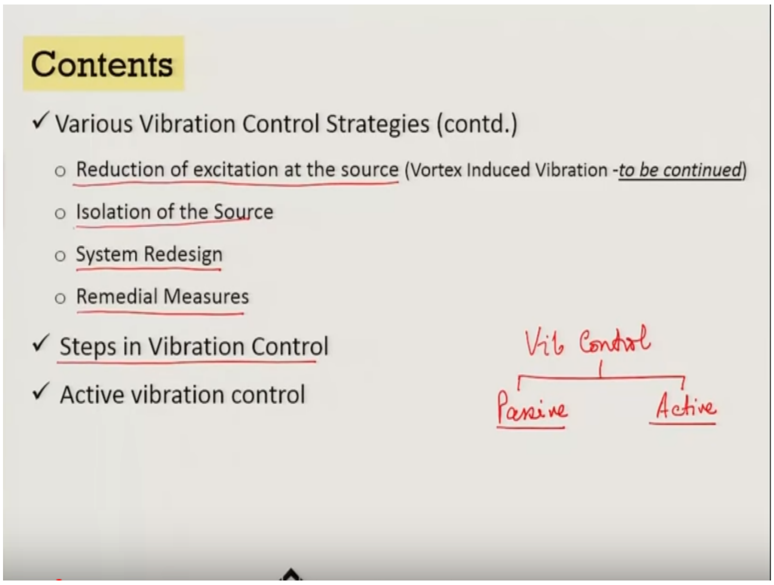
Principles of Vibration Control
Prof. Bishakh Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology-Kanpur

Lecture – 02
Strategies & Steps In Vibration Control

Welcome to the second lecture, on principles of vibration control. If you remember that in the last lecture we have talked about various vibration control strategies and particularly we have focussed on the reduction of excitation at the source itself.

(Refer Slide Time: 00:25)

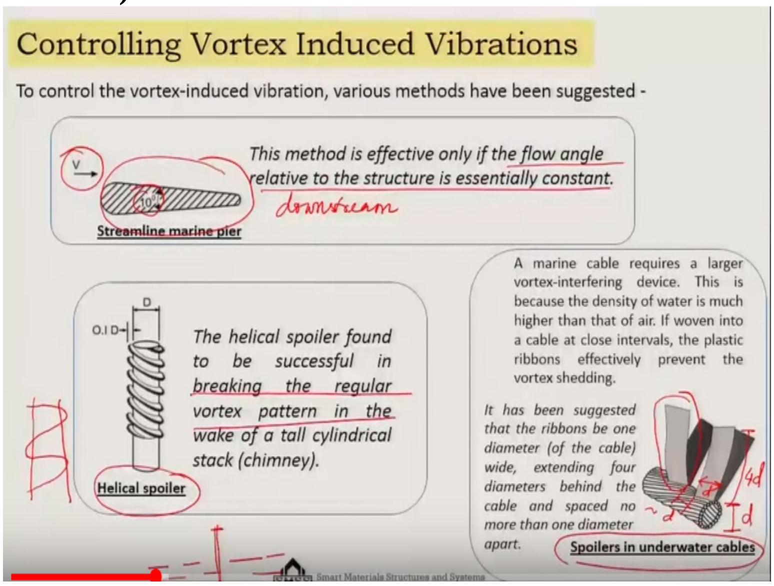


In fact, on that category we have talked about what is induced vibration and I also said that how we can use the knowledge of the strouhal number, the relation between the strouhal number, and the Reynolds number and with the help of that how you can redesign your system. There are also few more tricks involved in it. That we will be discussing today. Also along with that I will also talk about other vibration control strategies like vibration isolation at the source itself.

Then we will talk about you know considering vibrate and vibrating system. How we can redesign the vibrating system and finally we will talk about some of the remedial measures. Then I also intent to tell you summarizing the whole thing that in case of a vibration control problem what are the steps that one has to take one by one and finally I will touch on very important I would say urgent part of this vibration control because in the first itself.

I told you that vibration control itself is nowadays broadly divided into 2 categories like one passive vibration control where essentially it is a one loop system. The system response is not needed and the another is active control vibration where the system response is definitely need and the closed loop system is to be developed So that also I will initiate. So this is what our plan for this lecture.

(Refer Slide Time: 02:14)



So let us first you know talk a little about the control of vortex – induced vibration, how to control such vibrations. Well, if you have a uniform stream velocity ok. The stream velocity is you know essentially the flow angle related to the structure should remain constant. In such cases you can actually design a streamline pier system which is like you know in a particular degree, in this case its ten degree.

