NOISE CONTROL IN MECHANICAL SYSTEMS

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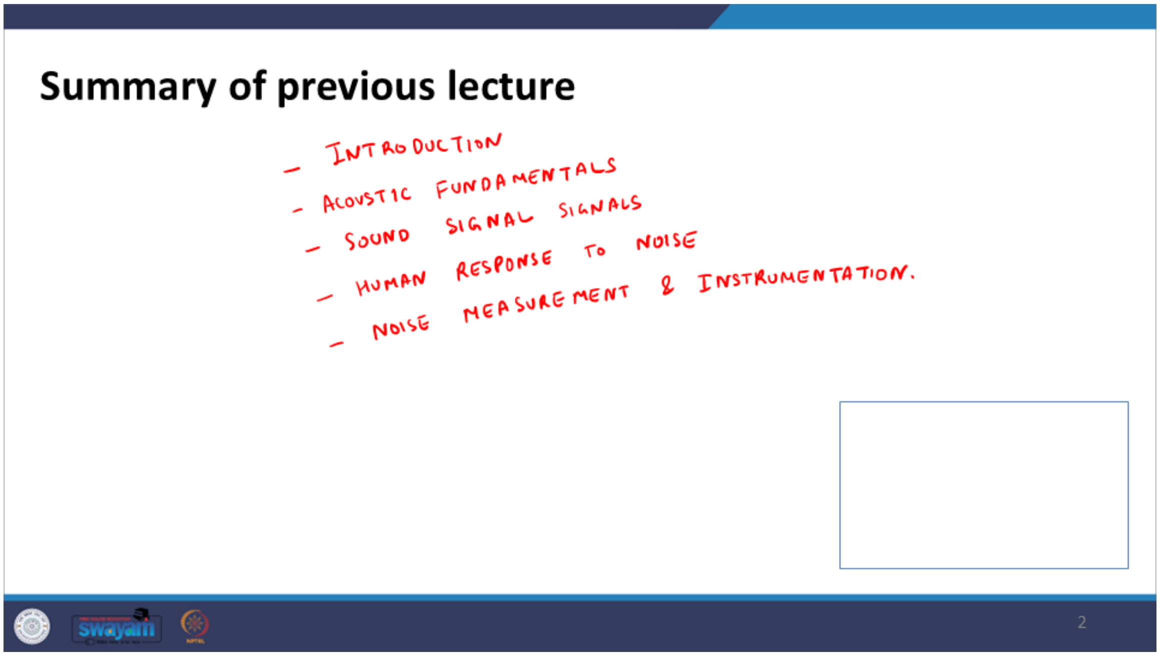
Week:6

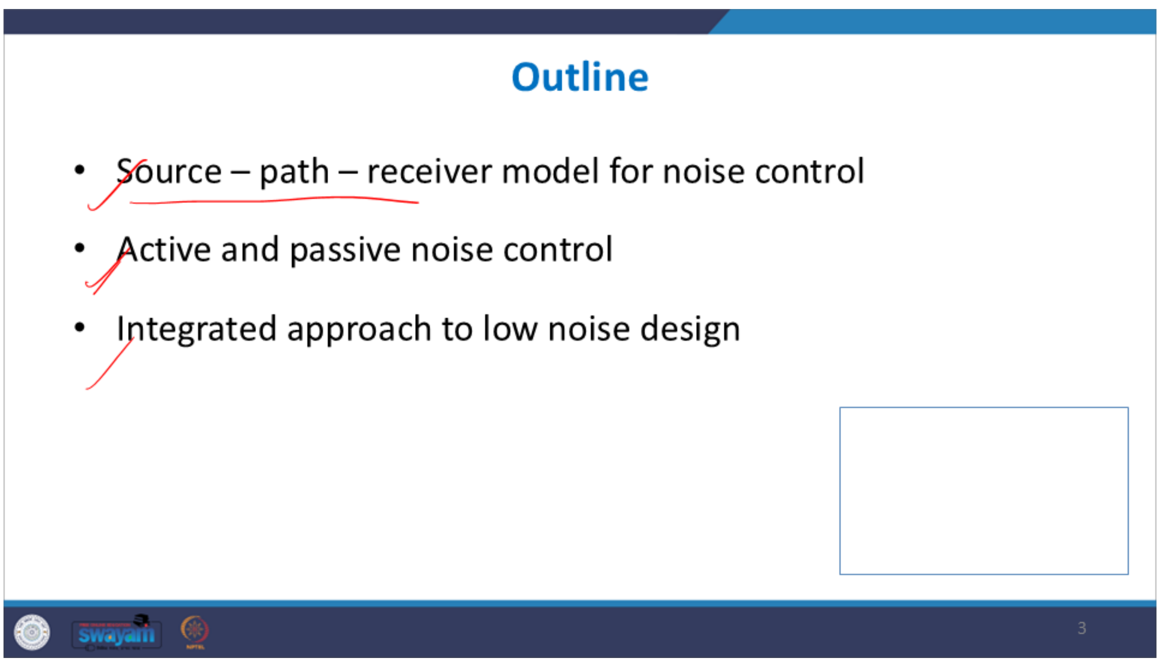
Lecture:028

Lecture 028: Principles of noise control

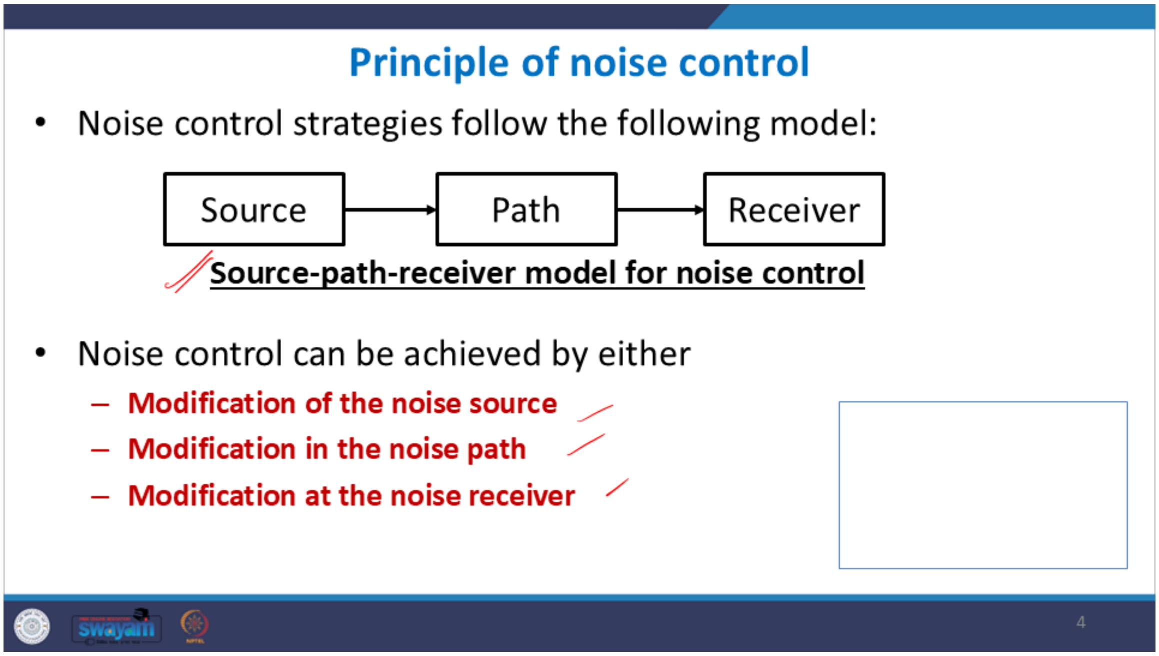
Welcome to Lecture 28 in the course on noise control in mechanical systems with myself, Professor Sneha Singh. In this lecture, we will begin a new module, which is the module on noise control principles or the principles of noise control. So far, we have covered various modules. We introduced this course and sound and noise. Then, we introduced some acoustic fundamentals. Then, we studied sound signal analysis, various spectral analysis, time domain analysis, and so on, octave band analysis. Then, we studied the human response to noise because noise itself is a subjective perception. The human response to noise, and then we studied noise measurement.



