Vibration Control
Prof. Dr. S. P. Harsha
Department of Mechanical & Industrial Engineering
Indian Institute of Technology, Roorkee

Module - 2
Basic of Vibration Control
Lecture - 3
Reduction of source – III

This is Dr. S.P Harsha from Mechanical and Industrial Department IIT Roorkee, as in this course of vibration and control, we are discussing about the basic vibration control. And in this particular chapter, we are going to discuss about the reduction at the source when the source is inducing the vibration either by the fluid flow, or by you know like we can say any kind of the interaction is there of the solid. Say by for the cutting operation or for any kind of operations, we know that when the solid surfaces are being under the interactions, there is a clear vibration generations are there, and the same time it is propagating in such a faster way.

So, in the previous two lectures of the basic vibration control, we discussed about that how effectively we can reduce the vibration expansion or the transmission, you know like by adopting the isolators or any kind of damping feature involved in this. But, all these you know like the examples, which we quoted in the previous lectures, were either for the solid interactions or even you see we found that when the system is excited by any kind of external excitations.

In this lecture, we are going to introduce that when the air or liquid or any kind of fluid when it is flowing through, the pipe or any kind of such devices. Due to its turbulence nature, because of you see the you know like, when these things are being passed out the high velocity and the pressure, both pressure velocity is coupled together. And they are creating some kind of vac formation or the turbulences, and due to that the huge amount of vibrations are being generated.

Though, this is a clear fluid solid interaction and this these vibrations, because of the inertia forces of fluid or because of you see the interaction of these you know like the forces. At the restoring forces by you see these pipes or any device and the inertia force interaction, we know that the vibrations are quite significant and because of that you see here, we can get the huge amount of sound as well together.

Because, the sound waves are being straightway you know like putting the huge amount of energies towards that, so we will take various examples in this lecture. And we will see that how effectively we can reduce these flow induced vibrations in that first, what is the basic mechanism in this, and then what is the effective way of reducing. And that is why you see this flow induced vibration is also coming under the basic vibration control in which the reduction at source is this. So, as we move further we find that what are the you know like the ways, through which the turbulences are occurred in the path of the fluid flow, and then through that the various vibrations are coming.

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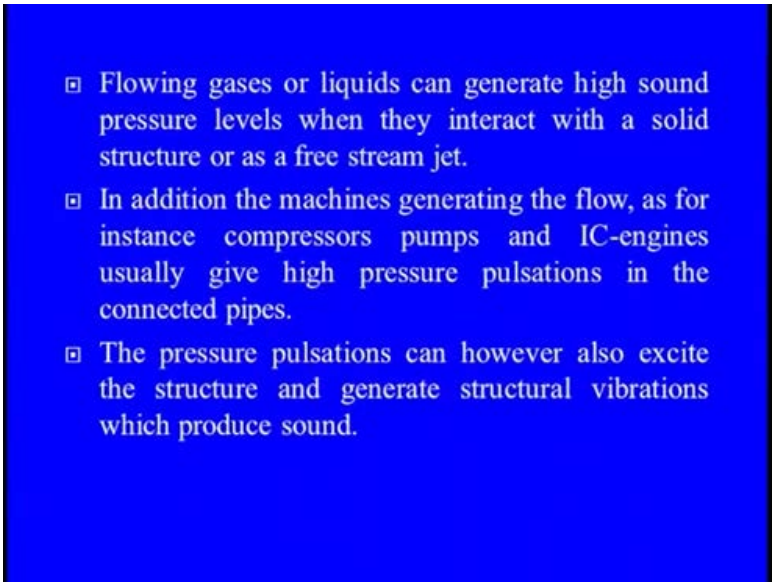

So, in this way first we are going to see that how you see the flowing gases or the liquids can generate the high sound pressure levels, because when they interact with the solid structure as I told you there is a clear impact of the energies. And with this energy, which simply consumed the huge amount of forces, they are straight way you know like under the impact forces. They are straight way generating the high pressure level of sound or the vibrations, just like you see we can say either for the solid structure or we can say a free steam jet.

They are straight way creating huge amount of kinetic energy or we can say the forces are there with this energy, with the high velocity, and then you see here the huge amount of we can say the forces through these forces the high. We can say the frequencies of the vibrations can be generated with high pressure levels of sound, and in addition the

machining even what are the machine, during the machining process or these machine which are generating the flow.

Like for instance we can say compressor pumps or IC engine, they are also giving the high pressure fluctuations or the pulsations. And these high pressure pulsations are simply creating the huge amount of oscillating feature in the pipe, and then the high amount of we can say the amplitude of the vibrations are being generated. So, the pressure fluctuations or the pulsations can; however, also excite the entire structure, and they are basically the root cause of these structural vibrations through, which the sound is also produced at a higher pressure levels.

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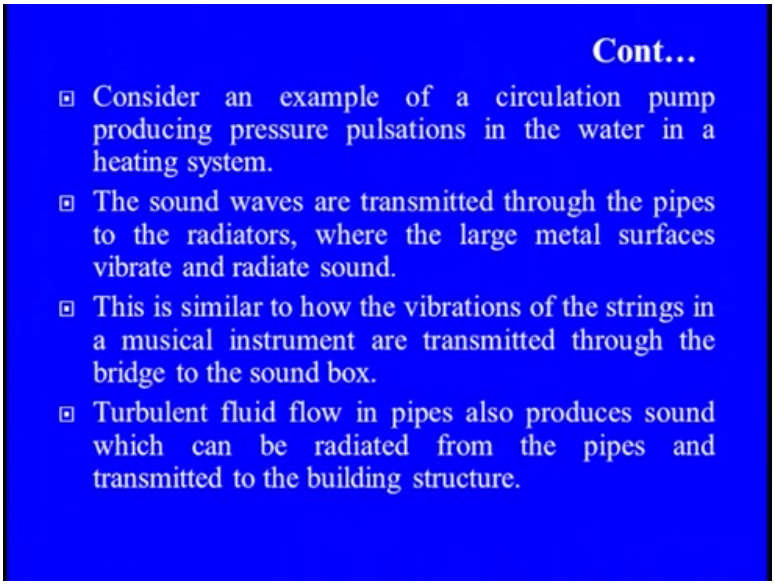

So, with these considerations of any circular pump, which is you know like producing the pressure fluctuations or any kind of you see the oscillation in the water, in any kind of heating system is a great source of the vibration or the sound generations. And these sound waves which are simply transmitting through these pipes, to the radius are; obviously, creating the huge amount of oscillation in those pipes.

Where, the large metal surface vibrate and the radiator is creating, so much sound, and since you see here these all things are being happening during the process of heating or cooling operations. When these radiators are being under the operations, we know that it is a great damage to the pipes through which these flows are being occurred, because of the huge vibrations.

And this is even similar to how the vibrations of the string in a musical instrument are being transmitted through the bridge of the sound box. So, you see here you know like these vibrations, which are being transmitting through this solid media through pipes or through these musical instrument wires. Since, they are you know like it is a as we discussed already that vibration is a molecular phenomena, the transmission through these metallic surfaces are, so fast.

And so significant that they are producing enormous amount of sound or the pressure level, and another feature through which you see the vibration is creating is the turbulence. The turbulence we know that the turbulence is always being there due to the significant effect of the inertia forces over the viscous forces, as we are simply defining these through the Reynold number.

So, when the inertia forces are quite significant in those cases, we know that there is a clear deviation in the path of the fluid flow from the steam line flow. And this deviation is creating a greater amount of molecular interaction of the fluid flow, and when this is happening, certainly you see here there is a clear deviation in the entire fluid flow path, and this creates the turbulence the irregular path of the fluid flow.

And this irregular path, which technically we are saying that turbulence of fluid flow, in the path of that in the pipes is also producing a great amount of sound and the vibrations. Because, you see more and more impact forces are there from the fluid on the surfaces of the pipe, and which can even radiated from the pipes and transmitted to the building of any structures. And these vibrations are being transmitted, because the pipe has a solid structure, and this is a you know like a clear transmission of these vibrations are.

So, our interest here is how the flow induced vibrations are basically lies, in the fact that the source of the vibration is the dissipation of the energy caused by this factor turbulence. In other cases by even the 80's that produce due to the oscillating lift forces, that even impregnates object immersed in the fluid with the vibratory movement. So, either we are saying through this eddy passage you see here, which are being you know like created due to the vac formations or even the turbulences, which are being coming out due to the irregular fluid flow.

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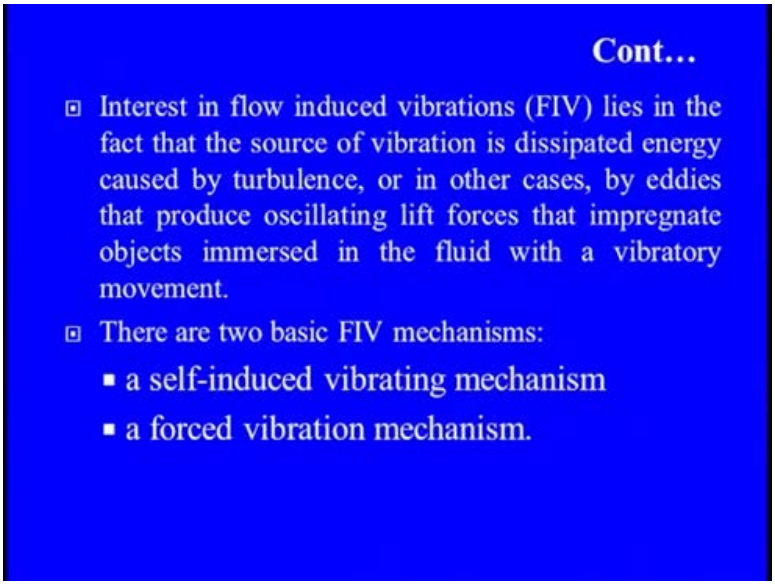

They are the basic cause for flow induced vibrations in the structures, and if you want to see the mechanism of the flow induced vibrations, then there are two main features are there. One the self induced vibrating mechanism, because you see here according to the structure though, you see the flow is say along the steam line, but the shape itself is causing, so much turbulence, because of the variation of we can say the pressure into the velocity and the path itself is creating the turbulence.

Second the forced vibration mechanism, that you see the impact forces or some kind of you see, you know like the impulsive nature of forces due to the abrupt change of the fluid passage. When it is being happened then certainly you see here, the turbulences or any eddy formations can be caused and they are causing the vibrations in that. If you are looking towards the basic mechanism again, we have find that there are various applications in that through, which these vibrations are being generated through the fluid.