So one can do that from the you know from the structure fluid interactions and one can get an optimal design but this kind of a shape of pier which is a streamlined so this is the up streamside and this is the down streamside and so you know actually by designing this you can get a good vortex say you know you can stop vortex vibrations essentially by designing a this kind of a pier.

You will see this you know next time if you look at it that in many of the bridges you that this techniques is used to cut the source of vortex induced vibration. There is another thing also we will see that in chimneys or in cylos that you will see that they actually use some kind of a spiral stir all around a chimney or a cylo. So next time if you look at a cylo which is used for storage of let us say cement and all such things you know so we will see that such type of a spiral is built all around it.

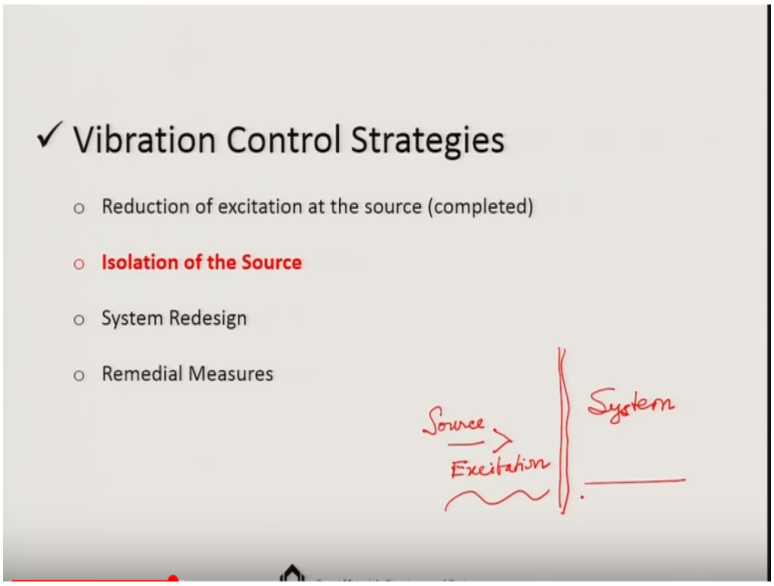
Now this spiral not only gives acess in terms of the control of the structure etc but also it helps immensely terms of breaking the regular vortex pattern is a very common technique used for you know various types of cylos and chimneys and this is also known as the Helical spoiler category. In a marine, particularly for the offset structures like cables etc. They use a slightly a different strategy, in this case for vortex separation

Here in this case you will see that they use plastic reborn which is generally woven with the structure itself generally, with the cable structure itself and typically they are quite weak. For example, if this one is of diameter d, you would see that this is also a same type of a size and the separation also you will see of very much of similar level of d, and generally this kind of a cantilever is about 4 times the d. So this is actually used for you know underwater cables as spoilers and cables ok.

And this is used a for cutting down the vortices so that the cable does not get affected by the you know the vortices that is generating the marine kind of an ambience. Now there is also I have not mention it here but I remember for sub marines also they use something in the tip odf the submarine see invariably that if this is a submarine body and then they have the periscope which actually they use in terms of watching what is happening over water and.

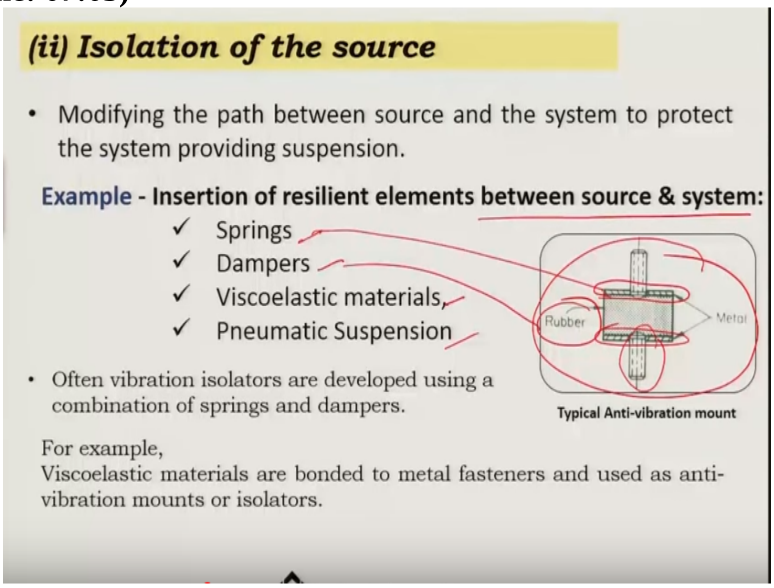
You will see that it also has a kind of you know a spoiler in it a kind of a spike which actually works like that a spoiler and that is used in terms of the sub marines. So there such various types you know, vortices is used in vibration control system that is used in the reduction of vibration at the source itself.