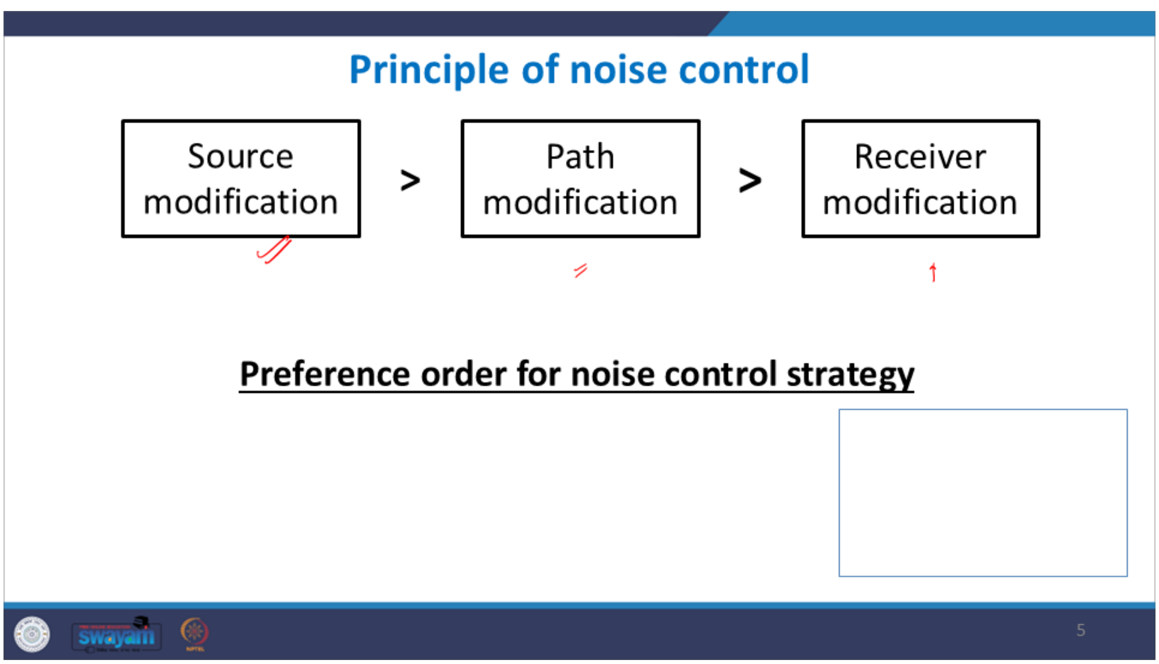
And instrumentation. So now, we will study the principles of noise control.



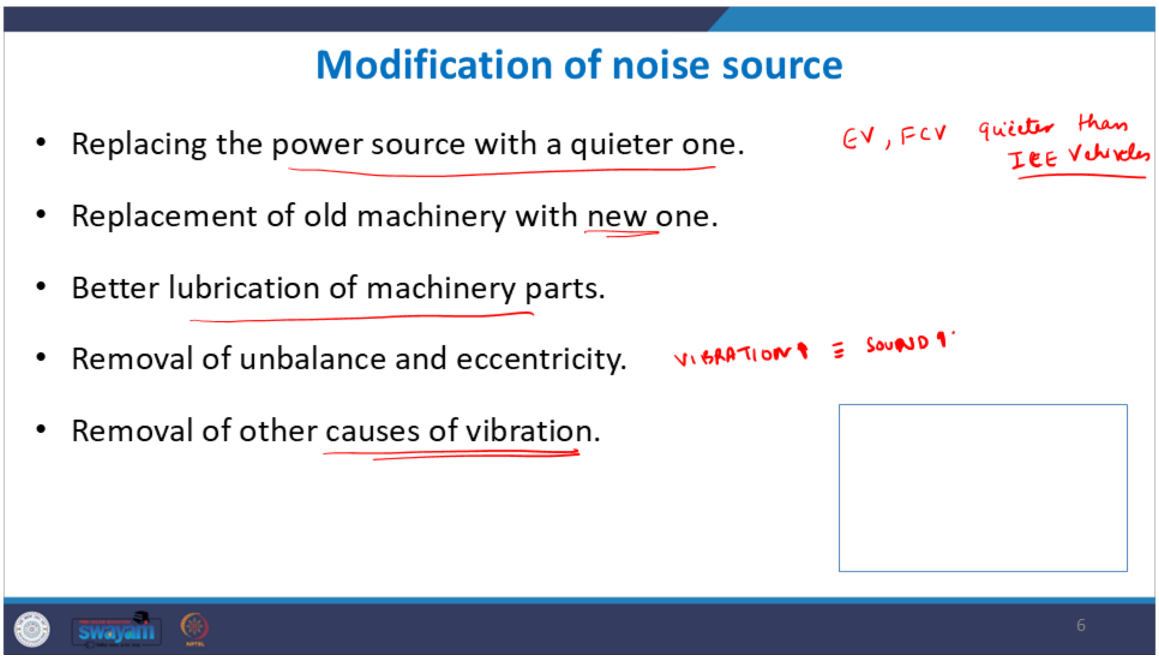
we will study the source-path-receiver model, then the various categories of noise control, like active and passive, briefly I will introduce, and then the integrated approach to low-noise design. Let us first see the source-path-receiver model. In general, a typical noise control strategy or the principle of noise control can be described by this model, which is



called the source-path-receiver model. what it means is that, let us say there is some noise source, and we want to remove or reduce the noise. The source is there, then from the source, the noise is being created. This noise is then radiating either through some structures or through air or various other pathways, and then through those pathways, it is reaching the receiver. Where the noise has to be controlled, the receiver, which does not like that sound and would like to control it. We have a source, and then from which the noise is generating, some path through which it is traveling, and then finally the receiver or the person who wants to reduce it.



That means that the noise control can either be achieved by either modification of the noise source, modification of the noise path, or the modification done at the noise receiver. These are the three scopes where it can be done. And typically, for a noise control engineer, the strategy is like this: you always give preference to source modification. That gets the highest order of preference. And when source modification is not achievable or out of your scope, then you go for the path modification. And once path modification in some ways is either not effective or somehow it is not feasible or costly, then finally you try for receiver modification. That is the preference order. You always first try to modify the source, if not possible, then path, then not possible, then receiver.

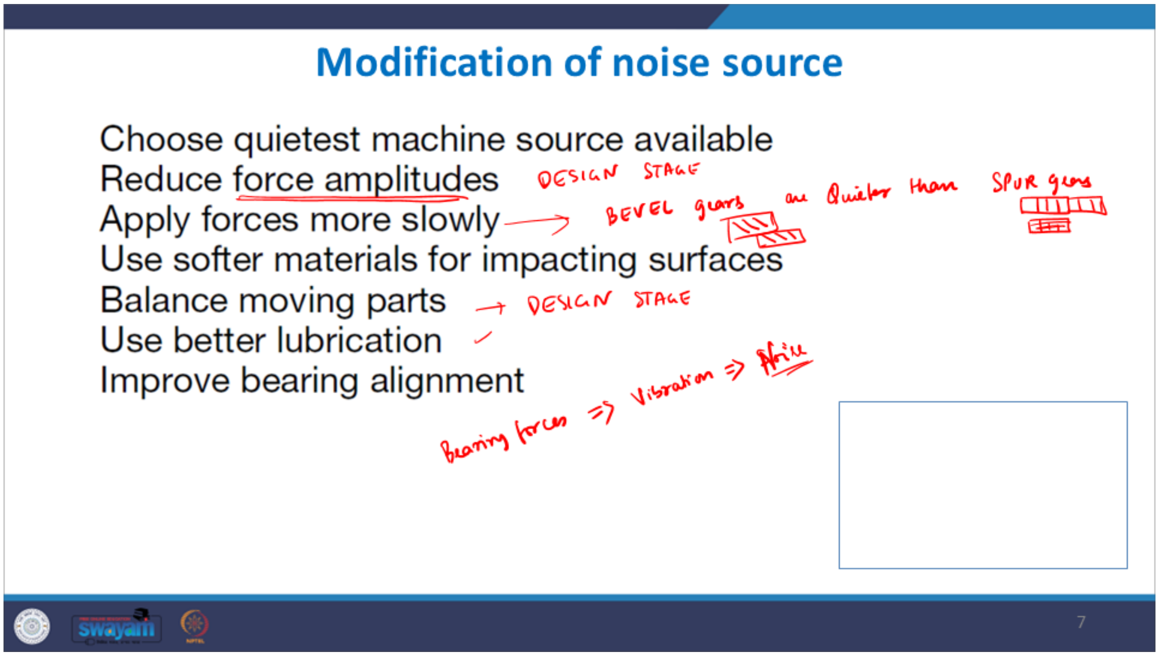


What are the things through which the noise source can be modified? The first thing would be to replace the power source with a quieter one. Let us say, for example, we have a combustion engine vehicle, it makes a lot of noise, and the engine being one of the major sources of the noise within the vehicle, you replace the engine with a quiet electric motor or batteries. You get electric vehicles, fuel cell vehicles, like that. And, these electric vehicles, the fuel cell vehicles, these are much quieter than the IC engine vehicles. Here, what happens is we have modified the power source. Whatever was the source that was creating the power, due to a certain mechanism, it was generating more noise. Now, it has been replaced with a quieter way of generating the power for that machinery. The other could be replacing the old machinery with a new one.

