Principles Of Vibration Control
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Lecture – 01
Introduction To Vibration Control

Good morning students. Welcome to the first lecture, the mooc lecture, on principles of vibration control. This lecture we will confer you the know the whole thing in manner first reference part.

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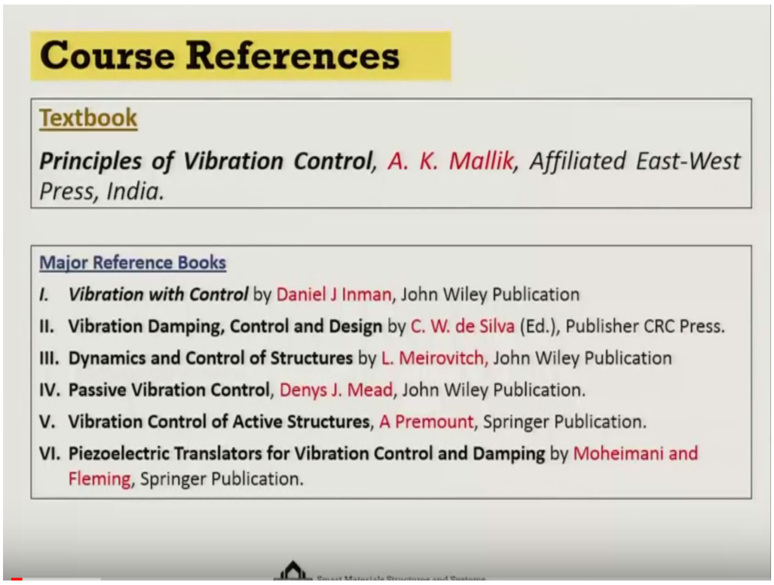

I should be telling you that you should having the principles of vibration control by A.K Mallik affiliated by East-west press, India is a very good text book, we would follow most of the sections and except the advanced forms where we go for some of the reference course in these books.

For example, we will see this book vibration control By Daniel Inman and we will also see Vibration Damping, control and design by the Silva. Dynamic control of structures, this is important particularly when we talk about active vibration control for passive vibration control, the principles of vibration control are well actually discussed in the book by professor A.K Mallik but there is a for a continuous system there is also a good book you can use for reference passive vibration control. That is by Denys J.Mead.

And for active control again vibration control of active control structures by Andrew Premount. Finally there is some part of it where energy harvesting I will be discussing so there this Piezoelectric transistors for vibration control and damping by Moheimani and Flemmings wook will be important for you. So one basic text book we will use in this course and six reference books as and when it is required I will mention it to you.

You should try to catch hold of it from the library or from internet and you should try to see these books or read these books. So today is the first day in which it will be an introduction to principles of vibration control

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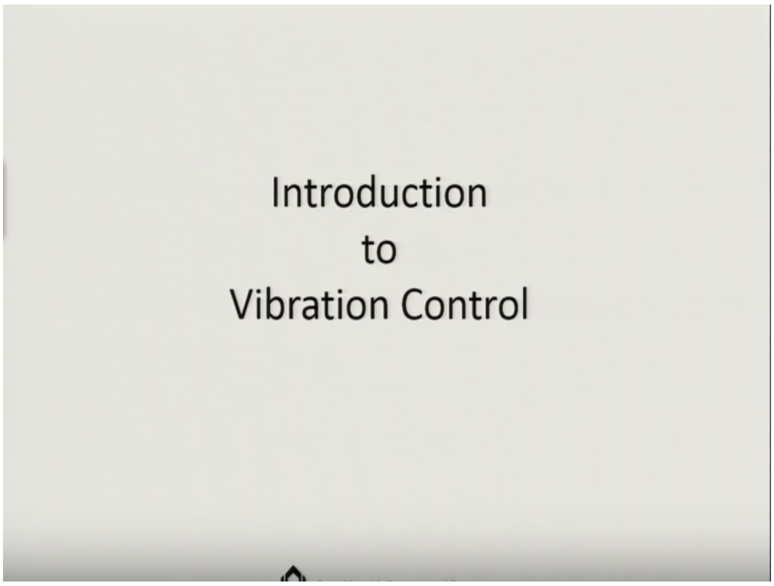

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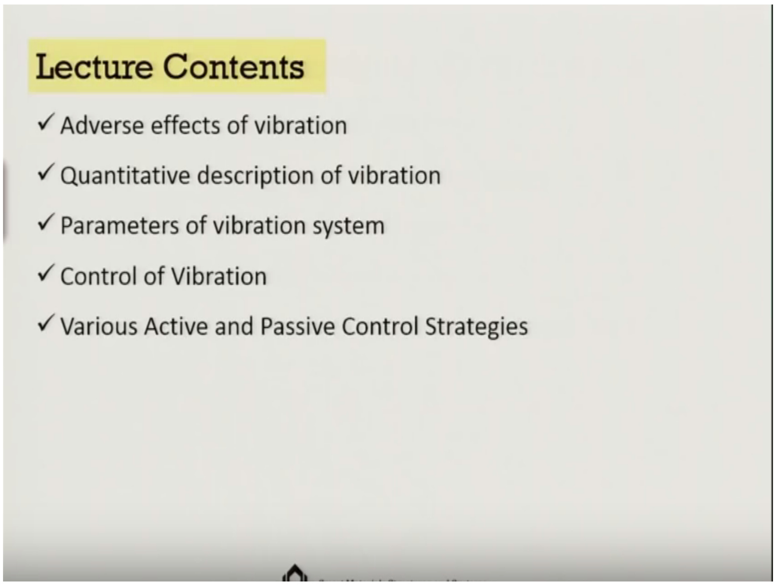

Now in this lecture we will talk about what are the adverse effects of vibration because that will give us a motivation why should we go for vibration control. And then we will try to also talk about that how can you quantify the vibration in what are the quantitative parameters that you can use for this.

So the parameters of the vibration system or a vibrating system Then of course we will talk about how can we control the vibration in terms of strategies that means we will talk about various active and passive control strategies and some of them I will try to kind of elaborate them in this lecture and some in the next lecture. So that is what you know is our plan in terms of spreading the lecture.

So the first important thing is that what is a vibration in terms of I will rather say that what is a mechanical vibration so that we will be considering because vibration itself is a very extensively used term for many application.

