NOISE CONTROL IN MECHANICAL SYSTEMS

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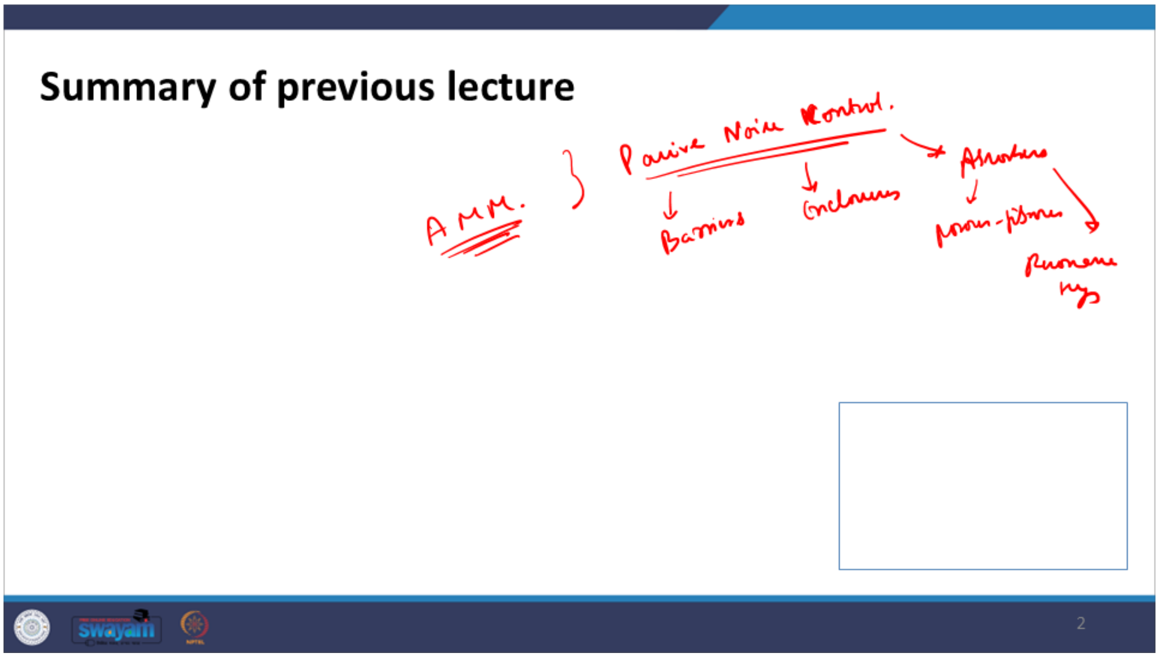
Week:11

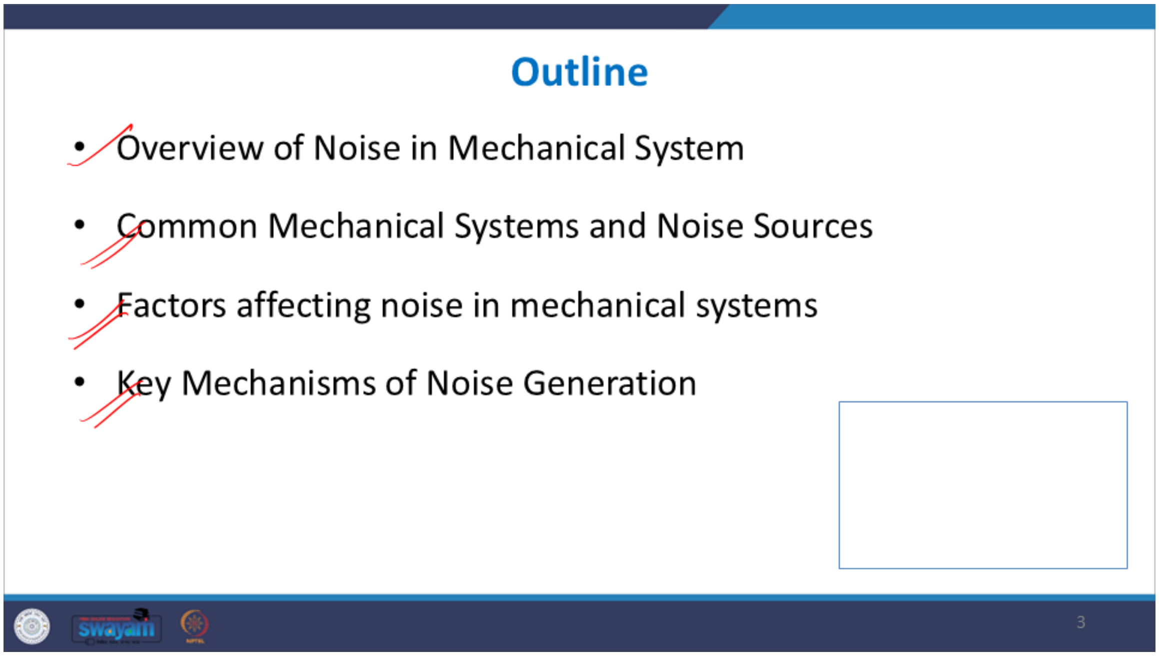
Lecture:53

Lecture 53: Noise in Mechanical Systems:1

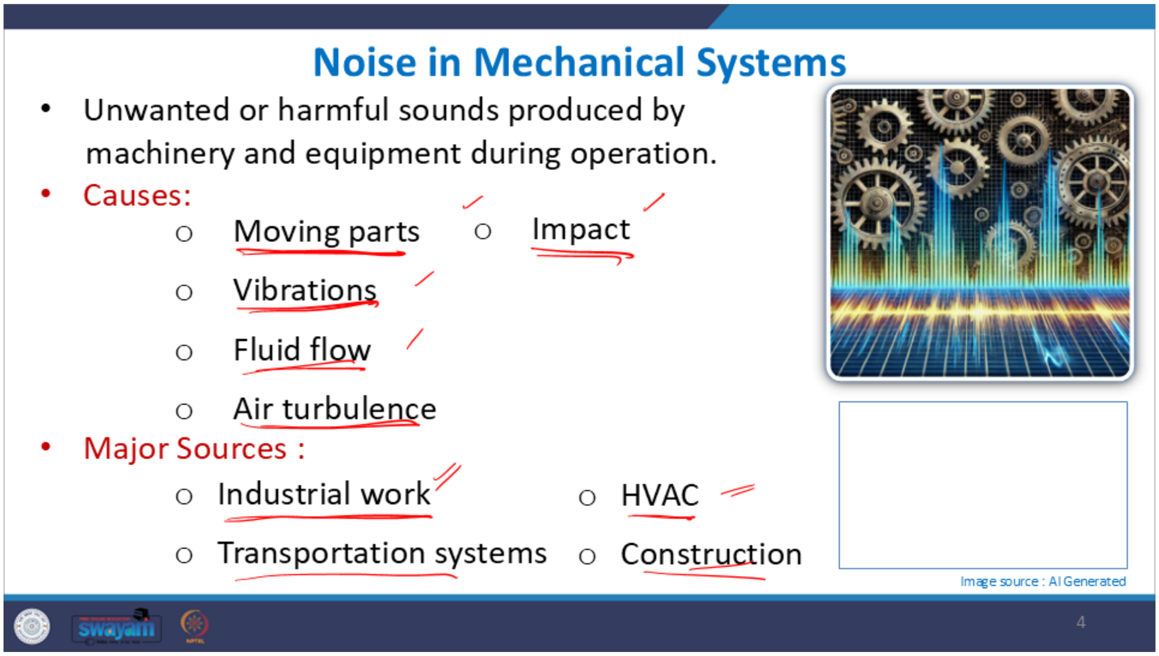
Hello and welcome to this lecture series on noise control in mechanical systems with myself, Professor Sneha Singh. We have just completed the module on acoustic metamaterials and their performance for noise control and various kinds of sound wave manipulation. So, this is what we have completed. So, with this module, we conclude the overall topic on passive noise control. What are the various kinds of devices, such as barriers, enclosures, and absorbers? Within the absorbers, you have porous fibrous absorbers and the resonance type. And then you have these metamaterials. So, various kinds of materials we have discussed and how they help in controlling noise.