With time, what happens when you have new machinery is that it usually functions very smoothly, you have better lubrication, smoother parts, the surface finish is better, and all the parts are properly installed and tightened. But with time and usage of the machinery, slowly it starts to degrade, Corrosion happens on the machinery parts, and the surface harshness comes. Then, some parts get loosened up, and as the machinery gets older, it starts producing more noise. Most of the time, this happens in machinery. Once the machinery is too old and very noisy, if you replace it with a new machinery, then the noise levels are going to go down. again, this is one form of modifying the source. Then, suppose you have some machinery component. Usually, the noise is created when two parts are impacting together. In machinery, it could be the meshing of the gear or the bearings. whenever two parts are contacting or meshing with each other, it creates a lot of noise. if you provide better lubrication, then the impacting between the two rigid bodies is smoother, and the noise generated due to the surface harshness or roughness between the two impacting bodies gets reduced with better lubrication. That also improves the sound.

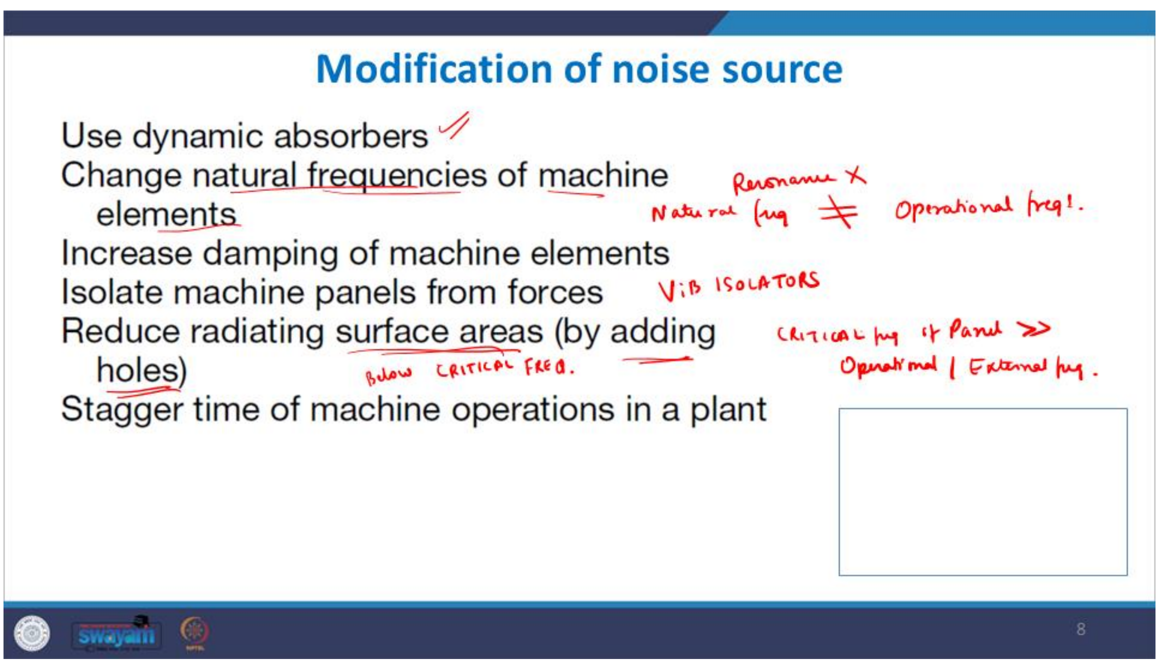
Let us say, for example, I am riding my vehicle, that with new cars, from the sound of the car itself, I can know what the condition of the running car is. Sometimes, if the car is not properly lubricated, the engine oil is not there, etc., after a point in time, it creates weird noise once the parts have more friction and abrasion between them. You give proper lubrication to these vehicles and cars, and then you will see that suddenly the sound quality has improved, and the sound level has slightly gone down. Lubrication of these impacting or colliding parts, which are creating the noise, will also reduce the noise level.

Sometimes, there could be manufacturing defects in the machinery. Maybe during the design stage, when the designer designed the machinery, they balanced all the forces acting on the machinery, and accordingly, the various components were designed. But due to some manufacturing defect or due to just the corrosion of the machinery over long-term usage, some kind of unbalance has resulted because of some unbalance in the masses and stiffness, etc. and some kind of eccentricity in the shape of the part. Due to this it creates unnecessary vibration because, when we are designing machinery, we are balancing all the forces, so that the machine is working with minimum force. But due to this unbalance or eccentricity that may result, there could be an additional force that comes in, and due to the acting of this force, it vibrates the machinery, so the vibration of the machinery part increases, which ultimately increases the sound level coming out of the machinery. And various other causes of vibration that may be happening in the machinery can also be removed. You can choose the quietest machine source available in a factory setup.



You can reduce the force amplitudes because, if you reduce the number of forces acting in the machinery, you would get a quieter machinery. How do you do that? This is achieved at the design stage. Once you are designing new machinery to serve a particular purpose, you look at what the operating conditions are, what it has to perform, and what the typical loadings are that the machinery is going to be subjected to. If by some way you are designing and you are able to balance the loading or the way this force is acting, you are able to reduce the amplitudes of the force by modifying the machinery part and modifying the point of contact of the forces. Then you are able to reduce the forces that may be acting on the machinery while it is able to achieve the same functionality. Then you would be designing a quieter machine. Similarly, there could be some way through which, even if you cannot reduce the magnitude of the forces acting, you can make sure that the forces don't act instantly, so there is no sudden impact between the bodies, but there is a slow application of the force. For example, let us say the bevel gears used in any kind of machinery are quieter than the spur gears that are used. What happens in the bevel gears, the way these gear teeth are usually, when two gear teeth mesh, you have this spiral kind of arrangement. This bevel gear, two bevel gears meshing, and in the spur gears, you have these vertical gear teeth. When they come together, this is how the meshing is. When the two teeth are meshing up. They are all at once the contact is happening with the entire tooth, and the forces, they are sudden applications of the force. The spur gears, in general, are quite louder, whereas you have the bevel gears, they are achieving the same kind of power transmission as the spur gears but with the same functionality. Because, the teeth are meshing slowly as the gear rotates, not all at once. Due to that, the vibration induced is less, and hence they are quieter.

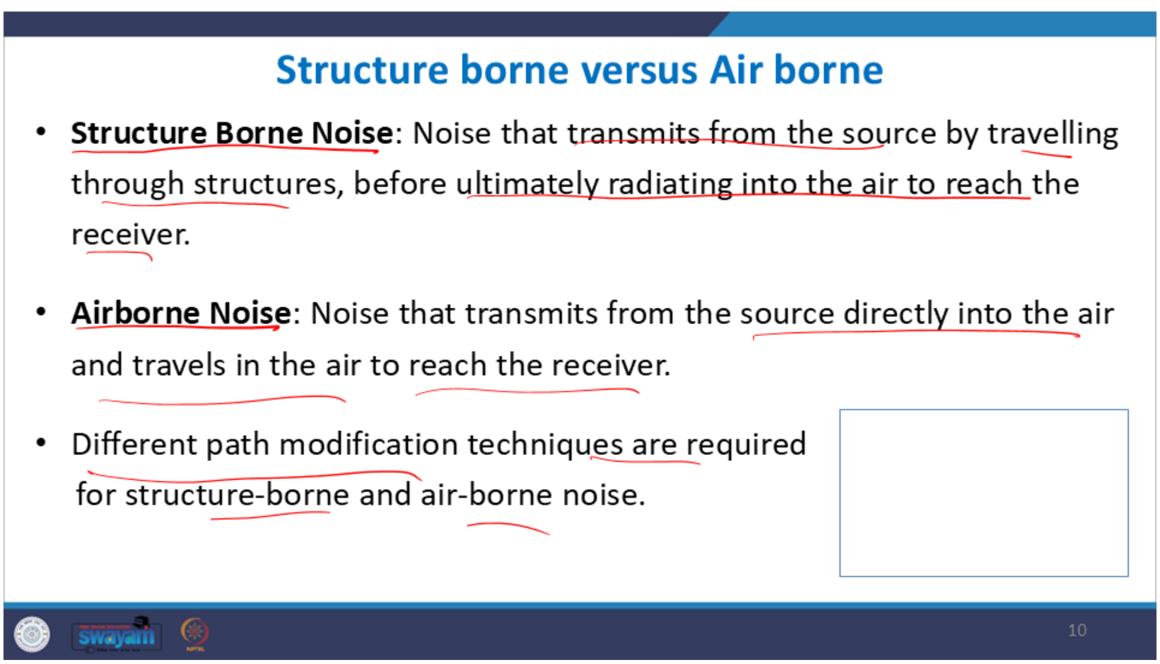
Then, softer materials can be used for the impacting surfaces. Whenever you have machinery, you have two or more parts that are colliding together, and some parts are impacting, which is creating a lot of noise. You can use softer materials, provided, it is able to achieve the same functionality. You can balance the various parts to see that there is no excess force in the machinery. This again is also done at the design stage of the machinery. Where it is designed to have the least amount of excess force. Better lubrication I have already covered, and then improving the bearing alignment. Usually, bearing forces are one of the major bearing forces in most of these rotating machineries. They are a major cause of vibration, which then leads to noise. If the bearing is properly aligned, then the forces acting on these bearings are again getting balanced, and excess force is not there, and the vibrations can be reduced. These are all the methods in which what we are doing is we are sort of in the machinery itself, we are doing the modification that it becomes quieter.



