

NOISE CONTROL IN MECHANICAL SYSTEMS

Prof. Sneha Singh

Department of Mechanical and Industrial Engineering

IIT Roorkee

Week:10

Lecture:46

Lecture 46: Acoustic Metamaterials



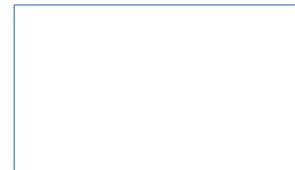
The slide header features a blue and white color scheme. At the top, there are three logos: IIT Roorkee, Swayam (Free Online Education), and NPTEL Online Certification Course. Below these logos, the title "Noise Control in Mechanical Systems" is displayed in a large, dark blue font, followed by "Lecture 46" and "Acoustic Metamaterials" in a smaller, blue font. The presenter's name, "Dr. Sneha Singh", and her department, "Mechanical and Industrial Engineering Department", are listed below the title. At the bottom of the slide, there is a photograph of the IIT Roorkee main building, a large white structure with a central dome and multiple columns. A small number "1" is visible in the bottom right corner of the slide.

Hello and welcome to this lecture course on noise control in mechanical systems with myself Professor Sneha Singh from IIT Roorkee and we have been discussing about the various strategies for passive noise control and we started with discussion on the various kind of acoustic materials that are available. For passive noise control we discussed about various kind of materials. We had the barriers and the absorbers and now we will discuss about the new material which is called as the Acoustic Metamaterials. The introduction the working principle and the classification of these. What is the need for having a specially engineered material or a meta material for passive noise control this is because most of these traditional materials they have certain limitations for example the traditional barriers

Summary of previous lecture

PNC → Barriers
→ Absorbers

A



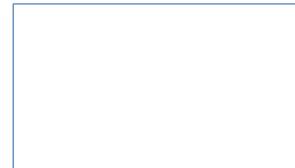
SWAYAMI



2

Outline

- Acoustic Metamaterials 
 - Introduction
 - Working Principle
 - Classification



SWAYAMI



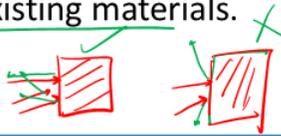
3

and the porous fibrous absorbers they all need much larger thickness and volume in order to attenuate the sounds at low frequencies.

With the increase in the thickness because in order to interact with these low frequency sounds, they should be able to interact as much as possible with these low frequency sounds and be able to attenuate them or be able to dissipate their energy. But the low frequency

Limitations of Traditional Materials

- Traditional barriers and porous-fibrous absorbers need much larger thickness and volume to attenuate sounds at low frequencies.
- There is a limit to the degree by which a barrier material can bend the sound waves (Diffraction limit). *Mass-Frequency law* $f \downarrow \lambda \uparrow$ *Material dimension \uparrow* *follow Snell's law*
- Acoustic Metamaterials are engineered materials that are designed to overcome the limitations of traditional acoustic materials, such that they can control, direct, and manipulate sound waves like no existing materials.



sounds because the frequency is low so the wavelength becomes much longer. And what happens is that we have something called as the mass frequency law which if you are interested you can study on your own from the books but for this course, we are not discussing about that physics behind the mass frequency law but ultimately the conclusion of that is that. In order to attenuate the sounds, the thickness of the material or the length by which the sound waves are going through a material, the net path length that the sound wave is taking through the material has to be of several orders of its wavelength. Several wavelengths must be used in order to attenuate it. And we know that low frequency means a larger wavelength. If frequency is low, the wavelength of these sounds is high, which means that the material dimension or the net length that the sound waves are covering is has to be much higher because several wavelengths must go through in the path length that the sound wave takes through these materials. And therefore, for attenuating such low frequency sounds you need a much thicker and much voluminous material. Be it a traditional barrier material or a porous fibrous absorber but we have recently seen that suppose we have some resonating element like we have the Helmholtz resonator the perforated panel and micro perforated panel then be by the effect of resonance itself we are able to get a sharp peak at a lower frequency compared to the traditional materials. That is one of the ways to do it. There is another limit, there is a limit to the degree by which you, a barrier material can bend the sound waves.