Either, we are talking about the single phase fluid or multiphase in that the steady state or transient nature, we will find that there are various categories are there. So, if we are talking about say, the single phase in a steady state we know that there are internal and external flow. In unsteady state we have the pulsating turbulent or we have the sudden change in flow, so these are the three broad category.

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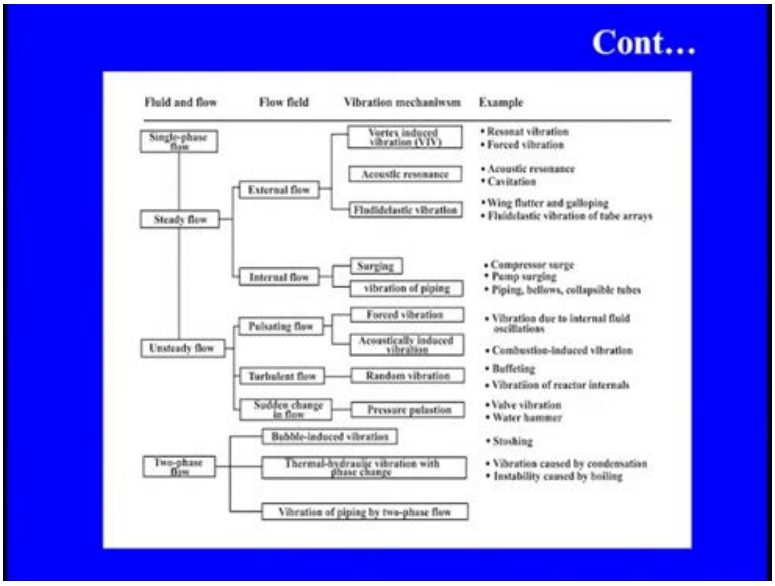

And if you are talking about the two phase flow, then we know that we have either the thermal hydraulic feature and second is the vibration in typing when that bi phase flows are being occurred in that. So, in these broader categories irrespective of whether the external internal flow, or pulsating to a sudden change or in turbulent this. We can say the turbulent flow or in 2 phase flow irrespective of whatever the thermal exchange or a bi phase flows are there, they are basically inducing the vibration at the various levels in the entire fluid structure fluid solid structures.

So, when we are talking about say steady state, single phase flow in external feature we have either the vertex induced in which you see the eddy formations are there like the resonance the vibrations or the forced vibrations. We have the acoustic feature and we have you see the fluid elastic feature of that, through which the vibrations are being generated. Second if you are talking about the internal part, we know that the surging is a very common feature of the pump, and through that there is a vibration creation or induction in the structure.

Second even the vibration of the pipes in which you see the fluid flow even the steady state fluid flow is moving in the pipes, but there is a clear vibration is there through these fluid flow in the pipe itself. The pulsating nature like because of the forced vibration of any external or internal force generation, second acoustically induced vibrations, like you see in the various we can say the combustion features are there.

In the forced vibration we know that when there is a clear internal force, the fluid interactions are there and due to that the oscillation is happening in this. Even when we are talking about you see the sudden change is clearly change, the sudden change in the structure is basically changing the pressure in corresponding velocity of the fluid, and due to that there is a clear turbulence feature is there in that or else we can say that you see the random vibrations.

All of sudden the exciting energies are being there or all of sudden, there is a change in the pressure to velocity and because of that in this energy exchange from kinetic energy from potential energy to the kinetic energy. There is a great amount of turbulences are occurred in the fluid motion, so what I mean to say that these are the basic mechanism, when the fluid is flowing irrespective of the single or bi phase flow, there is a clear vibration induced is induction is there in the structure because of that.

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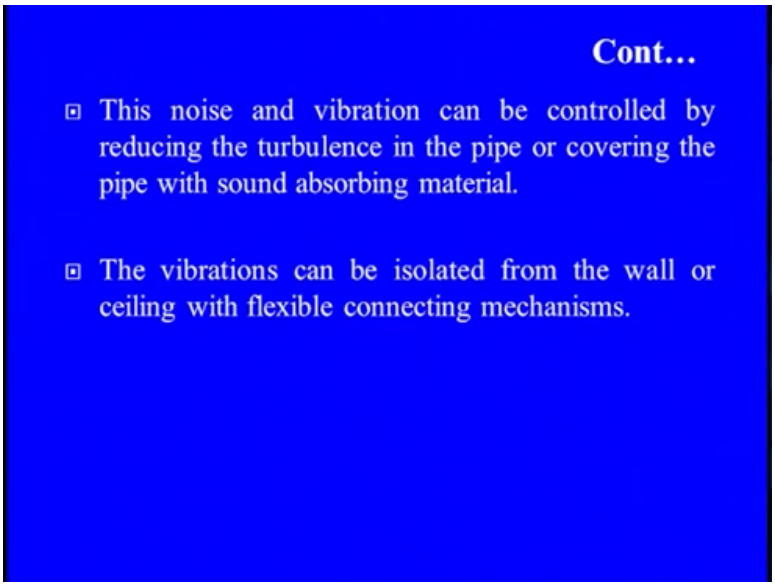

So, this noise and vibration, which is being generated due to the fluid flow can straight way be controlled by reducing the turbulence, which is the main cause for this vibration generation in the pipe or covering the pipe with the sound absorbing material. Because, of you see when it is being transmitted into the other feature, we can straight way obstruct the path of the transmission, and we can reduce this. The vibration can be isolated from the wall or the ceiling with the flexible connecting mechanism, this is also one of the way to just you know like putting the absorbing material to reduce that.

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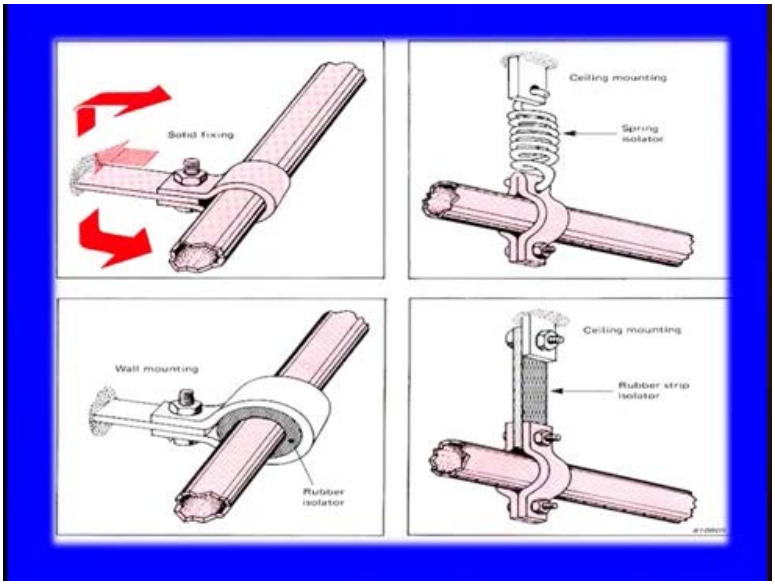

As, you can see on the in this diagram, that there are 2 main examples are given here, the first one we have you see a solid fixing is there in that, and this is straight way connected to a wall. We know that due to this action, any you know like we can say the transmission of that through this pipe there is a clear vibration is transmitted through this path.

And this vibration is straight way going to the entire structure, where it is being hanged and you see here, because of that the entire wall or the structure where it is hanged is being under the oscillating feature. In other case you see here when it is you know like the ceiling feature is there, this even the spring connector is there which is also somewhat the energy absorber, due to the oscillating motion can you see know like control the vibration, but not in the effective manner.

So, you see in the first case as we have seen that, we can straight way adopt the isolator in terms of the rubber and we can put in between the interaction of this binding and the entire we can say this pipe. So, this pipe when it is generating any pulsating feature due to the fluid flow can be effectively controlled by this rubber, and when it is being controlled it will not transmit to this solid interaction from this pipe to other joint.

In other case instead of having the spring, which is nothing but you see you know like under the same oscillating feature, and sometimes that is absorbing or extending part, but instead of that if we are putting the rubber here. That will certainly allow some kind of

we can say the oscillating part, when the fluid is just passing through that, but more of the energy is being absorbed by this part. So, it will not transmit to this wall feature, where it is hanged, so these are the two effective you know like we can say the technique through, which we can control when the pulsating nature of you see the pipe or any hanging material is there.

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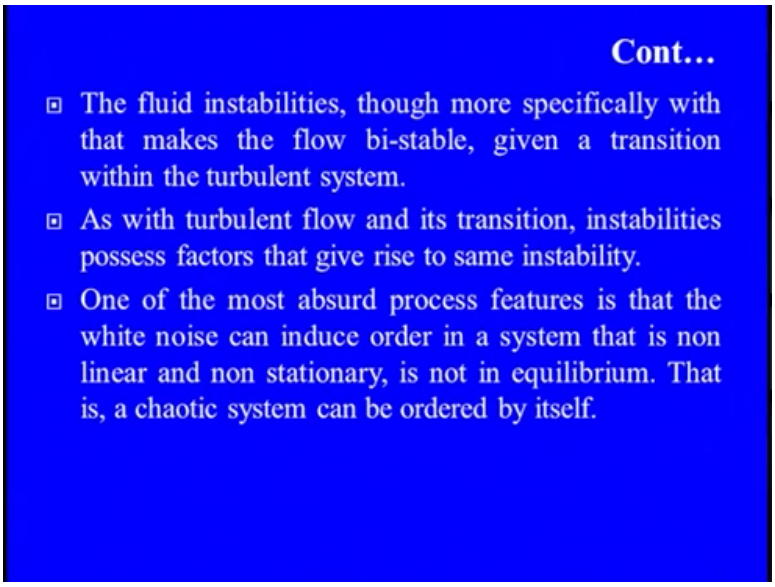

So, in that you see here the fluid instabilities through more specifically, we can say with that makes the flow bi-stable give a clear transition from steady state fluid flow to the turbulence system. Because, you see here this bi-stable feature of the fluid is always creating some different deviation of the fluid molecules, when they are just passing through the pipes.

As, with the turbulent flow and it is transition which is of more dangerous, the instability poses factors that give rise to the same instability, so sometimes you see here this turbulence. When it is being coming under the transient nature clearly indicates the instability in the entire structure, and one of the most absurd process feature in that is a white noise, coming out from the structure. And this you see is clearly inducing in a different order in the entire system, that we are getting a non-linear and non stationary responses. So, even this non-linear and the non-stationary responses even cannot be featured out by any of the control technique, and even this makes the entire system in non equilibrium. So, even we are trying to control the things, but system would not

control, because you see here there is no clear relation between the exciting input and output excitations, because of the non-linear surface structure or the non-linear responses of that.