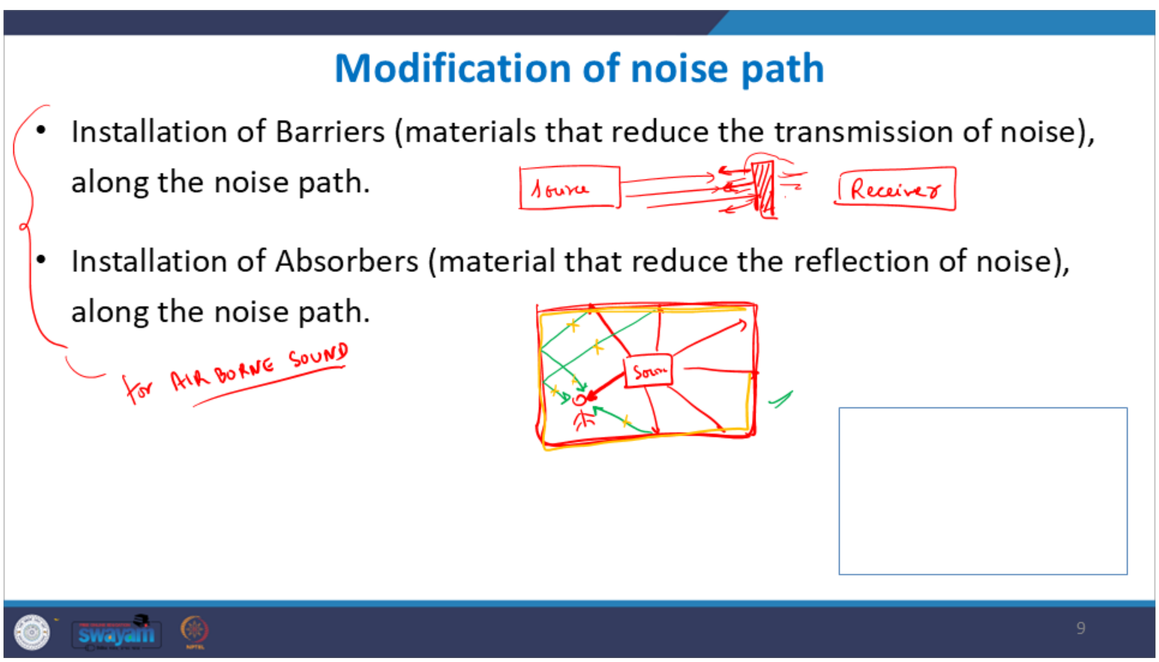
In the same way, if the vibration is a major part of noise generation, you can use dynamic absorbers that can absorb these vibrations. You can use the vibration isolators, you can make sure that the natural frequencies of the machinery elements are different from the operational frequencies because you don't want the resonance to set up. Because then the vibration amplitudes are going to increase. The natural frequencies should never be equal to or even near to the operational frequencies of the machinery.

You can add dampers to reduce the vibration amplitude. You can isolate using various vibration isolators so that the vibration from the machinery to the path gets isolated and does not transmit. You can reduce the radiating surface area. There are many times when you have machinery with large panels, and the machinery starts, whatever the mechanism of power generation, due to which a lot of vibration is set up. This vibration then transmits to the panels of the machinery, and these panels radiate the sound forward. We have discussed the radiation from these panels.

How do the panels radiate? the panels can be designed in such a way that you reduce their surface area because a certain amount of acoustic energy is radiated per unit surface area. You can add holes or some other method so that the structural integrity of the panel is maintained while the surface area is reduced; then you can reduce the radiation. In the lectures on radiation through infinite panels, one method discussed was where you can play with the incident frequency. Whatever the critical frequency is, that below the critical frequency, there is no radiation. You can make sure that the critical frequency of the panels is much higher than the operational or external frequencies that may excite these panels. Then you can also reduce the radiation of sound from these panels. And then you can operate the machinery by giving breaks, not continuously, which can also improve the performance and bring the noise level down. Now, what are the methods of modifications in the noise path of the machinery?

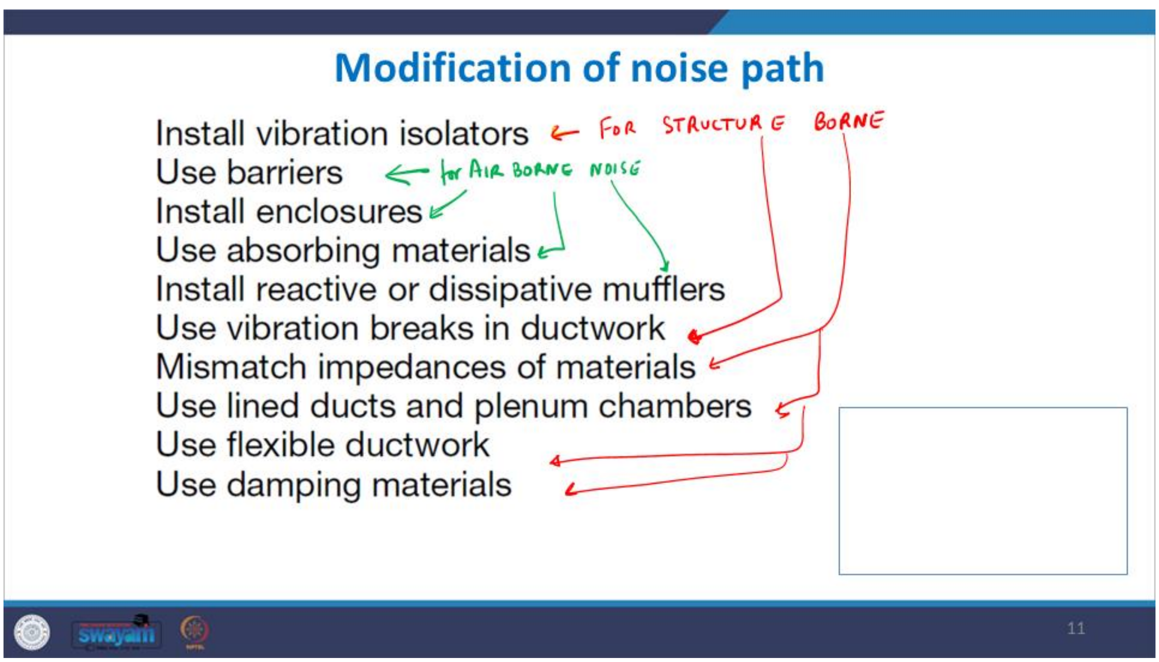


let us see what the noise parts are, so usually, the noise can transmit from the source of the machinery to the receiver. By either through the structure, the solid structures, or through the fluid medium, which is the air, so we can have structure-borne noise and the airborne noise. So whenever what happens, noise is transmitting from the source, traveling through these structures, and ultimately radiating into the air to reach the receiver. That is usually structure-borne noise. For example, let us say I have some kind of heavy machinery which is vibrating, and I keep it directly on the floor, or I keep it on a stand, and the stand itself vibrates. let us say, for example, I have a big loudspeaker. Instead of suspending it in the air via some technique, I am keeping it on the hard surface. Here what happens is that the speaker is vibrating. Now it is coming in contact with the hard surface, which is the stand of the speaker, then the stand itself starts vibrating. What happens is that the vibrations from the source, which is the speaker, are now transmitting to these stands. So here it is a structure-borne sound. The sound is first transmitting through these stands and then going through the floors and the walls, and finally multiplying many folds, and then finally radiating into the air and reaching the receiver. In the same way, you can have the other pathway, which could be directly from the source. The noise is directly emitting into the air and traveling to reach the receiver. And based on whether the noise is reaching the receiver via structures or via air, you have different path modification techniques for the two types of noise pathways. So suppose it is an airborne sound, if this is for airborne you can install barriers, which are materials that reduce the transmission of noise.