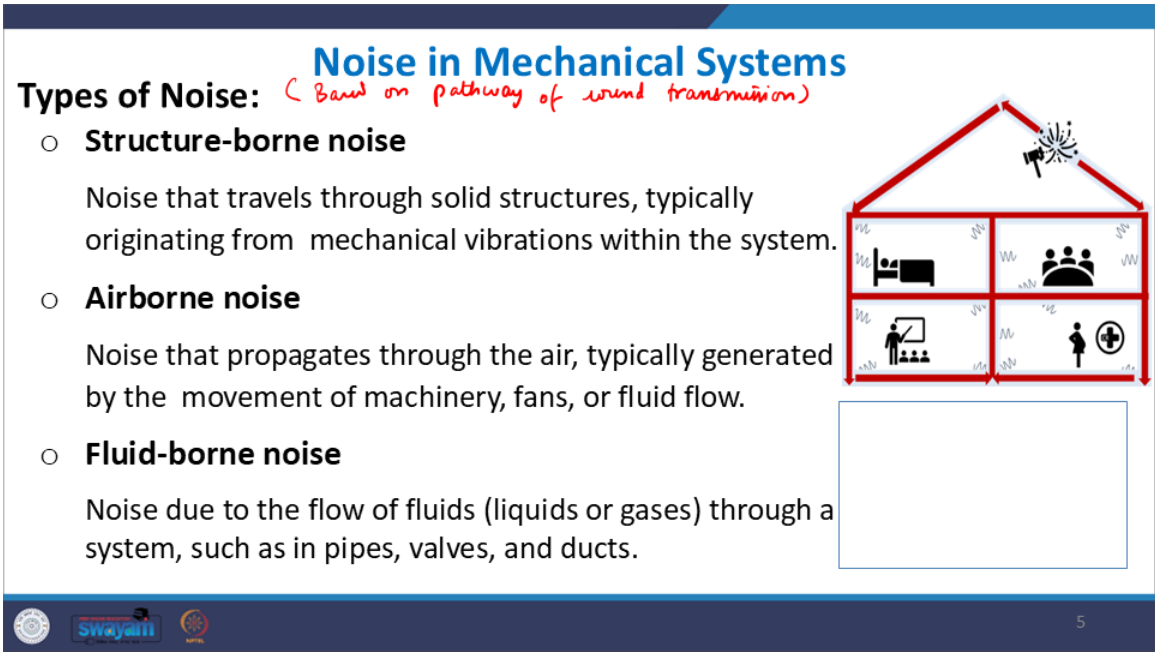
So now we will begin with what noise is in mechanical systems, and we will see some specific cases and case studies on how this noise can be mitigated using the fundamentals of noise control that we have learned so far. So, we will first take an overview of noise in mechanical systems: what are the common sources of this noise, what factors affect them, and what are the key mechanisms by which this noise is generated in various mechanical systems.



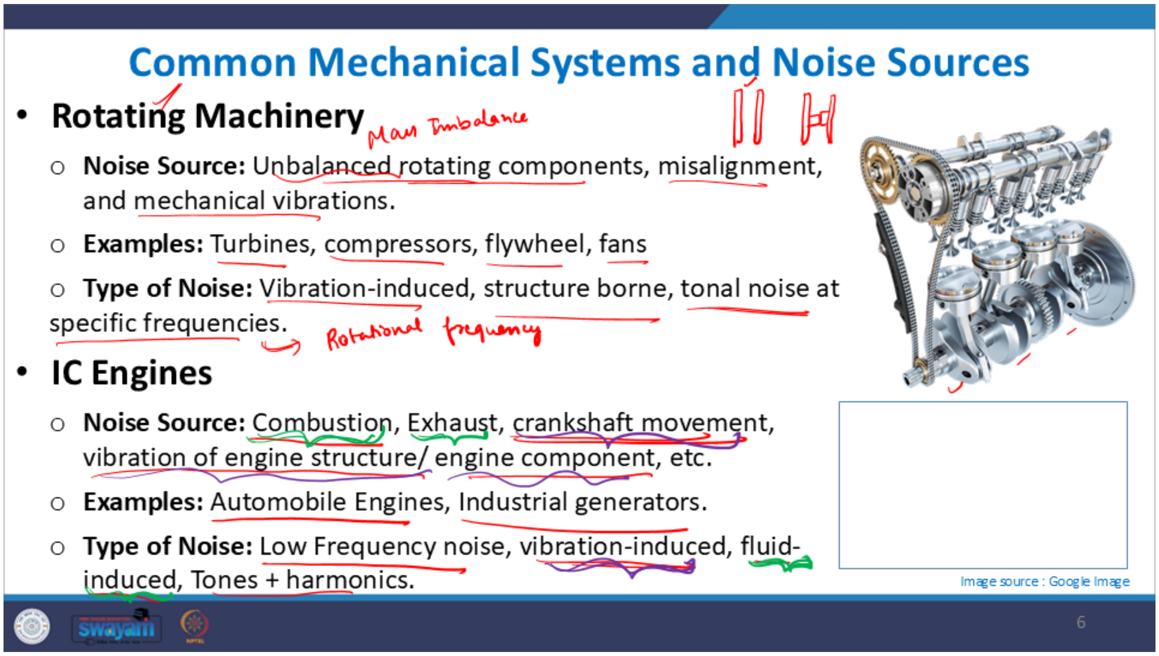
So, noise in mechanical systems—you know that noise is the unwanted or harmful sound produced by machinery and equipment while they are operating. So, what are the various causes? Essentially, you know, if it's a mechanical device, it is made up of some kind of parts that are rotating or moving with respect to each other. That is what any mechanical component or system basically is—components doing some kind of motion, sliding, contacting, or meshing together. So, these moving parts can create noise, especially when they collide together, creating a sharp impact that can produce noise. The vibration of the various components, the plates, etc., can create noise. Then, the fluid flow—some of the mechanical systems might use, you know, the flow of air or the flow of liquid. Water or coolants could be coolants; it could be some kind of gases, refrigerants, etc. which might be flowing through various kinds of pipeways, and this fluid flow then also creates noise. Then, the same airflow—sometimes, for example, most fan-based equipment— has a lot of airflow or various kinds of aerodynamic devices. They would have this airflow, and at certain higher operating speeds, the flow becomes turbulent in nature, and this turbulence can also create noise. So, as a summary, these are the key things which can create noise in mechanical systems. Obviously, the major mechanical systems are the industrial machinery employed in industrial work, in the HVAC systems, in the transportation systems, construction systems—all of this. Then, finally, they are able to create noise because of these primary causes.



