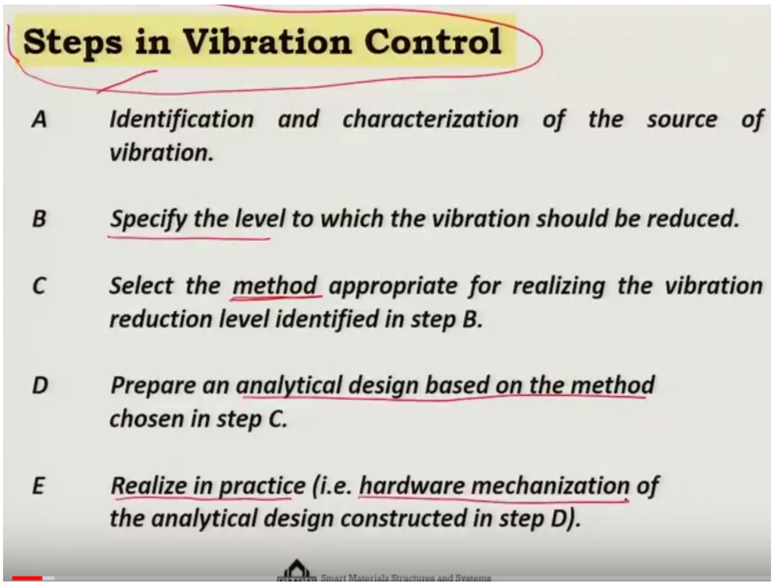
Principles of Vibration Control
Prof. Bishakh Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology-Kanpur

Lecture – 03
Strategies, Active Control, Detuning & Decoupling

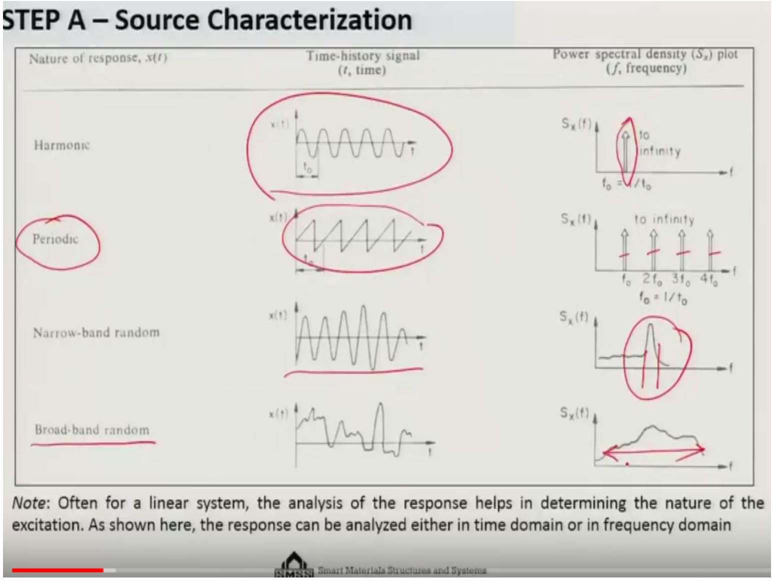
Welcome to the third lecture, on principles of vibration control. Now in the last lecture I was telling you about steps to control vibration that you have to keep in your mind. I would like to elaborate little more. So if you remember that the first step I said is the identification and the characterisation of the source of vibration. And then the second stage is that you have to specify the level to which this vibration should be reduced.

(Refer Slide Time: 01:14)



And thirdly, you have to choose the method out of the 5 different techniques we have discussed earlier. And then fourthly you have to prepare an analytical design based on this method, which we will be actually discussing in this course. Finally, you have to realise in practice. That of course we have not discussed here. But you know that you have to do some hardware mechanisation in term s of actually implementing the whole thing.

(Refer Slide Time: 02:10)



So in the step A, if I elaborate it a little more then the step A is telling that identify and characterise the source of vibration that means you have to do a source characterisation. That is very important because we always try to find out that what is the frequency contained in the vibration, if it is periodic vibration. If it is not a periodic random vibration that also come out and accordingly we have to take a strategy.

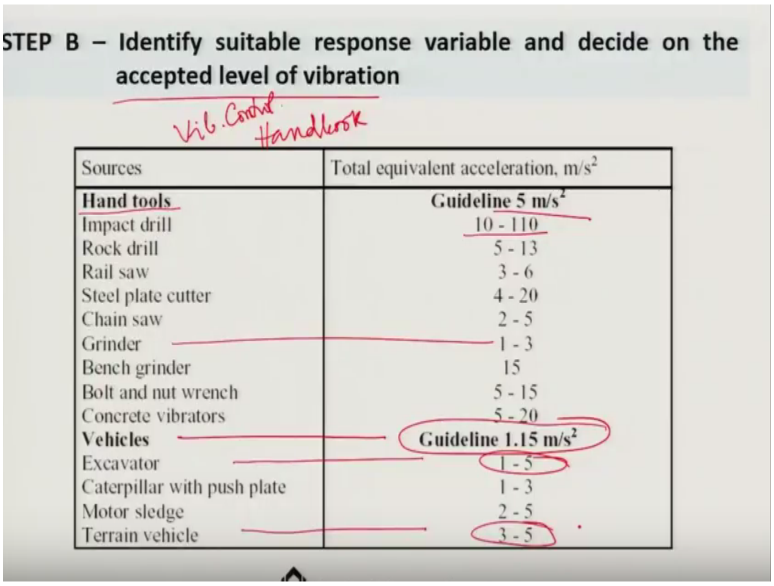
Let us say if we take an harmonic excitation pure single harmonic excitation frequency in the time history signal and we carry out a fast (( ))(01:59) transform we will get only one peak which would mean that is containing the signal is containing only one natural frequency of the system which is most probably the resonating frequency of the system and then we were lucky because we have to design the system modification only around that particular frequency.