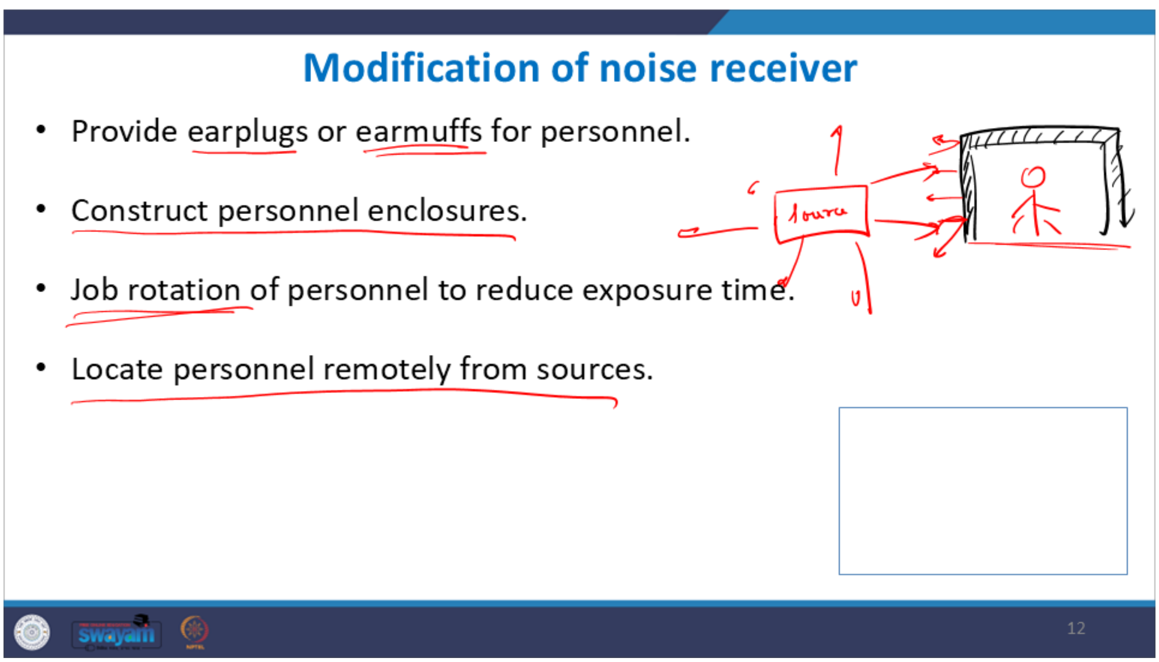
let us say, this is your source. This is your receiver, and the sound is transmitting through. Suppose you put some hard material which stops the sound wave from propagating, it is a high-impedance medium. It is stopping and blocking the sound waves, reflecting most of it that is coming by. It is going to attenuate the sound at the speaker. You can install such barrier materials. Or, in another way, suppose it is a closed room. You have a machinery source or some kind of source, and these are hard reflecting surfaces of the room, and you have some listener here or some receiver. The sound is reaching directly from the source to the receiver, whereas the sound is emanating in all directions. Because of reflections, it is reflecting back to the receiver through these various pathways. The direct sound is getting multiplied because of these reflected waves that are coming. In such a confined environment where the reflections are quite significant, if you install some absorbers which stop these reflections. Basically, you do certain treatments on these walls. They simply absorb these sounds. these reflections are stopped.

Then, the noise level can also be brought down. these are like modifications in the pathway in which the noise is traveling. Some techniques, some individual techniques. let us see, what happens. I will try to categorize it as structure-borne and airborne.



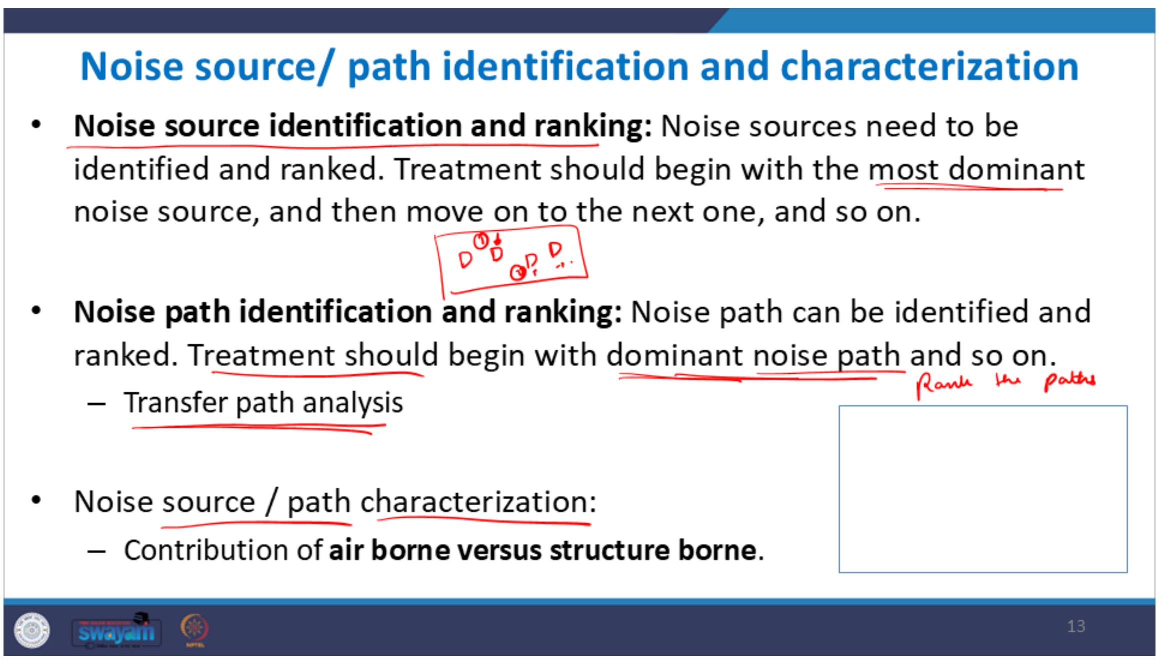
for example, structure-borne here, this is for structure-borne noise because it is transmitting through the structures in the form of vibrations induced in the structure. You can use, vibration isolators. And for airborne, let me use a different color coding. For airborne, I am using, green color coding, and for structure-borne, I am using red. Similarly, the installation of the enclosures is for the airborne sound. Absorbing materials, again, like in the previous case, here it is for the airborne sound. The use of reactive and dissipative mufflers, again, this is for the airborne sound, using vibration breaks in the ducts. So many times, ducts and pipelines are a source of radiation of noise. If you, instead of having a continuous ductwork or pipe, you just have, interconnections between these pipes. So, you interconnect the two, the various pipes, or you include some kind of isolations or some kind of dampers. At different distances in the pipes. You are sort of trying to break the vibration path, you are trying to break the vibration path or the path through which the structure-borne sound is traveling through these ductworks. Then, a mismatch in the impedance of the materials again will help in, transmitting the noise from one part of the material to the other part.

Lining of the ducts, use of plenum chambers. Flexible ductwork, all of this will stop the structure-borne noise.

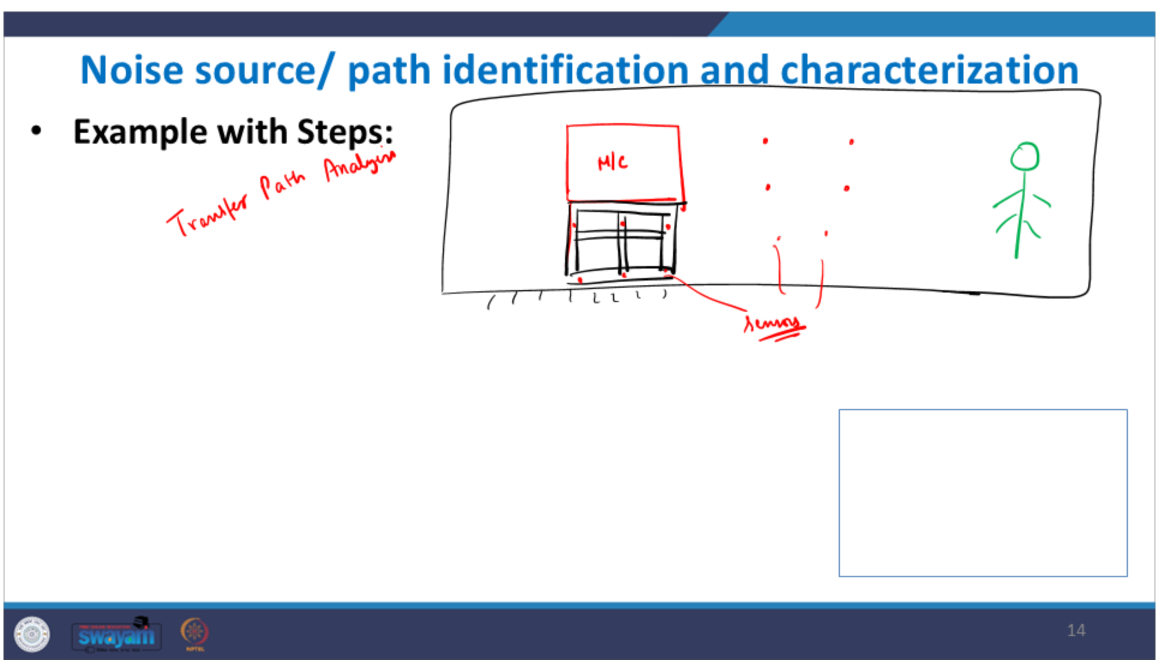


Finally, if suppose source and path modification is not possible, and you want to control the noise at the receiver, then what you do is simply provide earplugs or earmuffs to the personnel who have to be protected. You can construct some particular acoustic enclosure, so suppose this is some machinery source. This is your personnel, and a lot of noise is being generated by this machinery source, so you can enclose it in thick barrier material enclosures so that some form of sound is attenuated while passing into the enclosures. It is sort of reflecting these sounds so that it doesn't reach, so they can be isolated.

