Acoustic Materials and Metamaterials
Prof. Sneha Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture - 23
Microperforated Panel Absorbers – 3

Welcome to lecture 23 on the series of Acoustic Materials and Metamaterials. I am Dr. Sneha Singh of Mechanical Industrial Engineering Department at IIT Roorkee. So, in this lecture we will continue a discussion on Microperforated Panels and will conclude. So, in the last class we studied that is there are certain limitations with single leaf MPP absorbers that they are not able to provide absorption wide range and the so that was one of the major limitation that they are not able to provide the absorption wide range and then certain modifications are then done to the single leaf to get to try to eliminate this limitation.

So, in the last class we studied about one such modification that was what happens when a porous material is filled inside such MPP and we found is that provided we choose the total resistance due to this M porous material correctly and it does not become a hard blocking material and it can allow sufficient air to pass through. So, in that case the porous material will end up increasing the absorption magnitude and broadening the absorption peaks.

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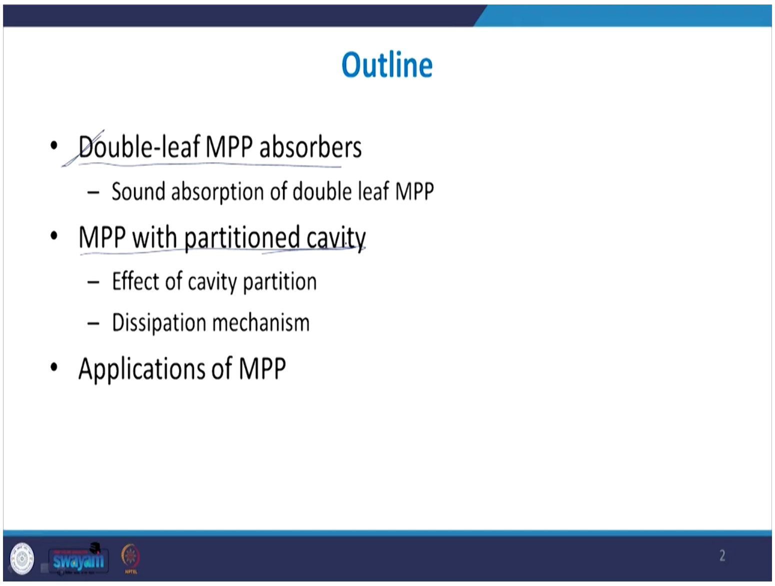

Outline

- Double-leaf MPP absorbers
  - Sound absorption of double leaf MPP
- MPP with partitioned cavity
  - Effect of cavity partition
  - Dissipation mechanism
- Applications of MPP

In this class we will study about 2 such another 2 modifications which is if we have double leaf MPP and if we have the MPP with a partitioned cavity and then we will see what are the applications of MPP in various industries.

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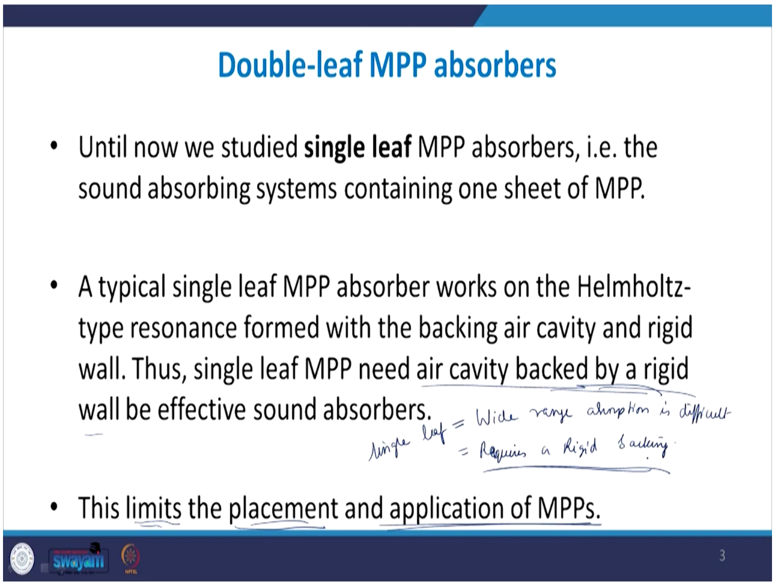

Double-leaf MPP absorbers

- Until now we studied **single leaf** MPP absorbers, i.e. the sound absorbing systems containing one sheet of MPP.
- A typical single leaf MPP absorber works on the Helmholtz-type resonance formed with the backing air cavity and rigid wall. Thus, single leaf MPP need air cavity backed by a rigid wall be effective sound absorbers.

Single leaf = Wide range absorption is difficult
= Requires a Rigid backing.

- This limits the placement and application of MPPs.

So, what is a double MPP absorber? So, till now we have studied that we had a single microperforated panel which was having an enclosed cavity behind and then a rigid wall backing. So, what if we have 2 such layers of microperforated panel?

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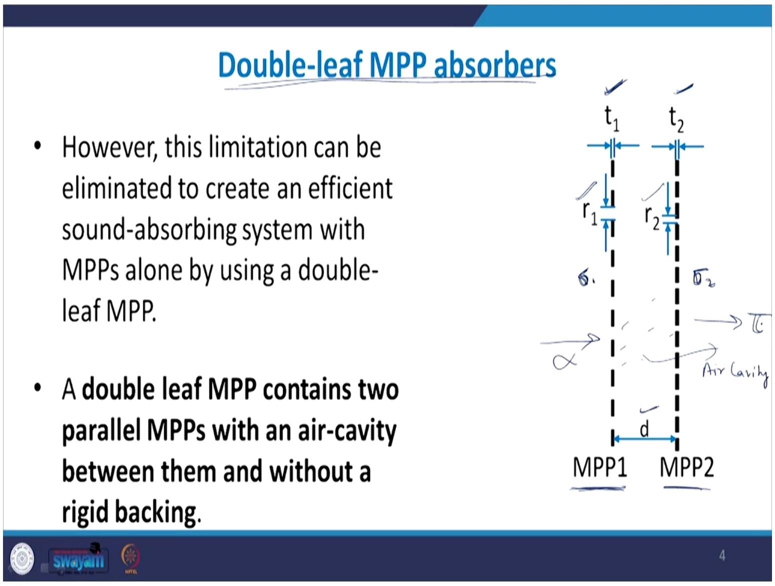

Double-leaf MPP absorbers

- However, this limitation can be eliminated to create an efficient sound-absorbing system with MPPs alone by using a double-leaf MPP.
- A **double leaf MPP contains two parallel MPPs with an air-cavity between them and without a rigid backing.**

So, in that case, so, this is the double leaf MPP absorber. So, a simple construction is where you have an MPP 1 and MPP 2. So, one of the limitations with single leaf is that first of all it is not able to provide a wide range absorption and the second one was that it always needs to have a air cavity backed by a rigid wall.

So, there is a requirement for a rigid wall at all the times for an MPP to work. So, single leaf requires first of all wide range absorption is not possible is difficult rather to say for a single leaf and the other limitation was that it requires a rigid backing. So, this design constant is always there and that is and because it always requires a rigid backing. So, this limits our options to place and apply the MMPs in various portions.

So, we can only apply it on the walls or near the walls, we cannot apply it mid way or in some complicated inside some complicated machinery component because every time we have to only apply it near a rigid backing. So, these were the 2 limitations.

So, this double leaf MPP tries to overcome both this limitations, specially this requirement for a rigid backing. So, this is a basic construction of this double leaf MPP, what we have? We have 2 MPP layers and the distance between them here I am representing with the variable d and usually in most of the cases these MPP layers they have difference different whole radius because we know that as whole radius and porosity changes then the absorption characteristics also change.

So, it is better to have 2 layers one by one with different whole radius and porosities. So, that we can get 2 different absorption peaks and we can have a more broader way broader absorption. So, that is why these parameters, so, when MPP 1 and MPP 2 which was chosen the thickness is of the first one I am representing by t 1 and for the second one I am representing by t 2 and similarly whole radius by r 1 and r 2 and we can simply represent the porosity by 1 sigma 1 and porosity of the 2 by sigma 2.

So, the control parameters are varied for both the MPP layers and they maintained at a particular distance and here this there the air cavity is actually the air inside the air between both these MPPs. So, here a rigid backing is not required, it may be used. So, when we will later study we will see a few graphs where rigid backing is also added and then without the rigid backing also we can use this kind of MPP.

So, now that now here in this particular construction there is no rigid backing. So, when there no rigid backing which means that some transmission will take place the rigid backing was making ensuring that the sound is getting absorbed, but from the other end the transmission is not happening because the sounds are getting reflected from the rigid backing.