And even these non-linear responses are of non-stationary one, so there is no clear frequency excitations are there at this abrupt change or because of this. And this is sometimes even creating the chaotic situation within the system itself, so we need to see that when such things are being happening, we need to control effectively the turbulent flow of the fluid when it is just passing through this.

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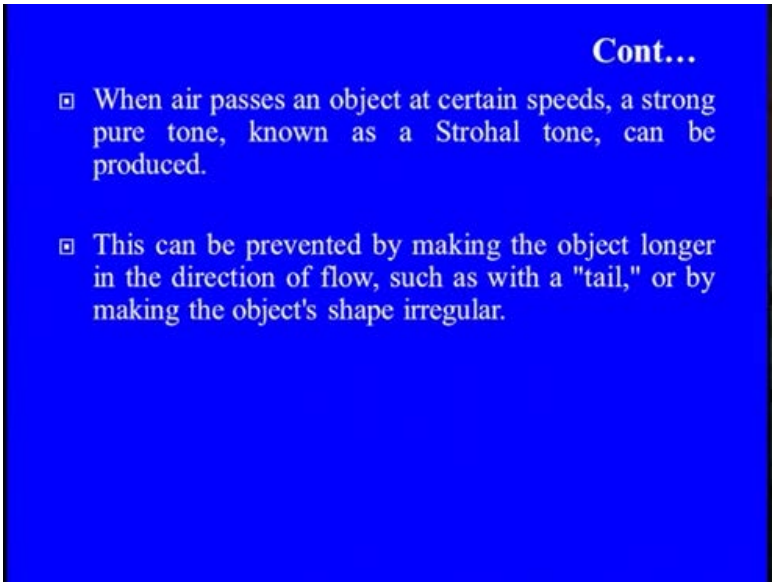

So, when you see either the air or any liquid is passes, at a through the object at a certain speed we know that they have a strong pure tone, sometimes we are saying that this is the strohal tone. And when it is being produced certainly you see here, there are greater amount of energy, because of the resonant condition is coming out from the system and which makes the system vibrate at the larger level, and also the same time it producing the huge amount of sound energy as well.

This can be prevented by making the object longer, in the same direction in which the flow is occurred, such as you see the tail or anything or by making the object sharp irregular. So, that we can deviate the path and the different excitations will coming out from the system, so that the resonant condition where the pure tone is coming out, or even the huge amount of energy is coming out can be deviated from that. Just like you

can see that this diagram, when you see the air steaming is coming out you see, we know that due to this you know like the circular path, we are absolutely in the pure tone feature.

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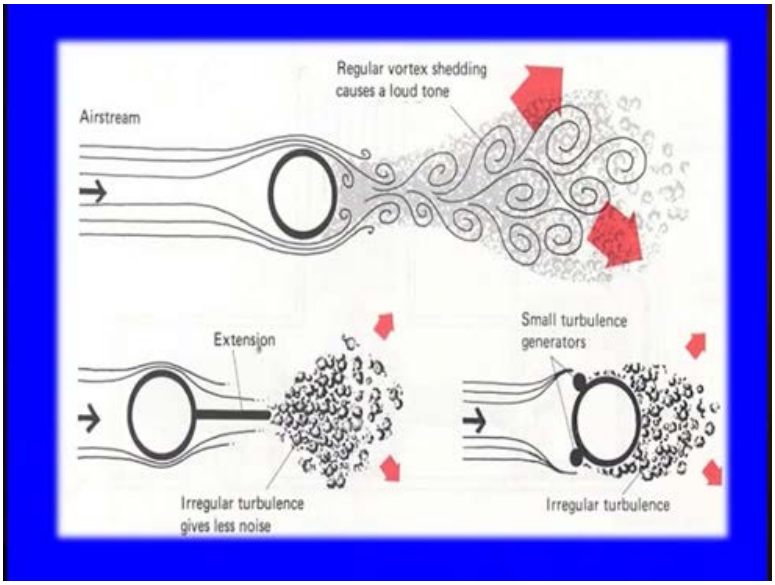

And because of this regular vertex shading, because of the vertex flow here, they are causing the clearly loud tone, and with the huge amount of energy and the air is passing from this or any fluid even rather. So, we can see that the enormous amount of energy and you see the higher vibration oscillations are there absolutely at the exit of this, and we would like to control this.

So, for that what we are doing here, we are simply keeping a clear deviation by putting the longer tail there, so that you see here you know like the longer tail you can see that this. So, when it is just coming out this tail is providing a steam line flow to avoid the vac formation, exactly exit of this part. And then you can see that a very small irregular turbulence is can straight way give the less noise and less number of oscillation, or else even you see here, we can straight way put.

These generators the generations in which you see here, they are we are putting, because they are straight way deviating the path of the air. So, that at the exit we do not have a regular turbulence in which you see here or the regular vertex through which you see the huge amount of energies are coming. So, this is irregular turbulences are there, and this irregular turbulence cannot frame the same kind of you see, the vibration excitation at the

resonant condition or the natural conditions. So, that is why you see we can deviate the path for just avoiding, the resonant condition or we can say the pure tone in the sound.

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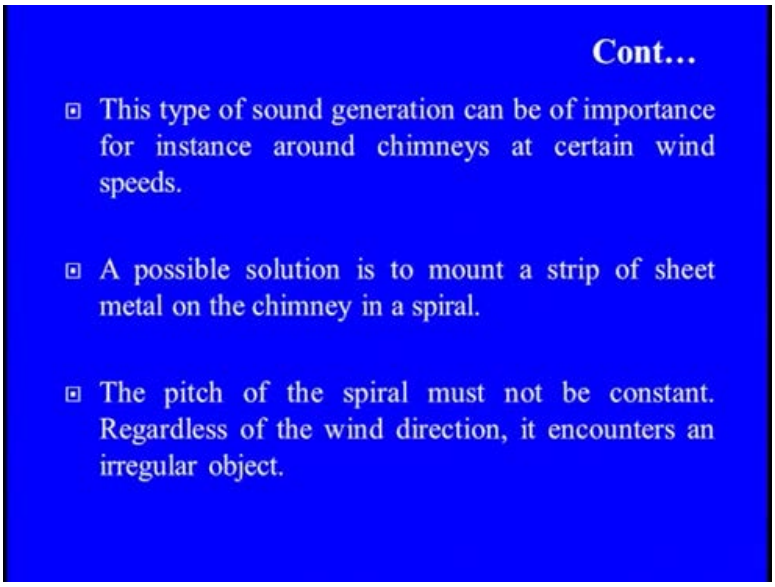

So, this type of sound or vibration generation can be of importance for many instances around the chimneys of certain wind speeds. And when such things are happening we know that there may be a clear burst at the outside of this or we may have huge amount of sound, when the things are coming out from the chimney. And you see here a possible solution can also be just to mount a strip of the sheet metal on the chimney, in a very spiral manner.

And when such things are happening we can have a clear deviation in the turbulence by putting this irregular feature, and the pitch of the spiral should not be in the same constant way. Otherwise, you see here again it will tune itself and create a different kind of resonant condition, or this the sound the pure tone, the regardless of the wind direction, it encounters an irregular object and creating the irregular turbulences itself.

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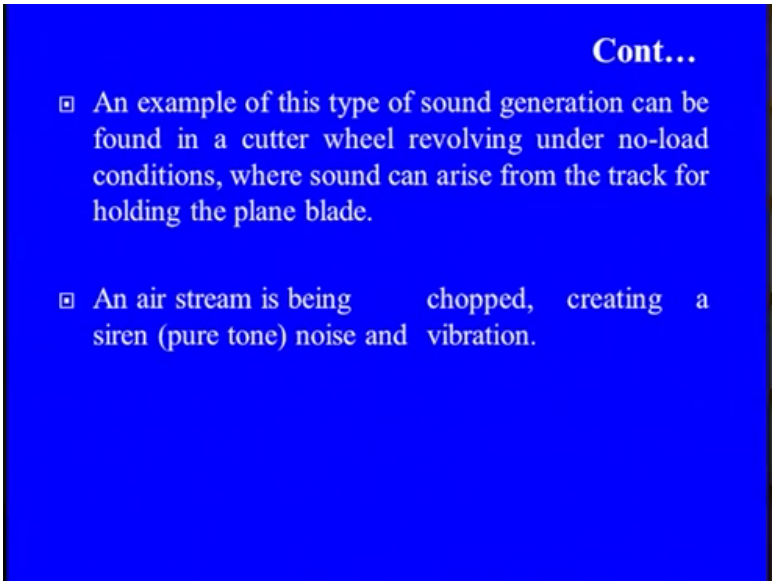

So, you see you know like this example of this type of sound generation can also be found, in cutting of the cutter wheel which is revolving under no load condition. And when you see there is no load condition, the sound can also arises from the track of the plane blade, when it is being travelled and the wind is just crossing there. And air steam in that is straight way being chopped and creating a pure tone, or the resonant conditions are being occurred which can create the huge amount of sound and the vibration as well.

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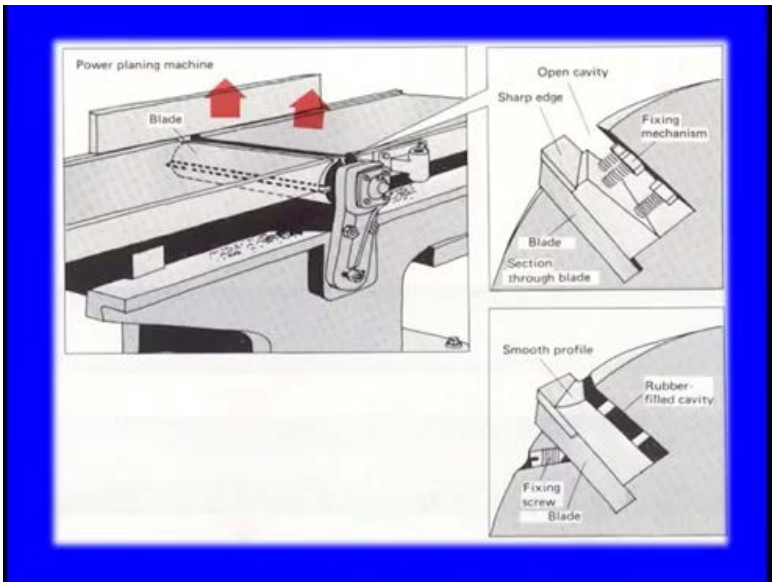

In the another example, we can see that when we are doing any planing machine, you see here the planning operations the power planing machine. We know that when the things are being you know like just coming over the blade, like the sheet metal or something you see here that is a clear solid interfacing is there at that point at the blade. So, if you do not have any isolator there, there is a huge amount of vibration, because of the solid interfacing or there is a huge amount of we can say the sound is being generated through that.