But many a times we would not be that lucky we will still get a periodic excitation it need not be at a single frequency of course. Something like a saw wave which will be have such many such peaks. So that means you have to actually design for your damping system or vibration control system for various frequencies not for one frequency. Sometimes it can be narrow band random excitation. That means instead of a short peak you will get band. Ok.

In this type of a single (())(02:57) band in which you have to actually control the vibration of the system. And sometimes it can be actually random broad band. That means the spectrum is like pretty flat in nature. Ok. Something like you know in terms of say 1 real application could be that when the rocket is launched. In the launching pad, the launching pad will be subjected to the a broad band random excitation so which means you have adopt suitable you know control.

Strategies because you see your material if it is tuned at a 1 single frequency it will not be effective in this case. So it has to be such that many frequencies or so to say a wide band of frequency it should be able to be sensitive to that. So accordingly you have to choose your strategy in terms of vibration control method. So that is the source characterisation. Next of course is that what is the suitable response variable and what is the accepted level of vibration.

(Refer Slide Time: 04:03)



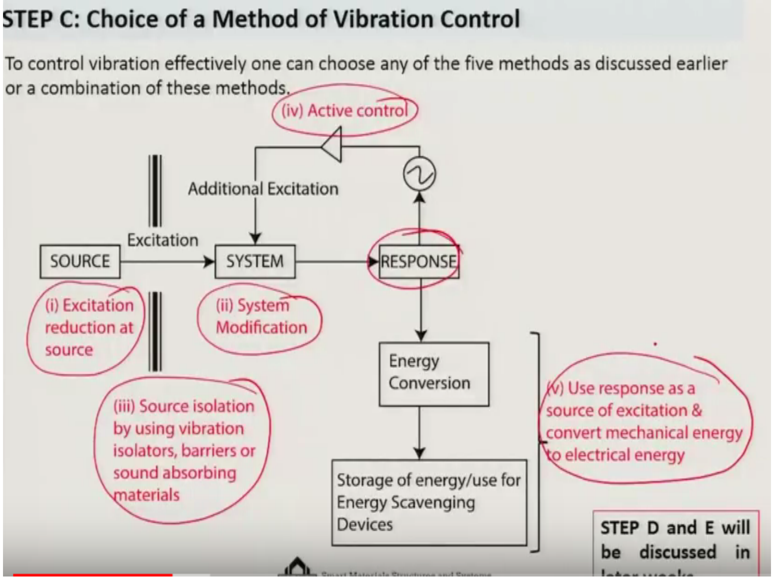
Sources	Total equivalent acceleration, m/s²
Hand tools	**Guideline 5 m/s²**
Impact drill	10 - 110
Rock drill	5 - 13
Rail saw	3 - 6
Steel plate cutter	4 - 20
Chain saw	2 - 5
Grinder	1 - 3
Bench grinder	15
Bolt and nut wrench	5 - 15
Concrete vibrators	5 - 20
Vehicles	**Guideline 1.15 m/s²**
Excavator	1 - 5
Caterpillar with push plate	1 - 3
Motor sledge	2 - 5
Terrain vehicle	3 - 5

This needs a little bit of experience of course if you do not have experience to begin with you use the so called you know the hand books various types of hand books are there So use the hand books you know the vibration control hand books that are available in libraries. So if you do that you will see that corresponding to different types of applications like it is suppose if it is hand tools what is the acceleration permissible. It will be like something 5 meters per Second Square.

If it is drill it is much more because it is a you know actually handled in a rough atmosphere. So it is much higher. If it is something like a grinder, it is much lower 1 to 3 meter per Second Square. If it is vehicle, then also it is much lower it is about 1.15 meter per Second Square. If it is an excavator, it is 1-5 meter per Second Square. If it is a train vehicle, it is about3-5 meter per second square because depending upon the application the hand book will tell what will be the safe acceptable level of vibration.

So that means when you taking up the job of vibration control at that point of time whatever is your level of acceleration the moment you are bringing it down below this level. You are safe and that means your design is over. So this is what we carry out at step B.

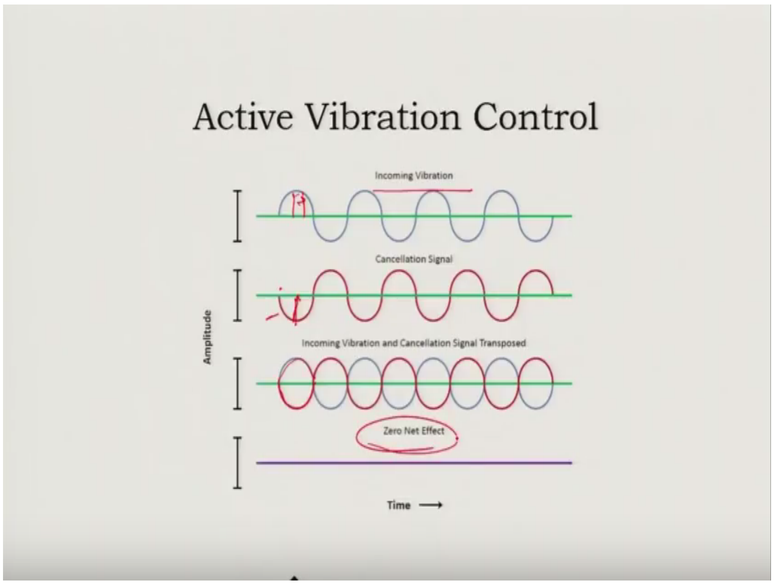
(Refer Slide Time: 05:48)



Next is the step where you actually choose a method of vibration control. If you remember in the very first class I have talked such methods five such methods one is excitation reduction at the source itself, another one is system modification, another one is source isolation then you have active control where you are actually taking the response of the system into consideration.