So, it was sort of blocking the transmission of sound from the other end of the material, but in this MPP because now we do not have a rigid wall, so, some transmission will take place from the other end. So, some sound wave will be absorbed, but some transmission will take place through this backing.

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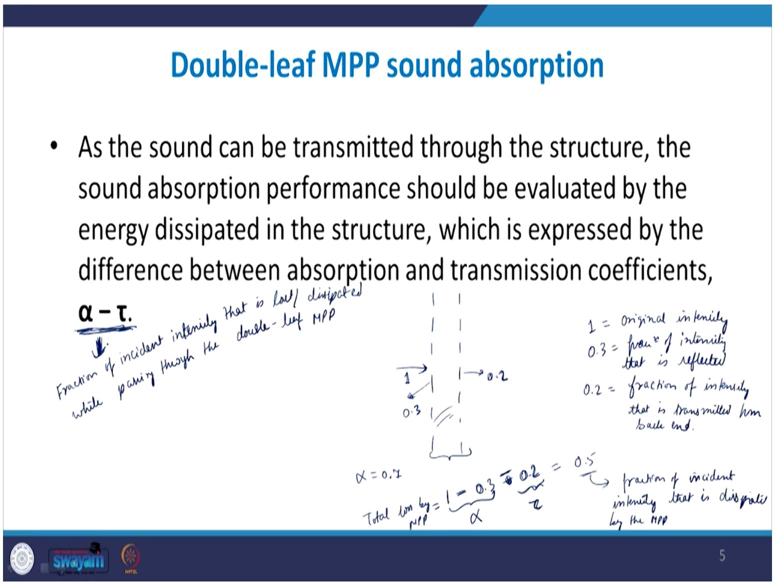

Double-leaf MPP sound absorption

- As the sound can be transmitted through the structure, the sound absorption performance should be evaluated by the energy dissipated in the structure, which is expressed by the difference between absorption and transmission coefficients, **$\alpha - \tau$.**

Fraction of incident intensity that is lost/ dissipated while passing through the double-leaf MPP

1 = Original intensity
0.3 = fracⁿ of intensity that is reflected
0.2 = fraction of intensity that is transmitted from back end.

$\alpha = 0.7$

$$\text{Total loss by MPP} = \underbrace{1 - 0.3}_{\alpha} - \underbrace{0.2}_{\tau} = 0.5$$

fraction of incident intensity that is dissipated by the MPP

So, if we represent the sound absorption coefficient by alpha and this transmission intensity coefficient or the intensity or the fraction of intensity that is getting transmitted from the other end of the absorber as tau. Then a better way of measuring the performance of such MPP is using alpha minus tau because what is the purpose of this MPP to reduce the overall noise both before the material as well as after the material.

So, let us see that this was a layer and some intensity of 1 was incident on it and so, only an intensity of 0.3 what reflected. So, overall alpha becomes 0.7. So, 30 percent of the wave got reflected in this end, but 0.2 of it got transmitted from the other end 0.2 of the original intensity; so, 7 30 percent of reflection and 30 20 percent of transmissions. So, overall loss is what? The overall loss is going to be 1 minus 0.3 plus 0.2 sorry minus 0.2.

So, if 1 is equal to the original intensity and 0.3 is the fraction of intensity which is reflected and 0.2 is the fraction of intensity that is transmitted from other end from the backend. So, in that case the total loss that is happening, the total loss by this MPP material is not 0.7 because 0.7 would have been the loss if nothing came out of it.

So, the total loss effectively is going to be 1 minus 0.3 minus 0.2 which over here becomes 0.5. So, 30 percent of the energy is reflected 20 percent is transmitted and the remaining 50 percent of it within the material is dissipated. So, this is the fraction of in incident intensity that is dissipated or by the MPP. So, this is the energy that the MPPs controlling. So, a better way of measuring the performance of this MPP could be alpha minus tau. Here this is what by definition; this is alpha because it is 1 minus the intensity reflection coefficient.

So, 1 minus r square and this is tau. So, alpha minus tau will give you this gives you what? It is the fraction. So, in this they gives us the fraction of the incident intensity that is lost or dissipated while passing through the double leaf MPP. So, this becomes a better measure. So, before we were studying the plot of alpha versus frequency and has to study what is the absorption by the MPP, now we will study the plots of alpha minus tau versus frequency to see what is the effective absorption by the MPP. So, we are removing the transmission part.

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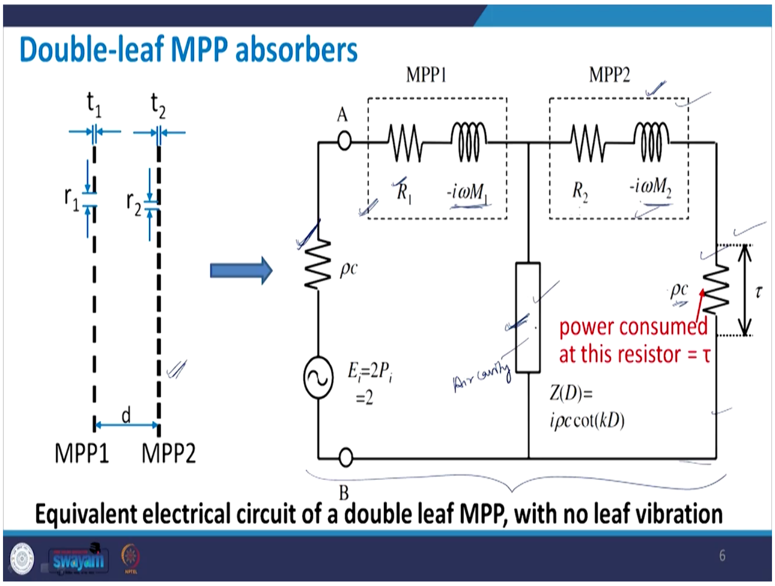

Double-leaf MPP absorbers

power consumed at this resistor = τ

Equivalent electrical circuit of a double leaf MPP, with no leaf vibration

So, now, here if you look at this figure again then if there was no first material, so, first material the sorry the second layer was not there we just had a 1 microperforated panel followed by a rigid backing when it would be represented by the first circuit here only this first loop here. So, where we had it could be represented by this is the impedance of the incident medium, this is the impedance of the incident medium, this is impedance by the MPP panel and this is the impedance by the air cavity backing air cavity.

So, the Z of MPP and the Z of air cavity they are in series and that is why the total acoustic impedance that we derived for single leaf was Z of MPP plus Z of cavity. So, this is the original circuit. So, we can represent this MPP connection as a electrical circuit and this is how we can represented. So, when a second layer is added at a distance d then what it does is that now this layer is acting as a parallel layer to this air cavity.

So, both MPP 1 and MPP 2 they have a common air cavity in between and they are acting in parallel. So, the equivalent air circuit the electrical circuit is like this. Here this is the impedance of the MPP 2 and this is again the incident rho c due to the incident wave and this is the common air cavity in between. So, if you solve this circuit, so, we already know we have a model by that was proposed by Professor Dayuma and in that model the total Z of an MPP was given to you.

So, you know the r 1 value which is the real part of the Z and the imaginary part of the Z. So, these values can be found from the model proposed by Professor Dayuma which I had discussed in the very first lecture on MPP.

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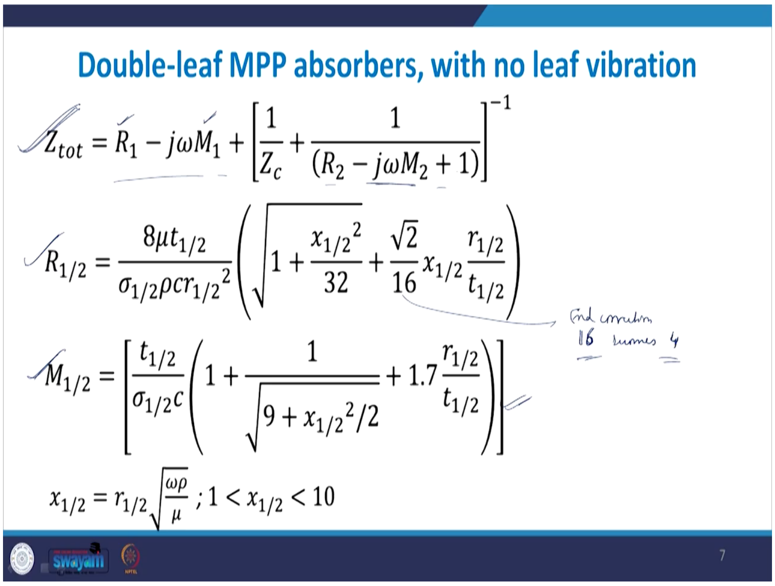

