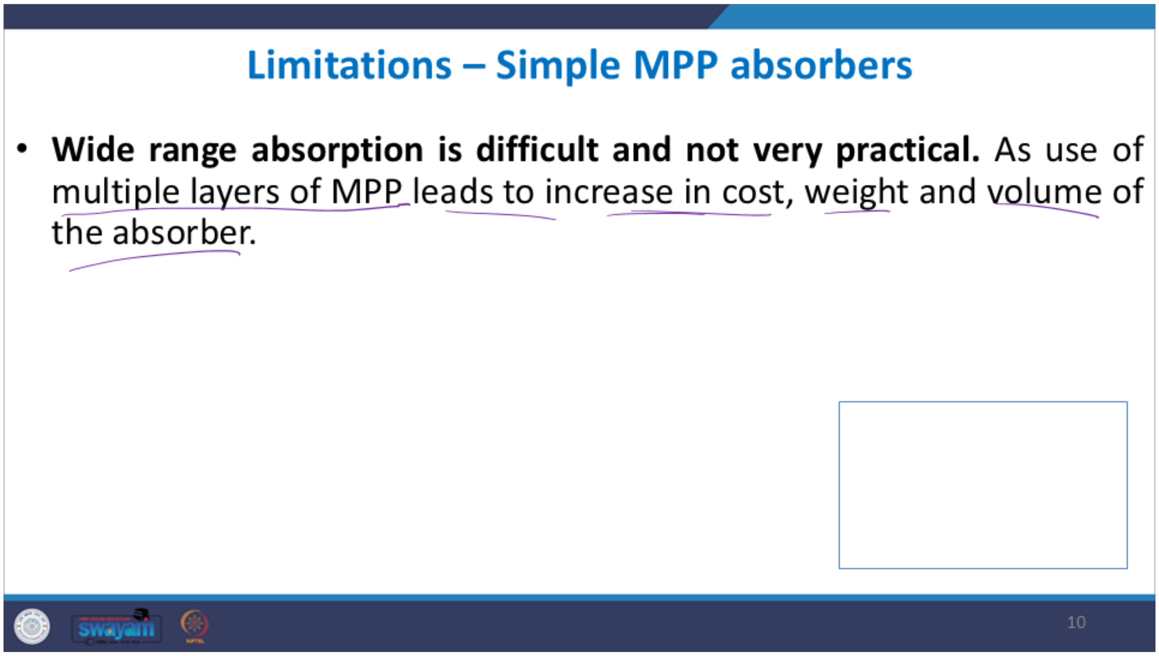
$$d = \frac{\lambda}{2}; for\ minimum\ absorption$$

and its integral multiples. the reason for this is the same as what has been discussed in the perforated panel—why this kind of depth leads to higher absorption and this leads to a lower magnitude of absorption. The depth of the cavity affects the magnitude of the absorption not just by this relationship but also at certain values, you will get some maxima and minima, so care has to be taken while designing the air cavity depth.