And then also the last 1 in which we use response as the source of excitation and convert mechanical energy to electrical energy. So that is the step C where you are choosing a method of vibration control. Then of course we have to carry out a kind of a analytical design and then you have do the hardware. This we will discuss as we will be proceeding in this particular course.

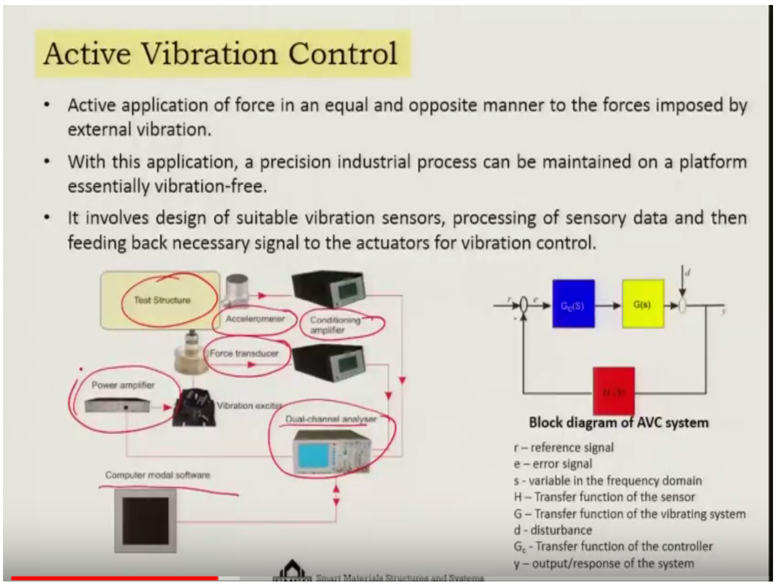
(Refer Slide Time: 06:43)



Now I have discussed about many of the control strategies but not so much about active vibration control, may be in this introductory session. I will talk a little bit about it. So in the case of the active vibration control as you can see suppose an incoming vibration then the cancellation signals is actually exactly you know same in terms of the magnitude but oppose it in terms of the face.

If this positive this is negative. As the result they are actually cancelling each other. As you can see and there is 0 net effect that you are getting out of it. That is what we are theoretically we try to achieve in active vibration control but you need for it. Well.

(Refer Slide Time: 07:34)



You need quite a few things. Suppose if this is a test structure you first need to measure the response of the test structure. May a time we do this with the help of a sensor which is known as accelerometer. It actually measures the acceleration of the system and then there is conditioning amplifier which actually throw away all the noises and it comes to a dual channel analyser or a pc for that matter.

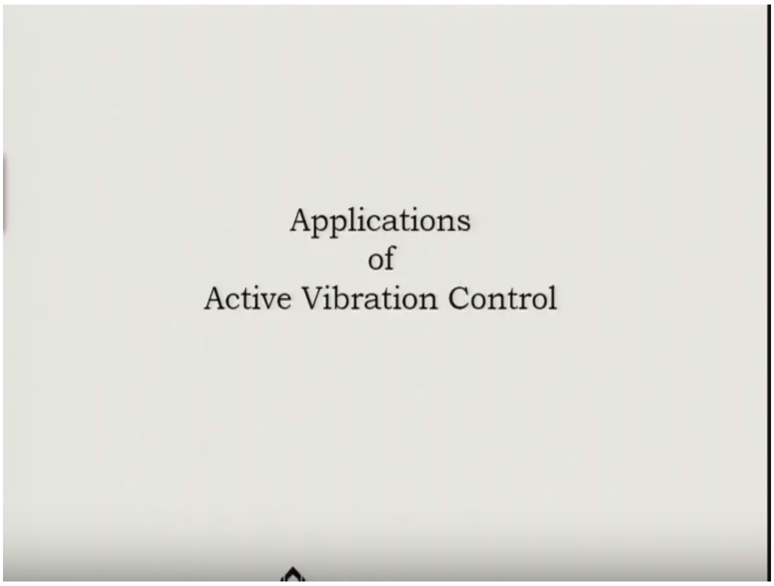
Then also you sense another thing which is the level o force that is exciting a system through a force transducer that also can come through a signal conditioning and come this dual channel analyser. Now based on these and computer based model software, you determine that what will be your cancellation type of the signal that is this part of a signal you determine at this stage. So once you do it what you do you use a power amplifier because the nature of signal is known.

Now you have to increase the power with that you drive a vibration excitor that vibration excitor drives the force transducer again and that actually nullifies the whole thing. So that a closed loop strategy. In terms of a closed looped system, if you look at it then you must say that may have the reference signal in mind some cases this reference level will be 0 some cases it may up to an acceptable level and then you have a controller find, and you have a plant you are driving like using the force transducer.