So suppose you have some kind of thick barrier material and some sound wave is coming and hitting it from different directions. You can think that, it can scatter them using the Snell's law. It will follow the Snell's law. and scatter it accordingly. It will follow the Snell's law, which we have studied in the acoustic fundamental. And hence, there is a limit to which it can diffract. This can happen, but you cannot expect that, if suppose you have some barrier material like this, some traditional barrier material like this, and some sound wave is coming and you want to achieve a lot of manipulation, you cannot expect that it will do something like this, revert it in the other way. It will do something like this. It is going to revert it in the other way or maybe some kind of wave is coming like this and it is going to divert it in a much larger way or something like that.

Extreme level of bending cannot happen. So there is a limit to which the sound waves can be bent because they have to follow the diffraction limit. They have to follow the Snell's law. So traditional materials they have only a limit till which they can bend and manipulate sound waves. To encounter these limitations such as the limitations with respect to low frequency sound control, the limitations with respect to the level till which the sound waves can be diffracted, we have new engineered materials which are called as the Acoustic Metamaterials.

Acoustic Metamaterials

- Metamaterial = 'meta' + 'material'
- In ancient Greek: meta → beyond
 material → matter
- Metamaterial is a material engineered to have a property that is not found in naturally occurring materials.

5

These are engineered materials; they are designed to overcome these limitations so that they can control. Direct and manipulate the sound waves like no other existing material.

what does this word mean? metamaterial—it is made of these two components: meta and material. From the ancient Greek language, meta means beyond, and material means matter. Beyond matter, which means beyond the limits of naturally occurring materials.

These are materials that are engineered to have properties not found in naturally occurring materials.

Acoustic Metamaterials

- **Acoustic metamaterials (AMMs)** are engineered materials that comprise of periodic arrangement of sub-wavelength microstructures (called "unit cells") that are designed to manipulate sound waves in a manner not found in conventional acoustic materials.
- **AMMs** are able to achieve extra-ordinary sound wave manipulation by controlling the critical acoustic properties of the material namely:
 - Adiabatic bulk modulus (B)
 - Effective mass density (ρ)



 6

Let us now come to the official definition of acoustic metamaterials, which through the next various set of lectures where we discuss, we will be referring to it by this acronym: AMM, the acoustic metamaterials or AMM. what are they? They are engineered materials that comprise a periodic arrangement of subwavelength microstructures.

These sub-wavelength microstructures are also called unit cells, and they are designed to manipulate sound waves in a manner not found in conventional acoustic materials. First of all, they are engineered; they are not naturally found in nature but rather man-made into a certain material. And they usually comprise a periodic arrangement of some small structural elements or unit cells. And overall, they achieve extraordinary manipulation of sound waves.

And what is the principle behind it? Why do they achieve this extraordinary sound wave manipulation? They are able to control the critical acoustic properties, which are the adiabatic bulk modulus and the effective mass density of that material. So now it is made

of a periodic combination of these unit cells. What are the unit cells? They could be of different shapes and sizes depending on which metamaterial you are considering. So basically, it is a combination of these small building blocks, or unit cells, and these building blocks or unit cells themselves are made of conventional material.

Working Principle

- Unit cell is made of conventional materials with conventional values of B and ρ .
- But, due to the **shape, geometry and arrangement of unit cells**, the overall material behaves as a homogenous material with an effective bulk properties not found in nature. i.e., at macroscopic level B_{eff} and/or ρ_{eff} for the metamaterial have extreme values (zero, negative or extremely high positive values, etc.).

7

For example, if you have an array of cylinders, an array of solid cylinders, each of the individual solid cylinders is a conventional material, but then you have arranged them in a certain periodic fashion. Together, this periodic arrangement now acts as a metamaterial and is able to manipulate sound extraordinarily.