If, suppose, in a factory setup, you have various workers, and they have to work on heavy machinery, you can rotate the workers so that, not all the workers, they are within the permissible noise dose limit. You can do the rotations of the workers in the heavy machinery. Or you can simply make a factory setup such that all the machinery is operating in a single room, and the personnel room is quite further away from these machine resources. So when you begin as a noise control engineer to try to apply, so these are some of the options you have with you, what you can do. For the receiver, what you can do for the path, what you can do for the source. Various options are there and more, but how to choose which option to apply for a particular case at hand?

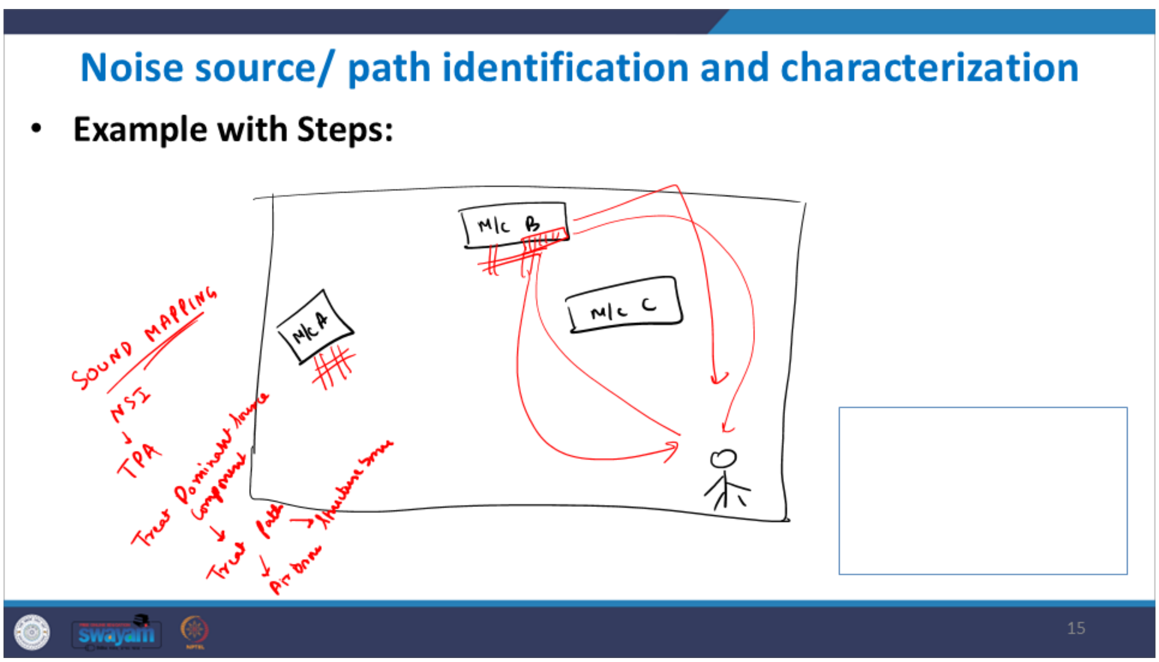


For that, to begin with, you can do noise source or path identification and characterization. what it means is that in order to determine, because you cannot do everything. When you have some kind of noisy environment, there are plenty of options to reduce the noise, but because of resource constraints, time constraints, and money constraints, you cannot apply all these procedures. You have to prioritize which one will suit your case the best. For that, what helps you in prioritizing and choosing the best options is that you first identify which are the most dominant noise sources. There are various noise source identification techniques. They are not part of this course, but if you are curious, you can go and read about it. There are various kinds of techniques like beamforming, holography, and localization techniques. Through those techniques, we are measuring and trying to identify which are the most dominant noise sources. Suppose you have some kind of setup where you have so many machines. You can identify that this is the most dominant noise source, followed by this and this, like that. And you can rank them, and your treatment should always begin with the most dominant noise source before you move on to the second one. In case you have more resources, time, and money left, then you can move on to the next one and the next one, and so on. But priority should start with the most dominant noise source because once that is quietened, that will be the most effective. Then, in the same way, just like you sort of identify and rank the noise sources, you can do the same thing for the pathways as well. You identify what are the various paths through which this noise is reaching the receiver, and then you try to find out what are the most dominant pathways and you rank them. You rank the various paths. From this part, the maximum transmission is happening, followed by this path and so on. you can use techniques such as transfer path analysis and so on. And based on that, you begin with the treatment of the most dominant path and then the next one and the next one, and so on, given that you have additional resources left. In the same way, you can also characterize these paths. Once you are trying to identify and rank the paths, you can also find whether it is an airborne path, whether it is a structure-borne path, how much of structure-borne and how much of airborne is happening. And accordingly, you can decide the treatment.



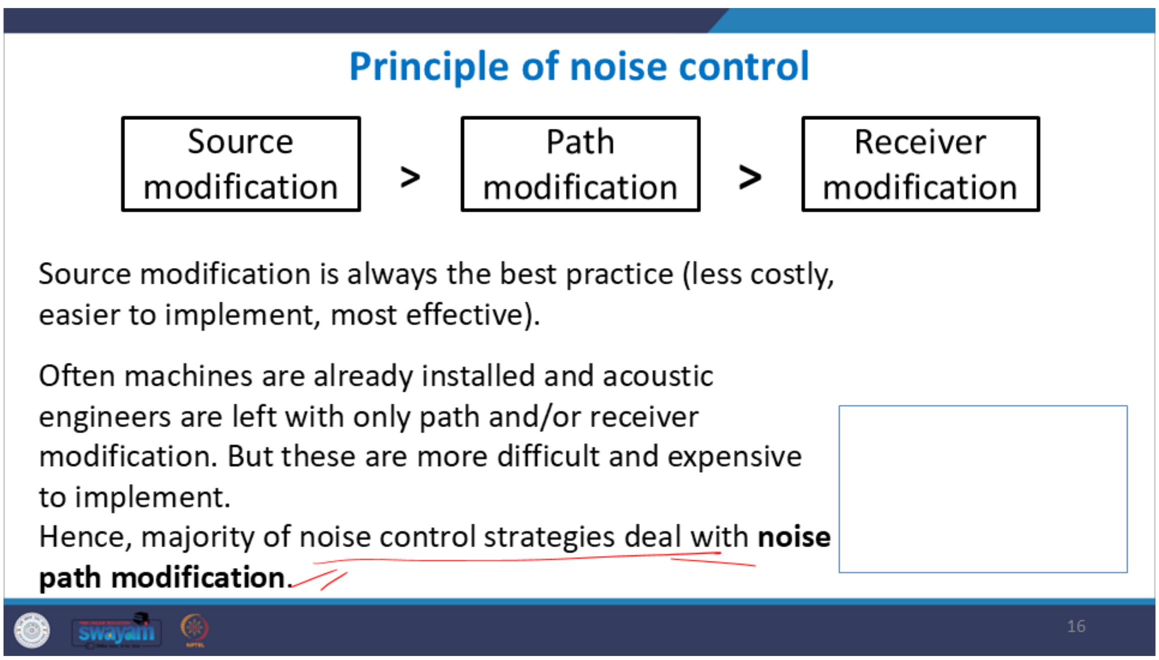
let us say, some examples. We have some machinery which is installed in these mounts. this is some kind of mount or stand for the machinery on which it is set, and then this is the ground, and we have the receiver somewhere here. Firstly, suppose here I only have one machinery. I see that, this is the most dominant machinery. There are no multiple machineries here. I can directly begin and see, what are the dominant paths. I can use the technique called transfer path analysis. Again, something which is not part of the course, but it is a technique through which I find out the contribution of the different pathways. I can find out, I can install, microphones at these various identified paths at various locations.

I can install accelerometers here. These are the various sensors. I can have sensors to measure the force amplitudes and the pressure amplitudes. And based on the data, I can find out which pathway is the most significant one. And on that pathway, if it is a structure-borne pathway, I can put isolators and damping materials. If it is air-borne, then I can install barriers along that pathway and so on.