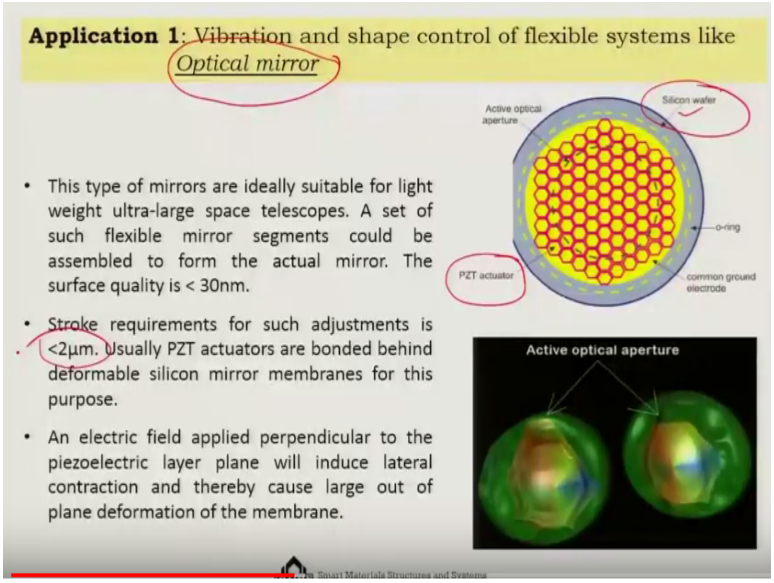
You are driving the test structure. So the controller is driving this gas and there can be some disturbances in which you wish or not is coming in to the system. You are measuring the response which is full of all these things that is what you are measuring through a accelerometer and then that is coming to another game which you are deciding here in the computer and with that you are feeding it back to the system here. Ok.

So and that is your par amplifier to the force transducer route whatever is happening here. So that closes the whole loop and you do it in such a manner that if you do it for sometime then gradually the vibration comes down to the tolerable level. That is the strategy of active vibration control.

(Refer Slide Time: 10:09)



(Refer Slide Time: 10:29)



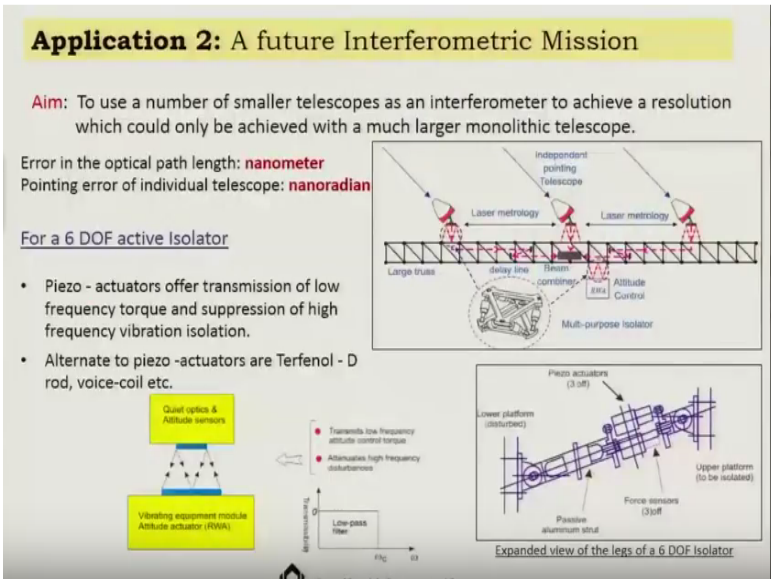
There are many applications of this active vibration control. 1 such application is the vibration and shape control of flexible systems like optical mirror. This is of course you know having 2 applications. 1 is in space application another is in mems type of systems.

Now here the poin t is that we are looking for a very high precision shape control. So if we have you a kind of a silicon wafer which is polished in such a manner that it can in work like a beautiful kind of a reflector. Now these at the back of this you have this hexagonal piezoelectric actuator. This piezoelectric actuator they work in very interesting way that if you apply the voltage in this piezoelectric actuator they change their shape.

And as they change shape they are trying to do they will take this silicon wafer along that and as the result entire length is going to change its shape. So you can see that once you are actuating with the pzt actuator how this change in shape is happening. Now this the good part of piezoelectric actuators is that it works in a very high bandwidth almost to the giga hertz level which means that it reacts very fast and also the stroke requirement is quite low here so you have to deform too much.

But you have to deform very accurately which is what the piezoelectric actuator are very good on. So thus you can control the aperture and also you control the vibrations in such flexible systems. So that is one application of active vibration control.

(Refer Slide Time: 12:04)



The other application is also having a space application. This is with respect to the deep space observators. As you all know that the (())(12:16) telescope has kind of you know has over leaved it s lifetime. So the time has come for us to have a new telescopic system which can be used in terms of observing the universe beyond you know our solar systems to the far away areas of the universe.

Now to do that this ia future interferometric mission I am talking about. Here no longer we will be using on single telescope. Rather we will be using multiple such telescopes. See you can see many such telescopes looking at small areas of the space and now what you are doing, You are thinking the signals from each one of them and you are assembling them together at one single point such that the error because the moment the signal is travelling these paths there will be some error.

The error has to be in the nano meter level. Such is the tolerance level. So tight and the pointing error of individual telescope is about also in the nano radial level. To do that we take help of two things 1 is for the path correction we use a kind of a delay line so that all the signals will come almost at the same time. So by suitably changing the position of the mirror we can do this path correction. So that if thing is coming very fast we can tell it that hold on.

We will increase your path a little bit more so that you come almost at the same time when the slow 1 is coming. So that you know the idea is that we should be looking at the universe at the same point of time all around it. Ok. There should not be any time delay in between it. So it is something some signal some information reaches very first was we slow it down and if some reaches slow we tune it with the faster 1 so that we get a coherent single you know time picture of the universe.

The second part is that so this is a big flexible structure we are talking about that means this large truss here this will be hallow is having the small bit of pertubation you do it in the space it will start to continuously vibrate and if it vibrates then you cannot achieve your nano meter level of you know accuracy in the optical path neither that pointing error of nano radial etc.