(Refer Slide Time: 06:23)



Next, I will talk about isolation of the vibration that means in this case vibration at the source is not controlled, so if there is a source, the source is giving you excitation so excitation is coming and you have to save your system. Next is the system in light. Now how to give some kind of a barrier in between the 2 so that, the excitation at the source does not disturb the system that is what we have to think of in terms of the isolation of the source so let us see what are the things that we can do for it.

(Refer Slide Time: 07:05)

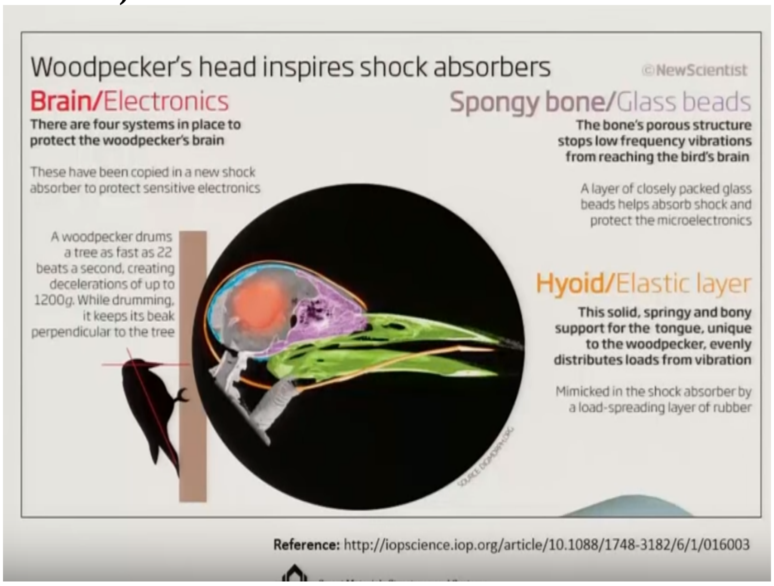


Well, as you know I earlier I told you that you can use various types of springs or dampers ok springs or dampers or viscoelastic materials which works partly as a spring and partly as a damper or, Pneumatic suspension. So can use these type of things. That means you have to use them as an insertion between the source and the system. So that the vibration from the source does not get transmitted to the system and many times you know that this like a very common anti vibration mount you will find in which you have rubber.

So this works like a damper and you also have the metallic inserts here and this is serving 2 purposes one is that it forces the rubber or it enhances the energy dissipation in the rubber and the other thing is that it also works like a good spring candidate and so then there are stands which we can fix it.

So essentially you can use this type of a system in terms of a combination of a spring and dampers you can say and for vibration isolation from a noisy source to the system So this is with the help of we call it viscoelastic material based isolation and we will later on talk about more about this kind of material properties.

(Refer Slide Time: 08:36)



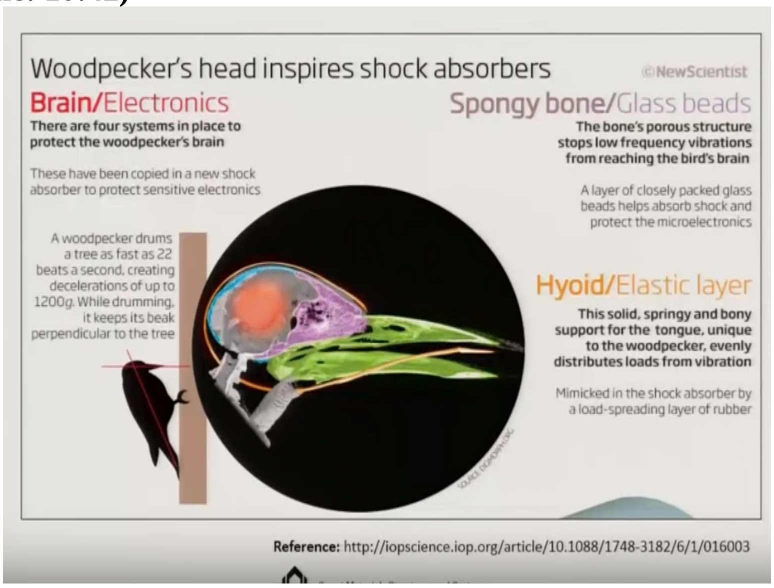
Now, I will bring you to very good example which is the example of a wood pecker's head which inspires shock absorption. Before that I actually explained this part to you Let us just see a wood pecker in action.