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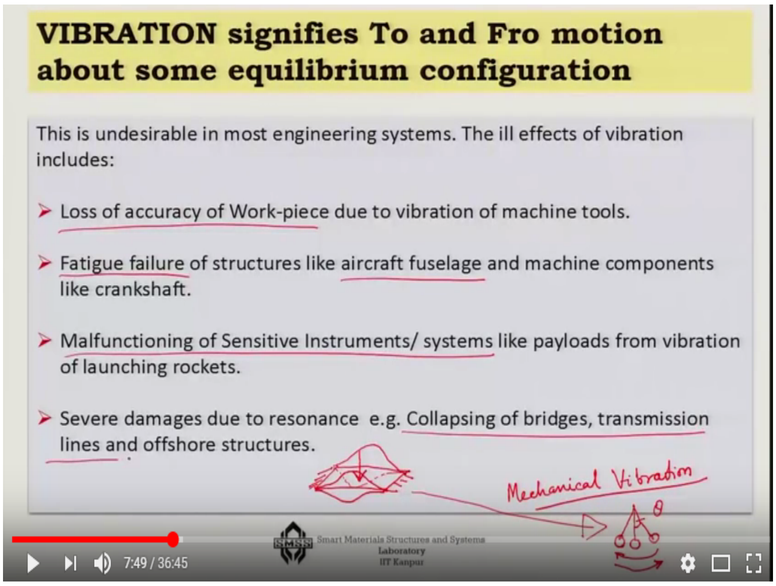

But in the context of mechanical vibration this will be a some kind of to and fro motion about some equilibrium configuration. So whenever you will think of it ,you will think of that it is like you have a pendulum. You have given a small displacement to the pendulum by an angle teta .and the moment you do that the pendulum starts to move. It is a single degree of freedom system and a small angle but it starts to move oscillate until and unless the air finally dance the pendulum

So this kind of a small to and fro motion now of course the motion of the pendulum that is a not a vibrated motion but it is a to and fro motion. If you in fact and this is a very good actually a symbol of vibrated motion instead of taking the pendulum now suppose if we take something we are more familiar. For example, we take a plate. Ok

So here is a plate for us. And on this plate suppose the plate is supported in the 2 sides, and on the central point of the plate I am applying a force. So that the plate gets deformed a little bit I am not deforming it too much and then I release this force So I am say do that then the plate starts to vibrate very much motion to and fro motion of the pendulum that we have seen so it will start to vibrate like that up and down, up and down.

Until and unless the damping inside the plate and the air damping etc will lead back to the stop position So that is like a similarity between that what is happening to a pendulum case and what is happening to an actual case of vibration,a case of mechanical vibration which we will consider. Now these vibrations is undesirable in all the engineering systems

Because as you can see that this particular plate case that plate is vibrating you know back and forth and back and forth and you considered that the plate is a part of the aircraft fuselage so what will happen is that something like a fatigue failure will happen to the system. So if a structure is subjected to repeated tension and compression in a tensile stress and a compressive stress that is what that is how we define the fatigue loading .Then all a variation of a tensile stress or a variation of compressive stress anyone of these 3 variations.

Let us say then the structures you know the cracks inside the structure get sufficient energy to propagate and in a long run, the structure fails which we call as the fatigue failure. So naturally fatigue failure is undesirable in vibration. There are also other cases. For example, you are trying to actually make a very nice small work piece for some machine tool application and the tracking tools starts to vibrate.

Then there will be a loss of accuracy of the work piece. I will explain it soon with the help of some Slides. Similarly, there could be cases of malfunctioning of sensitive instruments or a systems like a payload due a vibration in a launching rocket or there could be a severe damage due to resonance in terms of collapsing a bridges or transmission lines of offshore structures.

So all these are various ill effects of vibration. Now it is not that vibration is always very bad at least you know that there are some cases where vibration is very much desirable. One case you think of readily is the case of musical instruments. Because in the musical instruments once if you vibrate it at a particular frequency and if there is no noise in it that is if you desirable condition is that it keeps on vibrating at a pure frequency level.

Or may be its harmonics or super harmonics, the sound that is generated from a musical instrument is that becomes you know very much you know like a attracting to our hearing system. So as the result vibration is desirable on musical instruments. Similarly, there are some other applications for example, there are some applications of assembly where actually we use vibrations in terms of the assembly system.

Then you might have seen how concrete you know is compacted in some of the construction sites there the vibration is used in terms of mixing the concrete very well with the gravels. So like that there are some cases where the vibration is actually desirable but in this particular course we will consider cases where vibration is not desirable and in somehow we have to control this vibration.

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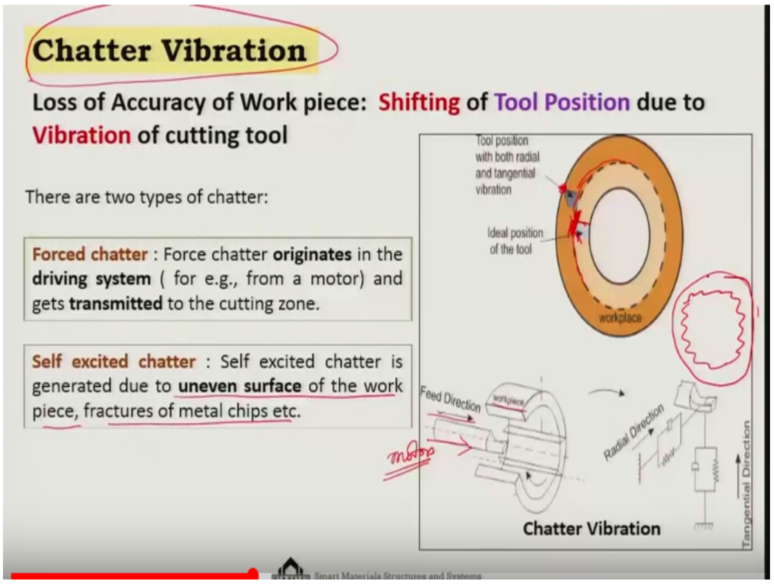

Now I told you that I will elaborate each one of these cases. For example, the first case the loss of accuracy of work piece you know as shifting of tool position due to vibration of cutting tool. Suppose you see that these is the thing that you have to carve as you can see these dotted lines and the cutting tool is placed her. Ok. So we are carving material out of a very kind of a shaft and this is the ideal location but whenever there is a vibration then the tool actually cannot be remain at this location.

It is going to this particular location due to vibration. So see you can see the same thing happening here that there is the work piece here. This is the work piece. And there is feed direction of the tool and there is a vibration that is happening and as a result it is not staying at this location but going to some other location. So naturally if this happens then you will not get a smooth cut rather we get a very zigzag kind of a cut. You know which is not desirable at all

So this will happen that means the machine will completely fail or at least it will give a degraded performance due to the chatter vibrations. In fact, there 2 types of sub chatters that can happen. One is called a forced chatter which originates in the driving system itself. For example, there is some problem in the motor that is driving the tool and as the result that gets transmitted to the cutting zone. So it is coming from the motor That is what can be a case of forced chatter. The other case can be self excited chatter.