Each individual unit cell could be either a solid cylinder, a solid sphere, or it could be some kind of hollow cavity or a Helmholtz resonator. Each of these conventional materials, each of these unit cells, is actually made of a conventional material. It is a regular structure and has conventional values of B and ρ . But due to the shape, the geometry, and the arrangement of these unit cells. That complete arrangement now behaves as a homogeneous material with effective bulk properties that are not found in nature. Which means that the B and the ρ of the unit cell could have normal values of the materials normally found or the naturally occurring materials. But when combined together in a certain shape and geometry, the overall B effective and the overall ρ effective of that assembly will then have extreme values. It can either have zero, negative, or extremely

high positive values, different kind of values as you would hope. The assembly of this collection of unit cell is together called as a metamaterial it is a collection of the unit cells.

Working Principle

$\rho_{\text{cell}}, B_{\text{cell}}$
 $\rho_{\text{med}}, B_{\text{med}}$
 $\rho_{\text{eff}}(\omega), B_{\text{eff}}(\omega)$

For $\lambda \gg a, d$
Sub-wavelength dimension

$\rho = \text{density}$
 $B = \text{bulk modulus}$

- AMM as a periodic arrangement of unit cells is equivalent to a homogenous material with new bulk acoustic properties.

let us see here schematically. Here what is happening is that we have got some unit cells which are made of conventional material having conventional B and ρ and they are periodically arranged in some host medium and together this material behaves as a homogeneous material having some ρ effective and B effective which is of an extraordinary value. And this property happens only when the dimensions, the individual dimensions of the unit cell and its spacing, they are much smaller than the wavelength of the sound wave under consideration. If you see here, what you can say that metamaterials, when they have the dimensions which are smaller than the wavelength, we also call it as the subwavelength dimension. The unit cell here is having sub-wavelength dimension. when the dimensions are much smaller than the wavelength under consideration, then they behave extraordinarily. They do not behave extraordinarily at all the frequencies, but most likely at the frequencies where the λ is much greater than the dimensions of the unit cell and then they behave extraordinarily and are able to manipulate the sound waves extraordinarily. If you see here, the individual dimensions are much smaller than the wavelength. Which means that we may be able to construct a metamaterial so that its overall dimension is smaller than the wavelength of the sound wave and we may be able to attenuate the sound wave using that. We could be able to solve this problem of low frequency sound absorption. Why?

Because for lower frequencies, the λ is usually much greater. and for conventional materials we need their volumes and thickness to be much higher of several orders of magnitude of λ . Whereas, if we make a metamaterial to attenuate them, we can make it with the dimensions which are much smaller than λ . Because, they behave or they work efficiently only when the dimensions are much smaller than the wavelength under consideration. We can get a metamaterial assembly whose dimensions are smaller than the wavelength and they are still able to control them.

With a smaller thickness material or with a smaller volume material, we may be able to achieve a lower frequency sound control. Let us see it was said that, they are able to manipulate the sound waves basically by manipulating these two parameters which is B and ρ . How is this achieved?

Effect of Bulk Acoustic Properties

- **Linear acoustic wave equation** for sound propagation in fluid:

$$\nabla^2 p - \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} = 0$$

$$c = \sqrt{\frac{B}{\rho_0}}$$

← Thermodynamic speed of sound

- ✓ p = acoustic pressure function
- ✓ c = speed of sound wave in the medium
- ✓ B = bulk modulus of the medium
- ✓ ρ_0 = mass density of the medium at equilibrium


9

Let us see how the bulk acoustic properties affect our sound wave propagation. Recap on what we have studied in the acoustic fundamentals part of this lecture series.