So, instead of putting that a solid feature, we can also adopting there some kind of fixing mechanism, in which you see here the isolator can be putted there, you see that we have a isolator in this. And in that particular smooth profile of the blade, when you have isolator during the solid interaction of this part. There is a absorber behind that and the huge amount of energy can be absorbed, and we can avoid the transmission of this vibration in this.

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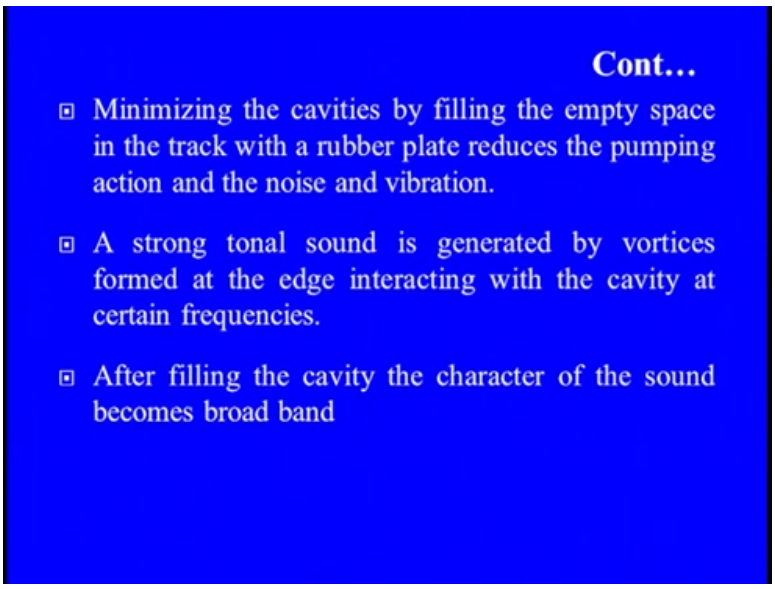

So, in other way you see here if we can minimize, the cavities by filling the empty space in the track with the rubber plate as we have seen the previous case, it can straight way reduce the pumping action, and the noise and vibration can be straight way reduced. Because, if you have the empty space certainly whatever the air, after you know like these operations whatever the air which is passing through, they may come in the pure tone feature, and they may create the huge amount of vibrations.

And the strong tonal sound which can be generated by the vortices which are being formed at the edges of the interacting with the cavities at certain frequencies, and due to this vac formation or the vertices there is a clear chance of having maximum noise or the sound at that point. So, after filling these cavities with these rubber plates, we can straight way absorb the huge amount of energy which is being coming out or we can avoid the vertices formation there itself. And you see we can say that whatever the vibration or sound which is being there it can becomes the broader band, so a clear peak tone cannot be formed and it can be straight way avoided by simply adopting.

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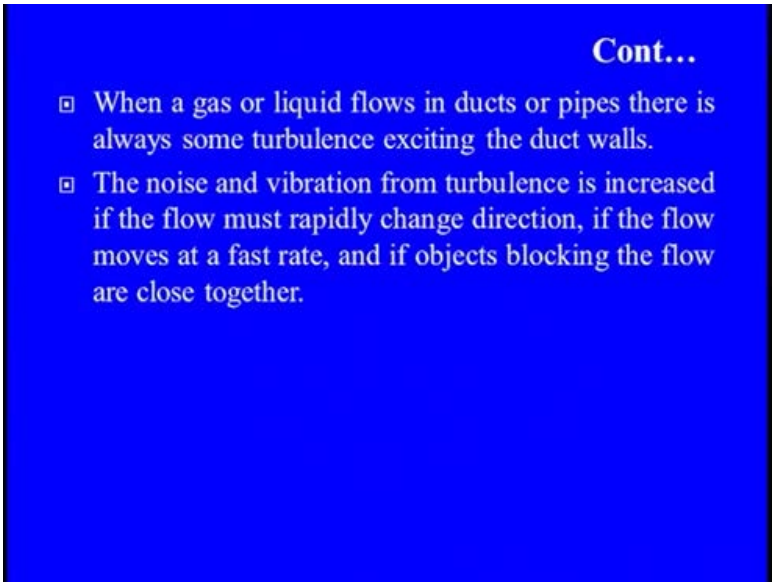

The rubber plates can be filled in these vertices, or when a gas or liquid when it is flowing through the ducts or the pipes, there is always some kind of turbulences as we already discussed, and through these turbulences they are exciting the entire duct wall. And whatever the vibration and noise which is being generated through this turbulences, it can be increased if the flow it is more rapid into the various directions means the flow velocity is quite high. And if the flow is moving at the faster rate, and if any object is coming in between certainly more and more turbulences are there more and more you know like the back pressure formations are there through which there is a clear impact of the fluid with the solid surfaces.

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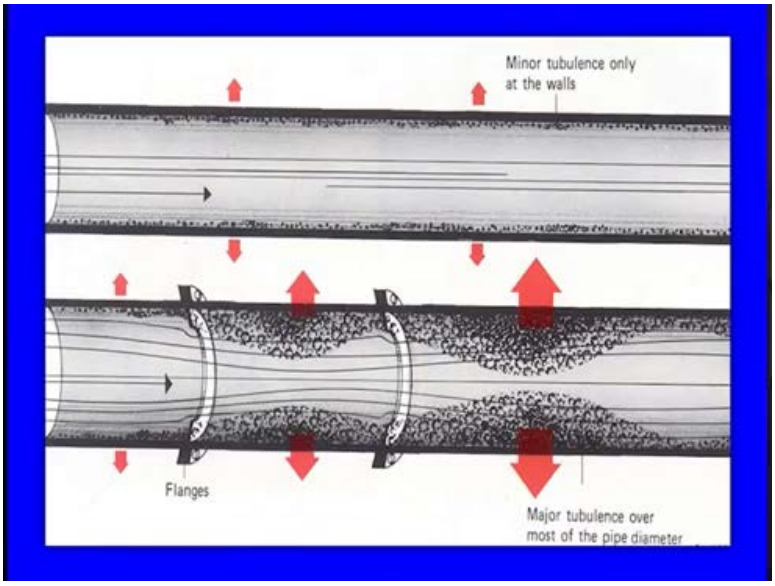

So, this is also one case in which we have a clear significant vibrations at the interaction of the fluid and solid, so like this you see here we have a clear pipe line, through which you see here you know like the flow is just passing through. And with this you see here when there is a clear you can see the first one when we have a clear fluid flow, and along the steam line no obstruction is there we can straight way say that the minor you see you know like the turbulences are there.

And you see here through this we can straight way control the effective deviation of the fluid flow path, but if we have in other way like these flanges are there, and through that you see here these vac formations are being coming or even the disturbances are there in the fluid flow. You can see at these obstructions we know that there is a clear interaction in between the pressure and velocity, or in other way it is a clear interaction between the energy exchange.

And this makes system more turbulence, and due to that the huge amount of these vibrations are being generated due to the solid the turbulent fluid and the solid wall interaction. So, you see here you know like we know that when such things are happening, we need to avoid such thing or we need to put some kind of isolator on top of these pipes. So, that whatever the vibration, which are being generated it can be damped out due to the rubber or any kind of external material on that.

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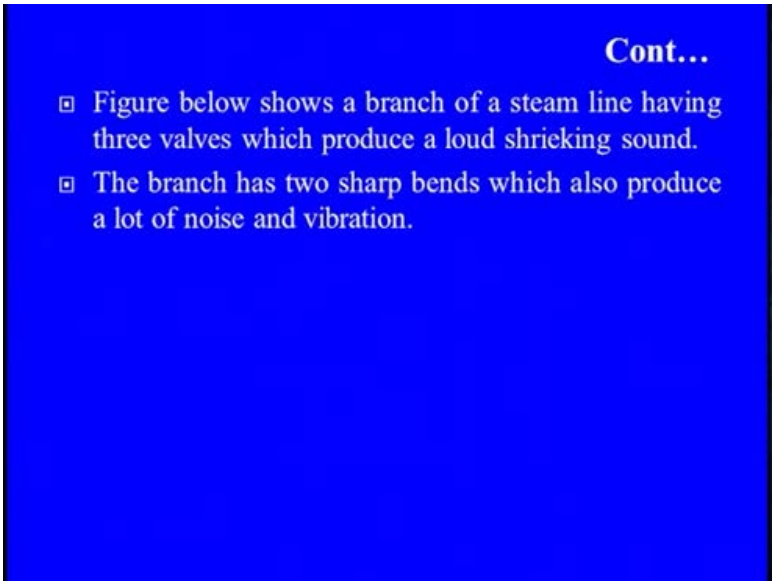

Even one of you see the different example is we can even put a branch of the you know like put the branch along the steam line. So, that you see here the sharp ends, whatever the sharp bends which are being coming out can be you know like deviated it paths as you can see that.

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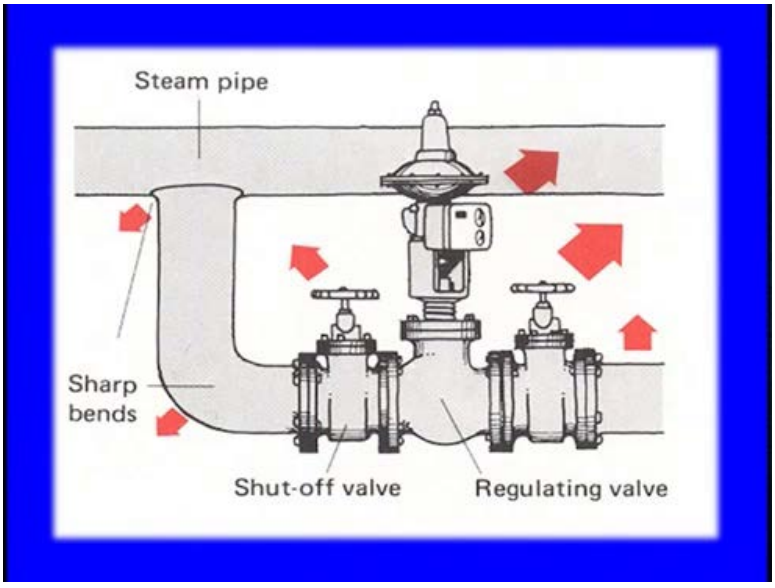

In this diagram we have the steam pipe and this is you see when it is passing through this these are some of the abrupt changes, when they are just passing through this here it has a simple this axial flow when it is just entering here. Again we have you see the you

know like the band there, and these you know like the sharp bends is straight way creating some kind of the impulsive forces.