Double-leaf MPP absorbers, with no leaf vibration

$$Z_{tot} = R_1 - j\omega M_1 + \left[\frac{1}{Z_c} + \frac{1}{(R_2 - j\omega M_2 + 1)}\right]^{-1}$$

$$R_{1/2} = \frac{8\mu t_{1/2}}{\sigma_{1/2}\rho c {r_{1/2}}^2}\left(\sqrt{1 + \frac{{x_{1/2}}^2}{32}} + \frac{\sqrt{2}}{16} x_{1/2} \frac{r_{1/2}}{t_{1/2}}\right)$$

End correction

16 becomes 4

$$M_{1/2} = \left[\frac{t_{1/2}}{\sigma_{1/2} c}\left(1 + \frac{1}{\sqrt{9 + {x_{1/2}}^2/2}} + 1.7\frac{r_{1/2}}{t_{1/2}}\right)\right]$$

$$x_{1/2} = r_{1/2}\sqrt{\frac{\omega\rho}{\mu}}\,; 1 < x_{1/2} < 10$$

So, here, now if you in this particular circuit if you solve for the total impedance what you get is this in series with the parallel of this. So, you these are in parallel. So, they are solve together and then whatever equivalent resistance we get from this resistance in parallel we add them together to this in series. So, the first resistance plus this is going to be now these 2 resistance are in series. So, the total becomes rho c again because we are representing everything in the relative terms.

So, Z of MPP we represented as a relative Z with respect to the incident medium. So, Z by rho c is what we are representing. So, rho c the relative impedance then becomes 1. So, this we can take as 1 and this will be the impedance relative to this rho c. So, this will be r minus this will be r plus 1 we are, so, these 2 are in series. So, they are added together. So, r plus 1 and we will be the real part and this will be the imaginary part. So, r 2 plus 1 and then this is the imaginary part.

So, this is the total resistance in this particular circuit in this particular loop and this is in parallel with the Z of cavity. So, 1 by Zc and this equivalent is what is then added in series to this. So, this gives us the. So, you can represent this double leaf as a electrical circuit and then you can solve for the total Z and then you know the individual parts R 1 and M 1. So, by the model we are I had already given an equation for this in the first lecture.

So, R of 1 slash 2 can be represented at this 8 mu t 1 of 1 or 2 divided by sigma rho cr under root of 1 plus x square by 32 plus under root of 2 by 16 R by t, if you add end correction end correction then 16 becomes 4. So, 2 formula were given to you in the very first lecture on MPP. So, using that formula you can find out what is the real part of the impedance of MPP and the imaginary part of the impedance of the MPP.

So, this is known to us individually based on the various design parameters and then we can solve this to get the total of the circuit or the total due to this double leaf MPP. And when you find the total Z, so, usually these things are not done like hand calculations we have computers we are writing the algorithms and then numerical studies performed. So, all these value is spread into a computation tool, it does the computation and then it sees how the alpha varies with the various design control parameters.

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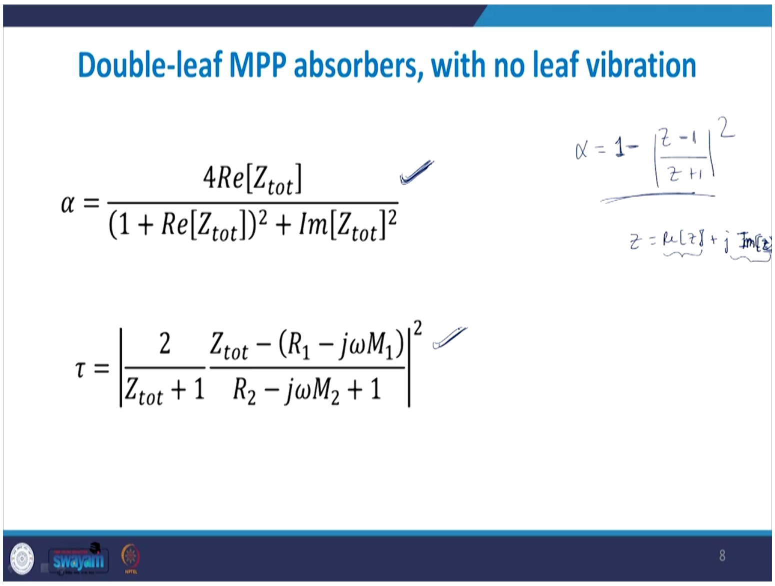

Double-leaf MPP absorbers, with no leaf vibration

$$\alpha = \frac{4Re[Z_{tot}]}{(1+Re[Z_{tot}])^2 + Im[Z_{tot}]^2}$$

$$\tau = \left|\frac{2}{Z_{tot}+1}\frac{Z_{tot}-(R_1-j\omega M_1)}{R_2-j\omega M_2+1}\right|^2$$

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

$$Z = Re[Z] + j\,Im[Z]$$

So, once the total Z is calculated alpha can be obtained by this equation because alpha is given by 1 minus Z minus 1 by Z plus 1 whole square, where is Z is equal to some real part of Z plus j times the imaginary part of Z. So, Z can be representing by its corresponding real part and imaginary part and this is the overall function.

When you solve it, this is the equation you get and if you want to go more into details of this equation you can also referred to the lecture on sound medium at the sound propagation at medium boundaries where we derived that the R for a medium is given by Z 2 minus Z 1 divided by Z 2 plus Z 1 and 1 minus R square then was found and it was represented by this form of equation; tau was also found in the same lecture you will find the equation for tau. So, both derivations are given to you when you study the lecture on sound propagation on medium boundaries.

So, where you can solve for the Z total and you can find out what is alpha what is t and then you can plot alpha minus t sorry alpha minus tau. So, you can plot these this quantity alpha minus tau which will give you what is the total performance as a function of frequency ok. So, this is when; this is when we consider that both the thin panel. So, we do not have any rigid backing and they do not have any strong support.

So, sometimes the panel when the sound is incident on the panel, it can also cause the panel to vibrate along with the air. So, this is when the panel is not vibrating. So, there is no leaf vibration or no panel vibration but they can be a case when the panel itself can start vibrating as a sound wave is incident on it.

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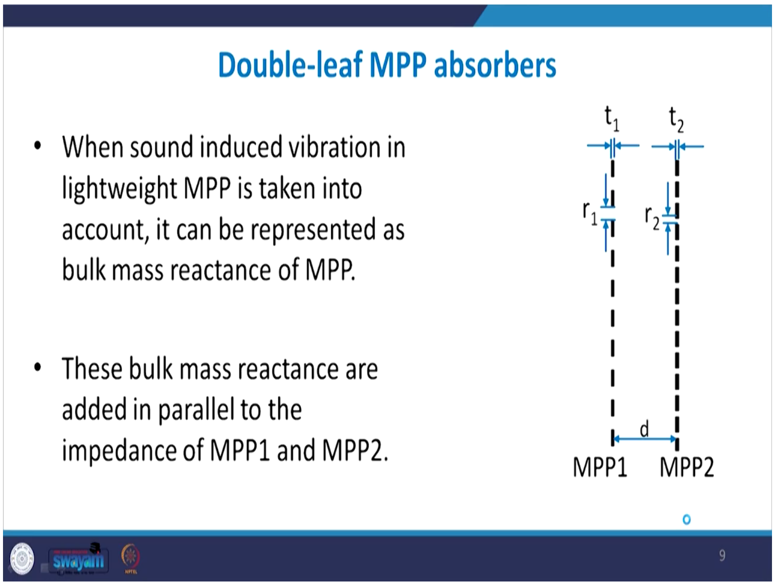

Double-leaf MPP absorbers

- When sound induced vibration in lightweight MPP is taken into account, it can be represented as bulk mass reactance of MPP.
- These bulk mass reactance are added in parallel to the impedance of MPP1 and MPP2.

So, in that case overall the leaf vibration has an effect that it adds an additional in not a impedance, but it adds an additional reactance part which is directly proportional to the mass of the panel.