When the chatter is generated due to uneven surface of the work piece raptures of metal piece extra that means you know the cutting tool can be the you have chosen is not really very proper and instead of cutting it is undergoing a lot of friction and that is generating a some kind of a self-excitation in the system. So in that case also you get a similar degradation in terms of the performance of the system.

So you can have chatter both as a forced chatter as well as a self excited chatter and for depending upon on the case to case we have to different strategies of vibration control.

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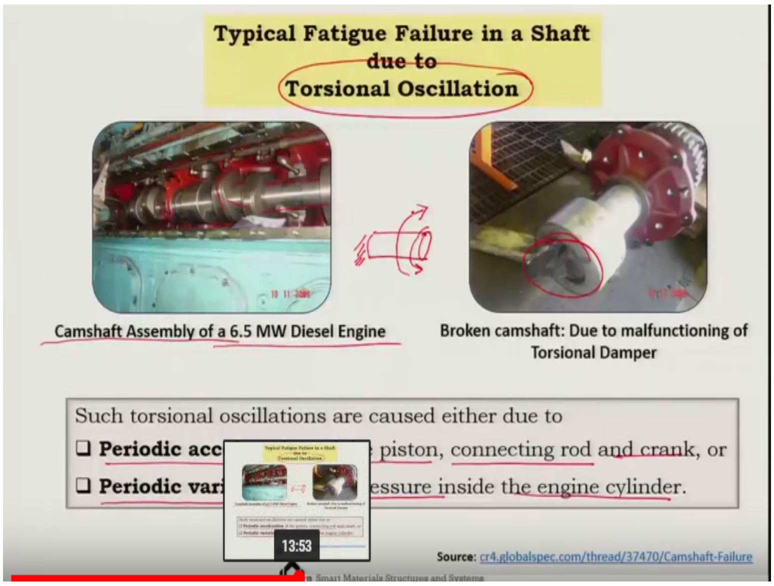

I was talking about fatigue failure now fatigue failure not only happen to an aircraft structure but can happen to any mechanical system. For example, we can think of a diesel engine and many times if you look at a cam shaft assembly of the diesel engine then you can see that it is designed in such a manner these cams and the cams shaft you can see that it actually generates a kind of a periodic excitation force.

That periodic excitational force actually creates a periodic acceleration of the piston the connecting rod and the crank. So this crank you know is subjected to a periodic excitation force. Now if that happens you know that this kind of a system at the end develop a fatigue and as the result you will see this kind of a failure that has happened to a system. Not only happens due to this periodic acceleration but also it can happen but if there is a periodic variation in gas spacer inside the engine cylinder

So fatigue failure is a kind of a very common you know failure which is due to what we will call the torsional oscillation. Ok. This excitation comes to the shaft in terms of torsional oscillation of the shaft. So unlike the last case where there was these you know up and down to and fro motion in this case the motion is actually in terms of torsion

That means suppose you have a shaft like this one end is closed and so due to this periodic excitation it will rotate right and left right and left as if you are actually as if you are twisting the system right left right left continuously this kind of periodic oscillation will occur to the system and the result there will be a breaking of the crank shaft.

And now I also told you that 3some other cases is very important where you do not want the vibration to get transferred to a system which you want to save which is very you know sophisticated system which is very much prone to vibration. So one such case is actually the rocket.

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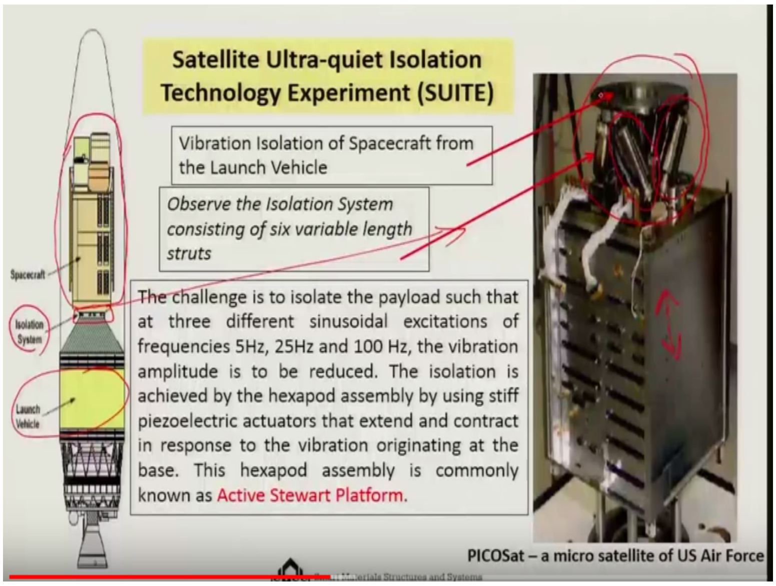

As you can this is a launch vehicle of a rocket and it has an isolation system like this and this spacecraft which is so expensive so you know a kind of a fragile system you always want to save it. So this isolation system is designed in such a manner that the vibration from the launch vehicle will not actually go to the spacecraft.

In fact, if you just expand this and see this here that this isolation system is also known as the Stewart Platform based on six actually such kind of shafts and in each one of the shafts they actually work as a kind of a low frequency cutoff system so this hexapod shall work in such a manner that even if there is excitation from the bottom they actually cutoff these and that table in the platform becomes free from vibration. So this is a Stewart platform in which the system is implemented.

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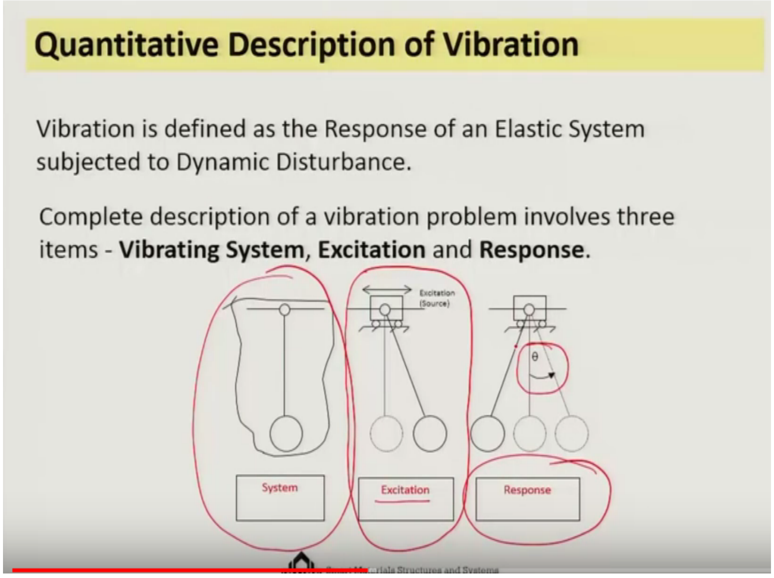

Now we will come to the Quantitative description of the vibration because I already have shown you a enough evidence that vibration is not desirable, vibration is going to create failures. So the point is that in order to do something effective I need to quantify the vibration. So there are 3 things that are important in any vibrating system that is the system itself

I have shown you through analogy that vibrating system itself, the Excitation of the system as you can here that this is the system which is undergoing an excitation due to base excitation ,and the Response of the system .So once again these 3 things if you can quantify first of all what is a system that is vibrating how the system is getting excited that if we can quantify and due to that excitation what is happening to the system like in this case the angle of amplitude you can see that is a response .So that is actually quantifies the entire description of the vibration.