And these impulsive forces you see here when they are just passing through these walls, they are creating huge turbulences and because of that the huge amount of you see the oscillation is happening in the entire structure, and the sounds are also there. So, it can straight way affecting the main function of this shut-off valve or any of this regulating wall there itself. So, you see here we need to avoid these things by simply putting, the by simply you know like adopting the smooth flow in the you see in the flanges or in these bends we can straight way adopt some kind of the steam line shape. So, that you see we can frame or we can avoid these turbulences there itself.

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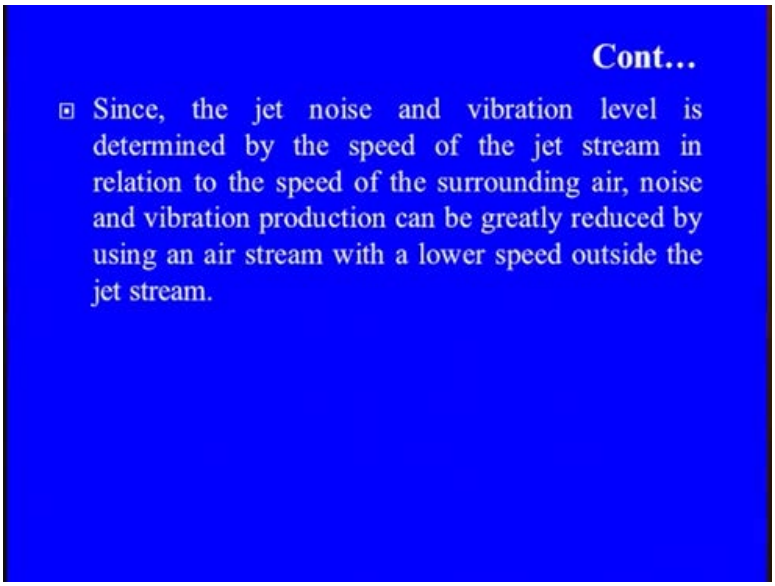

And since, the jet noise or the vibration level is determined by the speed of the jet, in relation to the speed of the surrounding air the noise and vibration production can be greatly reduced by using the air steam with the lower speed outside the jet stream. That means, you see here when we know that the jet stream is at the high velocity, it has the huge amount of kinetic energy the impulsive forces are quite significant, and because of that you see there is a clear interaction.

At this fluid to solid surface and these forces are transmitted, at a faster rate and can generate the high oscillating amplitudes, and when these things are being happening certainly, we know that there is a great amount of sound is also generated. So, if you

want to reduce this when you see the speed of sound which is being surrounded there we can straight way use the air steam features at the low speed outside. So, that the velocity can be reduced effectively and these impulsive forces, whatever the you see the impact forces are being coming out, they can be drastically reduced.

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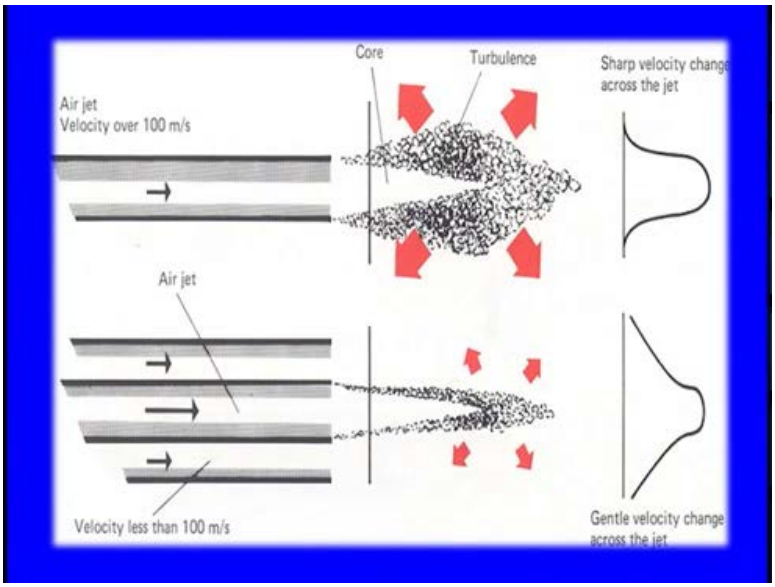

So, we can see this one the air jet you see velocity, which is being at this point and when they are coming out straight way, this is the core and the turbulences are being there. So, when it is there you see there is a clear velocity change, all across the jet you can see this one, and when this is being happening we have more and more turbulences are there. And this turbulence as i already told you, it is creating the huge amount of impact forces and creating the high amplitude vibrations, but when we are using the air streams there you see here, the various you see you know like the air streams.

And when it is just passing through this you can clearly see that, there is a smooth flow a smooth change in the velocity all across the jet. And when this is happening though there is a turbulence, because of you know like the jet part and high velocity impact, but this velocity which has a high impact is for a very small reason and through that we can reduce the turbulence occurred due to that.

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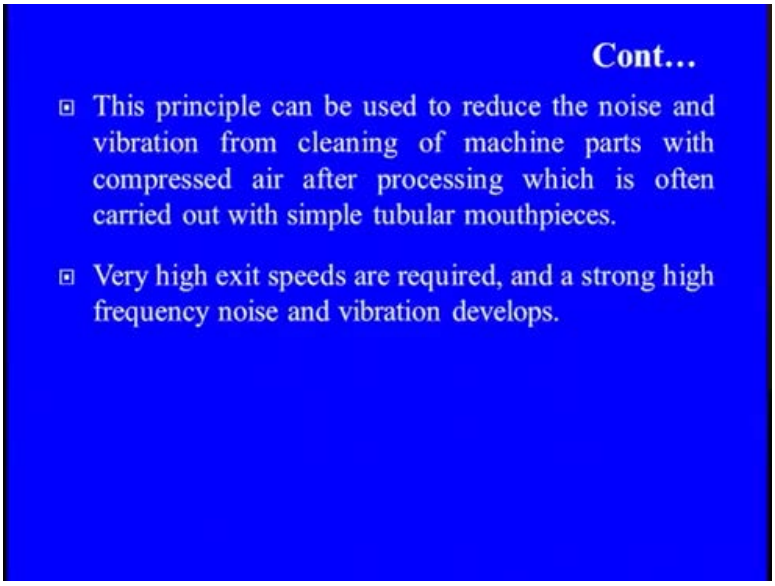

So, this is also one of the effective way of reducing the jet vibrations, you know like the jet flow and through that the vibrations are occurred, and this principle can be effectively used to reduce the vibration and the noise from cleaning of the machine part. Because, this is this has a great use we are using the jet to increase the velocity, but the same time the vibration is also increasing at the outlet part.

So, you see here, we can use this principle in reducing the vibration or a cleaning of machine part with the compressed air which is just processing. You see you know like simply for cleaning of this feature often carried out with the simple tubular mouthpieces, and very high exit speeds which are being required and the strong high frequency noise and the vibrations are being generated for that. Because, we need more velocity, but the same time high frequencies are there, and when a person is using this one certainly it is effecting not only the performance of the device, but also the person itself.

So, when we are doing this simple tubular mouthpiece can now be replaced as we discussed in the previous case by mouthpieces, which produced the less noise and vibration such as the dual. Now, we are using the air stream which is being passing the multiple featured, and in these mouthpieces when you have more than one, means the dual or even three flow mouthpieces. In this the mouth piece which is a part of the compressed air move, they are simply give the featured for lower speed outside at the

central stream, because you have more than one exits and when it is like that as you can see in this diagram.

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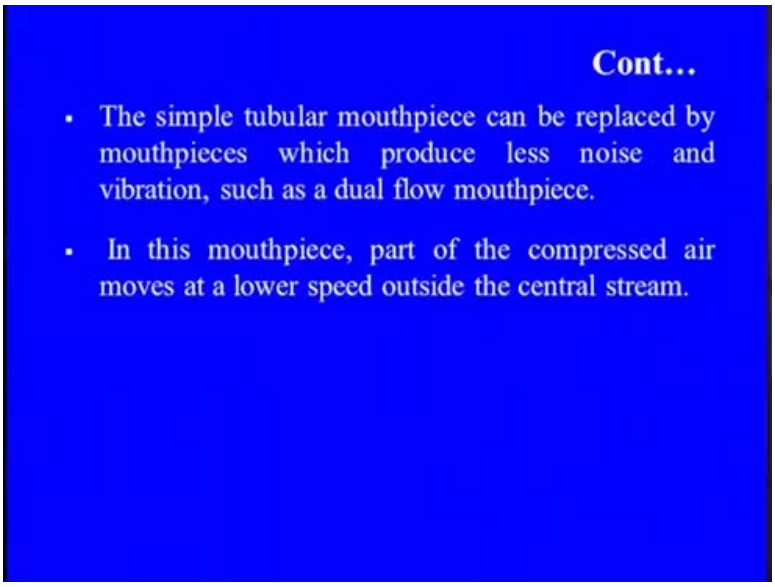

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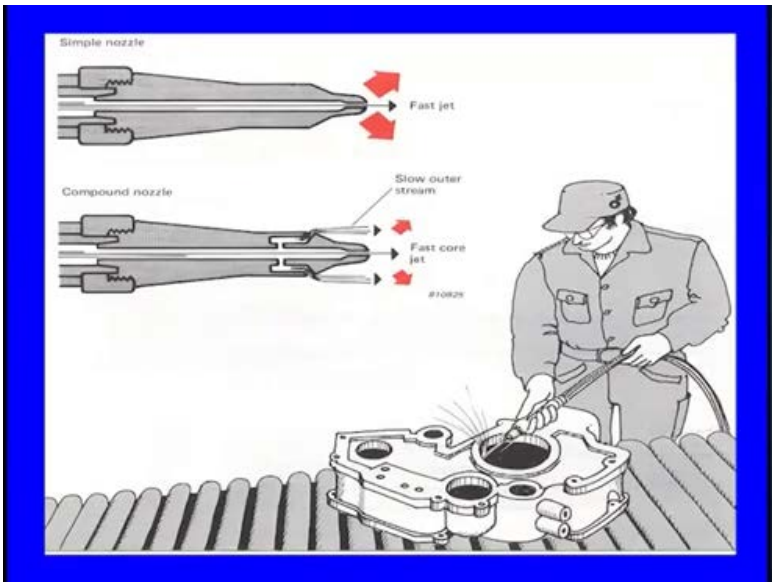

This is what you see the main action is there, when the all these you know like our engine parts are being cleaned out from this compressed air. We know that the entire this you can see the interaction the huge amount of energies are being coming out, because of the velocity the kinetic energy I can say, and the same time huge amount of vibrations are being generated, because of these impact forces.