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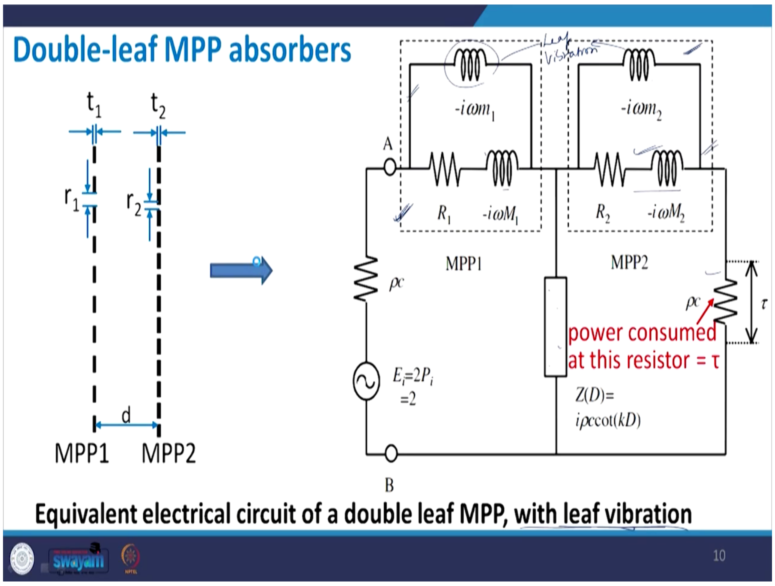

Double-leaf MPP absorbers

power consumed at this resistor = τ

Equivalent electrical circuit of a double leaf MPP, with leaf vibration

So, here this is the original impedance and because this leaf is vibrating, so, an additional reactance part which is omega into M times where M 1 is the mass of the first panel. So, this reactance is added in parallel, similarly of this leaf is vibrating then this is the original impedance and another reactance is added in parallel to account for. So, all of this accounts for the leaf vibration.

So, if the individual leafs are vibrating then an additional reactance is added to it. So, if only one leaf was vibrating then we will only take this one, let us say a only first panel was vibrating the second one was not vibrating then this part will be removed and only this impedance will be taken, this part will not be taken, it will be removed like this if only 1 leaf was vibrating.

So, whenever leaf vibration is added then a reactance is added in parallel which is directly proportional to omega times the mass of the panel. So, this becomes have a new circuit when you solve it you get another complicated expression. So, first of all you find out what is equivalent of this, these 2 are in parallel, what is the equivalent of this and then this is added in series with this and then these together are in parallel with this and the equivalent of the entire thing then is added to this equivalent to get the total Z.

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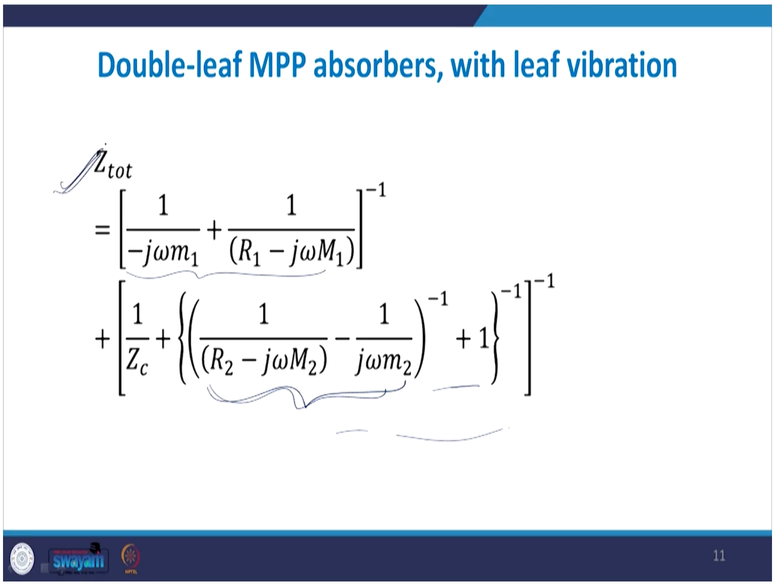

Double-leaf MPP absorbers, with leaf vibration

$$Z_{tot} = \left[\underbrace{\frac{1}{-j\omega m_1} + \frac{1}{(R_1 - j\omega M_1)}}\right]^{-1} + \left[\frac{1}{Z_c} + \left\{\left(\underbrace{\frac{1}{(R_2 - j\omega M_2)} - \frac{1}{j\omega m_2}}\right)^{-1} + 1\right\}^{-1}\right]^{-1}$$

So, solving this particular circuit; this is the if n result, I am directly giving you the n result. So, here this part is ok; so, this part is the this equivalent this particular impedance. So, it is the equivalent of these 2 being in parallel, this is the first part and then this is Z c. So, 1 by Zc plus 1 by the equivalent of this and whole inverse will give you the equivalent of this entire circuit.

So, this part, so, just like this part was the equivalent of this full block, this part is the equivalent of this block, so, this part is the equivalent of this block and then rho c is taken as 1 because you are finding out the relative impedance. So, this part is then added to 1 to get the entire the entire impedance of this whole circuit and then these are in parallels. So, the overall parallel thing is added to previous one.

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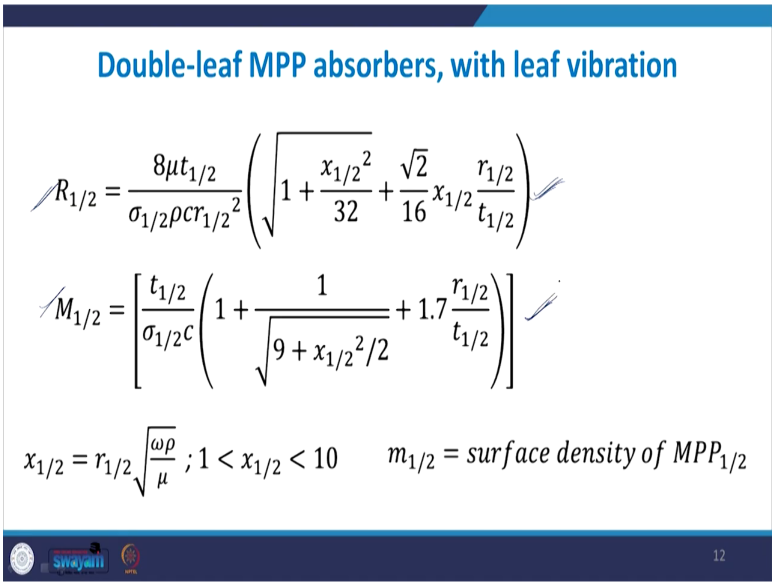

Double-leaf MPP absorbers, with leaf vibration

$$R_{1/2} = \frac{8\mu t_{1/2}}{\sigma_{1/2}\rho c {r_{1/2}}^2}\left(\sqrt{1+\frac{{x_{1/2}}^2}{32}}+\frac{\sqrt{2}}{16}x_{1/2}\frac{r_{1/2}}{t_{1/2}}\right)$$

$$M_{1/2} = \left[\frac{t_{1/2}}{\sigma_{1/2}c}\left(1+\frac{1}{\sqrt{9+{x_{1/2}}^2/2}}+1.7\frac{r_{1/2}}{t_{1/2}}\right)\right]$$

$x_{1/2} = r_{1/2}\sqrt{\frac{\omega\rho}{\mu}}\ ; 1 < x_{1/2} < 10$ $\quad m_{1/2} = surface\ density\ of\ MPP_{1/2}$

So, it is a this is the expression we get for Z total; R and M for both of the real part and the imaginary part for the impedance of an MPP again from the same model is already given to us, it is this expression.

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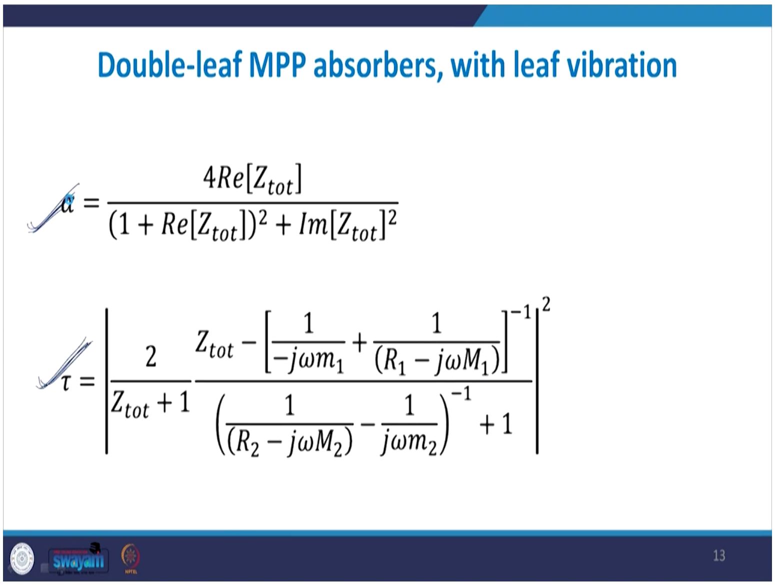

Double-leaf MPP absorbers, with leaf vibration

$$\alpha = \frac{4Re[Z_{tot}]}{(1 + Re[Z_{tot}])^2 + Im[Z_{tot}]^2}$$

$$\tau = \left| \frac{2}{Z_{tot} + 1} \frac{Z_{tot} - \left[\frac{1}{-j\omega m_1} + \frac{1}{(R_1 - j\omega M_1)}\right]^{-1}}{\left(\frac{1}{(R_2 - j\omega M_2)} - \frac{1}{j\omega m_2}\right)^{-1} + 1} \right|^2$$

Alpha and tau can be found. So, all of these calculations are if you are taking this course I will not be asking you to do all these calculations because these are series of complicated calculations; this is just for the understanding that what does the double leaf or what is the; what is the effect of an additional leaf behind.