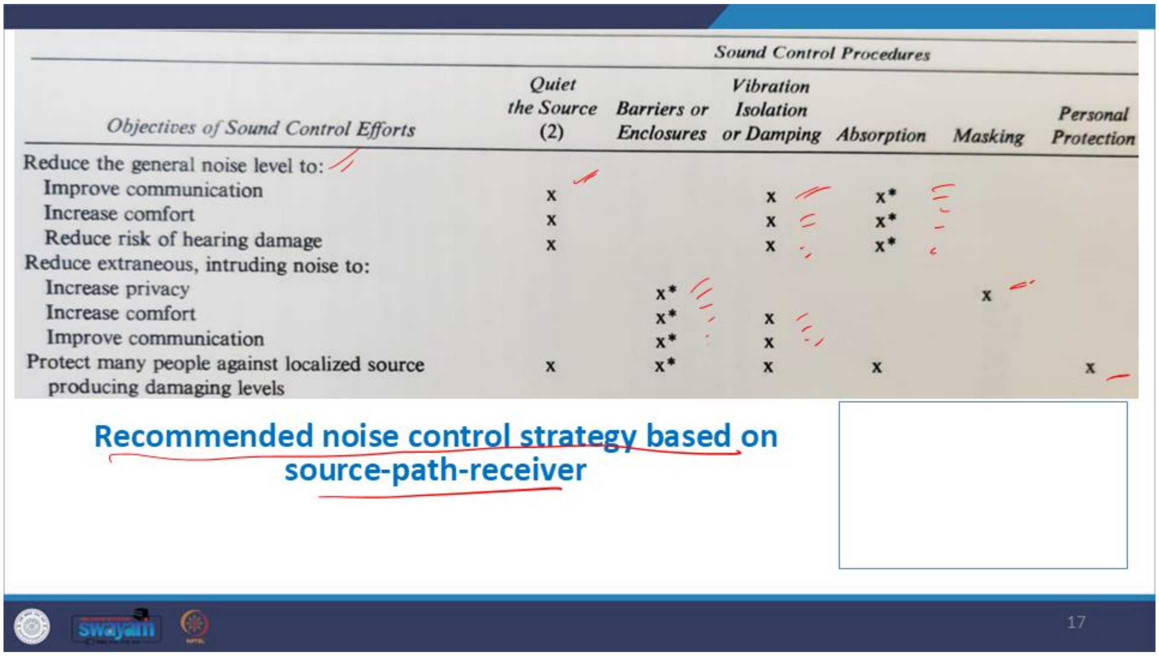
In the same way, suppose I have a setting where, we have a big factory. Suppose we have machine A, machine B, machine C, and some receiver here, so here again, I can do the noise source identification. I can, do something called sound mapping, which maps or gives me an image of the sound field in this area, from which I can know which machinery is creating the most noise, as well as which part of that machinery is radiating the most noise. suppose I find out that, this particular portion of the machinery is having the most dominant noise emission. My treatment can begin at that particular point, and then you identify, if suppose these machineries are mounted on certain mounts. You identify that this particular panel or structure is creating the most noise. What is this panel connected to? Whether there is a strand or a structure that is connecting these panels and the noise is forwarding.

Followed by sound mapping and noise source identification, you can do the transfer path analysis to find out the ways through which it is reaching the receiver, whether it is reaching it directly or reflecting back and being received or through the structures it is going, and then you treat the dominant source component using appropriate techniques, and then you treat the path because source modification will take priority. you first begin by treating the source itself, provided you are allowed to and it is not hampering the functioning of the machine. Once that is done, then you can proceed and try to modify the path based on whether it is structure-borne or air-borne. If it is air-borne, some air-borne techniques will be used; if it is structure-borne, then structure-borne techniques will be used for path modification.



Most of the time, what happens is that noise control engineers are called once the problem is persisting. There is some noise in some kind of industrial setup or machinery environment where the machinery is already installed, everything is in place, and then the engineer is called. the noise control engineers hands are tied down; they cannot change the machinery because they are not allowed to do so.

They are only left with the modification of the path. that is why the majority of noise control techniques cater to noise path modification.

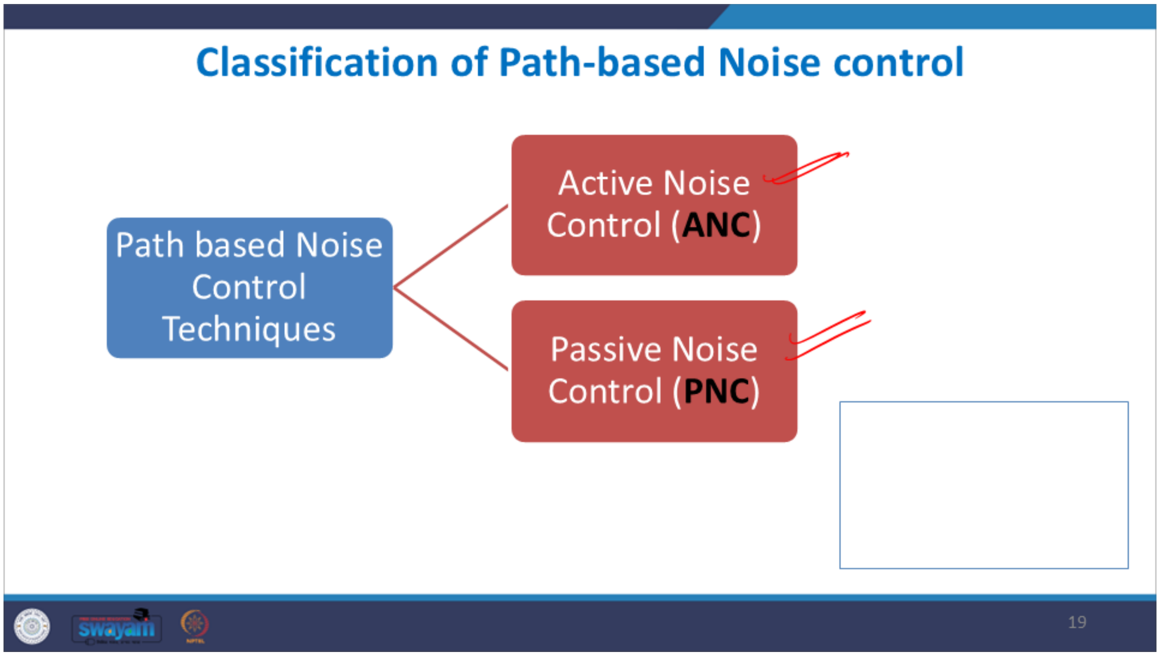


Objectives of Sound Control Efforts	Quiet the Source (2)	Barriers or Enclosures	Vibration Isolation or Damping	Absorption	Masking	Personal Protection
Reduce the general noise level to:						
Improve communication	x		x	x*		
Increase comfort	x		x	x*		
Reduce risk of hearing damage	x		x	x*		
Reduce extraneous, intruding noise to:						
Increase privacy		x*			x	
Increase comfort		x*	x			
Improve communication		x*	x			
Protect many people against localized source producing damaging levels	x	x*	x	x		x

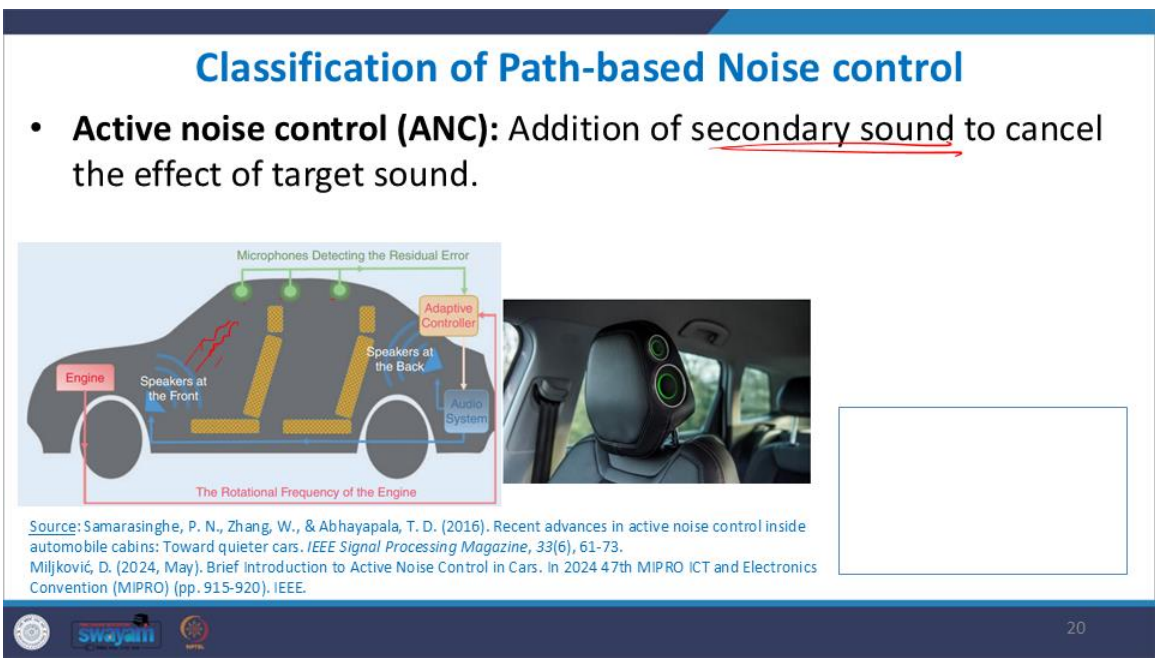
This is some of the recommended noise control strategy based on the source-path-receiver model. Suppose a general noise level has to be reduced; then the source can be quieted, isolation and damping can be done to structure-borne, absorption to the air-borne, and so on. If some extraneous noise is there which is intruding into this, then you have these barriers and enclosures to block the noise as well as some kind of masking you can provide.