And if it is you see you know like if the first part if it is a simple same straight line, you see the motion is there with the single nozzle the simple featured out. We know that the huge amount of oscillations are there and the sounds are there, but if you are using this you see here, in this the somewhat the compounded nozzle, in which you see we have these two featured that the main central scheme you see the jet forces are there.

The velocity is just going of the air, but along with that we have the two, the slow outer stream featured means we have additional way for which outcome. Though, you see it is also you know like going with this high velocity, but at least it can deviate the path and can you see like produce the less amount of oscillating feature and the sound itself.

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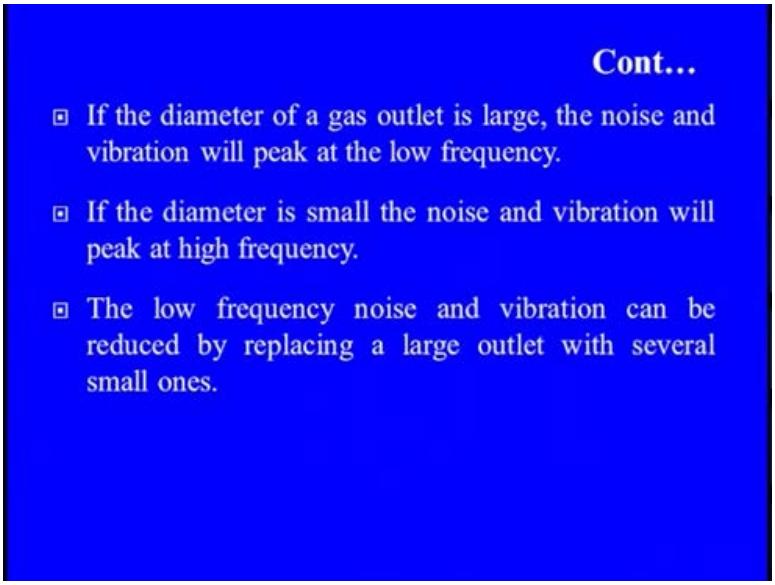

So, this is also you see one of the great use of using the multiple outputs on that, and if the diameter of gas outlet is large, then the noise and vibration will certainly you know like give a clear peak at the low frequencies. Because, we know that when the diameter is certainly you know like giving more and more diameter; that means, you see here it is a huge amount of the air which is being passing out that.

But, the flow itself gives you that the excitation is of low frequency irrespective of its amplitude, but if the diameter is small then whatever the these exciting frequencies are coming out, they have the clear peak at the higher frequencies. So, you see here our main theme here, is to reduce the low frequency vibration, so low frequency vibration can be straight way reduced by replacing the large outlet, with the various small outlet ones.

Because, you see we know that when, because as already we discussed the high frequency vibrations can be straight way, you know like controlled by putting some kind of you see the damping featured outlet. But, when you have a low frequency vibration, then we need to adopt some different methodologies for that. So, in this case instead of having one outlet which is creating more and more turbulences, at the low frequencies we need to adopt the various outlets for that. So, that these turbulences or we can say in other word the low frequency vibrations can be controlled effectively. So, this is of a great use we know that even when the jet flow is there, there is a clear exciting frequencies we need to categorize straight way, that what exactly the frequency terms and accordingly we can adopt the methodology for controlling these vibrations.

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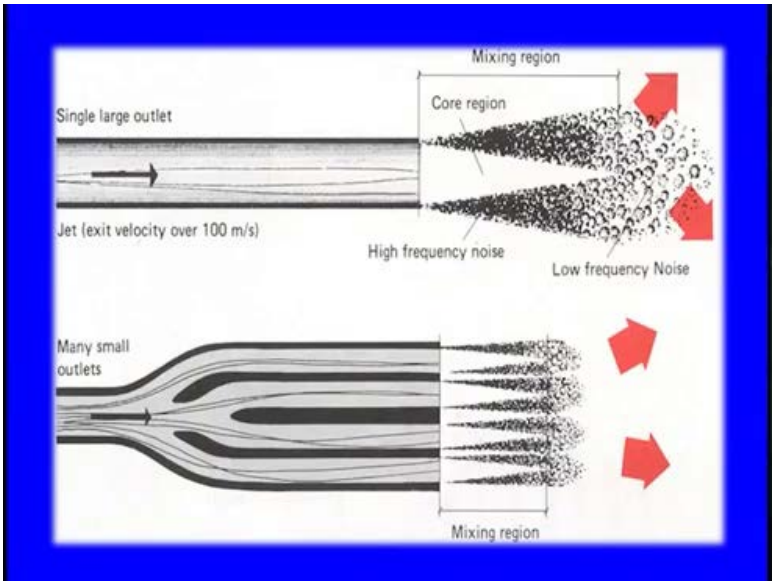

So, like you can see that another example is this, that we have a single outlet the jet velocity say at an at a 100 meter per second, when they are coming out this is what the reasons are where we can say that. Since, they are coming out with such a velocity, when they are meeting at the surface in the mixing region it is a huge amount of turbulence. And this turbulence though you see you know like we can say that, for high frequency regions there is a again well patterned flow is there, no not much you see though it is a turbulence, but not that even the chaotic form, but when they are mixed up.

At the low frequency reasons the huge amount of turbulences are there, and we have drastic situation at their itself. And our main theme here you can look at this figure our

main theme here is to drop this feature, so that we can avoid the low frequency excitation in the turbulent regions. So, for that instead of having a single input as we discussed, now we can you can see that we have 3 or 4 outlets, and in these all 4 5 outlets.

You can see that though the you know like the things are being coming out, but all these the flow at these point, we have the high frequency regions. And in that there is a well patterned even it is a turbulent feature, but you see here they are producing the less amount of vibration excitation in terms of amplitude or we can say the sound energies are becomes less in this case.

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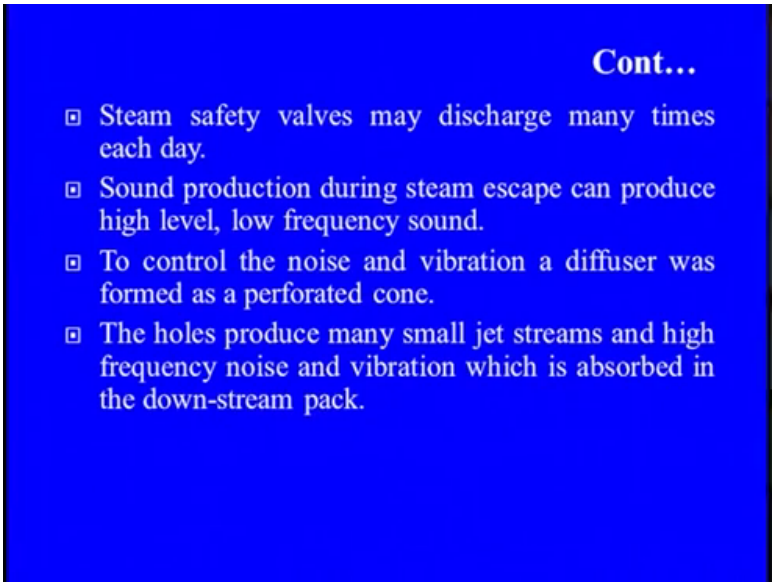

So, you see here as we have seen the steam safety valve is also you see you know like when the steam is just passing through, the safety valve is also coming under the similar kind of actions there itself. And the sound is also producing during the steam, which is escaping at the you know like which is simply producing at high level at the low frequency featured.

So, to control these things, the low frequency vibrations in that we are simply putting a diffuser with the perforated cone. So, that when you have a diffuser the energy is can be straight way converted and the same time you have a perforated cone, so that it can be deviated from its path. And to control you see the entire thing the hole whatever the holes which are being provided, in a perforated one they have many small jet steam and

the high frequency noise, which is being you know like converted due to this diffuser feature straight way absorbed in the downstream pack.

So, this is you see one of the effective technique, when you know that in this safety valve when such things are happening at the low frequency regions, you need to first change. And then you see you know like the energy feature, and then we can straight way use the holes for evaluating all these feature.

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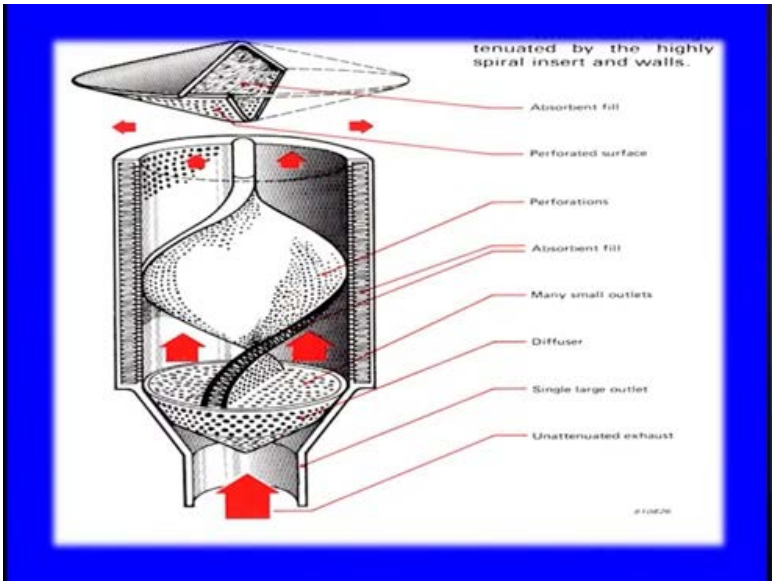

So, you can see that this is what the great application of this, the things are being coming in the safety valve here and from the lower side, you can see that this is the huge amount of that energy and the excitation level. Now, we have the diffuser feature with the perforated holes one the cone you see here, and when it is being passing through this there is a clear deviation in the path. And then you see you know like you can see that this is what the change in the energy, which is being coming out and then you have the perforated the entire spiral feature.

And when the entire energy is just passing through this spiral one, you know that even the spiral is not the single piece part we have the perforated one in between that. So, when they are passing through this, you can see at the exit of this safety valve, there is a very less amount of we can say the exciting feature in terms of sound wave or in terms of the amplitude of vibration. And then you see here at the exit part we have the absorbed feature, so you see the entire structure is just in such a way that, we are just trying to

convert the energy and the same time we are trying to absorb. The variation whatever you see you know like the energies are there, in that due to the perforated one and the deviation feature.