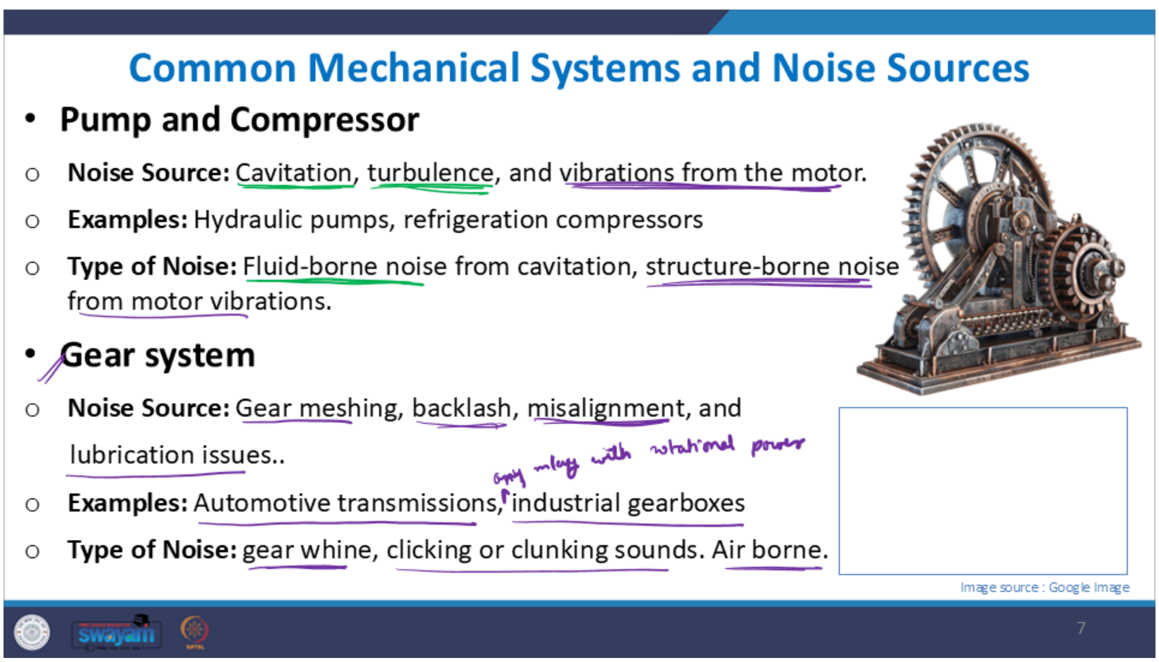
So, let us first see what the types of noise in mechanical systems are. We can classify the types of noise as structure-borne noise, air-borne noise, and fluid-borne noise. This is one type of classification here. The classification is based on the pathway of sound transmission. So, how is the noise reaching from the source to the receiver? If you track down what the pathway is that the sound wave is taking for propagation or transmission from the source to the receiver, you can classify it into these three categories accordingly. What is structure-borne noise? It is a noise that travels through solid structures, typically originating from mechanical vibrations within the system. So, what happens is that, essentially, if human beings are the listeners, we hear the sounds or noise through the air because it reaches the ear through the air. So, ultimately, air would definitely be the pathway. So, how do you classify structure-borne noise? It is for those cases where the noise transmits through various kinds of structures before propagating into the air. So, from the main source, it takes many structural paths to transmit, and from these structural paths, it finally propagates into the air and reaches the listener. So, the structures become one of the important pathways in the propagation of these sound waves. Okay, then you have airborne noise, which is directly from the source, the noise propagates into the air and reaches the listener without any intermediate structural paths. Then we have fluid-borne noise, which is noise due to fluid flow, such as in pipes, liquids, and gases that might flow through pipes, valves, or various kinds of ductways.



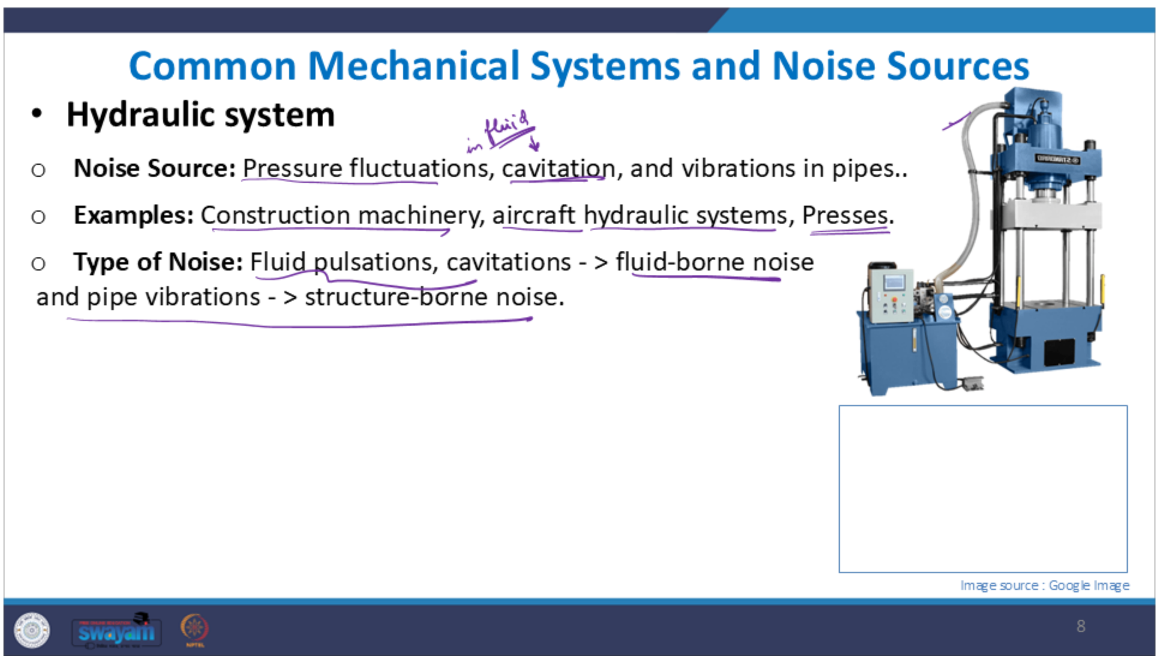
So, let us see some common mechanical systems and their noise sources. So, in any kind of mechanical system, you would have rotating machinery, okay. So, any kind of rotating machinery, such as turbines, compressors, flywheels, fans, etc. So, what is a major noise source here? Suppose in the rotating machinery, you have some unbalanced noise. So, due to some manufacturing defect or because the machinery has aged and wear and tear has occurred, there would be some kind of mass unbalance. So, an imbalance in the mass can result, and this happens. And when the machine is running, when that component is rotating due to this imbalance in the mass or the manufacturing defect which creates the unbalanced mass, there would be some specific noise generated at the rotating frequency of the component, which would be very annoying. And the other way could be mass imbalance this is the mass imbalance, so unbalanced masses. Which is creating the noise at the rotational frequency, even the misalignment. So, usually what happens is, these rotating machines are aligned to the other parts of the machinery and fixed to the various shafts, and they are supposed to come in contact with the other parts of the machinery. Suppose there is a fault in the design of the machinery or there are some loose fixtures you know, the parts of the machinery are kept loose, or the machinery has gotten old, and wear and tear has happened. So, because of this manufacturing defect, improper installation, or wear and tear over time, sometimes the shafts can shift and may not be properly aligned. So, maybe one shaft had to be like this, but due to the misalignment, some shafts are like this, and the contacting components are then meshing together in the wrong way, which also creates severe vibrations and noise. And similarly, any other sorts of vibrations happening in these rotating components can create noise. What is the type of noise then created in such rotating machinery? So, due to these phenomena—such as imbalance, misalignment, and vibrations—the type of noise created is vibration-induced structure-borne noise. It is usually a tonal noise at a specific frequency. This corresponds to the rotational frequency of that component. Okay. Corresponding to the rotational frequency. Then, let us see another common mechanical part. Which is an IC engine that is found in many kinds of machinery, such as in automobiles and industrial generators, etc. You find an IC engine. So, what happens here? What are the major noise sources in this case? First of all, within the internal combustion engine, you have the combustion of the fuel taking place. So, this combustion itself is an explosion. It is an explosion of this combustible fuel and the release of energy. And this combustion process itself is a noisy process. So, the combustion phenomenon can create noise. Then, the release of the exhaust at a high rate. So, when the exhaust is released at a high rate, it can create noise. And the engines are usually connected to the crankshaft, which converts the energy given by the engine into rotating motion. So, the crankshaft is used to convert the thermal energy of the combustion process into the rotational motion of the various machinery components. And this crankshaft movement itself is again a rotating machinery component. It can create motion. Noise, the vibration of the structure containing the engine, etc. And its components can also create noise. Usually, this is, you know, a low-frequency noise; it is usually vibration-induced, fluid-induced, and tones plus harmonics are both present. Suppose the engine components are rotating, for example, here. If the engine components are vibrating, this will create a vibration-induced noise. The crankshaft movement will also create a vibration-induced noise. Whereas the process of combustion is going to create a fluid-induced noise. It is mainly the flow of the gases. And the exhaust will also create mostly a fluid-induced noise. And the noise is created both as tonal noise; higher harmonics are typically created when the engine is operating.