This is a linear acoustic wave equation for the sound wave propagating in the fluid this is the thermodynamic speed of sound p is the acoustic pressure function the speed of the sound in the medium the bulk modulus and the mass density the various variables are given here. Now if you solve it so the equation of a forward propagating harmonic plane wave is given by this, all these derivations and discussions we have already done in the acoustic

Effect of Bulk Acoustic Properties

$$\frac{1}{j} = -j$$

If: B or $\rho < 0$: Then: $c = \sqrt{\frac{B}{\rho}} = jc_{real} \Rightarrow k = \frac{\omega}{c} = \frac{\omega}{jc_{real}} = -jk_{real}$

- Equation to a forward propagating harmonic plane acoustic wave is:

$$p = p_{max} e^{j(\omega t - kx)}$$

$$k = -jk_{real}$$

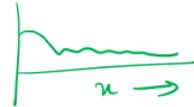
$$p = p_{max} e^{j(\omega t + jk_{real}x)}$$

$$\Rightarrow p = p_{max} e^{-k_{real}x} e^{j\omega t}$$

Acoustic wave that does not propagate over space but exponentially decays.



$$j^2 = -1$$



fundamentals module of this lecture series basically this is one of the solutions. This is the equation of a forward propagating harmonic plane wave. It is given by this formulation. Now, if you see here, what happens if either B or ρ becomes negative? Either of these values becoming negative. Now, we know that C , the speed of sound, is

$$c = \sqrt{\frac{B}{\rho}}$$

When one of them becomes negative, which means that we will have the speed of sound with a root over something negative, a negative value. It would become a complex number, some j followed by some real quantity.

$$c = \sqrt{\frac{B}{\rho}} = jc_{real}$$

It would be a complex quantity. when c becomes complex, then k , which is the propagation vector and the magnitude of it,

$$k = \frac{\omega}{c} = \frac{\omega}{jc_{real}} = -jk_{real}$$



Then, by the property of j being minus of j , what you would get is that k can then be represented as again a negative complex number, minus $-jk_{real}$. This simple mathematical formulation, this is the property used.

Now whenever either of B or ρ becomes negative, then basically your c becomes complex, and even your k becomes a negative complex number. Now, if you punch this value into your acoustic wave equation, what do you get?

$$p = p_{max}e^{j(\omega t + jk_{real}x)}$$

this becomes a sinusoidally varying component. Now, we have an acoustic wave which is fluctuating or propagating with time,

$$p = p_{max}e^{-k_{real}x}e^{j\omega t}$$

but it is not propagating or fluctuating way over space, rather it is exponentially decaying. Usually, a forward propagating wave would look like this it would be some wave moving forward in space. But here what we get is some wave and this is your x dimension. It is not propagating but rather it is exponentially decaying. The wave decays down and stops. We can control the propagation of wave by either changing B or ρ . Because then what the overall wave equation it will be varying sinusoidally, but it will not fluctuate with space basically, it will be an exponentially decaying wave. In a short distance, the wave will decay down and become 0—not 0, but almost a very low value. In a short distance itself, it will decay down; it will not propagate forward over large distances. That is how we can, make either of these properties negative, and we can stop the propagation of the sound wave as it passes through the material.

Effect of Bulk Acoustic Properties

- **Negative Bulk Modulus:** the acoustic material expands in volume upon applying compressive forces, and vice versa.



what do you mean by this negative bulk modulus? What is the meaning of it? The physical interpretation, It is the resistance to compression. When a compressive force is applied, how much a material can resist it. if a material has a higher bulk modulus, it means that it offers higher resistance to compression. When you apply a force, the change in volume is less, whereas if a material has a low bulk modulus, any compressive force you apply to it, the material sort of compresses and shrinks.

It shrinks easily or compresses easily. But a negative bulk modulus means the other way around—that you are applying some compressive force, but instead of decreasing in volume, it is rather expanding in volume and vice versa.