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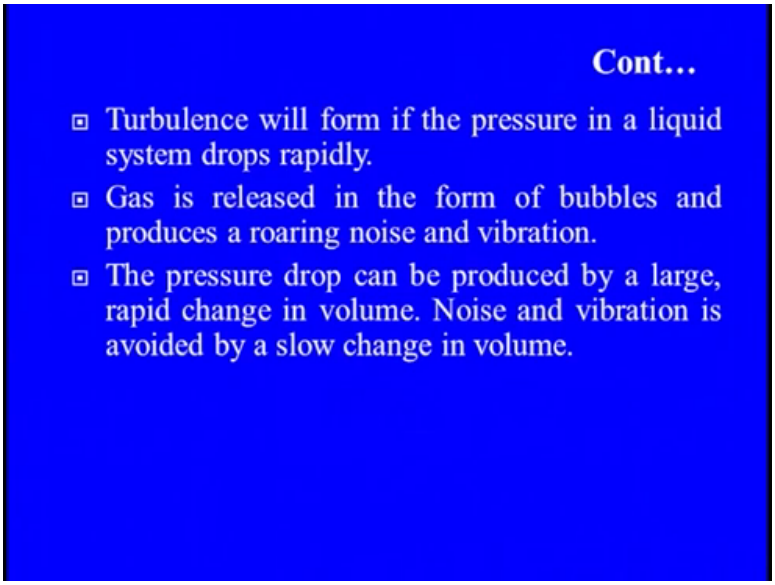

So, turbulence which is being you know like the one of the basic cause of vibration will also form if the pressure in the liquid is dropped rapidly, because when the pressure is dropping rapidly, there is a clear change in the velocities. And when the gas is released say in form of bubbles, certain you see here they are also producing the huge amount of vibrations.

Because, bubble formation is nothing but you see here it is a some kind of vac formation, somewhere we have a solid liquid a continuous liquid, and somewhere you see we have the air bubbles in which you see here the entire air featured are there. And the pressure drop, which is producing you see you know like the huge amount of vibration can also be you know like trap down by large and rapid change in the volume. And through that we can straight way have the clear vibration featured in this, and the noise and vibration can be avoided by slow change in the volume in such cases.

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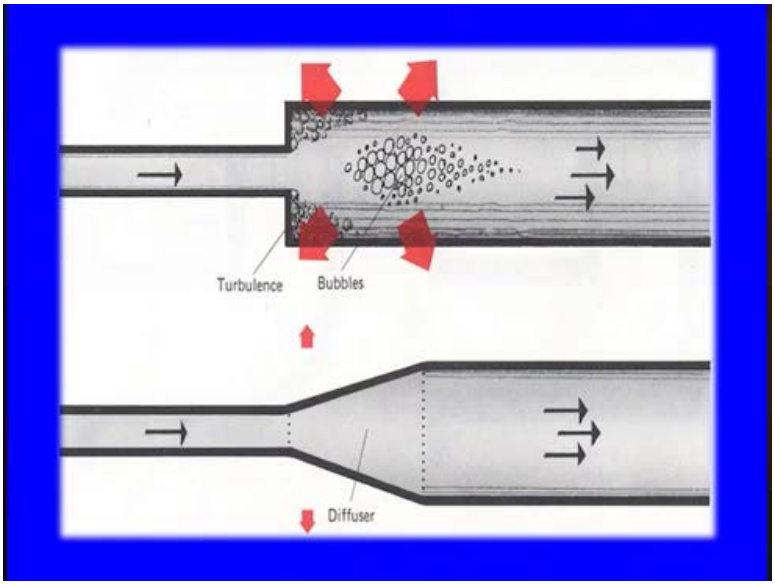

You can see this when the things are being coming, you see say the air is coming or any you know like the fluid is coming here, we have the abrupt change. And this abrupt change is a clear cause of the bubbles, and when these bubble formations are there we know that there is you know like discontinued feature of the flow of the fluids. And because of that there is a clear impact energies are there, impact forces are there in terms of we can say energy at these fluid to solid surfaces.

We can avoid the situation by making a smooth flow, so you can see that we have a diffuser and diffuser we know that it is a clear change, in velocity energy to the pressure energy. And then you see here, there is no bubble formation because of this abrupt change, and we can avoid the turbulence situation and at these point, where you see the abrupt changes are there, you can see that the very less amount of oscillating features are.

So, this is all you see here the various example, though you see the lot many examples are there, but our main theme in this chapter was that there are various ways in the industries, in which you see the fluid is flowing into the pipes or the various channels. And because of this turbulence or because of the abrupt changes or because of you see you know like the various different ways of the phases of the fluid, we have a clear vibration excitations. There is another way in the industry, where we will find that the rotating balance and unbalance is creating the vibration at the huge level.

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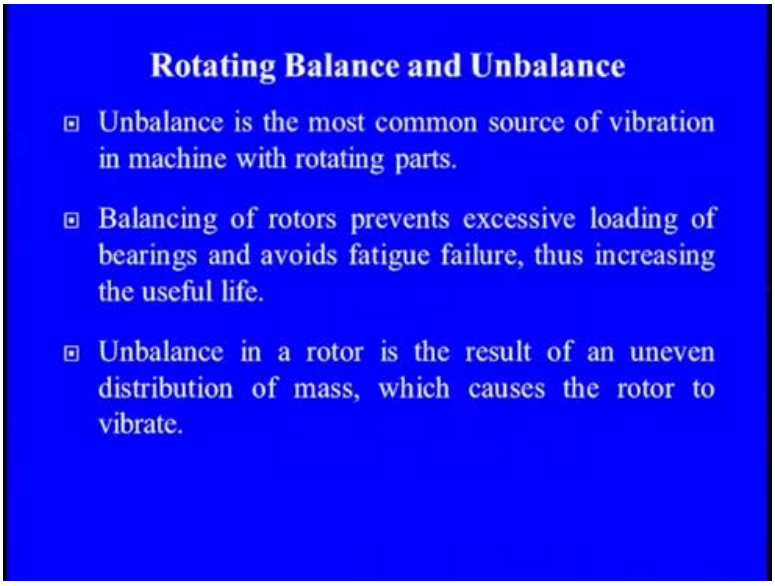

So, unbalance is a pretty common situation, we cannot avoid the unbalance in the rotating feature. So, when the parts when they have the robust design, it is a clear balancing feature in that, but when they are you see you know like say due to some wear and tear. Due to some you know like some depreciations are there, there is a unbalanced feature or because of some misalignment due to the clearances, there is you see you know like we have the rotating unbalances are there.

So, balancing of rotors even the small rotors or the bigger rotors, prevents the excessive loading the bearings and can be avoided straight way the fatigue failures of these parts, and thus you see we can increase the useful life. But, unbalance in the rotor is a result of uneven distribution of mass sometimes, and they are all straightway or even the eccentricity or even you see the rubbing actions, and it can clearly cause the vibration in the rotor. And this vibration which is you know like the production of these vibration, which is coming out due to the unbalance rotor part is absolutely, you know like coupled with the radial acceleration due to the rotation of centrifugal forces.

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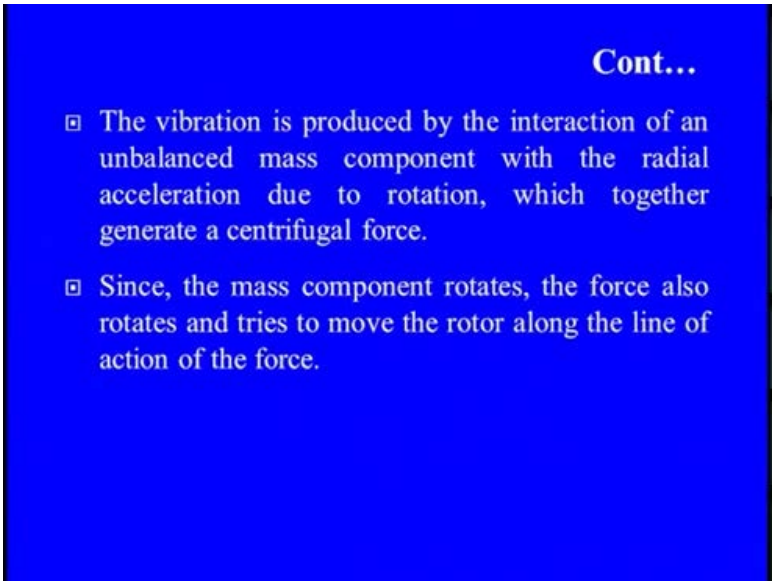

And since, the mass component rotates it is creating the huge amount of inertia forces, and they are try to move along the rotor in the same line of action, where the forces are being occurred. So, because of these you see here since you know like these inertia forces, they are generating along with the rotation of these, we can say in the same direction of the rotor of rotation. We know that it is creating the huge amount of we can say the unbalanced forces, and due to that the huge amount of exciting features are there.

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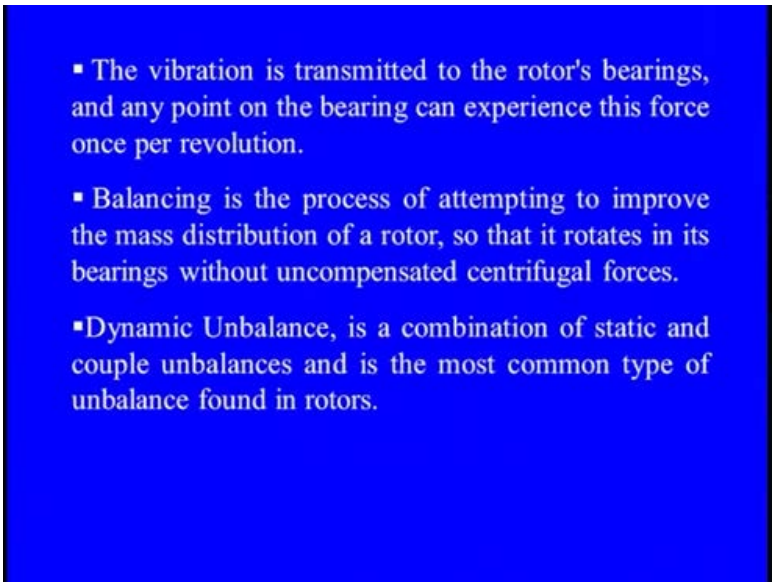

And the vibration which is creating due to that is transmitting to the rotor, to the rotors bearing, and at any point the bearing can be experience this huge amount of inertia forces in every rotation, because ultimately it is a structural transmission of the vibration. And then they are straight way causing the huge amount of damage, at the surface of the bearings with the contact surface of rotor and bearings. Even in the rotating elements various irrespective of we can say, we have the inner or outer races or any rotating elements itself.