So, an additional leaf means that one impedance is now being added in parallel with a common Zc. So, that is the overall effect and it is just to show you how such numerical computations are done. So, computation tools are available and all these complicated computations are done. So, when you get alpha and tau. So, you have found alpha and tau when there is no leaf vibration you have also found alpha and tau when there is leaf vibration.

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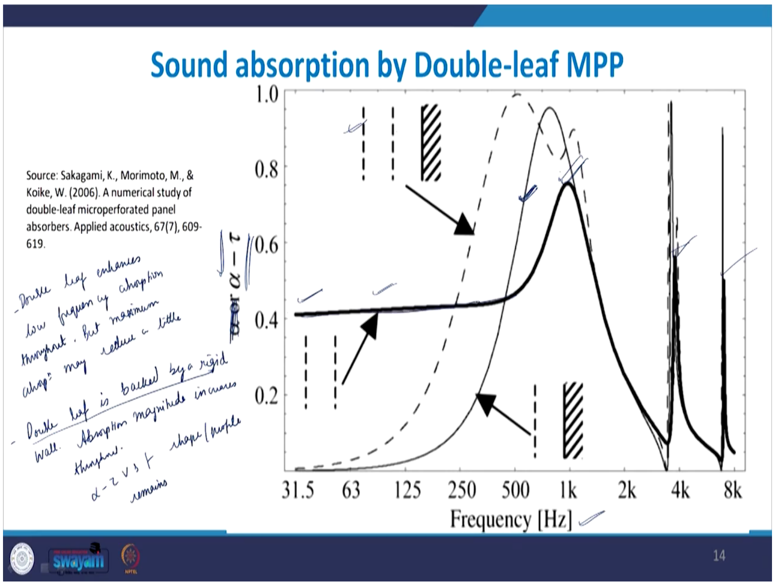

Sound absorption by Double-leaf MPP

Source: Sakagami, K., Morimoto, M., & Koike, W. (2006). A numerical study of double-leaf microperforated panel absorbers. Applied acoustics, 67(7), 609-619.

- Double leaf enhances low frequency absorption throughout. But maximum absorp^n may reduce a little
- Double leaf is backed by a rigid wall. Absorption magnitude increases throughout.

$\alpha - \tau$ vs f shape/profile remains

Then you can plot alpha and tau. So, alpha and tau can be plotted with respect to frequency. So, let us directly give you what is the effect of adding this double leaf. So, this graph shows the single the alpha minus tau of a single leaf. So, this is denote absorption by a single leaf, effective absorption. When another leaf is added to it, so, usually the absorption peak a degrees a related a little bit, but overall the absorption at the low frequency is enhance throughout.

So, throughout from the very beginning of very beginning till the resonance condition the absorption magnitude is enhance in this low frequency region and then it follows a same pattern. So, that is the effect of double leaf that suddenly low frequency absorption is enhanced throughout. And if we add a rigid backing and the end, so, if we have double leaf plus a rigid backing then in that case what it does is that it is it improves the low frequency absorption and broadens the peak, but it is not done throughout.

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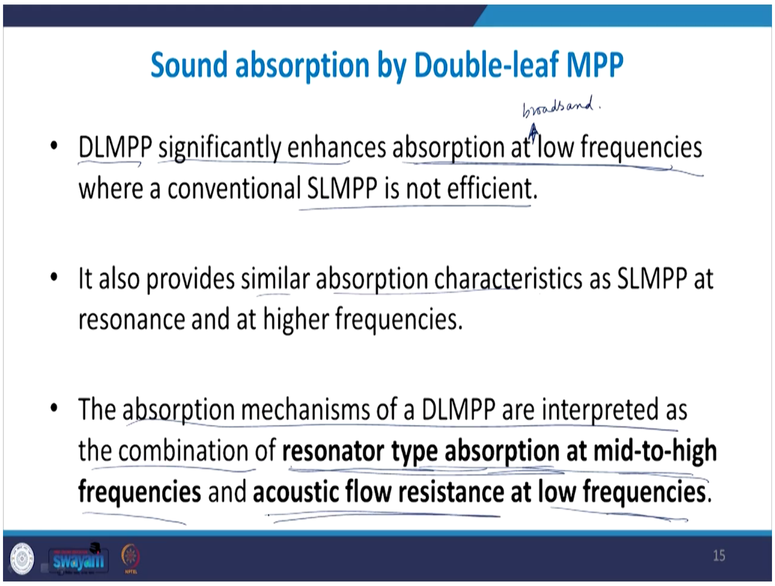

Sound absorption by Double-leaf MPP

broadband.

- DLMPP significantly enhances absorption at low frequencies where a conventional SLMPP is not efficient.
- It also provides similar absorption characteristics as SLMPP at resonance and at higher frequencies.
- The absorption mechanisms of a DLMPP are interpreted as the combination of **resonator type absorption at mid-to-high frequencies** and **acoustic flow resistance at low frequencies**.

So, I will write down the effect here. So, I can write down here also. So, when only double leaf; double leaf enhances low frequency absorption throughout which means throughout all the low frequencies, but the maximum absorption may reduce a little not much effect, but a little reduction and when the same double leaf is backed by a rigid wall, so, what happens is that now, the absorption peak is enhanced. So, absorption magnitude increases throughout.

So, the shape remains the same; alpha minus tau versus f shape a profile remains same, only there is an overall increment throughout. So, it just get a bigger peak it will not be a constant absorption. So, they would not be a broadband low frequency absorption you will still get a peak, but the peak will be broaden and it will be. So, it will be a slightly wider peak with increased magnitude. So, that will be the effect of double leaf by a rigid wall.

So, I am restating these results here. So, it the double leaf MPP it significantly enhances the absorption at low frequencies broadband let say, broadband low frequencies because it is happening throughout. And so, it can enhance it at all these broadband low frequencies where the single leaf MPP is not efficient. And it provides almost similar absorption characteristics at the resonance and higher peaks although it is slightly reduced, but it is within the limits.

Now, the absorption mechanism of a double leaf MPP can then interpreted as it is both a resonator. So, at middle to high frequencies it acts as a resonator and at low frequencies it is acting as a acoustic flow resistance. So, at the middle to high frequencies you see it takes the same form as a resonator, so, you get some peaks at certain frequencies, but at low frequencies there is a broadband absorption.

So, there is no peaks sharp peaks absorber, but there is a constant absorption throughout at the low peaks. So, you at the low frequencies, so, there is a constant absorption at low frequencies. So, you can assume that at low frequencies this particular double leaf MPP it is acting like a typical acoustic resistance which is independent of frequency. So, there is you are getting a constant value here and then suddenly if middle to high frequency it behaves a same way as single leaf MPP or as a resonator.