Then you have some other common systems, such as the pump and the compressor. So, what is the noise source in a pump? Because pumps are used in hydraulic pumps and compressors, they are usually used to drive the fluids in some specific format. The fluids are Highly pressurized fluids are driven through different kinds of pathways in these pumps and compressors. So obviously, fluid flow is definitely one kind of noise, and usually in the fluid flow, you have a phenomenon called cavitation that happens. The turbulence during the fluid flow can also create noise, and other than the cavitation and the turbulence due to the flow of the fluids, You also have the motor of this pump and the compressor vibrating, and this is also creating noise. So both fluid-borne and air-borne noise are present. The fluid-borne noise is due to the flow of these pressurized fluids, in this case, due to cavitation and turbulence, and the structure-borne noise is due to the motor systems. In this kind of machinery. Some examples of this machinery are hydraulic pumps, refrigeration compressors, etc. Let us now see that even gear systems are very common mechanical components in various machinery. This is a very important sub-component. It is found in various kinds of automotive transmissions, in the industrial gearboxes of various kinds of rotating machinery and plants. So, in fact, gear systems are very common components in almost every mechanical machinery. You find some kind of gear system wherever you have any machinery with a rotational system. Any machinery where you have to transmit rotational power will have a gear present to convert and transmit that rotational power. What are the common noise sources in this? The meshing of the gear is one. An impact between two bodies: the two bodies are coming together, meshing, and running over one another. So, what happens when two solid bodies collide and slide over one another? What could be the typical outcome? One possibility is friction. The friction forces would be present. The other could be the impact and collision. So, the gear meshing process could involve impact. It could also involve friction when the two gears are meshing together. Then there is the backlash between the gears, and the gears are connected to the shafts. If there is any misalignment in the shaft due to the reasons already discussed, that can also create noise because of the misalignment. The meshing is improper, and when the gears move together, they face a lot of resistance while meshing and running over each other, which creates a lot of noise. Then, if lubrication is absent, there is also a lot of friction. Due to the friction, surface roughness, and lack of lubrication, noise is created again. So, what is the typical noise we observe here? We observe a typical gear whine, which could be a sharp tonal noise. Clicking or clunking sounds could be observed, and most of them propagate as airborne sounds.



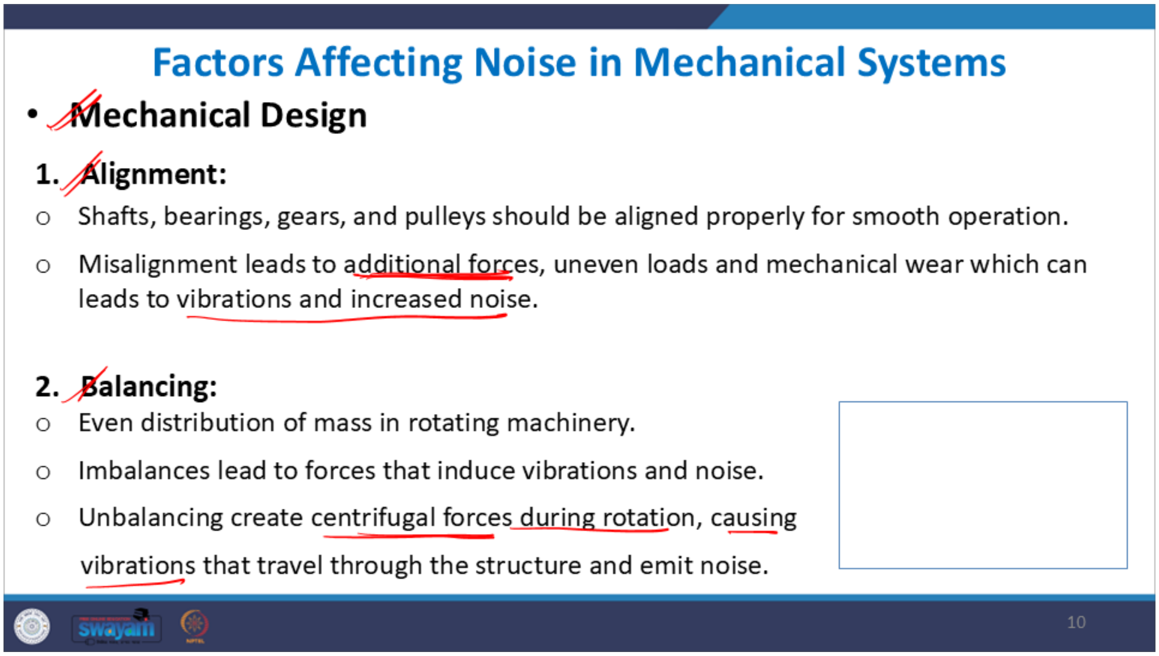
Then we also have hydraulic systems. In hydraulic systems, for example, construction machinery uses hydraulic systems. Various kinds of aircraft hydraulic systems are used, even in presses like hydraulic presses in industrial machinery. So, what you have are pressure fluctuations, cavitation, and vibration in the pipes because, ultimately, hydraulic systems use fluids to derive motion. So, the fluid flows through the pipelines. So, because of the pressurized fluid is going, the pressurized fluid is going through the pipes. So, there could be pressure fluctuations in the fluid, the hydraulic fluid, okay, the fluid that is flowing. there, the pressure fluctuations could be there, the cavitations could also result in the from the fluid and then the pipe carrying this pressurized fluid could vibrate in response. So, both the vibrations which is going to create vibration induced noise whereas the pressure fluctuations and the cavitations inside the fluid will then create a fluid borne noise. like this and this will the pipe vibration is then going to create a structure borne noise. So, you see both ways both these type of noise is generated.