So you must have some system which will not allow this vibration from the large truss to go to this telescope part. To do that what is used is called an active steward platform which is like a six degree of freedom isolated system. This isolate system any have piezoelectric actuators or terfenol D rods which is another smart material or voice coil etc.

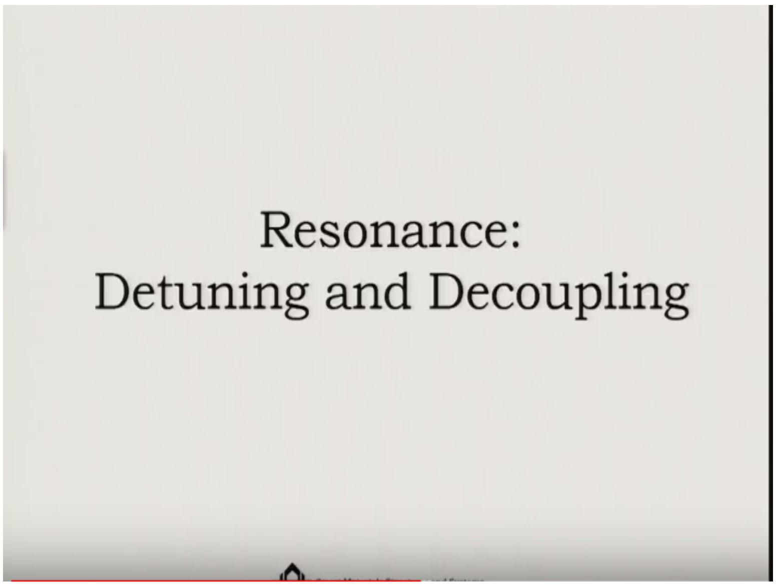
Now what does it do. What it does is that if there is a vibration that is coming to the base of the system that mean here then in order that this vibration would not reach quite optic s region or it will be it will not be coming up to this level what you have to do is this particular layers you can have to control their stiffness, mass etc such that the vibration signal does not reach there.

So how do I control the stiffness? Well By changing the leg length you can control th e stiffness by making it taller we will make flexible by making it shorter we will make it stiffer. How do I change the length of the each on e this string? Well Piezoelectric actuators precisely do that. If you apply a voltage that Piezoelectric actuator will expand or contract depending on the direction of the voltage.

And hence you can control the stiffness and hence you can control the path way so that this vibration does not reach the quite region. That is the principle of active you know Stewart platform. Essentially if you look at it that it works some like a low pass filter so that you know whatever is the low frequency part contained in the signal does not allow that and the rest of the things you know may get transmitted to the system.

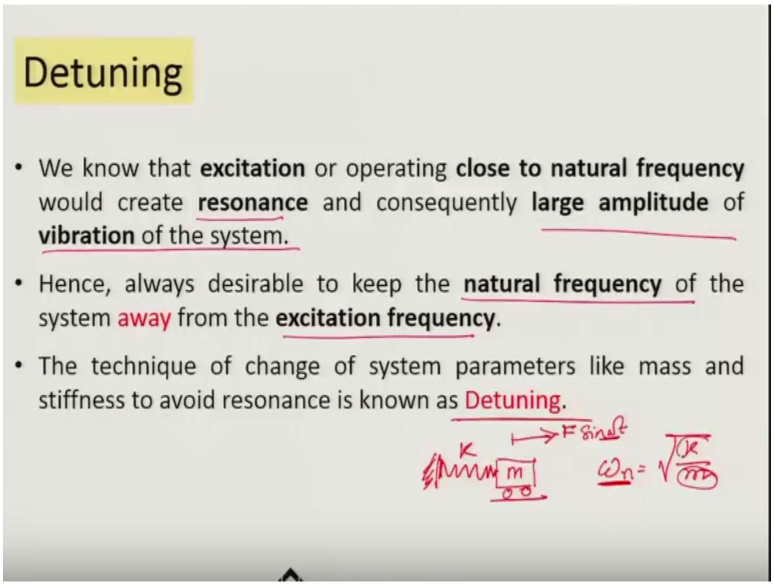
So it transmits the low frequency attitude which is the control top but all the high frequency disturbances it actually stops that. So that is what is a another application of active vibration control.

(Refer Slide Time: 17:10)



Now we will talk about a system modification which is in terms of detuning and decoupling. This is the system modification concept and we must look into it at length.

(Refer Slide Time: 17:20)

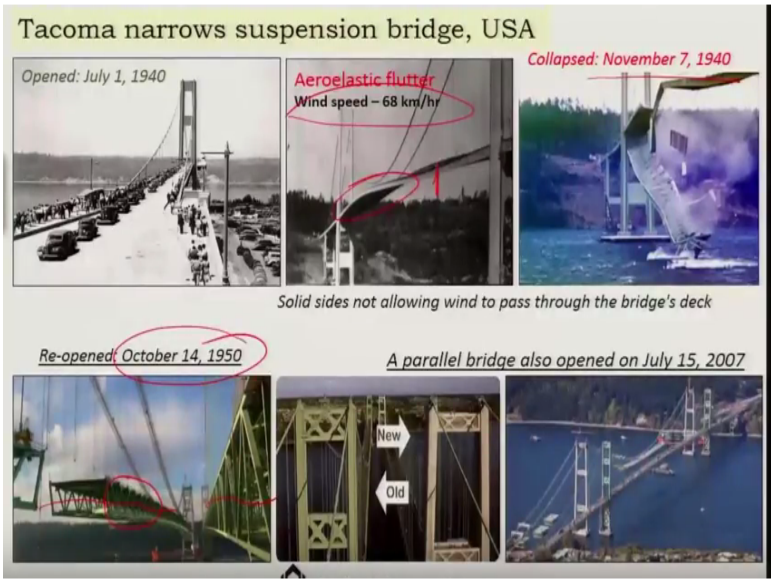


So what is detuning? Well. We know that excitation is operation close to natural frequency will create resonance. And consequently we will get a large amplitude vibration of the system. So hence it is always desirable to keep the natural frequency of the system away from the excitation frequency of the system. So this you know by suitably changing the parameters like mass, stiffness etc.