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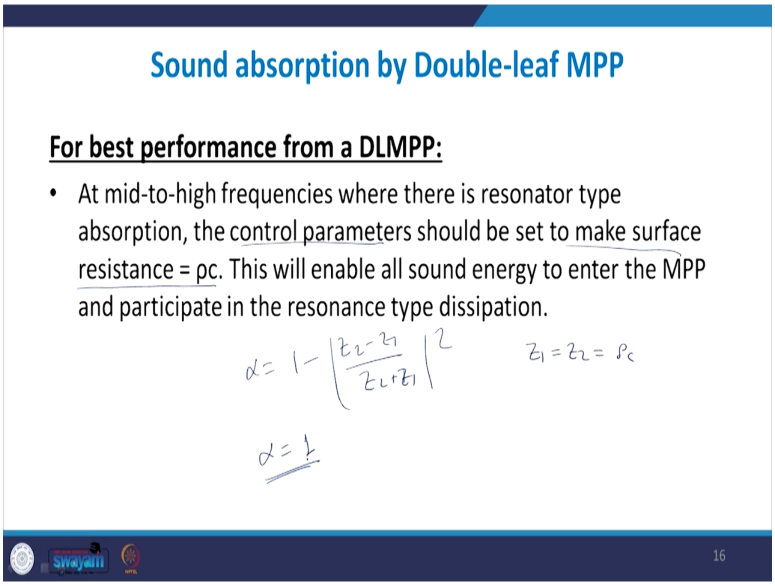

Sound absorption by Double-leaf MPP

For best performance from a DLMPP:

- At mid-to-high frequencies where there is resonator type absorption, the control parameters should be set to make surface resistance = ρc. This will enable all sound energy to enter the MPP and participate in the resonance type dissipation.

$$\alpha = 1 - \left|\frac{Z_2 - Z_1}{Z_2 + Z_1}\right|^2 \qquad Z_1 = Z_2 = \rho c$$

$$\alpha = 1$$

So, for best performance what you can do is that you can set the control parameter, so that the surface resistance becomes rho c at the resonance condition. So, when the impedance the surface impedance of the double leaf MPP is rho c and the incident medium surface impedance is also rho c. So, when the there is a impedance match then there will be a perfect absorption alpha will be equal to 1. We know that alpha is equal to 1 minus Z 2 minus Z 1 by Z 2 plus Z 1 whole square. So, when Z 2 Z 1 equals to Z 2 equals to rho c so, in that case alpha becomes equals to 1.

So, that can that this is one way of attaining maximum absorption that is you can equal the surface impedance to that of the incident medium at the resonance frequency.

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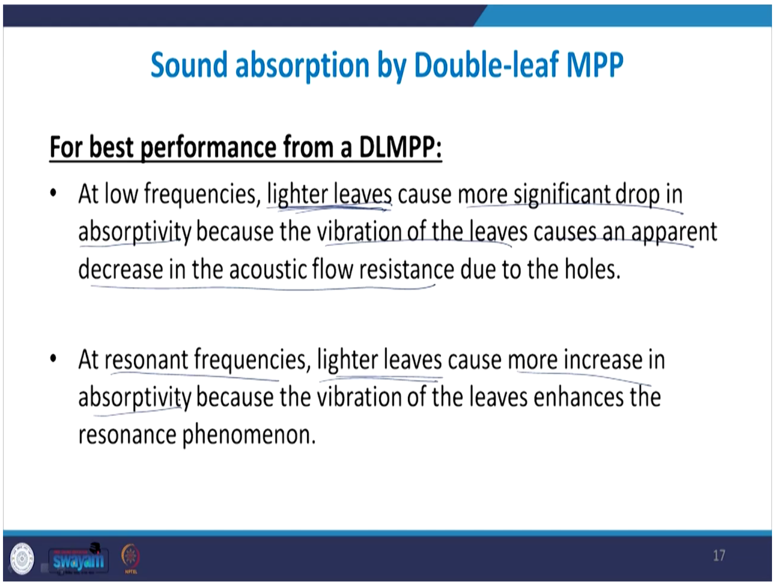

Sound absorption by Double-leaf MPP

For best performance from a DLMPP:

- At low frequencies, lighter leaves cause more significant drop in absorptivity because the vibration of the leaves causes an apparent decrease in the acoustic flow resistance due to the holes.
- At resonant frequencies, lighter leaves cause more increase in absorptivity because the vibration of the leaves enhances the resonance phenomenon.

Then some other things that can be done is that we can have at lower frequencies lighter leaves can be if the leaves are lighter they will cause more significant drop in absorptivity because here the vibration of the leaf will cause a decrease in the acoustic flow resistance.

So, in the low frequencies there are the absorption is mainly due to the resistance to the flow of air and if lighter leaves are used that they are vibrating along with the air, so, there is no the resistance to air flow is decreased. But at resonance frequencies the opposite happens, the lighter leaves they can cause more increase in absorptivity because it higher frequencies sorry at resonant frequency the absorption is because of the vibration. So, absorption is because now the sound energy is doing work to vibrate the air and the panel.

So, when the lighter leaves are used panel will vibrate, they will be stronger resonance and more energy will be lost. So, this is the a positive effect at low and the high frequencies.

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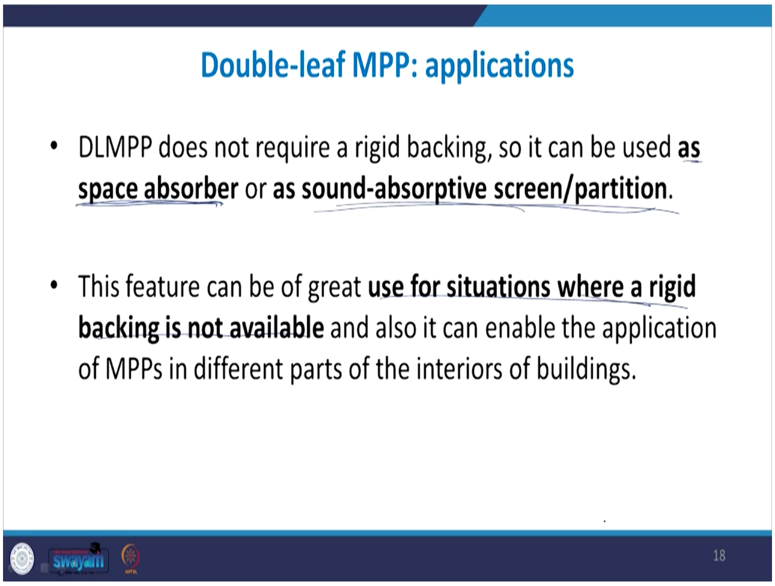

Double-leaf MPP: applications

- DLMPP does not require a rigid backing, so it can be used **as space absorber** or **as sound-absorptive screen/partition**.
- This feature can be of great **use for situations where a rigid backing is not available** and also it can enable the application of MPPs in different parts of the interiors of buildings.

So, they the application of this kind of double leaf MPP then becomes that now just like a MPP, now there is no restriction that it has to be applied only where you have a rigid backing. So, they can be used as space absorbers. They can be installed anywhere in mid way when there is no rigid backing, even in the open air conditions.

So, we are need not be and indoor application or an application nearer rigid wall backing they can be used anywhere in this space as a screen or a partition and they can also be used in some complicated areas where backing is not available such as the different types of different parts of machinery and buildings ok.

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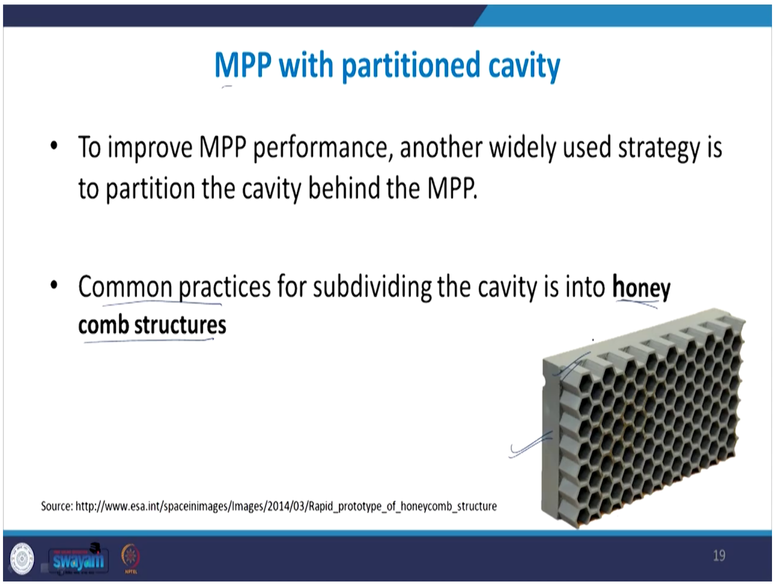

MPP with partitioned cavity

- To improve MPP performance, another widely used strategy is to partition the cavity behind the MPP.
- Common practices for subdividing the cavity is into **honey comb structures**

Source: http://www.esa.int/spaceinimages/Images/2014/03/Rapid_prototype_of_honeycomb_structure

So, the last form of modification that is usually studied that has successfully been able to successfully eliminate the limitation is when the cavity that is behind a single leaf MPP is partitioned or sectioned. So, one of the common practice is we use a honey comb structure. So, this shows a typical cavity partitioning. So, we have a we can have a microperforated panel on the top of it and behind we have again the air cavity, but now these air cavity is divided into segments or partitions and the common one being a honey comb kind of a structure for dividing the air cavity.