Effect of Bulk Acoustic Properties

- **Negative Dynamic Mass Density:** application of an external force or a positive pressure gradient in the acoustic material produces acceleration of particles in opposite direction of the force or the pressure gradient.

$$\vec{F} = m\vec{a} = \rho_{eff}V\vec{a}$$

$$\rho_{eff} = \frac{F}{Va} = \frac{\Delta P \times A}{A \times t \times a} = \frac{\Delta P}{t \times a}$$

$$= \frac{\text{pressure gradient}}{\text{acceleration}}$$

A layer of acoustic material

12

What is, like, the physical interpretation of negative mass density? the negative dynamic mass density. we know that suppose some force is applied to a fluid.

It can be given by Newton's law as mass multiplied by the acceleration it produces in the fluid particles. For an acoustic fluid medium,

$$\vec{F} = m\vec{a} = \rho_{eff}V\vec{a}$$

and mass can be written as the rho effective or the net effective density multiplied by the volume like this, and then ρ_{eff} can be written in this way and rearranged.

$$\rho_{eff} = \frac{\bar{F}}{V\bar{a}} = \frac{\Delta P \times A}{A \times t \times \bar{a}} = \frac{\Delta P}{t \times \bar{a}}$$

Now, suppose we are considering a thin layer of a material—any layer of a material—then the net force applied depends on the net increase in the pressure multiplied by A, which is the cross-sectional area of the fluid that you are considering. We are trying to establish what the negative dynamic mass density of a fluid medium is. F could be given by $\Delta P \times A$ —the net pressure change multiplied by the cross-sectional area of the fluid will give you the net force acting on that particular fluid element. And volume is the cross-sectional area of the fluid element multiplied by the small thickness of the element under consideration, and this is the acceleration. These cancel out, and what you get is

$$\rho_{eff} = \frac{\Delta P}{t \times \bar{a}}$$

What is ΔP by t?

It is the pressure gradient over the layer of fluid. Pressure gradient divided by the acceleration. If the mass density becomes negative—this effective mass density—which means that if an external force is applied or a positive pressure gradient is applied, then the fluid particles do not accelerate in the direction of the applied force or the applied positive pressure gradient; rather, they move in the direction opposite to the applied force or the pressure gradient. That is the meaning of then ρ_{eff} being negative means, it does not mean that there is no mass, there is some vacuum or a negative mass, it means that the response to the force or a positive pressure gradient is in the opposite direction, that is what it means.