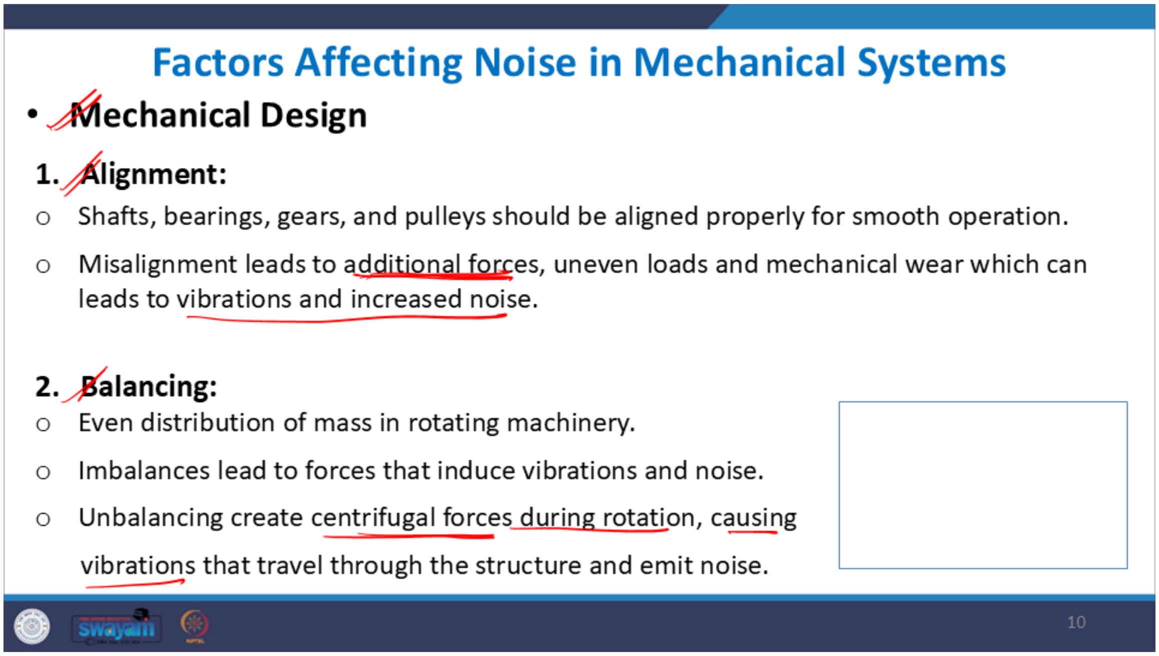
Then you know fans and blowers are once again an important kind of mechanical system and subsystems. So, here again this is it involves a lot of air flow, the air flows at different kind of operating speeds and you have your turbulence in the air. So, this turbulence can create noise. And then just the process of the blades cutting the fluid. So the blades are moving and the air is flowing through these you know fan blades. So it seems like you know when they are rotating the blades they are cutting the air and this process is creating the noise. And it is created at the blade pass frequency. What is it? It is the frequency at which the blades of the fan they are cutting the fluid and it is given by:

$$Blade\ pass\ frequency = \frac{N_{RPM} * N_B}{60}$$

So, it is simply the revolutions per minute of the fan multiplied by the number of blades because, per revolution, those many blades of the fan are cutting the fluid. So, per revolution, that many times the fluid is getting cut. So, N_{rpm} into N_b by 60, or simply the revolutions per second of the fan multiplied by the number of blades, because per revolution that many times the fluid is getting cut. This gives you the blade pass frequency. Then there are various other aerodynamic interactions, you know, where the fluid is interacting with the machinery components. All of this is creating noise in these fans and blowers. Some examples of the systems containing fans and blowers are the HVAC systems, the cooling towers, etc. And what is the noise generated? So, the turbulence phenomenon typically creates a broadband noise, okay? And the blade rotation creates the tonal noise. So, you have a combination of both a broadband component because of the turbulence and, because of the process of the blade cutting, it creates the tonal noise. At what tone does it create it? At the blade pass frequency, that becomes the tonal noise's frequency. At this frequency, the tonal noise is created, and all these are airborne. Okay, so as you saw, you know, in most of these mechanical systems, it is a complex phenomenon. You can't say that the noise is only created due to this phenomenon, and this is the type of noise. You see that in most of the mechanical machinery, you have a lot of components, and because of the interaction between these components, you have, you know, the fluid-borne noise, structure-borne noise, airborne noise. Tonal as well as broadband components due to the different sources. So, it is a combination of a lot of phenomena that happen in these mechanical systems.



What are the major factors that affect the noise in these mechanical systems? So, first of all and the most important one is the mechanical design, and that is why noise control is very important in the field of mechanical design. So, if the design is improper, it is going to lead to noise. So, just to put it in a very simple way, a simplified way would be that if any machinery is operating, the lesser the friction, the less resistance there is to the functioning of the machinery, the lesser would be the noise. And work very smoothly and face very little resistance to its operation, then the noise is going to be low. But if you increase the resistance to the operation of machinery, so instead of having a very smooth operation, now the machinery, the operation is no longer smooth. Either it could be due to a misalignment in the shafts or the imbalance of the mass, or it could be due to the surface roughness which is creating friction due to the wear and tear and a lot of other issues and improper lubrication which is sort of hampering the smooth functioning of the machinery, then the machinery is going to get noisy. So, here the noise from the machinery is very much correlated with how good the condition of the machinery is. So, if the machinery is in good condition and has been properly installed, it will make the least noise. So, in the design part, you have the misalignments of the various shafts, gears. The imbalance in the mass, this also creates noise because then, you know, when they are moving, there is a misalignment that is going to create some additional forces, unbalanced forces which will lead to mechanical wear and tear as well as vibrations, and that will increase the noise. Even the unbalancing will create an additional force or an unbalanced force. This is usually the centrifugal force during rotation, and this again will cause vibrations and ultimately lead to noise.



Then you have the material properties—what kind of material you are selecting—because some materials, when they collide with each other or when they slide over each other, they are essentially noisier compared to the sliding of some other materials. So, the stiffness of the material then becomes an important characteristic, as does the density. Rigid materials transmit more vibrations compared to the softer materials. So, rigid materials transmit more vibrations, whereas softer materials transmit fewer vibrations. They, in fact, absorb the vibrations along the pathway. So, the stiffness of the material is important. If the stiffness can be reduced, then maybe you can create softer materials that can lead to lower vibrations and lower noise. Then, density also—you know, denser materials tend to block the noise and act as sound barriers, whereas lighter materials will vibrate more and emit more noise. So, basically, stiffness essentially has to be reduced, and the density has to be increased to lower the noise. So, we would favor, you know, low stiffness and high-density material for noise control.

Factors Affecting Noise in Mechanical Systems

- **Mechanical Design**

3. Material Properties:

- Materials used in the construction of mechanical components affect both the generation and propagation of noise.
- **Stiffness:** Rigid materials tend to transmit vibrations more effectively, which can lead to higher noise levels.
- Softer materials can absorb vibrations, reducing noise.
- **Density:** Denser materials can block noise propagation, acting as sound barriers, while lighter materials may vibrate more easily and emit noise.

Then, the operating conditions also matter. For example, what are the speed conditions, the load, and the maintenance conditions? So, if you suppose you have some machinery which operates at much higher speeds, then higher speed corresponds to more aerodynamic noise, more turbulence, more airflow, and hence more noise. And then, suppose some machinery consists of heavy-duty machines; they involve heavy forces and heavy loads. They will also create more noise.

Factors Affecting Noise in Mechanical Systems

- **Operating Condition**

Factors such as speed, load, and maintenance directly influence how much noise a machine emits during use.

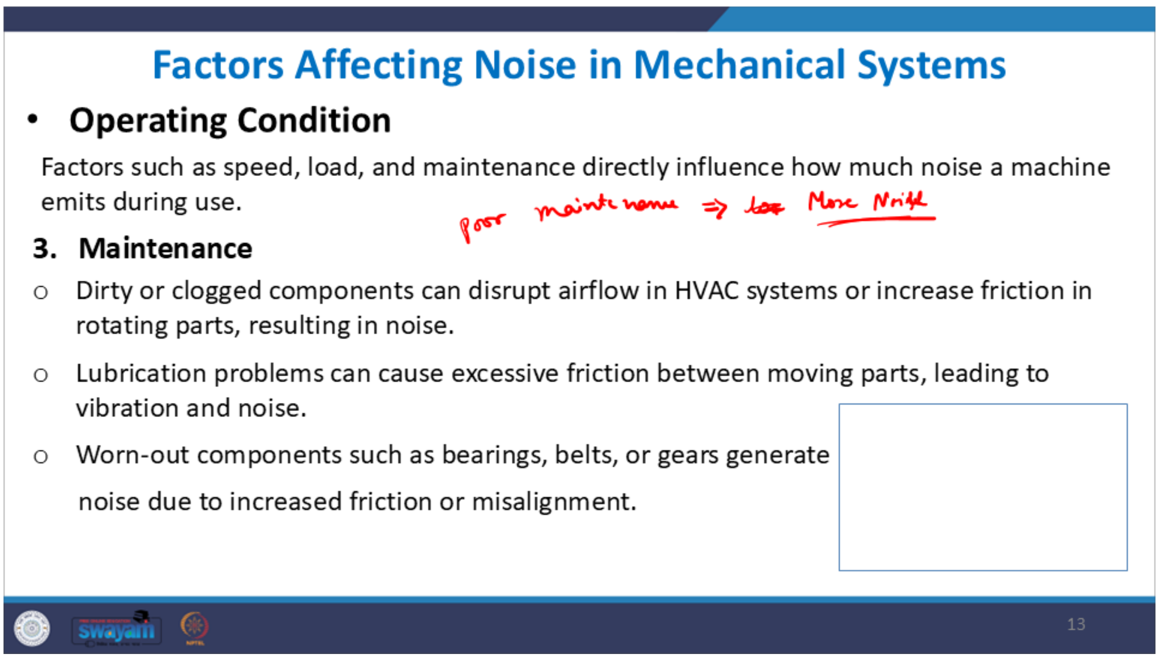
1. Speed:

- Faster rotating components produce higher levels of aerodynamic and mechanical noise.
- High-speed operation increases the intensity of airflow noise and turbulence, especially in fans and compressors.

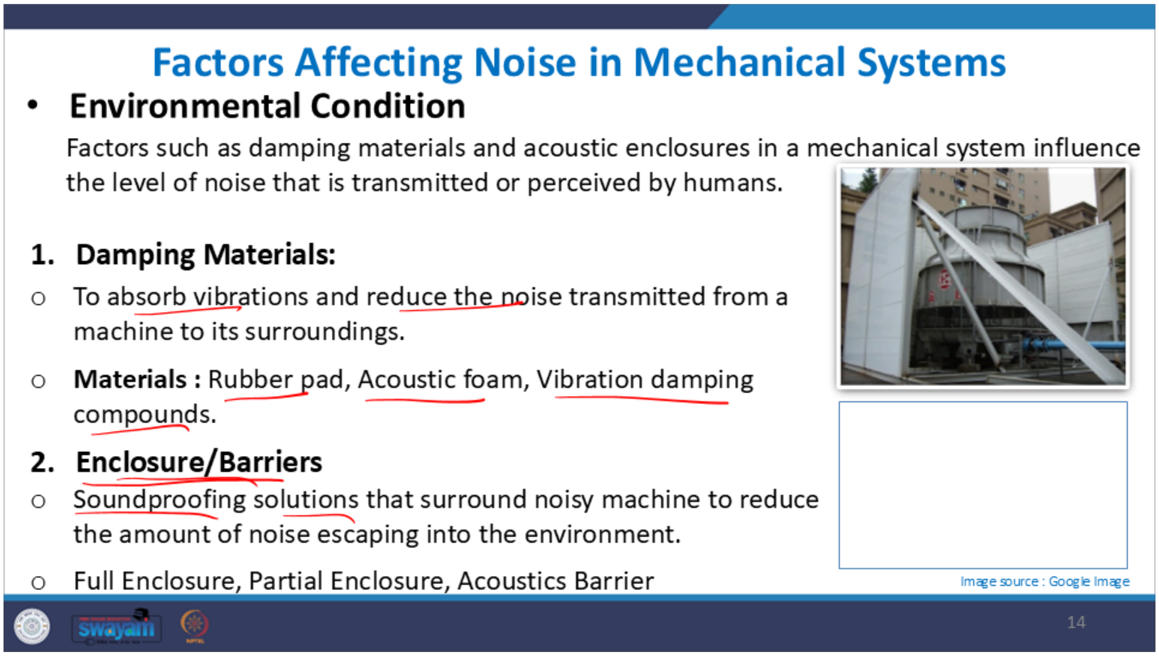
2. Load:

- Heavier loads cause more stress, leading to increased noise.
- Increased loads can cause components like bearings, gears, or belts to wear faster, resulting in more noise over time.

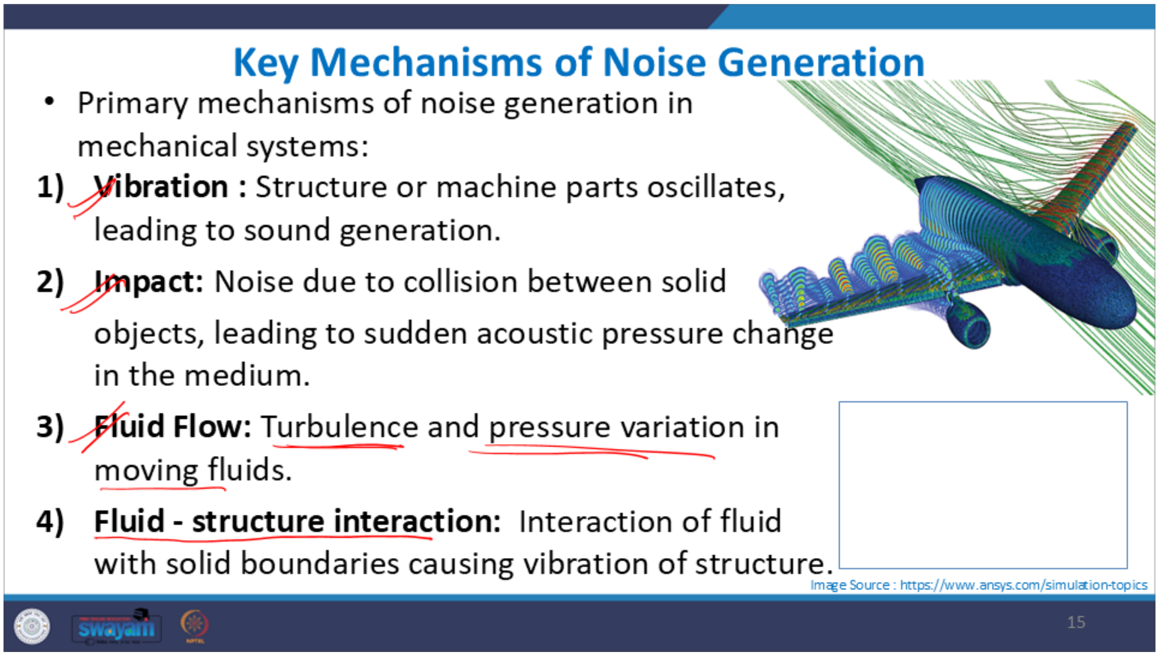
Then, the maintenance condition—obviously dirty, clogged components—will disrupt the airflow in the HVAC appliance and create more friction in the rotating parts. All of this is going to boil down to creating more noise, even the lack of lubrication, which will increase the friction between the moving parts, leading again to more vibration and noise. The wear and tear of components, such as in the bearings, the belts, or the gears, are going to generate more noise again because of misalignment, imbalance in the masses, or increased friction. Okay, so the machinery needs to be in good operating condition. If the operating condition is bad or the maintenance of the machinery is poor, then obviously poor maintenance would essentially mean— More noise. It will ultimately create more noise. So, proper maintenance is required for the machinery.