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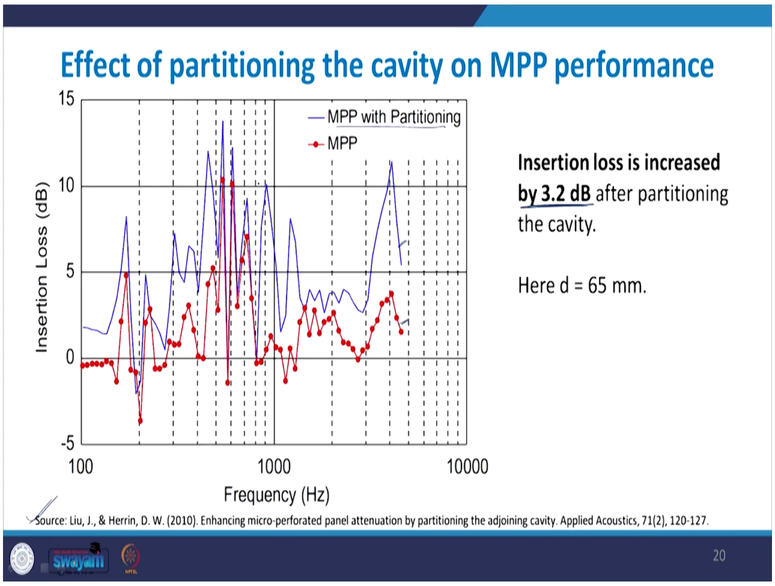

Effect of partitioning the cavity on MPP performance

Insertion loss is increased by 3.2 dB after partitioning the cavity.

Here d = 65 mm.

Source: Liu, J., & Herrin, D. W. (2010). Enhancing micro-perforated panel attenuation by partitioning the adjoining cavity. Applied Acoustics, 71(2), 120-127.

So, this shows the effect. So, here the source for every data is given to you. So, here this is an experiment carried out by Liu and Herrin in 2010 and they found that when a the cavities partitioned using a honey comb structure then suddenly this is the performance this is the insertion loss due to original MPP and this is the insertion loss due to the MPP without with the partitioning and overall the insertion loss has increased by 3.2 decibels.

So, they are able to reduce the noise mode by 3.2 decibels. So, as you can see throughout the alpha has being enhanced for such an MPP; so, performance increases.

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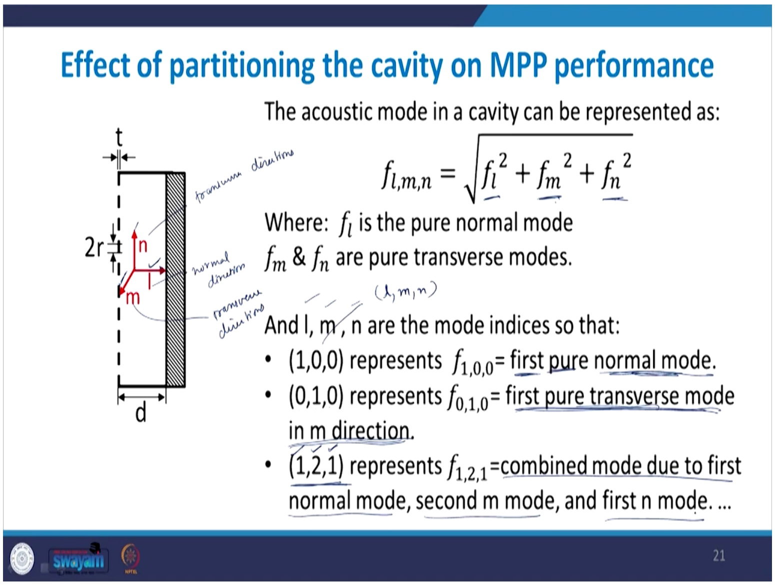

Effect of partitioning the cavity on MPP performance

The acoustic mode in a cavity can be represented as:

$$f_{l,m,n} = \sqrt{\underline{f_l}^2 + \underline{f_m}^2 + \underline{f_n}^2}$$

Where: f_l is the pure normal mode

f_m & f_n are pure transverse modes.

(l, m, n)

And l, m, n are the mode indices so that:

- (1,0,0) represents $f_{1,0,0}$= first pure normal mode.
- (0,1,0) represents $f_{0,1,0}$= first pure transverse mode in m direction.
- (1,2,1) represents $f_{1,2,1}$=combined mode due to first normal mode, second m mode, and first n mode. ...

So, how is this explained? So, when we have this sound when we have the air cavity backing then different modes can be setup within this air cavity to represent the sound wave propagations. So, we have this air cavity becomes a constant medium at one end we have a driving source and at the other end we have a rigid backing and within this constant medium, it will have certain modes and the modes can be represented by; so, if it is this is the 3 directions of sound wave propagation where l, m and n.

So, here you can see l is the normal direction this is the normal direction or the direction that is normal to the panel and these are all transverse directions, transverse directions. So, in that case the total the total frequency can be represented as a combination of the frequencies at the 3 different directions, the natural frequencies at the 3 different directions. So, we can represent the various modes by 3 indices which is l, m and n.

So, 1 0 0 means that l is equal to 1, m is equal to 0 and n is equal to 0. So, this means that the transverse frequencies are 0, only the normal frequency is getting its first value. So, which will mean it is the first pure normal mode. Similarly, if you have 0 1 0 which means that m is equal to 1 and n and m are 0. So, this is the value of l, m, n. So, when these 2 are 0 which means that normal mode has not setup this is not setup, only the only the total mode is only due to the transverse modes. So, this is the first pure transverse mode in the m direction.

And similarly if we have some expression like 1 to 1; so, this is a way to represent the various modes setup within a cavity. So, 1 2 1 means that the first mode the first mode in the normal direction, the second mode in the m direction and the first mode in the n direction; l is equal to 1, m is equal to 2 and n is equal to 1. So, this is a combine mode due to this first normal mode second m mode and first n mode. So, just to give you a notation because I will show you a graph where these notation is used.

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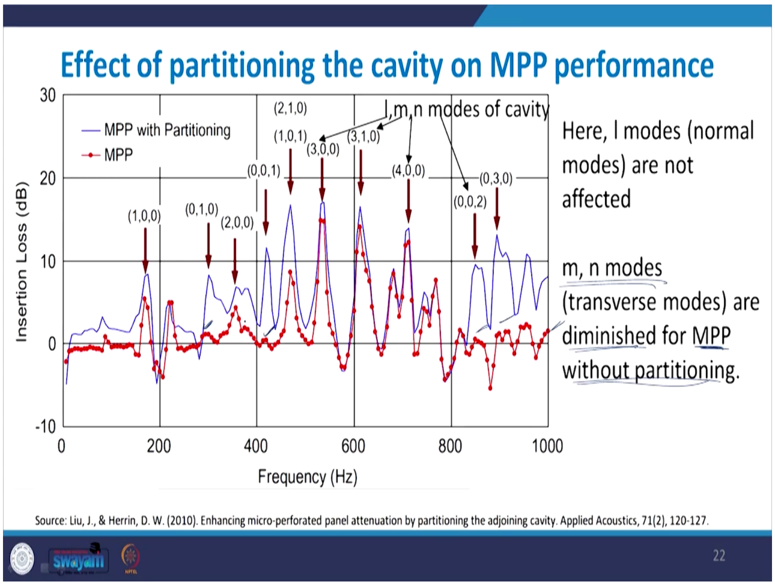

Effect of partitioning the cavity on MPP performance

Here, l modes (normal modes) are not affected

m, n modes (transverse modes) are diminished for MPP without partitioning.

Source: Liu, J., & Herrin, D. W. (2010). Enhancing micro-perforated panel attenuation by partitioning the adjoining cavity. Applied Acoustics, 71(2), 120-127.

So, the same scientists the same researchers, Liu and Herrin they wanted to find out what is the reason why partitioning a cavities improving the performance. So, they in the same graph they measured that the various peaks they correspond to these individual modes and what you see is that when the cavity is not partitioned or the cavity is kept this same then all the transverse modes like this one and then you can take the example of this one, so, whenever you are getting a transverse mode a pure transverse mode let us say even here.

So, whenever you are getting a pure transverse mode where l is equal to 0, the first indices become 0. So, in that case the magnitude is diminished only in the normal modes the magnitude is enhanced. So, the observation was that if no partitioning is done then the transverse modes they are diminished and when a partitioning is done then they suddenly in suddenly enhances the transverse modes as well.