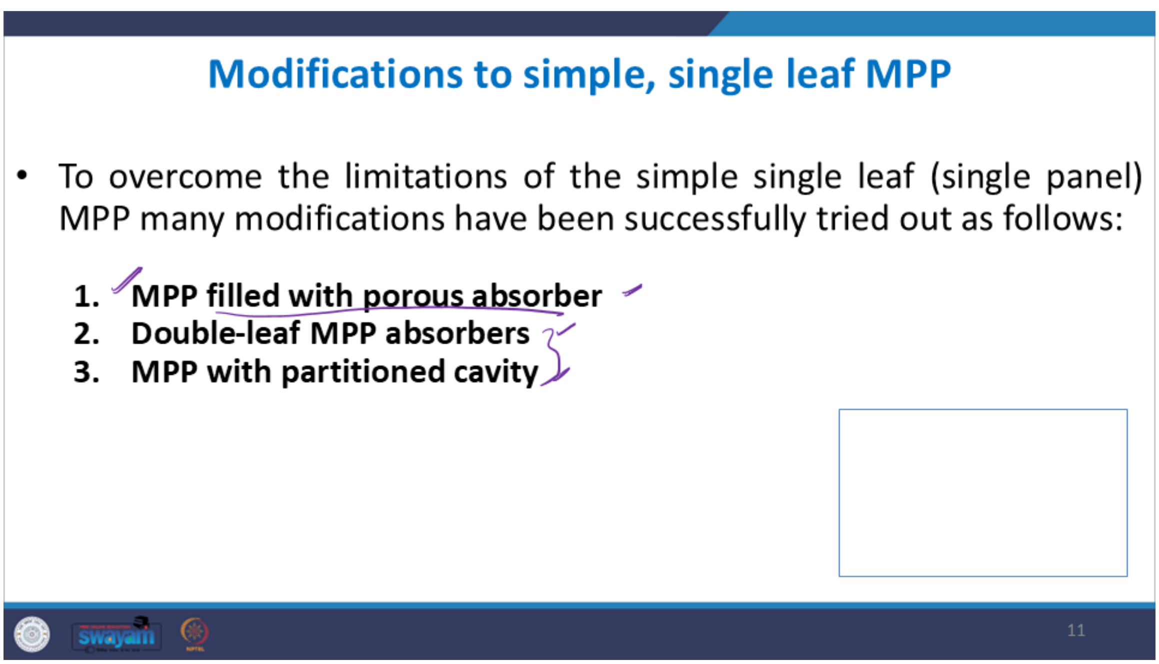


What are the advantages? They are thin and light—you have thin sheets followed by just air and a rigid backing. They are very light and thin in nature, they are durable, and non-combustible, high-temperature wear-resistant, given that, what kind of material you are making your sheet from. They can be painted to make them aesthetic. And high absorption, most importantly. Most of the advantages would be the same as the panel absorbers, but there is an additional advantage that the magnitude is now higher. Why?

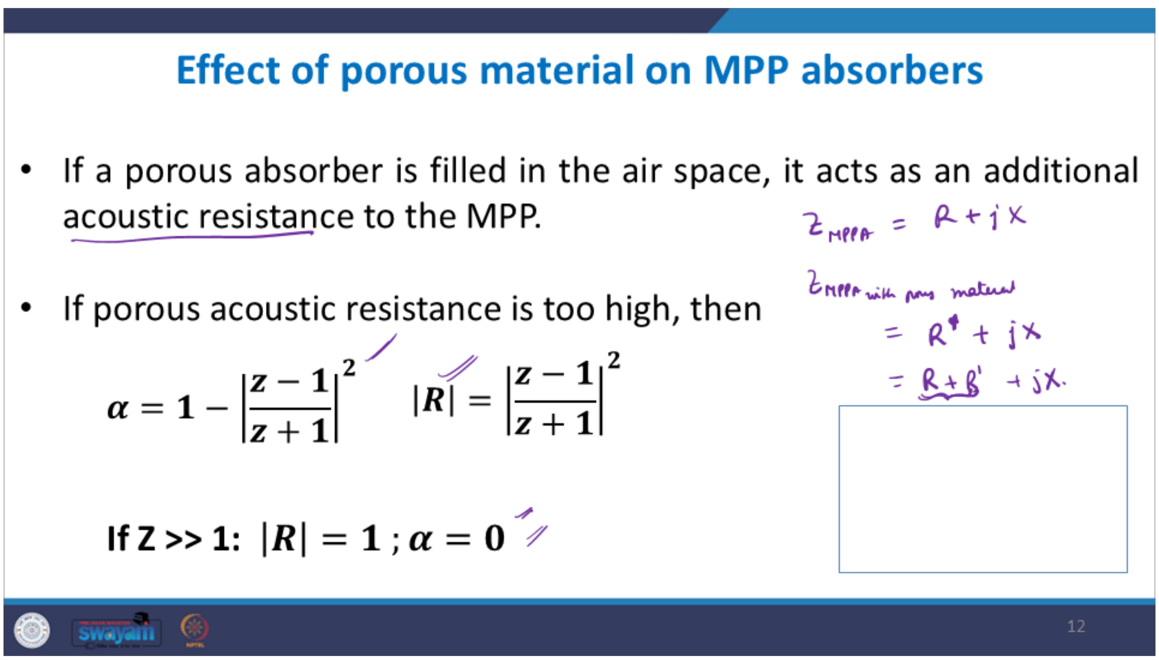
Because now we have an additional mechanism, which is the viscous loss, and because of that, the magnitude is rising up. Then, one of the major limitations of this is that wide-range absorption is difficult because, again, it is a resonance phenomenon which dominates. And only at those frequencies, we observe sharp peaks, albeit much higher in magnitude, but sharp and narrow peaks we are observing, and hence, wide-range absorption becomes difficult. How can you do wide-range absorption? You can install multiple layers of MPP leading, which can lead to an increase in cost, weight, and the volume of the overall absorber.