And suppose many people have to be protected from some noise level, some personal protection can be implemented. Suppose many distributed sources are there, you can go on to the noise source identification, quiet the dominant source, use these barriers, enclosures, isolators, and personal protection, and so on. For localized sources, again, personal protection can be done, barriers, isolators, and source quietening. Few persons and many distributed sources at damaging levels, sometimes these are more effective. When it is a reverberant environment with a lot of echoes, flutters, and reverberations, then you can use absorbers as the most effective technique, and so on.

Now we know that there are various ways through which the noise can be controlled: source, path, and receiver modification. These various path-based noise control techniques are divided into active noise control and passive noise control.

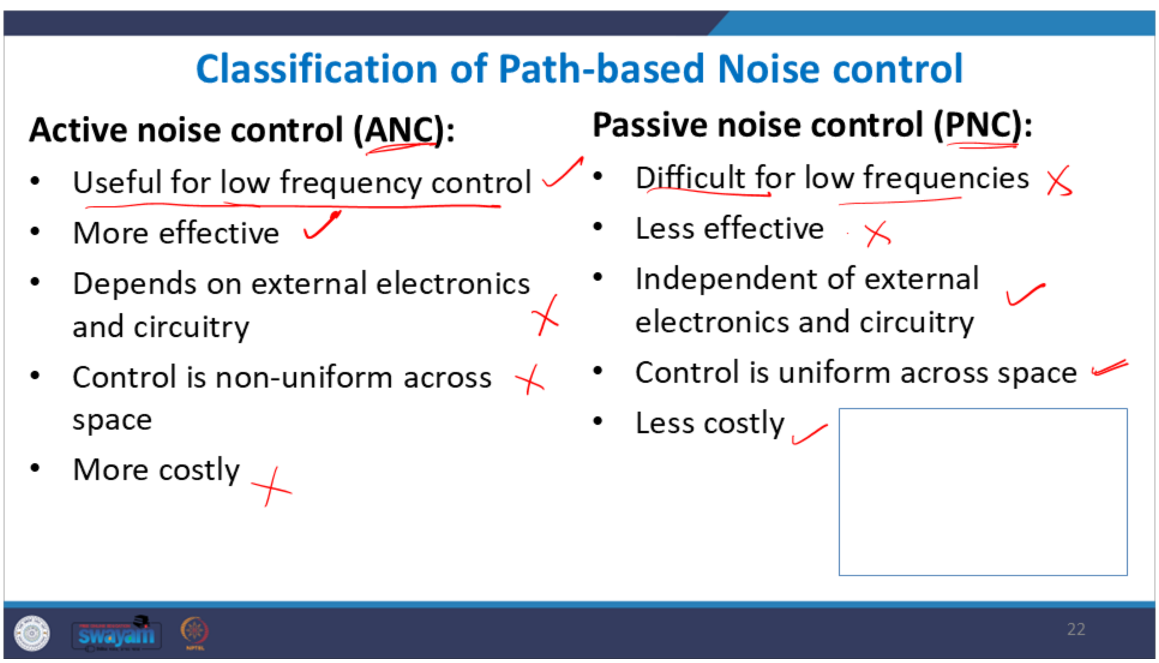


We will study about the active noise control from the next lecture onwards, and then we'll continue with a detailed description of the passive noise control.



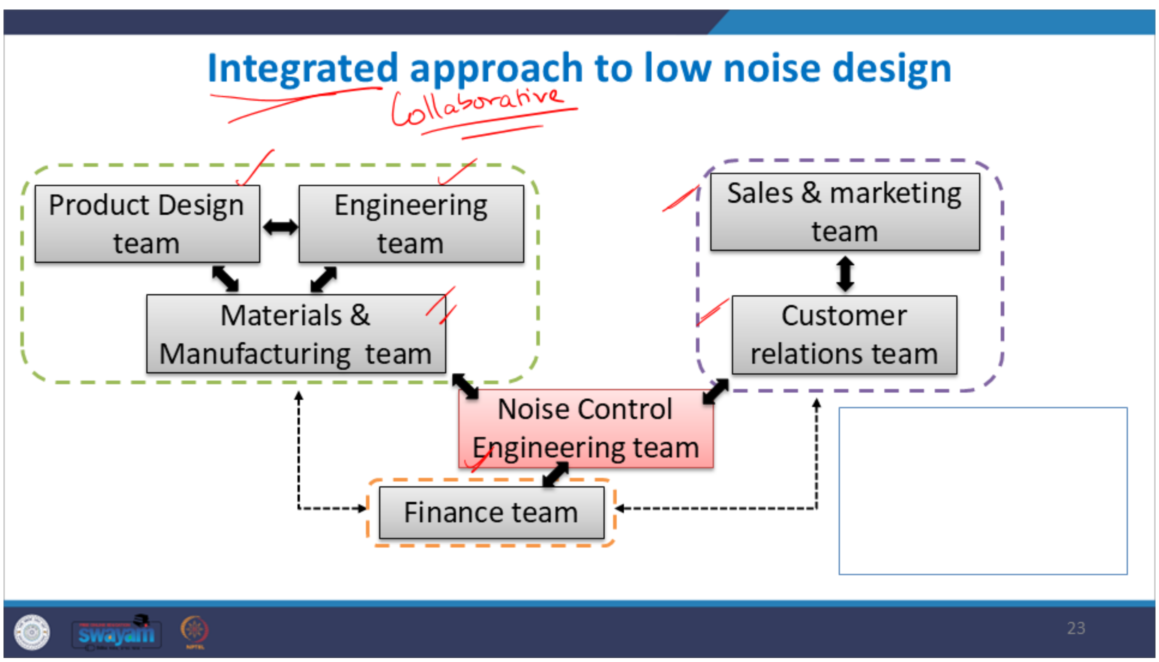
Here I will just briefly introduce this idea. In the active noise control, some secondary sound is added anti-phase with the target sound to cancel out the overall effect. Whereas, in the passive noise control, we don't add additional sounds.

Rather, we add various materials to block or absorb the sounds. And the advantages and the disadvantages are that ANC can be used for low frequency more effectively.



It is more effective for low frequency, whereas passive noise control techniques are very difficult for low frequency. Low frequency is a challenge for PNC, whereas ANC achieves that. They are, in general, more effective because you are introducing a secondary source, which is ideally trying to completely cancel the sound that is present in the fluid medium. Definitely, it goes to ideally zero. this is more effective compared to the passive noise control technique. However, this depends on various kinds of electronics and circuitry, whereas there is no complicated electronics and circuitry required. This is a negative point here, and here the control is non-uniform across space. Depending on where your electronic circuits are, you are taking your microphones, you are trying to produce the noise through the speakers, and then this noise is trying to cancel the other noise. The effect is very dependent on the space. It is very non-uniformly distributed, whereas in this case, there is a uniform effect. This is more costly, and this is less costly. We will study all of this from the next lecture onwards. And finally, I would like to close this lecture by saying that noise control engineering is essentially becoming an integral part of any kind of manufacturing and machinery design stage.

Suppose you have any company or any product that is being made or machinery that is being made.



You usually have these design teams, engineering teams, and the materials manufacturing teams that work together in a very collaborative environment to come up with a foolproof design and manufacture that particular machinery effectively. They also collaborate with the finance team so that the cost of developing the machinery can be minimized as much as possible to increase sales and profitability. The sales and marketing team and the customer relationships team ensure that the product is saleable, and there is a demand for it, and people are attracted to it. A lot of such machinery products can be sold. This is essentially a setup in any kind of supply chain, design, manufacture, and sale of any kind of machinery. Noise control engineers are also finding a place in this particular setup. And they also have their own integrated approach or a more collaborative approach. People cannot work in isolation. They need data from all the different clusters in a typical setup. with this, I would like to close the lecture.

Thank you.