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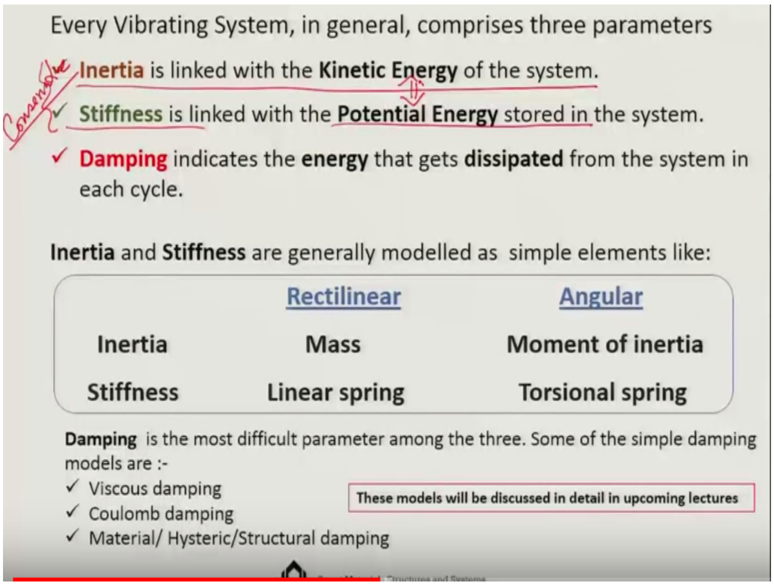

Now based on these first thing is we have to define the system itself the vibrating system. There are 3 things which are used to define a vibrating system. The first one is the Inertia which is linked to the kinetic energy of the system because there is a to and fro motion happening to the system So there is a kinetic energy actually associated with the system. Secondly with the potential energy stored in the system there is stiffness comes into picture.

If we consider only Inertia and stiffness then we can say that our system is conservative system in nature..Actually the potential energy and the Kinetic energy is interchanged and in such cases the vibration will continue for an indefinite point of time But in reality that would not happen .In reality some amount of energy is always dissipating and that will get transformed in terms of say thermal energy, say sound energy .This is what we called as the Damping, the energy which that gets dissipated from the system in each cycle.

Now when we will talk about Inertia, we will think about in a rectilinear frame. In that case the Inertia will be equivalent with mass and if we will think about in angular frame. In that case it will be equivalent with moment of Inertia. And when we talk about stiffness if it is you know in a rectilinear scale then it will be a like a linear spring. Ok.

In which you are applying a linear force and the spring gets deformed so that a linear spring however its counterpart in terms of angular reference frame is a torsional spring in the mechanical clocks that is to be used in our earlier days, we used to use the keys in order to give the torsional energy so that the later on the hands of the clock can convert the torsional energy and the clock is on running.

So that is you know that is the energy stored in actually potential energy in terms of torsional spring. Now damping is of course is a most difficult parameter among the 3 and they are various models of damping like viscous damping like coulomb damping, Material/hysteric/structural damping.

I will talk about it in the time will come. So these are the 3 things that are used in the terms of describing the system, the vibrating system. Inertia, stiffness and damping. Next we go you know the excitation and the response of the system as I told you there are 3 things that we have to talk about the system, the excitation and the response.

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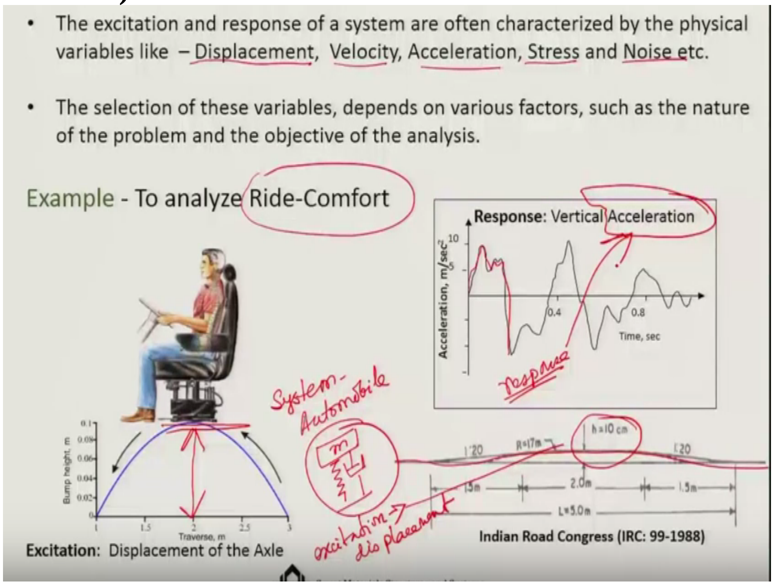

Excitation and the response of a system are often characterized by some physical variables depending on the application like displacement velocity, acceleration, or stress or noise etc. Now which will be used in terms of excitation and which will be used in terms of response actually varies in enormously from case to case.

I give you a very simple example. Many of you use you know a cycle or car for example. And you may have an experience actually going over a bump like these. Ok. Now if you, when you are going on a bump like these you would see that you know as soon as you are crossing the bump you will get a jerking motion and if you can place an accelerator on your car and you will see that the car is vibrating for a sometime and then the vibration is actually come down.

So you will see something like this kind of a response that is happening in the car. Now in order to have, in order to measure whether your car or your bike etc is a good or not we actually have a parameter called ride comfort. This ride comfort actually depends on 2 things. One is the excitation that is in this case is coming because of the bump and that is defined in terms of the displacement. Ok.

That means you can see what is the bump height here. So that is the displacement. ok. So the force excitation here is coming in terms of displacement and what is the response. The response is in terms of acceleration of the system mostly vertical acceleration that can be the other side acceleration.

So in this case the ride comfort case of this thing we have the system is like a you know a automobile system with its you may say the simplest description of the automobile system is something like a quarta car description of the system that means the mass of the automobile at least one fourth of the some spring and some damp parts.