To overcome some of the limitations of the simple single-leaf MPP, which is in order to improve the low-frequency absorption response, which is to broaden the absorption response.



Various modifications have been tried out. In fact, MPP is a very ripe area for research in noise control engineering, as the time is going by, new observations are being made, and new kinds of designs are being proposed in general as the time is going by. Some of the common modifications suggested are that you either add some kind of absorber filling into the MPP cavity, or you, instead of having one panel, can have two panels in the MPP absorber, or you can have the cavity with different kinds of partitionings, and each partitioning having different shapes and different fillings. Again, for this particular lecture course, we will only discuss MPP, which is filled with porous absorber, and these other two would be out of scope. Let us see what happens when the porous absorber is inserted. we have already seen what happens when we fill the cavity of a sealed panel absorber with porous material. We have also seen what happens when we fill the cavity of a perforated panel absorber with porous material. A similar effect is observed for an MPP.

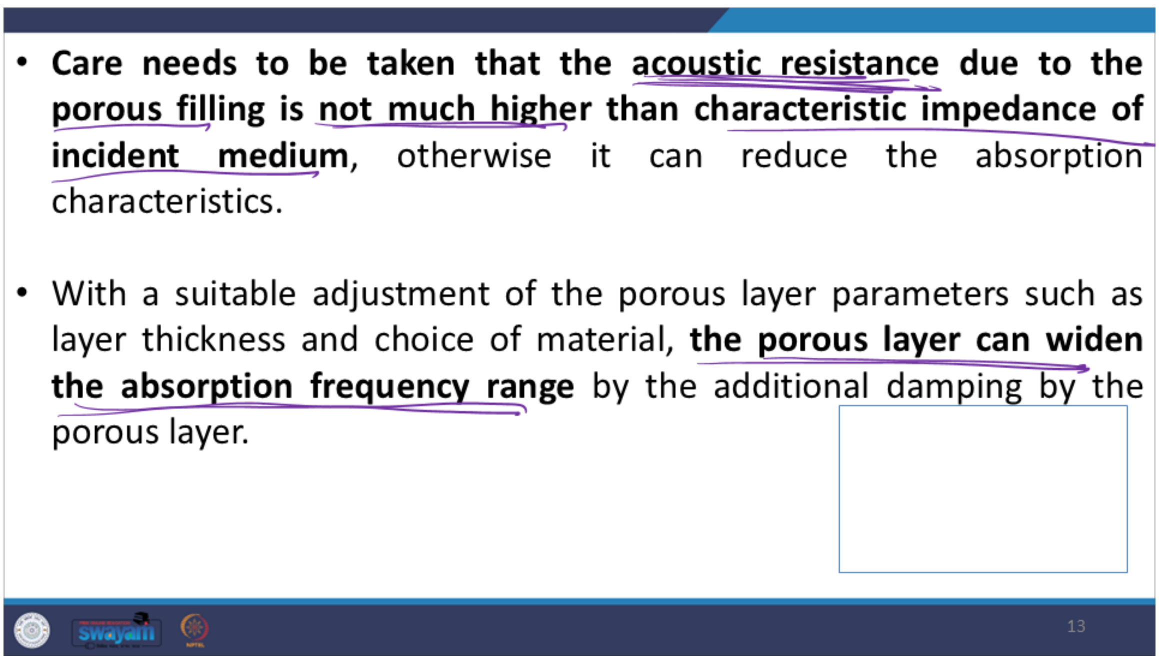


What happens? The porous material is added. you can think of it in mathematical terms—whatever is your Z of the MPP. The porous material acts as an acoustic resistance. whatever was your Z of MPPA with some real part and some imaginary part, now you have added the MPPA with some porous material. What will happen? The resistance part or the real part of your acoustic impedance is going to rise up because this could simply be thought of as the r initially plus the r dash due to porous material plus j x.

$$= R + R' + jX$$

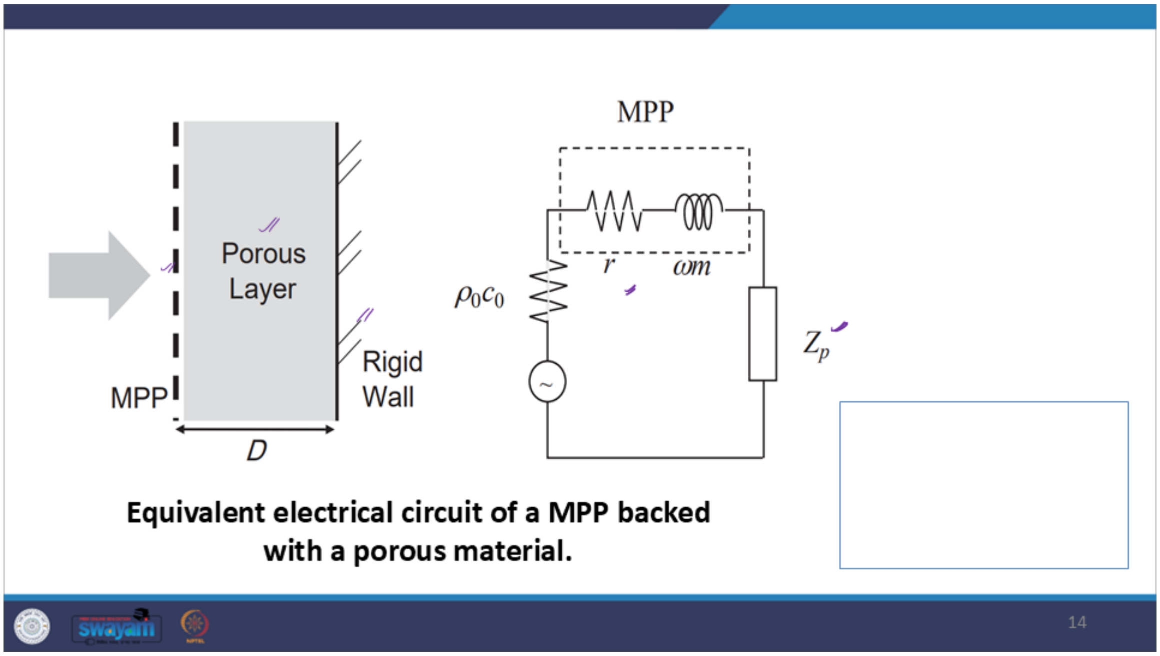
It directly adds the acoustic resistance to the model of the MPP, and hence the real part rises. Now, we know that α is 1 minus this—this is the alpha formulation—and r is given by this. Suppose if z is much greater than 1, then in that case, the r is going to become 1 and α is going to read 0. whenever you are adding porous material to increase the damping and to increase the resistance, there has to be a limit because if you reach a much higher or if you add too much porous material— sort of rises the overall resistance of the impedance, the resistance rises, then the overall Z increases, and α is going to become 0.