This is known as detuning of the system. Suppose if i take the single degree of a freedom system of a like a you know this kind of a system which has a mass m and it has a spring suppose here fixed at 1 point and this frictionless wheel system this is k so the omega a is square root of k by m. That is the natural frequency of the system. Now if I am exciting it at a frequency F sin omega t in order to keep this omega separate from omega n so that the resonance does not occur when omega is not in our hand.

But omega n is in our hand so we will be either increasing this stiffness or we will be you know changing the mass of the system or either by changing the stiffness that the mass we can kept this omega in away from omega. So that is what the strategy of detuning a particular system is. Now there is 1 beautiful example of this. This is the example of Tacoma narrow suspension bridge that you will all know. This bridge opened in July 1 1940.

(Refer Slide Time: 19:12)



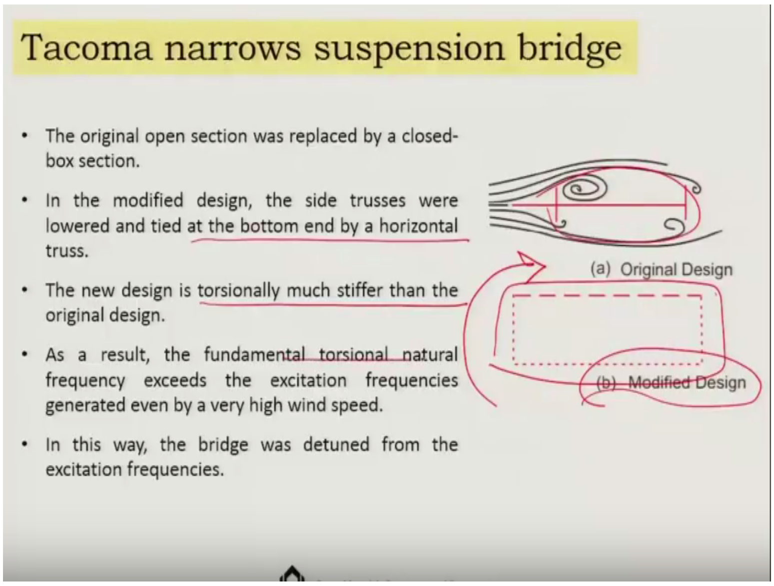
And you know soon after that the bridge collapsed. The bridge collapsed on November 7 1940. The reason is narrow elastic flatter Well this is of course you know a very complicated thing. But just to kind of you know tell you the essence of it is that the bridge was designed in such a manner that there is a kind of a vortex induced vibration that has happened when the bridge was excited by a wind speed of about 68 km per hour.

And as this vortex induced vibration you know the natural frequency of the system was pretty close. We will see the torsional frequency of the system later on. So as these coupling occurred, so this system started to go for large response as the large response happens then there will be this arrow elastic coupling that will happen to the system and there will be a flatter that will start and that would result in the collapse of the system.

Let us look into how the system would behave. Now you have seen that Tahoma narrow bridge has collapsed. In fact then you know the bridge is re designed and it was reopened in October 14 1950 and in this new configuration they have used this old guarded system. Rather they have used open spaces here.

So 1 of the reasons is that there was a lift force development at the base of the guarder which was actually exciting the whole system. Now this time this pressure radiant would not be developing because the wind can pass through this open section. So they have taken care of theat. And also they have designed it in such a manner that it would not get excited by those kinds of vortex induced vibrations. So the changes further.

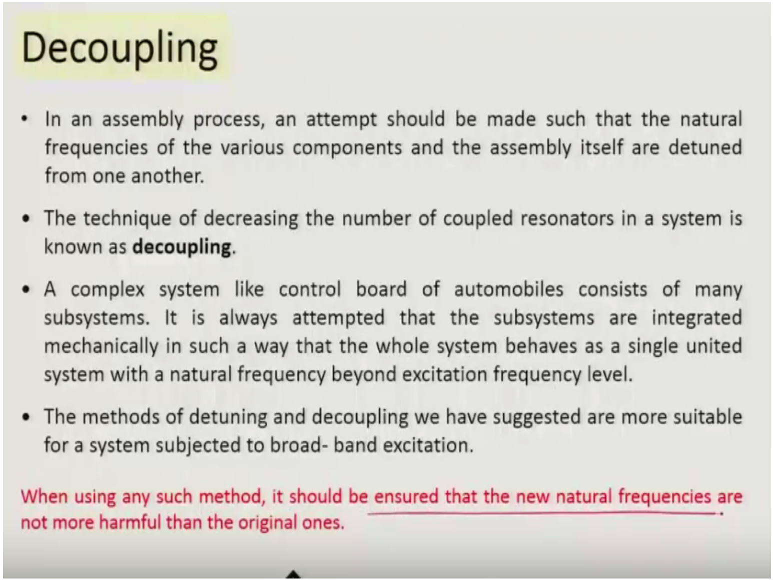
(Refer Slide Time: 21:34)



Of course latter on in 2007 another parallel bridge also has been opened on the same spot so we learn from a catastrophe. So this was the original section of the guarder and this is having a modified design as I have told you which has the side trusses load and tyre at the bottom end by a horizontal truss. So that this new design is torsionally stiffer because you this kind of instead of a open section you have closed cross section.