So that is what our system and our excitation is in terms of what you have seen here that is in terms of displacement and our response, the response here in this figure which is in terms of the acceleration. Now this thing can vary from case to case. This is just a case where this are the input and the output. There are many other cases that this will change.

Ok. For example, if you think of a standard case of a vibration of tool ok. So there you know the tool vibration case the excitation will be in terms of the you know either it will be the acceleration that it will be subjected to or it can in terms of a force that it is a variable force that it is subjected to and the response will be in the terms of displacement the velocity.

So from case to case this gets checked. Now what are the ways in which I can control the vibration because now we know how to quantify the vibration? The control of the vibration can be either through the passive action where it is independent of the resulting vibration system.

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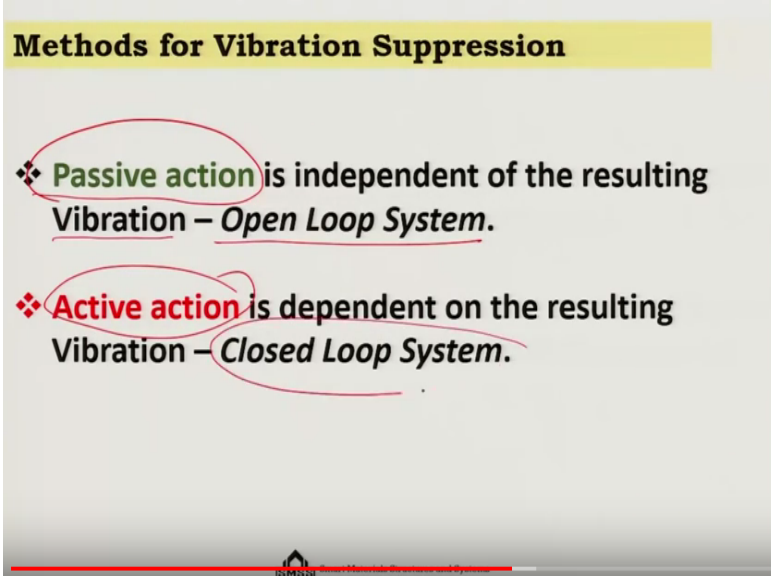

We call it as a Open loop system. Or it can be an active action where it is dependent on the resulting vibration. And we will call this as the closed loop system. So there are these 2 strategies. In fact, if we put all of them together all kinds of vibrations that is available today in this world you will see this broad picture here that you know the basic description of the vibration as I have just described.

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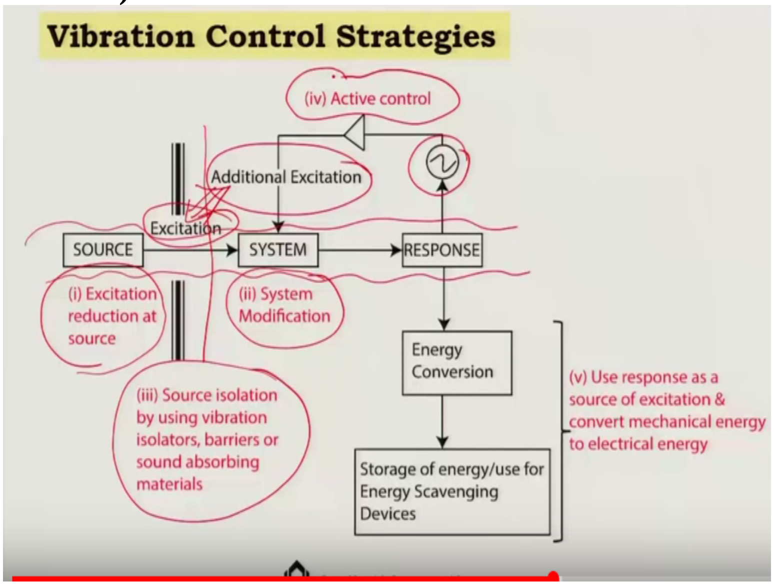

Source, system, and response. And the excitation is coming here to the source and the system is then getting excited and you are watching a response of it. Now to control it strategy number one could be there are five strategies involved that you will have strategy one could be that you reduce the excitation at the source itself, Strategy number 2 could be that you do some modification on the system so that it does not get vibrate.

The third one could be you put a varial like that the satellite thing you know that I told you that ultra quat(()) (25:05)satellite where the payload and the rocket in between you put a you know the active (()) (25:07) platform .Similarly you isolate this .That means you do not allow the source to go and excite the system. That is the third strategy.

These are 3 are generally passive strategies. Of course there some active variation strategies possible in 2 and 3. The fourth strategy is the you actually sense the response you do something like an additional excitation which cancels the effect of the original excitation.

So they negate each other. Ok. Force and a counter force. They are working together but in a opposite direction so the that they negate the ultimately the effect of the vibration. So that is the case of an active control because in order to determine what you will this additional excitation to know from the response what is the direction of motion then you have determine how you have to give this additional excitation.

Finally, some people have vey intelligently used the vibration itself in terms of generating energy So that is what is called as energy conversion. That is what our state. This is also known as energy harvesting So what happens in this case is as you that energy can never be destroyed it can transformed.

Now if that can be the case, then the energy that is in the mechanical vibration, we know that already in the some part of it will get dissipated due to damping. Like in terms of thermal energy or in terms of sound energy. But can we not exactly extract it more meaning fully such that we can generate a voltage out of it.

So, piezoelectric materials precisely do that. I will show u later on. That piezoelectric materials can precisely convert the vibration in terms of electrical energy. Then you can keep a you know a capacitor and the a battery system, so that you can check charge batteries out of it. So that is my fifth strategy of vibration control.

So if we about it in a nutshell the fist strategy should be always to reduce the excitation at source. Second strategy should be that you modify the system. Third is that you isolate the vibration. Fourth is you measure the response and find out a way to negate the effect of vibration by generating a counter force and fifth is you harvest the energy and convert the mechanical energy to some useful form of energy.

So this you have to keep in your mind. Talking about the first strategy. You will now talk about the reduction of the excitation at the source itself. There are many examples where we actually and this is the cheapest one that if there is any vibration you should always try to resolve the problem, the root cause of the problem itself whatever is causing it.

For example, if the vibration is happening due to the imbalance of inertia forces. Ok. so then actually you can use kind of a strategy to understand what kind of what is causing this unbalances inertia force and you try to remove that unbalancing itself. Then you do not have to do any more thing in terms of vibration control.