You have to add the porous material that can improve your absorption response, but remember that you also want to allow the sound waves to enter inside the material. The opposition should not be too much;

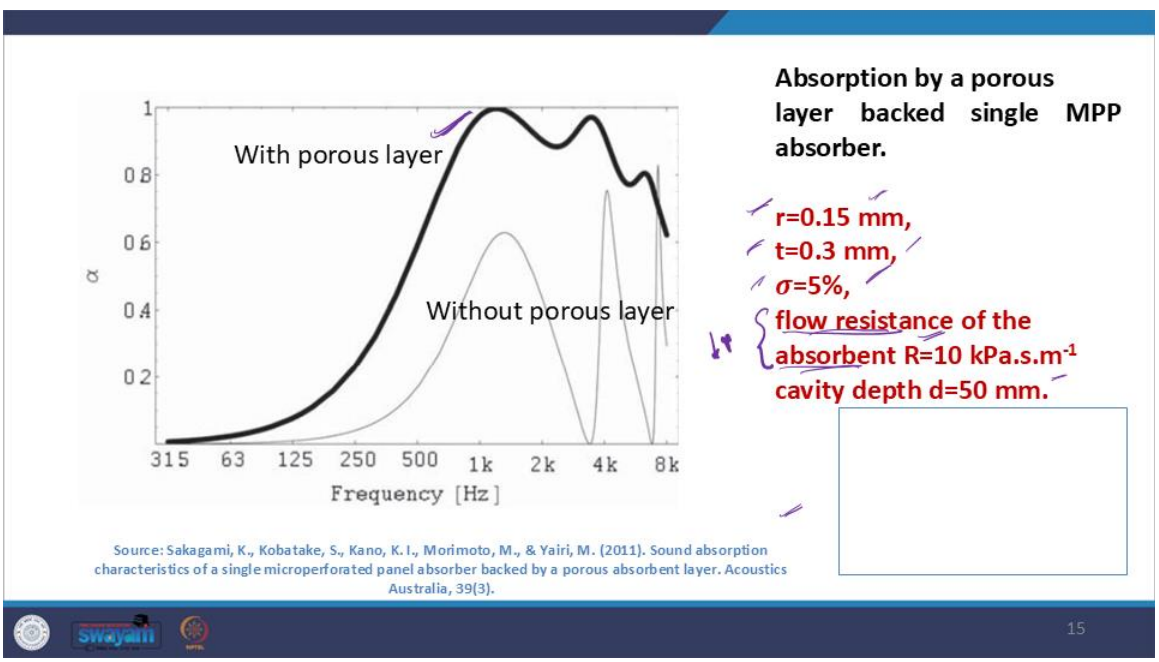


The resistance to the flow due to that porous filling should not be much higher than the characteristic impedance of the incident medium. Suppose you take this care and then appropriately select some porous material and add it—what will it do? It will have the same effect: it will widen the absorption frequency range, but that can come at the cost of a decrease in the absorption magnitude.

Let us see here: this is your MPP followed by a porous material, followed by the rigid wall. This is the electric circuit for this. You have the Z of the porous material and the Z of the MPP. They are now in series.



what is happening is that, sometimes, when you select an optimum porous material, you can observe an overall rise in the absorption as well.



iIn that case, given the appropriate filling is selected, it can lead to a rise in the overall absorption because it is increasing. In some ways it is going to increase because there is an additional mechanism that is coming into play. Not only the resonance and the thermo-viscous losses, but also you have the thermo-viscous losses within the porous material that is adding further to the loss in the sound energy or the sound energy dissipation. Sometimes this can also be observed, but a lot of care needs to be taken because if you select the wrong kind of material, it can lead to a decrease as well. here that is why some optimum parameters are given—, this is taken from a paper where what they did was: this is the radius of the MPP, the thickness of the panel, the porosity. And the flow resistance of the absorbent is given, which is this value, and the cavity depth is this. at this particular value, they observed that there was a significant rise by adding a porous layer. But if this thing increases or decreases, then that rise may not be observed. With this, we would like to close the lecture on MPP absorbers.

Thank you for listening.