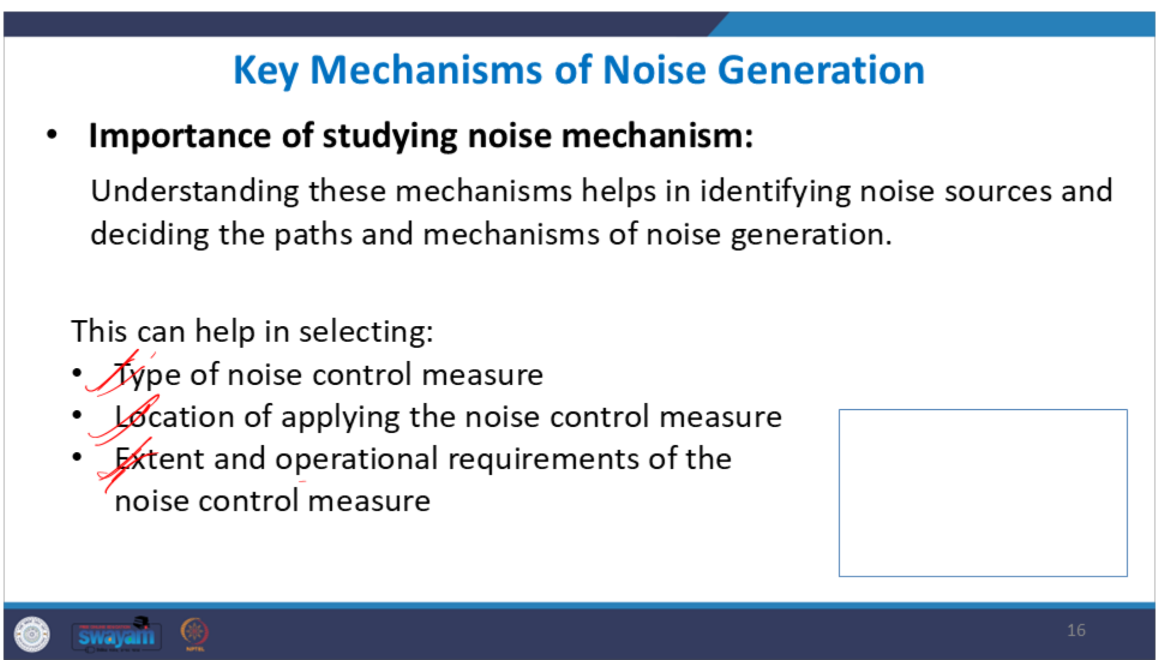
What are some other factors? You have the environmental conditions. For example, what are the surroundings of the machinery? Whether the machinery is enclosed by some barrier materials, or it is out in the open, or it is on some reflective factory floor—all of that is going to contribute to how fast the noise transmits and is perceived by human beings. You have various damping materials that could be used to absorb the vibrations and reduce the noise, such as rubber pads, acoustic foams, vibration damping, and compounds. So, if you use these kinds of materials around the machinery, the noise would be less for the same machinery. Similarly, if you use some good soundproofing barriers and enclosures, that would also bring down the noise of the machinery.



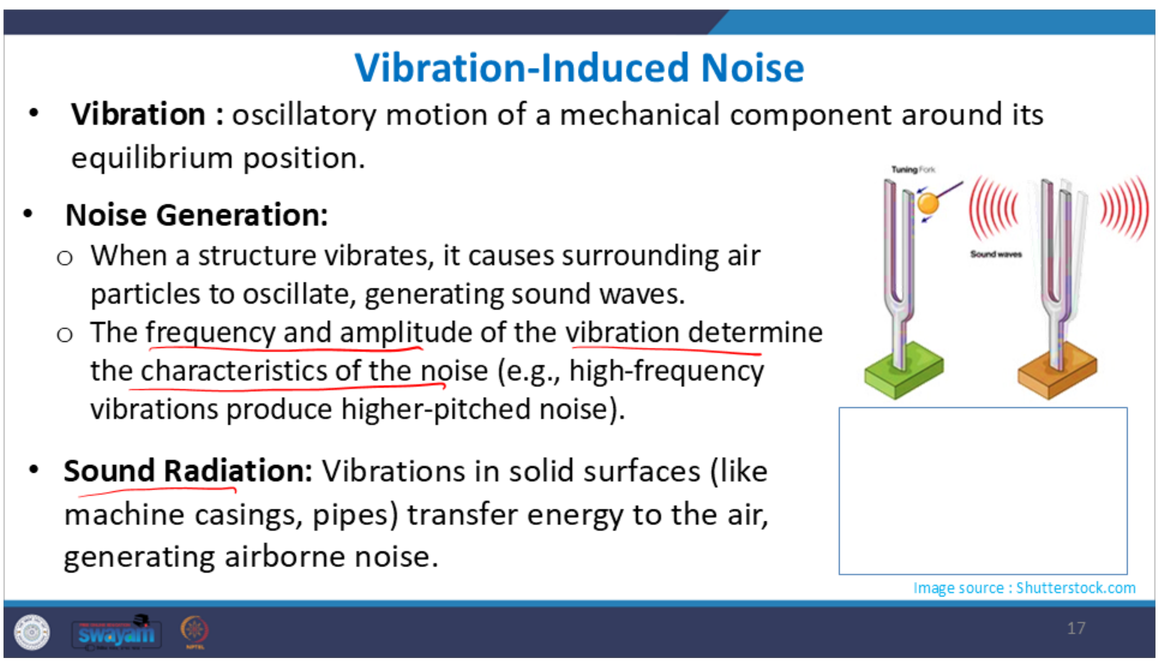
Okay, so some of the key mechanisms by which noise is generated in the machinery. Some of the primary mechanisms of noise generation are, first of all, obviously vibration. The vibration creates noise, which is essentially the oscillation of the structural components of the machinery. Then, impact occurs when structures collide together, and the sudden collision between two solid structures creates a sudden blast of acoustic waves or a sudden change in the acoustic pressure. Then, the flow of the fluid. The fluid flow creates turbulence and various kinds of pressure alterations in the fluid, which again leads to noise. So, these are the mechanisms by which the noise is generated. Then, we have the fluid-structure interaction, where the fluid is interacting with the solid boundaries and it is sort of an acoustic coupling. So, what is happening is that the fluid is flowing, and then there are some obstructions in the pathway. It collides with the structure and sets the structure into motion, and then the structure starts radiating sound. So now, here, what is happening is the fluid is sort of exciting the structure, and the excited structure is then radiating the sound. So, that is the fluid-structure interaction.



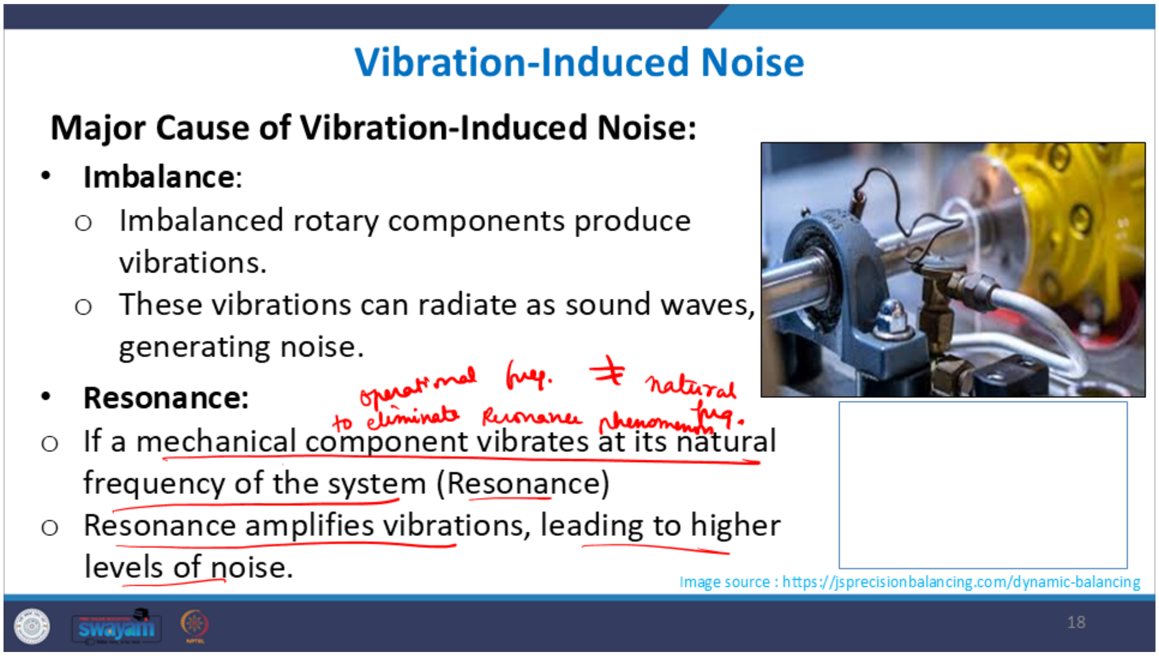
So, why do we need to study these key mechanisms? We need to study them so that we can understand the ways in which the noise is generated, and this will help us decide what paths we can take and what mechanisms we can use. So, we need it because, based on that, we can decide what noise control strategy we have to use and where we can apply that measure. What would be the extent and operational requirement for that noise control measure? So, definitely, you know how noise is created and how it is transmitted is very important so that we can decide the correct noise control treatment.