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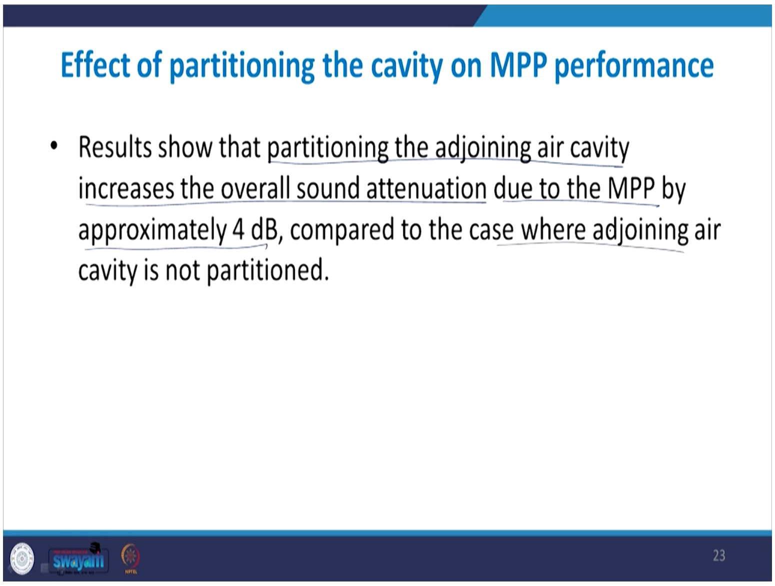

Effect of partitioning the cavity on MPP performance

- Results show that partitioning the adjoining air cavity increases the overall sound attenuation due to the MPP by approximately 4 dB, compared to the case where adjoining air cavity is not partitioned.

So, this is the result. It shows that partitioning of the adjoining air cavity, it increases the overall sound attenuation due to the MPP by approximately 4 decibels compared to when air cavity is not partitioned.

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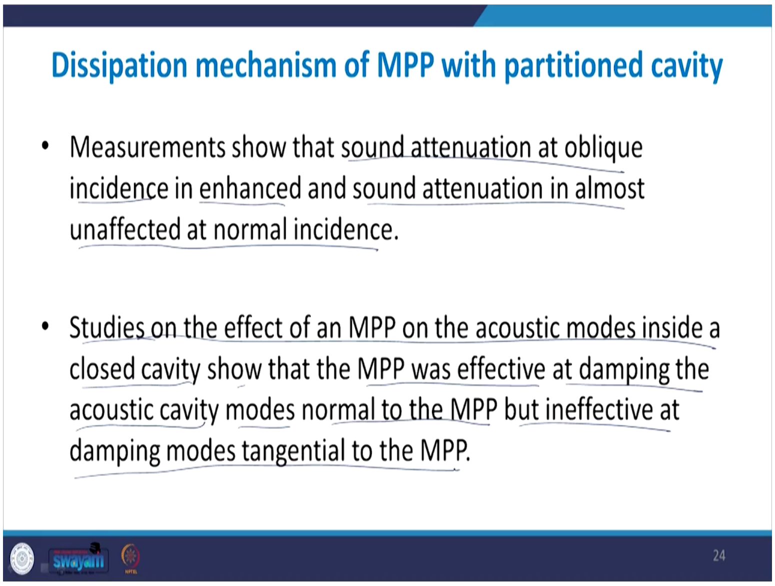

Dissipation mechanism of MPP with partitioned cavity

- Measurements show that sound attenuation at oblique incidence in enhanced and sound attenuation in almost unaffected at normal incidence.
- Studies on the effect of an MPP on the acoustic modes inside a closed cavity show that the MPP was effective at damping the acoustic cavity modes normal to the MPP but ineffective at damping modes tangential to the MPP.

And the resent was that from the measurements, it can be shown that the sound attenuation at oblique incidence is enhanced and sound attenuation in is almost unaffected at normal incidence. So, when the cavities partitioned, now the sound waves they have more directions to propagate rather than just the normal direction. So, they are also propagating along the transverse direction and the normal direction and these different modes are setup.

And, so, studies on the effect of a cavity on the acoustic modes inside a closed cavity shows that MPP was effective at damping, the acoustic cavity modes normal to the MPP, but ineffective at damping the modes at a tangential to the MPP. So, what it means is that the insertion loss is remaining unchanged at transverse is very less at transverse modes, the insertion loss was higher at the normal modes. So, this is what was observed that ion is higher for the original case ion is higher at the normal mode, but at the transverse direction it is almost low or 0.

So, partitioning the cavity, it is sort of imposing a condition that the waves can only travel along the normal direction. So, now, both the sound wave propagation along the normal direction is getting reduced, or the losses are taking place both at the sound wave along the normal direction and the losses are also taking place when the sound wave is propagating along the transverse directions. So, now even the transverse direction propagation is getting diminished or losses are taking place.

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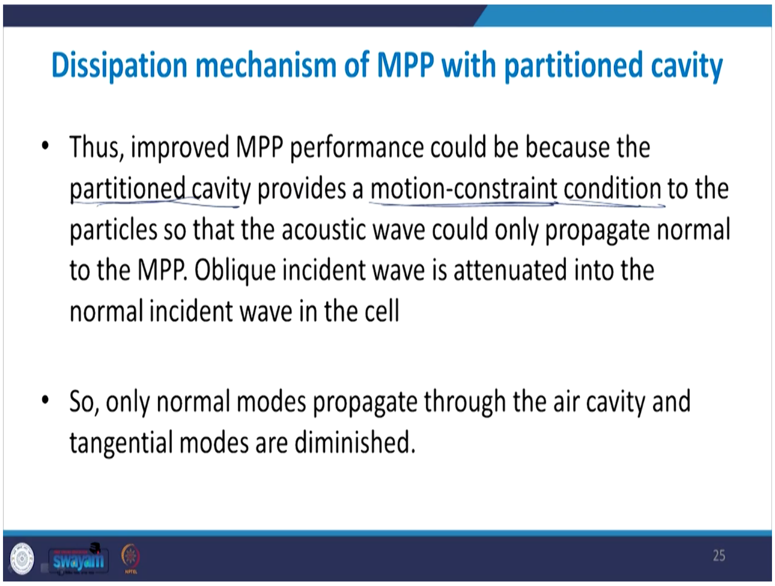

Dissipation mechanism of MPP with partitioned cavity

- Thus, improved MPP performance could be because the partitioned cavity provides a motion-constraint condition to the particles so that the acoustic wave could only propagate normal to the MPP. Oblique incident wave is attenuated into the normal incident wave in the cell
- So, only normal modes propagate through the air cavity and tangential modes are diminished.

So, that is what the cavity the partitioning is doing and overall the performance is increasing. So, this so, you can say that the partition cavities providing some sort of motion constraint condition. So, the transverse mode is diminished. So, along the normal mode the losses are due to the resonance phenomena, but along the transverse mode, now the losses are due to the motion constraint that is imposed by the cavity.

So, overall all these modes are diminished. So, we studied about these 2 particular these 2 particular sort of modifications we due to single leaf MPP and they are applied widely over automotive industries even in aerospace.

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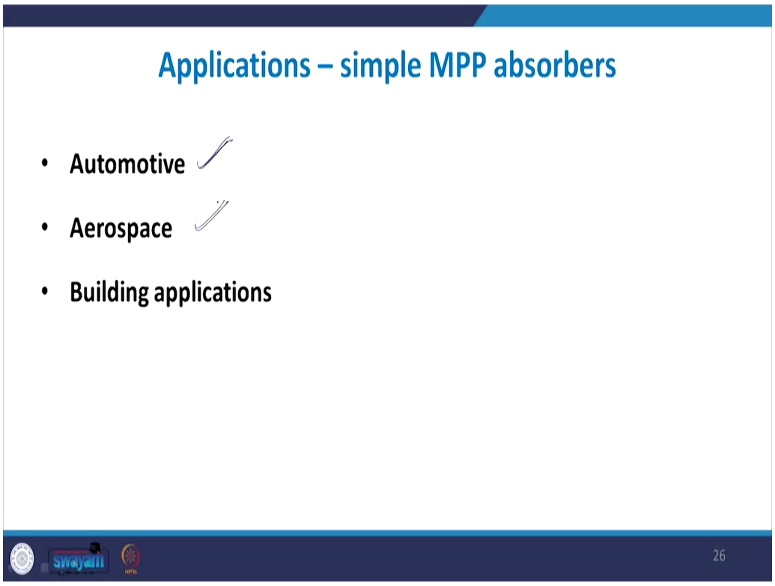

Applications – simple MPP absorbers

- Automotive ✓
- Aerospace ✓
- Building applications

So, you can see that the lining material that is used in the in an aero plane cabin, for example, in the Air India Dreamliner in the new series of it. You can see it has very very small microperforated holes.

So, that is acting as a microperforated panel. Similarly, the same kind of panels can be installed in the buildings as well. So, it has numerons applications in various industries and it is one of the newest materials that we have been studying. So, thank you for this lecture and in the next lecture we will start with our discussion on metamaterials.

Thank you.