So that means in terms of torsional excitation this is steeper. So it would not get excited. The fundamental torsional natural frequency exceeds the excitation frequency generated even via high wind speed. So thus you can say that the bridge was detuned from the excitation frequencies. So that is 1 strategy that we always take in terms of detuning. The other strategy we take is known as decoupling.

(Refer Slide Time: 22:25)

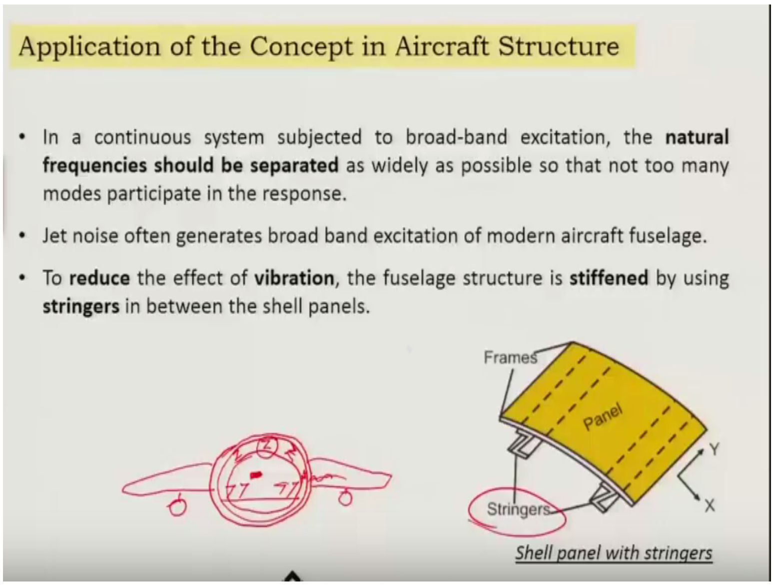


Now this is very interesting that in an assembly process an attempt should be always made such that the natural frequencies of the various comp1nts and the assembly itself are actually detuned from each other. So these techniques of you know reducing the number of coupled resonators is called decoupling. In a way you can think of it that suppose you have a single pendulum system, a series of single pendulums.

And they are isolated from each other then you know there is no problem. But if these pendulums are actually linked by a very weak, you know steel spring or stiffness. What happens then is that it behaves like a coupled resonator. That is you excite, at 1 point here suppose and this excitation will reach the next and this will reach the next and thus you know all the system will start to behave. There are many things that can happen including chaos in the system.

Once if u have a such a kind of coupled resonator. So the decoupling intends to cut this kind of you know re coupling between the systems. So that is what is the essence of the decoupling systems that when using any such method that it should be ensured of course that the new natural frequencies are more harmful than the original natural frequency of the system.

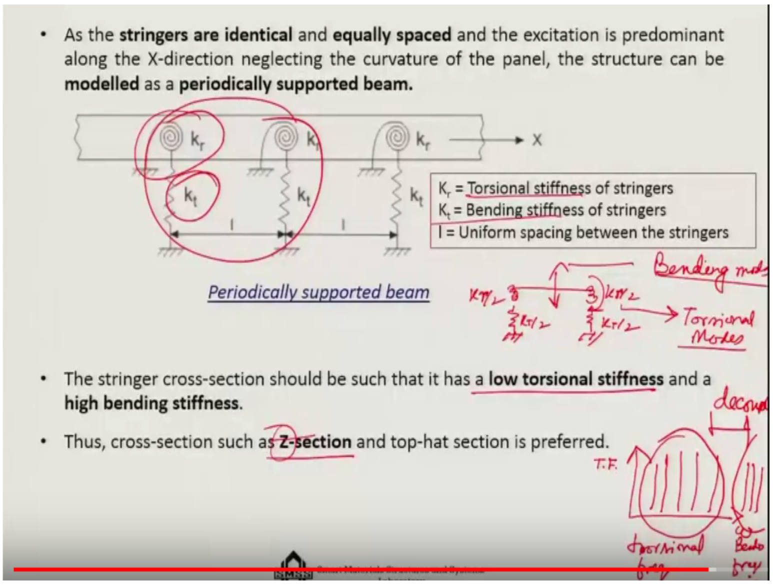
(Refer Slide Time: 24:23)



Now there is a very good application of the concept in aircraft structure. In any aircraft, you know next time if you can see that how this aircraft fuselage part of an aircraft so that means the central part where the seats will be there. Right we all sit. So here if you look at it then you will see that this is the shell like structure. Ok. All around it. So that what is an aircraft you know ring etc. Now if you look at it very closely that this shell like structure is having some kind of a actually second layer in it.

So there is this is the inside part of cabin. Now this are called stiffness. The reason why we give stiffness is that the effect of the vibration from the fuselage structure because you will be having the engines here. Right. So the engines will generate lot of noises. These noises you do not want it to come inside the cabin region. In order to stop that, you give this kind of a stiffness structure. Pretty much like what I have shown you in this, you know wood pecker example. Now what kind of a cross section I should actually chose in terms of the stringer.

(Refer Slide Time: 26:08)



In order to decide that we have to see that this kind of a structure can b e actually you know may an abstraction that as if you have continuous structure which have at every point a torsional stiffness and a bending stiffness. Torsional stiffness is like you know KR torsional stiffness and the bending stiffness is KT. Now if you consider a small part of this so that means instead of that repeated structure you have a small part of it.