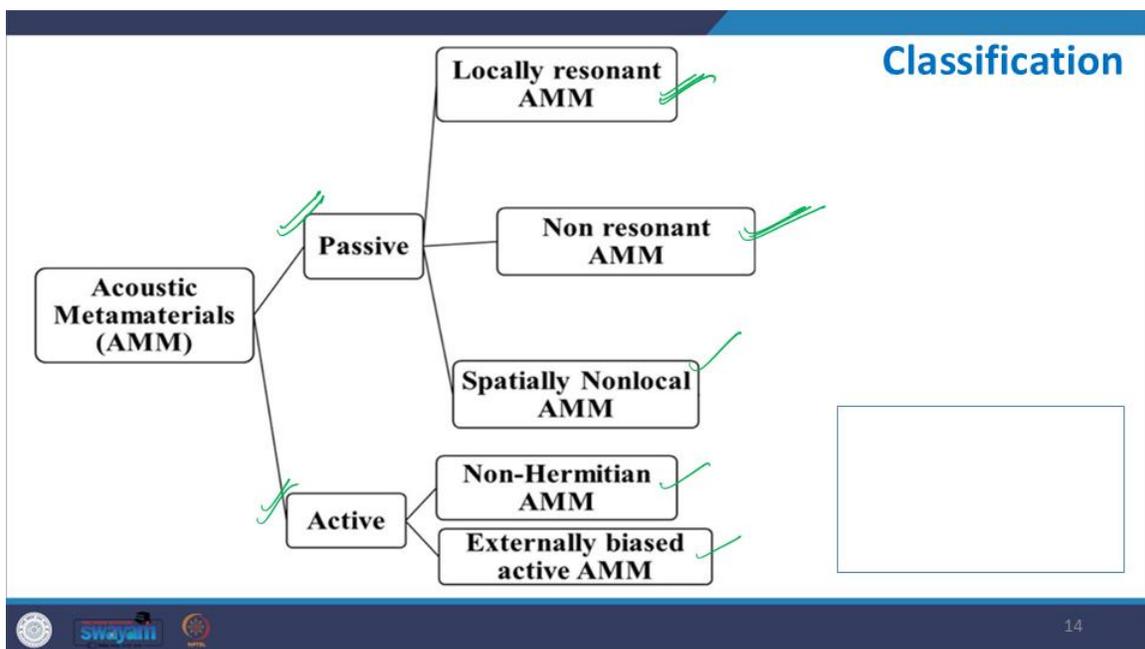
Effect of Bulk Acoustic Properties

- **A medium with a negative mass density or a negative bulk modulus does not allow acoustic wave propagation.**
- In the region of negative density and/or negative bulk modulus, materials do not obey traditional physical laws and remarkable sound manipulation is achieved.
- Most AMMs use the **principle of negative density** and/or **negative bulk modulus**, to attenuate sound waves.



Now we know that if either of these either ρ_{eff} or the B effective becomes negative we can stop the propagation of sound waves. They will not allow waves to propagate if we have a negative mass density or negative bulk modulus. In the region of negative density and or negative bulk modulus some materials they do not obey these laws. And this is what is the principle of AMM.

They use the principle of negative density or the principle of negative bulk modulus. Here the way the geometry is of the metamaterial, how they are arranged and what is the geometry of that metamaterial, they achieve extreme values of B and extreme values of ρ so that they can achieve extraordinary manipulation.



Now how are these metamaterials classified? You have a passive and a active acoustic metamaterial and then within the passive you have the locally resonant the non-resonant and especially non-local AMM. Within the active, you have got non-Hermitian and externally biased active AMM. Not everything is in your course. You can say that passive and active you need to know and what is a locally resonant AMM and a non-resonant AMM. That would be it.

What is a passive AMM? Just like how we studied about the noise control strategies and what is a passive noise control and an active noise control.

Classification of Acoustic Metamaterials

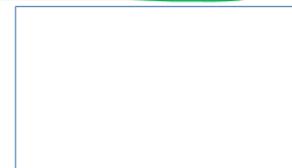
- **Passive AMM:** AMMs that do not require external energy, such as electrical or magnetic power, for manipulation of sound waves. The wave manipulation phenomenon is completely derived from the internal structural property of these metamaterials.
- The passive AMM are further classified as locally resonant, non-resonant, and spatially nonlocal AMM.



In passive noise control, what happens? No external energy is supplied. In the same way, in a passive AMM, you do not need any external energy. Such as any electrical power or magnetic power to manipulate the sound waves. The wave manipulation is completely derived from the internal structure of the material itself. How the material is structured—what are its internal structural properties? That itself governs how the sound wave is going to get manipulated. You do not need to supply external electrical, magnetic, or any other form of energy to it. Their classifications are locally resonant, non-resonant, and especially non-local. What is a locally resonant AMM?

Classification of Acoustic Metamaterials

- **Locally Resonant AMM:** these kind of passive AMM use local resonance to achieve negative bulk modulus or negative mass density or both. Here, a part of the AMM achieves resonance at certain desired frequency ranges and the acoustic energy gets trapped or dissipated locally in the resonance regions.
- This leads to attenuation or complete stop in the propagation of sound wave through the material. The frequency ranges within which no sound wave propagates through the locally resonant AMM is called as the band gap.