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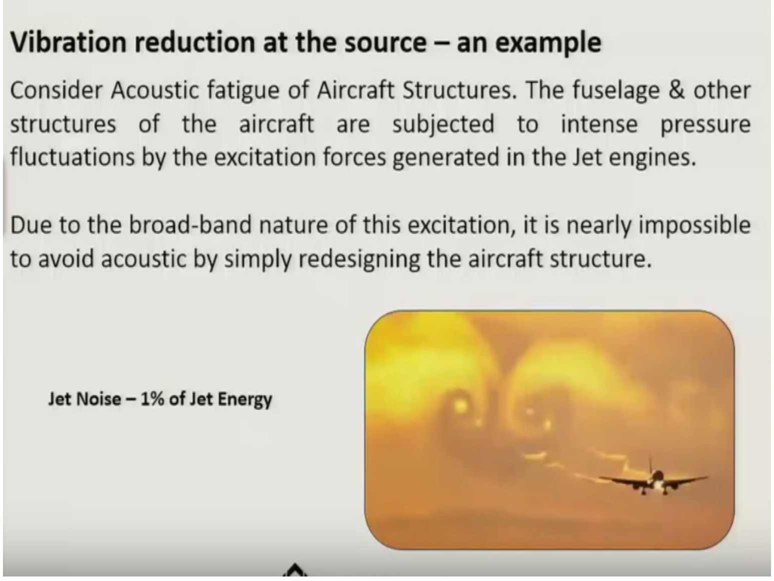

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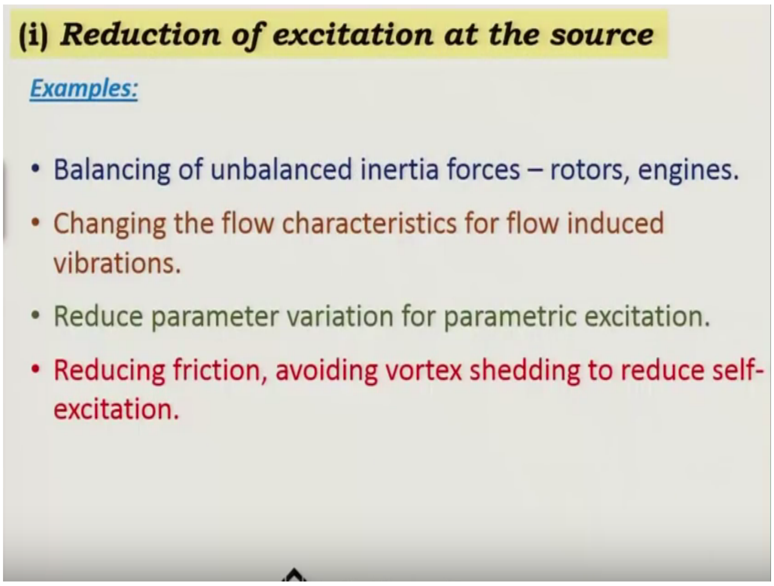

There can be cases where vibrations happens because of a flow. We call it a flow induced vibration. I will give you some of the examples of it where you will see that the flow induced vibration is taking place So in that case also if you can change the flow characteristics then you can actually remove the vibration at the source itself.

There are the cases of the parametric excitation where you remove the parametric variation, so that this parametric excitation does not take place. There can be a cases of some of the examples belonging to this cases only like friction or avoiding vortex shedding etc to reduce the self-excitation of the system.

So the point here is that if you can identify what is causing the vibration and if is in your hands to modify the characteristics that should be always your first strategy to control vibration. Some examples, I will give you for further elaborations. Many have seen you know in terms of see the aircraft exit.

So what to say air shows etc or if you are close to an airport you would see that these exhausts coming out of an aircraft is actually coming and generating what it is like this. This what is causes a terrific sound.

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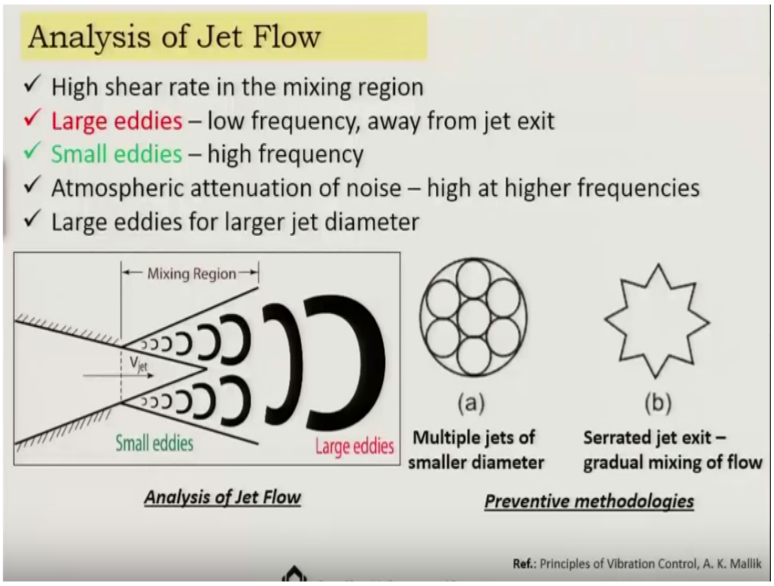

It not only creates the problem to the surrounding. But it creates a problem to aircraft itself. This sound actually hits the aircraft. Jet noise is about one percent of the Jet energy of an aircraft. Now how do we control it because the root cause we know is because of the exhaust that is coming out that is actually generating small eddies and these eddies as long as they are small eddies they are actually of a high frequency but they gradually expand and they become larger eddies.

Then they become actually a low frequency and that happens away in the jet itself and these you know the larger eddies are very large for the jet diameter and you know they are at low frequency so that that not get attenuated very easily. So the challenge is that you can stop the generation of these larger eddies. How can we do it?

Well if u look at these exhaust in the state of having a single exhaust, if you can these kind of small exhaust, if you can have an elated exhaust then what will happen is that you will not see this expansion of these larger eddies but you will see lot of smaller eddies and as I have already told you that smaller eddies having high frequencies.

They get attenuated easily, so by using this kind of a system you can actually you know remove the root cause of the vibration that the smaller eddies from the jet noise will get attenuated easily will not heat the aircraft at all. So that is the one example of reduction of the friction at the source itself.