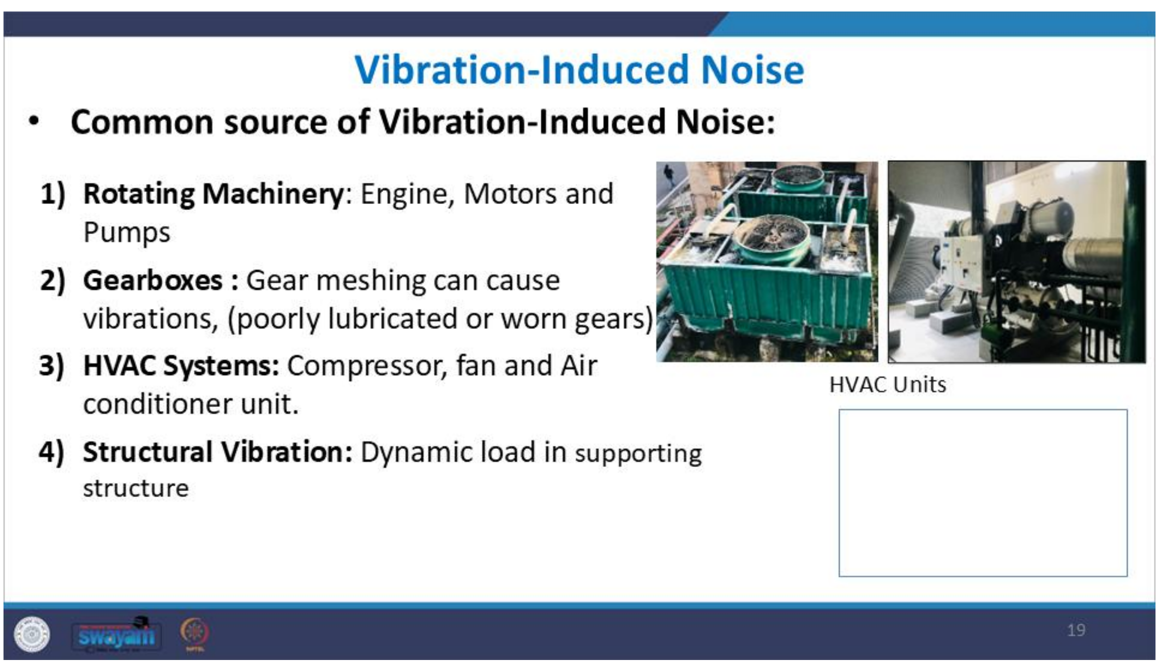
So, let us study the first case, and then we can close the lecture. So, the first case is vibration-induced noise. What is vibration? It is a kind of oscillatory motion of a mechanical component around its equilibrium position. So, in our lectures on acoustic fundamentals, we have seen how vibrating structures essentially set the surrounding fluid particles into oscillatory motion, and then, via these longitudinal oscillations, the pressure fluctuations carry through as noise. So, the structure vibrates, causing the surrounding air particles to oscillate and generate sound waves, and the frequency and amplitude of the vibration determine the frequency and amplitude of the noise, okay? And then, not just this, we also have an additional phenomenon known as sound radiation. All of this we have already covered in the acoustic fundamentals. So, just a quick recap that the extended large plates And the extended plates can radiate the sounds and transfer the energy to the air, generating more airborne noise.



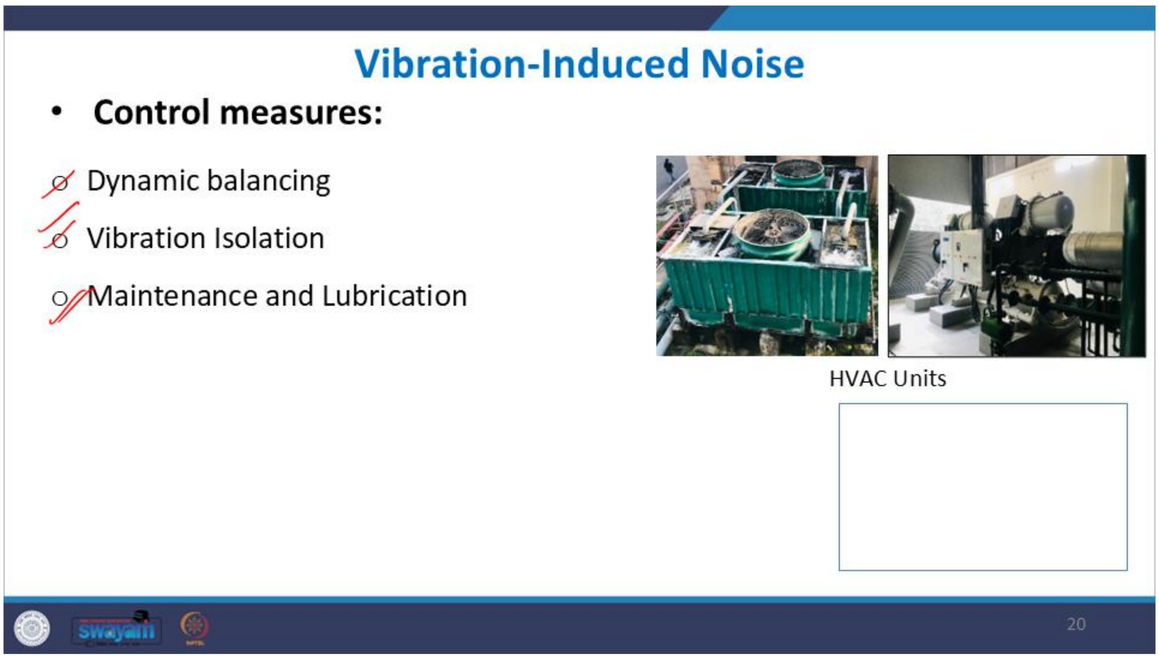
What are some of the major causes in mechanical systems? We have imbalance, which happens, and then we have resonance, which means that if the operational frequency matches the natural frequency of the system, then the structure is set into resonance, leading to very high vibration and a much higher level of noise. So, the operational frequency should obviously not be equal to the natural frequency. It should be as far away from the natural frequency as possible to eliminate the resonance phenomenon.



So, what are the common sources of vibration-induced noise? We have rotating machinery, such as engines, motors, and pumps. Then we have gearboxes, where gear meshing causes these vibrations. Then there are HVAC systems, compressors, fans, air conditioning units, etc. The various kinds of structural vibrations. So, essentially, if you have a mechanical system, there would definitely be more than one source of vibration-induced noise.



And what could be the control measures? You can do dynamic balancing. You can balance the mass, fix the alignment, use vibration isolators, and apply proper maintenance and lubrication. All of this could help in, you know, controlling the vibration-induced noise.



So with this, I would like to close the lecture. Thank you for listening.