These are those kinds of passive AMMs which use the principle of local resonance, and they are able to achieve this negative bulk modulus and negative vast density—or both—using that principle. If you think about a metamaterial as an array or as a periodic combination or a combination of individual unit cells or microstructures, okay? it is an assembly of unit cells. Then, within that assembly, somewhere locally, some element is resonating, okay? when the sound wave is hitting, maybe a couple of unit cells or a small region within the metamaterial, when the sound wave hits, it sets those unit cells into resonance. The fundamental frequency of the unit cell matches with the incident frequency of the sound wave. And those unit cells are set into resonance, and they start resonating. Just like how we had studied in the case of Helmholtz resonator or the other resonance-type absorbers, whenever the resonance is there, basically, the sound wave that is hitting at resonance is rather driving the sound power, or the sound energy is getting used up in vibrating the resonating element at high amplitudes, and this leads to the use of the sound power, and it is lowering down. In the same way, in the case of metamaterials al Suppose, at a certain incident frequency, some unit cells are set into resonance. What will happen?

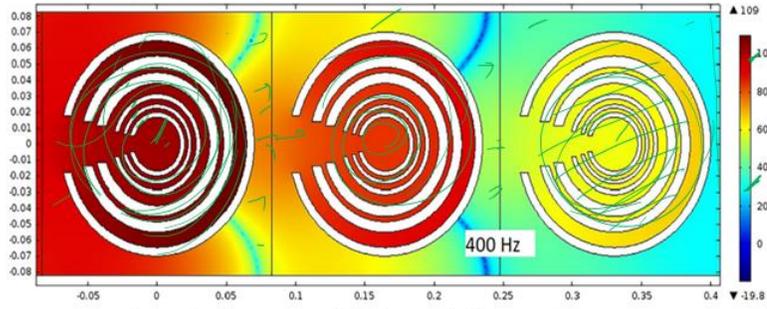
The sound waves that are getting incident on that particular region which is set into resonance, those elements will start to vibrate at a very high frequency. All the sound energy that is incident in the part where the fundamental frequency matches with the incident frequency then the sound wave the sound energy gets used up in driving that element in resonance okay and that's how the energy gets trapped or dissipated locally in those regions where resonance are observed or set and the frequency regions over which the resonance happens and no sound wave propagation happens is also called as the band gap or the range of frequency where no sound wave propagation is allowed.

This figure shows a typical locally resonant AMM, it is a sonic crystal which we will study in some of the subsequent lectures. What is happening here or it is made of a concentric C shaped element. And what is happening here is that each of the C-shaped element is acting like a Helmholtz cavity. Helmholtz resonators or Helmholtz cavity. when the sound wave is hitting, it is sort of creating resonance and at a particular frequency where the fundamental frequency of this element matches with the incident frequency, resonance phenomenon is observed and the wave particles they move at a very high amplitude.

There is a sharp rise in the acoustic pressure why because inside these cavities you have the resonance happening and the fluid particles they are oscillating at a very high amplitude. And whatever sound wave was incident now it is getting used up in sort of oscillating this fluid particles at a very high amplitude.

Classification of Acoustic Metamaterials

- **Locally Resonant AMM:**



A periodic array of C-shaped Resonators.

Source: J. Radosz, "Acoustic performance of noise barrier based on sonic crystals with resonant elements," *Appl. Acoust.*, vol. 155, pp. 492–499, 2019.



Basically, what you observe here is that locally the sound wave or the sound pressure rises here which is shown by the darker color and because most of the energy incident is now getting used up and is concentrated in this region the outside regions now have a low pressure. This happens for all the all such resonating elements at whatever. The sound wave was incident here. Much of the energy of the sound wave got trapped in the first part of this resonating element, and the remaining low-pressure wave then passed. Then again, some of its energy got trapped into this element, and the remaining more dissipated energy passed, and then it encountered another resonating element. Its energy got trapped within that element, and here you observe higher pressure, while at the end of it, you had a much lower pressure. you basically started with something here, and you ended up going into this scale. Step by step, upon encountering each resonator or resonating element, the energy got trapped inside the resonator itself, driving the particles, and the remaining low-energy wave then passed on to the second element, and the phenomenon continued. Thus, the resonance helped in gradually decreasing the overall sound energy.