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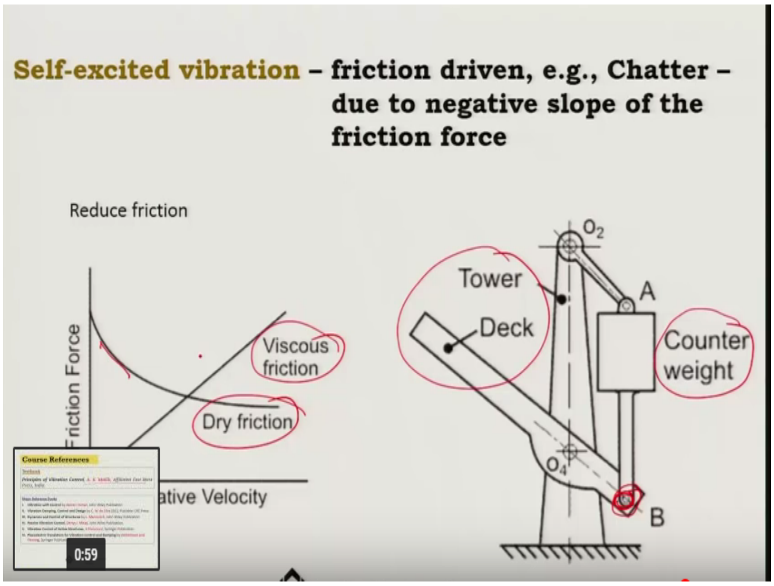

The second example is the case of self excited vibration. This happens for chatters of friction driven excitation you know for bridges For example so this is an example for a Tower deck bridge that means the bridge can be opened up or down Now if you look at this particular part of the bridge here it is subjected to enormous amount of counter weight and if you don't have a proper lubrication then there will be a high friction in this region.

And as a result there will be friction driven excitation and if there is friction driven excitation as you see a difference between a viscous friction and a dry friction and this case the slope is positive as a result you are going to have a self excitation in the system That means there will be positive work done which will be in the system and as a result instability will come so that is a case of a self excitation in the case of in this kind of the bridge system.

The other case is in terms of flow induced vibration which is also we will call it as Karman vortices. In such cases as such has been seen and I will show you through a small you know a kind of animation.

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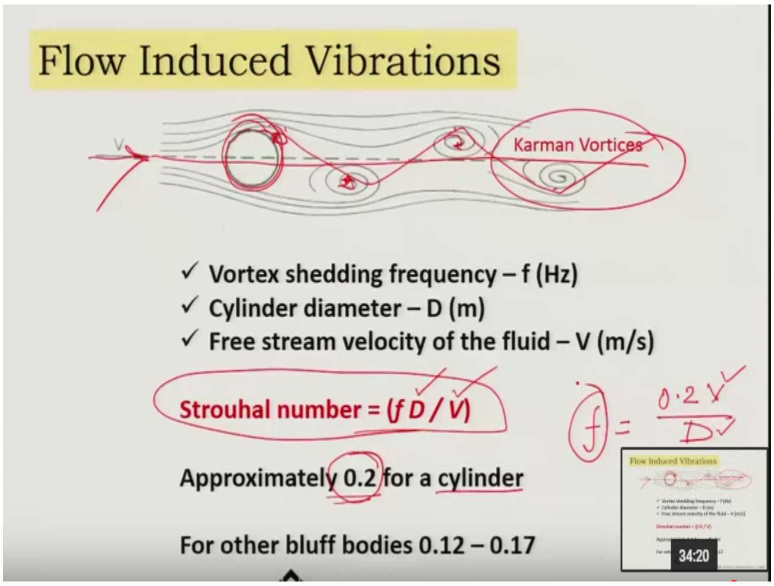

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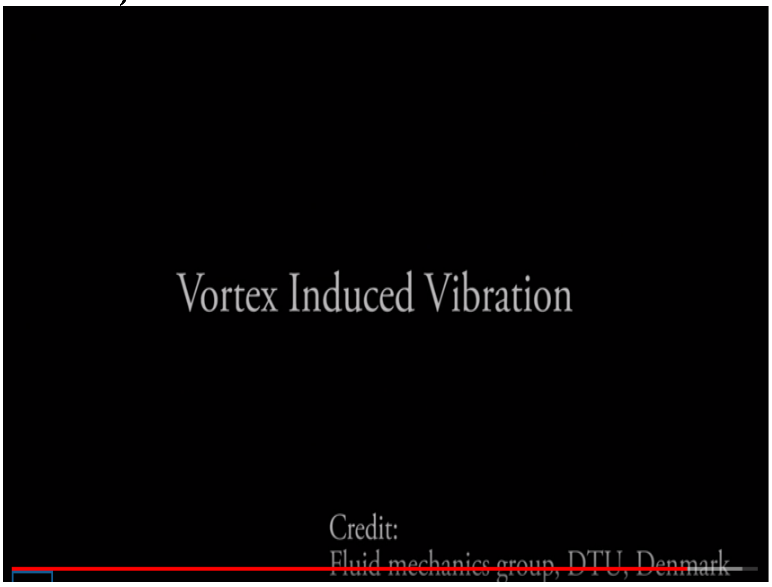

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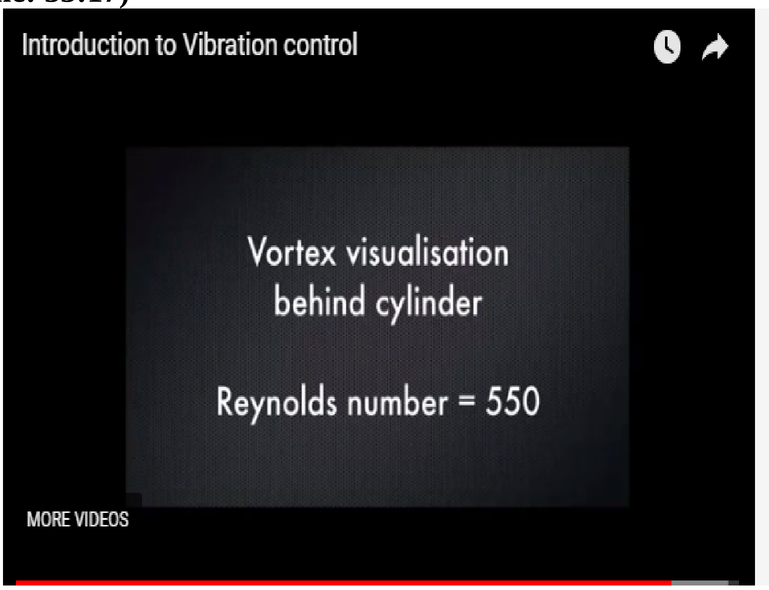

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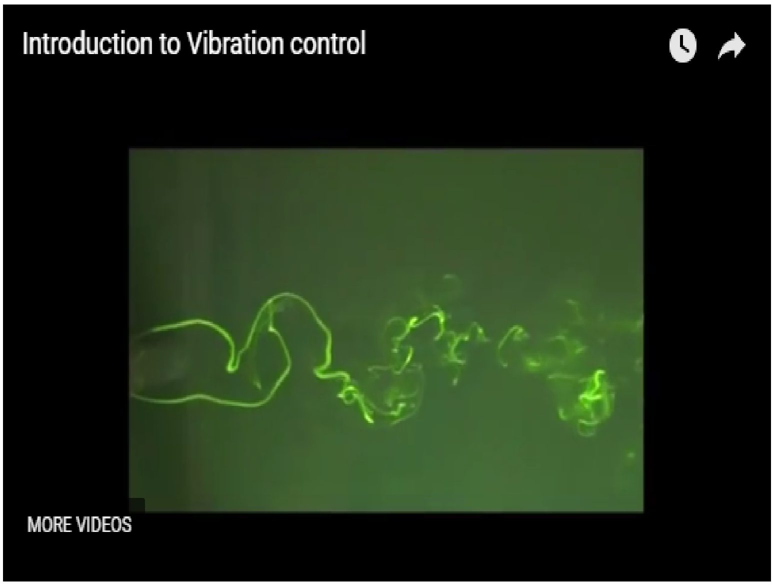