So, balancing is must in that, and it is the process of attempting to improve the mass distribution of the rotor, so that it can rotate in a proper way on its bearing without creating the huge amount of the centrifugal forces. But, you see here this is not the straightway criteria, we need to go with the because this is the rotating actions, so we need to go with the dynamic unbalanced feature we need to understand this.

So, dynamic unbalance is nothing but it is a combination of static and coupled unbalances. So, you see here the static unbalance is also creating a some kind of the dynamic unbalancing feature, and it is the most common type of unbalance which are being find out in the rotor featured.

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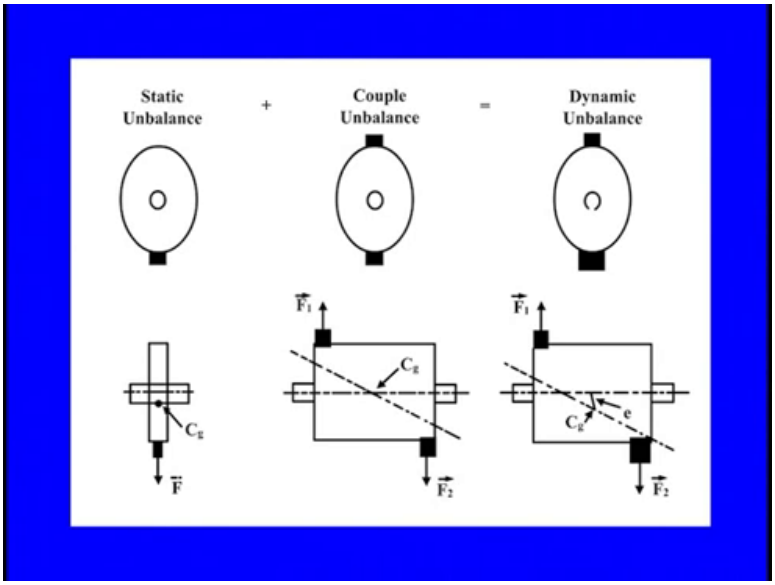

You can see on the diagram featured we have the static unbalance, in which the c g is somewhat lowered down due to the force, because of the radial force of rotor, somewhat you see it is acted towards the downward direction. And the c g is somewhat even in the

microns level it is being downed, and if you are talking about the couple unbalance, you can see that this couple which is not passing through, this sharp diagonal edges.

It has some you see the deviation, and because of that the centre is shifted here, and when we added both the thing the static unbalance, and the couple unbalances. The dynamic unbalances is that it is of more drastic nature, because you see you can see that on the both forces we have a clear unbalance, and then this uncoupled feature which is somewhat this one it is even more lower down.

So, due to the rotor load, there is a you know like eccentricity is created and due to this you know like the coupled feature, you see the entire structure is deviated from its main path. So, you can see that this is the dotted line is clearly showing that, what exactly the eccentricity is being created, because of these dynamic unbalance.

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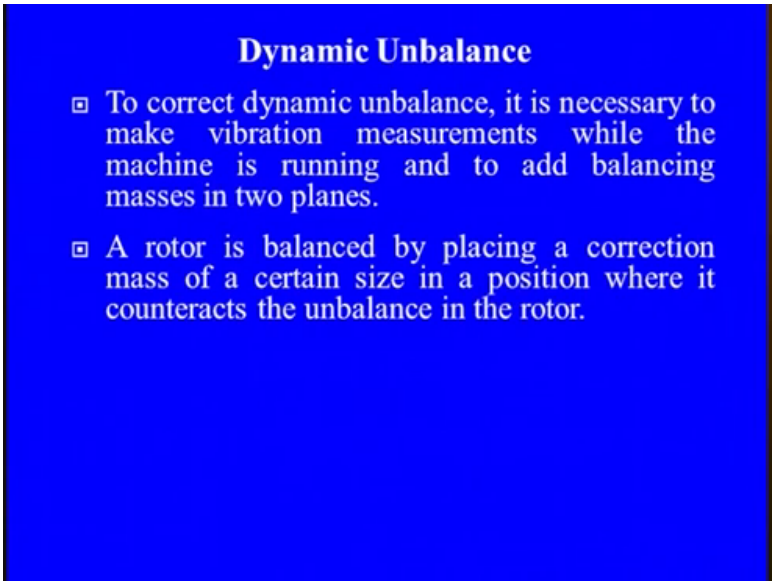

So, to correct the dynamic unbalance which is the major cause for the vibration in any rotating feature, it is necessary to make the vibration measurement, while the machine is being running. And we need to add the balancing masses into these planes in both the planes you see here, because ultimately we need to shift the c g the centre of gravity, with the centre of mass to exactly at the one point.

A rotor is balanced by placing a corrective masses of a certain size, in those positions where it counteracts the unbalance in the rotors, because ultimately we want to make the

mass balance there itself. And to do that you see here we need to correct the dynamic unbalance, we need to see in all these vibration measurement, in such a way that it will give a clear picture about how much unbalanced forces are generated at a specific speed.

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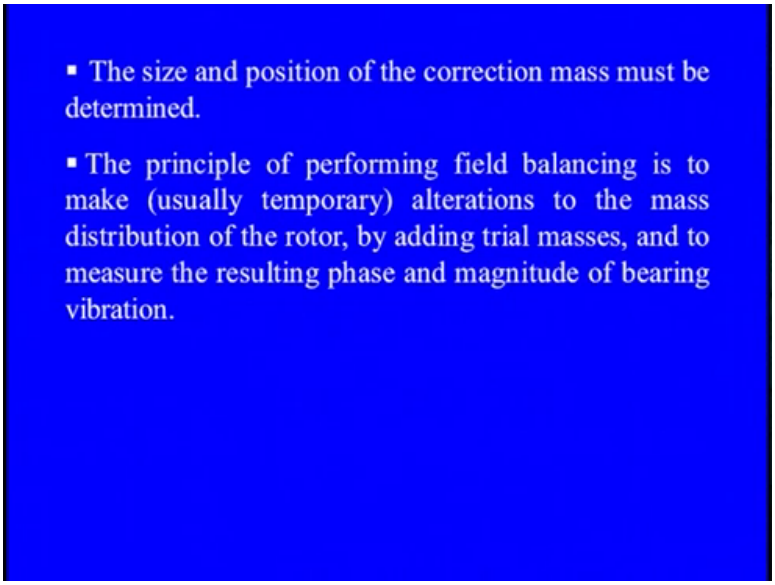

So, for that we need to size and position the correct masses, and to do this there is a principle for performing the field balancing, generally you see the field balancing you know like immediately, we need to apply the conditions there itself. So, we need to put those mass distribution in such a way that, the additional trial masses as being simply you know like adopted at certain places.

And to see that how much these forces are being generated, or how much you see the oscillation being coming out in terms of the accelerations. And then we can simply measure, the resulting phase and magnitude of the bearing vibration, because ultimately the rotor unbalance having you see the clear impact of these centrifugal forces on the bearing itself, and there is a clear damage of that.

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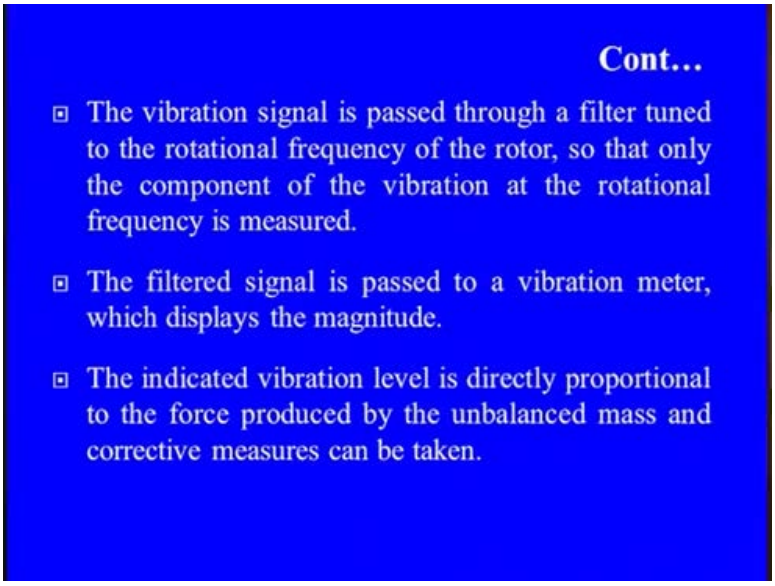

So, you see here in these cases it is clear that the vibration signal, which is passed through this filter is having a clearly tuning with the rotational frequency of rotor. We know that when the rotor is rotating at a certain speed, there is a clear rotational frequency generally we are termed as x. So, that the only component of the vibration is coming out due to rotor balance or unbalance is having the x, we can straight way put the filter in the signal, to reduce the low level noise in that.

So, that we can clearly find out that what is the peak level of the vibration, and what is it is frequency and the amplitude is, and this indicated vibration level is directly proportional to the force produced by this unbalance masses. So, we can put the balanced masses there, and we can reduce the forces and by this the corrective measures can be taken e straight way.

So, this dynamic unbalance is one of the common criteria in any of the rotating machine, and you see by putting the masses the vibration can be suppressed out, we can make a proper balance. So, that the centre of mass can be straightaway you know like just put in the same lying in the same plane, as per the centre of gravities and then we can balance the entire featured.

So, in this lecture we mainly discussed about, that how the flow induced vibrations are being there, how you see you know like the control methods are being straight way apply along the flow of the fluid, whether it is a air or any liquid. And finally, we discussed

about when you have the rotor unbalance, because of you see any reason, because of the non uniform mass distribution or because of eccentricity. How we can find out first, and then how we can control the rotor unbalances towards the balancing feature and towards the flexibility, we can simply adopted the various masses along the length of the rotor and we can control that.

In the next lecture, now we are going to discuss, so till now you see we discussed about the basic vibration control, now we are going to adopt the other methodology known as the feedback control. Since, we know that our desired level is this or we just want this thing of the vibration amplitude, and it is coming like this output, what is the difference is there one is your desired, one is the actual output the difference is giving you the feedback feature in that.

So, again it is a very subjective feature according to what the kind of applications are, we are going to discuss about the basic vibration theory involved in that. And then we are going to discuss about how we can adopt this feedback control system, along with the stability considered with the Lyapunov, the Lyapunov was you see is the scientist, who gave a clear theory about the system stability. So, we are going to discuss that feature along with our feedback control in the next lecture.

Thank you.