Non-resonant AMM—this is yet another type of acoustic metamaterial. They derive their exotic properties by allowing the incident sound waves to pass through a network or complicated maze of some sub-wavelength channels—curled-up channels. Due to this, various phenomena can be observed:

to either a decrease in the speed of sound, a lot of internal reflections, a lot of thermo-viscous losses, and so on. Let us see here: we have a point A where the wave is incident, and then it has to come out from point B. Instead of traveling through the air medium from point A to point B, now we have this complicated structure, and this shows the cross-sectional view of that structure. It is covered on all sides; this shows the cross-sectional view. Now, instead of going through a straight path, it is forced to travel in this way. This shows the path taken by the wave in order to reach the point B. The wave has to travel a much longer distance to reach from point A to B, instead what it could have done is simply travelled in a straight line. We are elongating the path. Now it is interacting more with the solid material of this element, this unit cell. At each of the turns there will be an internal refraction scattering and diffraction happening. There will be some losses happening at each of the turns when the sound wave is turning due to diffractions and scatterings.

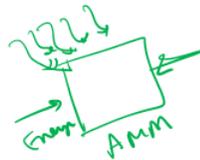
And at the same time because the sound wave is travelling there is an inherent air resistance the sound wave starts decaying over a certain space. And now it has travelled over a much longer distance. With per unit length there is a certain rate of decay due to the air resistance and hence there will be a decrease due to that. In addition to that let us say here suppose there was no such metamaterial present and the sound wave had to travel from A to B. It would have traveled the speed of the sound in the air medium is let us say c then from A to B let us say is this is the square of side a so this length here is what a this length here would be $(\sqrt{2} \times a)$ so the speed is simply the distance by time so here in the first case the when it had traveled safely speed would be given by the distance by time.

When there was no material, it would have travelled the same distance at a lesser time. the speed of the sound would be low, but now the same distance it is travelling, but it is going through such an elongated path in this case that to cover the same displacement from point A to point B it is taking a much longer time compared to any other element compared to when this particular metamaterial was not present. Now due to this metamaterial, the wave now takes much longer to travel through a certain distance and hence the speed of the sound is decreasing because it is covering this distance in a much longer time because of the elongated path.

That is why the decay is also happening there. The last type of acoustic metamaterial is the active acoustic metamaterial. Now they derive their unnatural properties by supplying an external energy source to the structure, and their acoustic response can be tuned or tailored arbitrarily in real time by configuring the digital electronics that control the metamaterial's acoustic properties. Basically, you can have some AMM. And some energy source, and

Classification of Acoustic Metamaterials

- **Active AMM:** AMMs that derive their unnatural acoustic properties by supplying an external energy source, such as electrical power or magnetic field, to the structure.
- The local acoustic response can be changed almost arbitrarily and in real time by configuring the digital electronics that control the metamaterial acoustic properties.



when the sound wave hits, depending on the frequency content of the sound wave, the external energy can be used to either increase or decrease the spacing of the unit cells or the various geometries.

Does an adaptive noise control, change the properties of the acoustic metamaterial in real time.

Classification of Acoustic Metamaterials

- ✓ Further reading if interested: **S. Singh**, G. Pavan, and C. Chalurkar, (2024). "Acoustic Metamaterials for Noise Control Applications", In: Handbook of Vibroacoustics, Noise and Harshness. N. Garg, C. Gautam, S. Rab, M. Wan, R. Agarwal, and S. Yadav, Eds. Singapore: Springer. Online ISBN: 978-981-99-4638-9, Print ISBN: 978-981-99-4638-9.
Doi: https://doi.org/10.1007/978-981-99-4638-9_30-1



For further reading on this, you can refer to one of the book chapters written by us, and you can learn about each and every acoustic metamaterial. Thank you for listening.

Thank You