Of this whole thing that whenever there is a you know flow at a particular (( ))(33:28) then if there is any bluff body then which is facing the floor. Ok. What will be happening is that there will be formation eddies in the downstream region and they come in a very interestingly you know a kind of the way it is anti symmetric with respect to this line. Ok. So we call this as vortex line.

One here one here another here. So there is a zigzag line formed out of that. Now this vortex shredding frequency what it creates is that it creates a kind of a harmonic variation of lift force on that bluff body itself and as a result these body will start to get excited. So there is a number called strouhal number that determines this.

For example, a cylinder this strouhal number is 0.2 and this strouhal number is function of the vortex frequency f and cylinder diameter d which is possibly known to you, free stream velocity is known to you. So by knowing this 0.2 you should be able to find out the vortex shedding frequency. Which will be 0.2 in this case 0.2 V over D.

So you know V You know D and you should be able to find out your votex shredding frequency. Now if that frequency is close to the structural frequency of the system it is definitely going to raise on it is definitely going to create a havoc. So you need design your system such that this does not happen.

This is just we showing Reynolds number R with respect to the strouhals number is varying as you can see the Reynolds number as the flow velocity fisting velocity increases the strouhal velocity changes as strouhals number changes I need a very large state, beyond a certain reynolds number.

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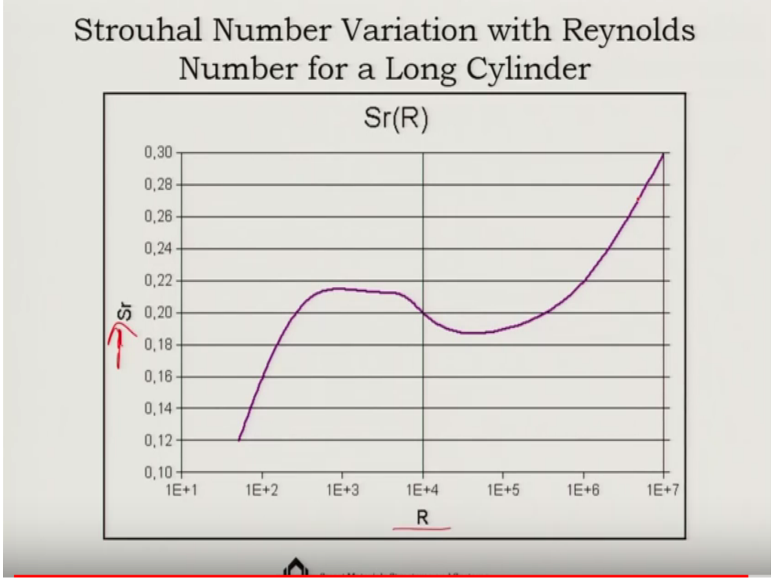

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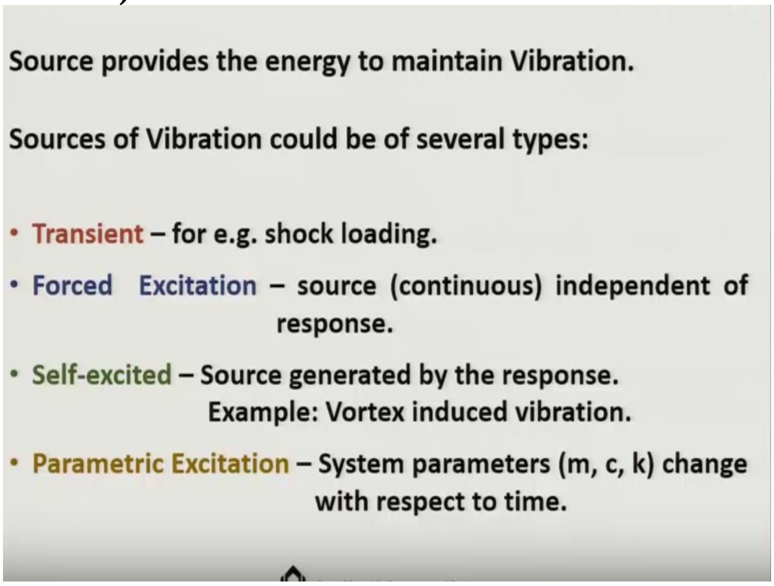

So in this case the source provides the energy to maintain the vibration and the sources of vibration could be transient, could be forced excitation, self-excited, could be parametric excitation. We need work on each one of these cases to the root cause of it order to you know reduce the chances of vibration of the system.

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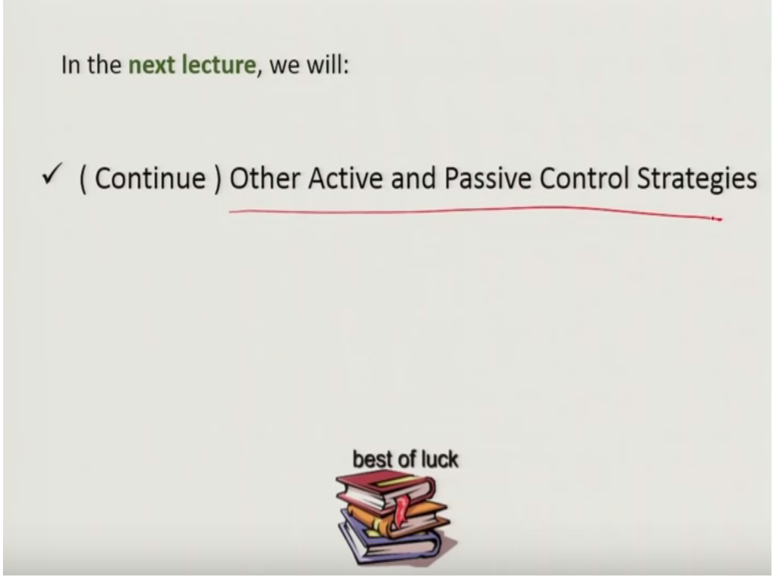

This is where we put an end. In the next lecture we will talk about active and passive control strategies. Thank you.