That means in this small part you have this kty to kty 2 and you have this springs. Ok. In so this, KRY2, KRY2 Ok. And KTY2,KTY2 that means I have just isolated only 1 part of it. Ok. There are many such units. So I have taken half it because it is a repeated structure. Now in this structure there are 2 different system of excitation.

1 is like this. And another is like this. There is torsion of the system. So corresponding to each 1 you have you know the stiffness or the spring stiffness is in place. As it happens for

this type of systems these you know transverse motions are going to give you the bending modes and this 1s are going to give you the so called the torsional modes of the system. Now if the torsional modes ands the bending modes are all present you know in terms.

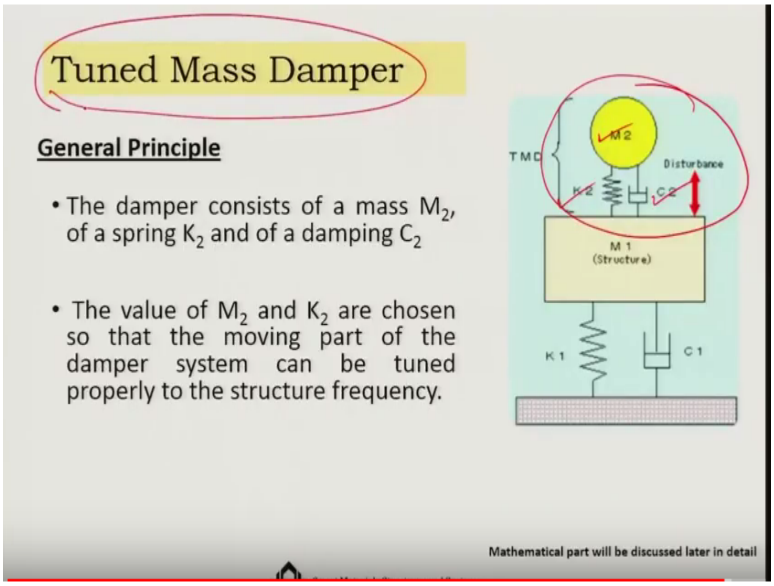
If I look at the omega versus the response or the amplitude of the system so the transfer function If i look at it or I may see that there are many peaks in it and some peaks here. So what I want is that we want all the torsional peaks in 1 region and we want all the torsional frequencies. These are the bending frequencies. And we want the bending frequencies to be separated. That means de cupped. That means there is some kind of a gap between in that.

So we should choose the strategy to do that is all there in terms of choosing the proper cross section of the stiffness. If you choose something like a jet section then what happens because it is an open section so it will give you a low torsional stiffness. So you get all the torsional modes in a certain frequency pattern.

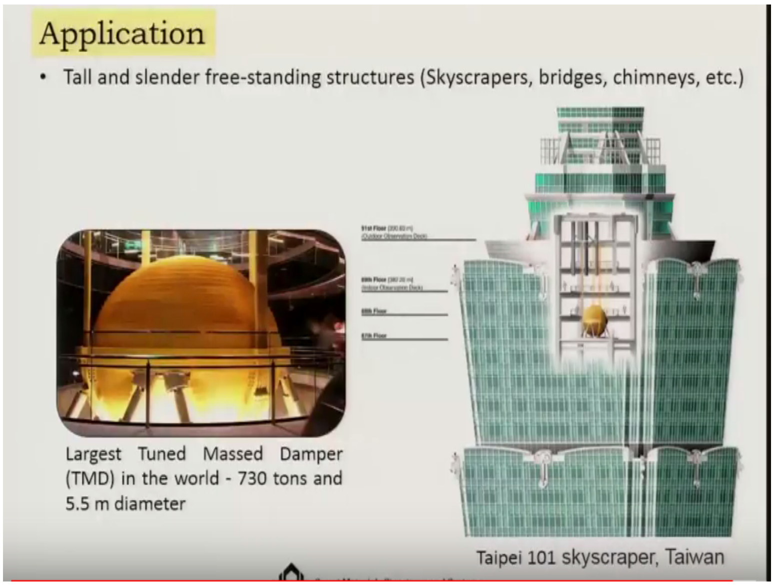
And because it has a lot material away from the neutral axis, so it has a much higher you know bending stiffness. And as the result the bending frequencies are much higher. So thus you are decupling between the torsional mode and the bending mode. That means if there is torsion you are ensuring there will no bending also and vice versa. So this is another fine example of decoupling of the modes. Next is in terms of the tuned mass damper. Here we are adding another sacrificial system. Ok.

So you can control the mass of the sacrificial system, the stiffness and the damping in such a manner that the primary system that the vibration of that system calms down and the secondary system may get large amplitude does not matter because you are sacrificing the secondary system. Thus you are saving the primary system. So that is the concept of the tuned mass damper. We will talk about the mathematical part of it in much more detail in the future lectures.

(Refer Slide Time: 30:14)



(Refer Slide Time: 30:20)



And all these, now this has got many beautiful applications like the stall and slender free structures like sky scrapers, Bridges chimneys. You will find in many cases. In the top of it there is this kind of a large tuned mass damper. Ok, that is put in these towers etc in sky scrapers, sometimes actually they do not able to put separately but they put as I told you a big water tank on top of it and this water tank works like a secondary system which is attached to a sky scrapper.

So this is an application in terms of you know a kind of secondary system. So this Taipei you know in this sky scrapper you would see this kind of an application of a tuned mass damper system. So this is where we will put an end and in the next lecture we will learn about various damping models. Thank you.