As you can see here that this is a wood pecker which is hitting on a stain of a old tree. Now it has see how working on this particular tree. And you jus note down that it has a very sharp beak. In fact, the beak is very rigid. So first of all it is choosing a very suitable spot. Ok. Where possibly you know it is good for its beak and you see now it has actually choosing this part.

Ok. And it is chiselling out the wood bit by bit. Ok. And the entire purpose is to build a small hole and a nest inside so that it can lay eggs etc. And you see how effectively it is removing the wood in order to make a very nice hole and which can be use in the form a nest for the wood pecker. This particular thing of course cost a wood pecker a lot because if you you know really follow the type of number of times.

It actually does this is quite enormous shock and as well as it is a very fast process and everything it is doing by endangering its brain. The nature must have done something in order to save it brain So now that you have seen that the wood pecker has made beautifully this hole. Let us go where to see what are the things that this wood pecker has done in order to save itself.

(Refer Slide Time: 10:42)



So let us see the strategies that the woodpecker has actually taken in order to save itself and its head and yet continue with the beautiful way of actually you know of making holes in a state solid state.

See you may find that this beating frequency could be something like 20 to 30 kind of 20 to 30 hedge or so and the deceleration is 1200 grams because the beak is striking the stain and it has to stalk the entire force and it has to do the entire same thing if it continuously vibrates then the hole will not be done in a nice manner.

Now in order to save the wood pecker from the brain damage the way the nature has designed the system there are couple of things which are very interesting that one is that it has given it a beautiful spongy bone structure. The spongy bone structure such that it can actually absorb the shock much of the shock the beak itself accounts very rigid.

And the tongue is connected to the elastic all around in such a manner that the load gets very uniformly distributed all over the skull. Not only that between the brain and the skull you always see that the small gap that is provided by the nature so that the brain matter does not get disturbed when the wood pecker is actually going to hit the wood at such a tremendous speed.

Now one of these the spongy bones that indeed works i just want to show you with the help of a very small experiment.

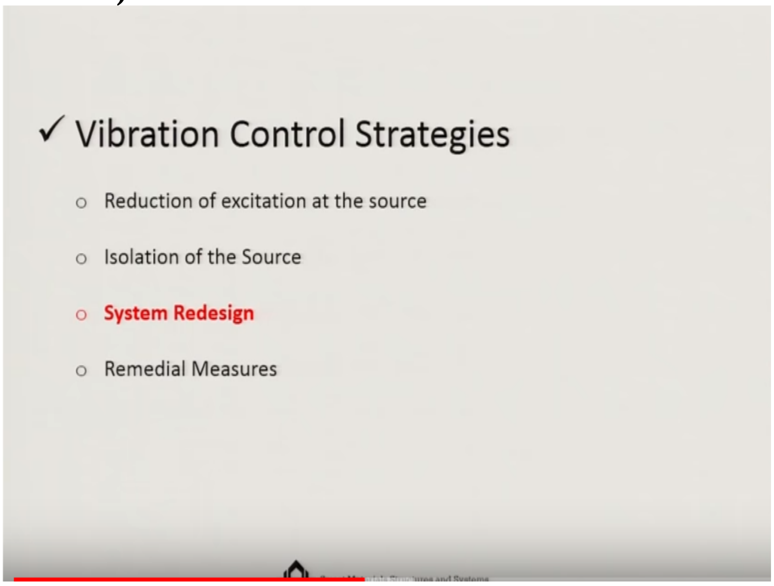
(Refer Slide Time: 12:58)

What we have in front of us are actually 2 glasses one glass is empty and another glass i have filled it up with the small glass marbles ok. Somewhat i have tried to like you know make an imitation of the kind of a spongy bone system that an woodpecker will be having. Now if i hit this one in which there is this kind of glass pieces absent you just see what is the sound that it is producing. So you can see that there is a distinct ringing sound is coming from this glass.

You know and this sound is continuing because there is no way that this energy is dissipating into the system. Now in the second case you have the glass beads here. Now if i hit it with the same intensity you can hear the thud sound which is not at all ringing like this. So what it means is that whenever i am striking this the vibration the mechanical energy is not able to excite the air inside rather the energy is getting dissipated because of the friction between these beads in all these beads.

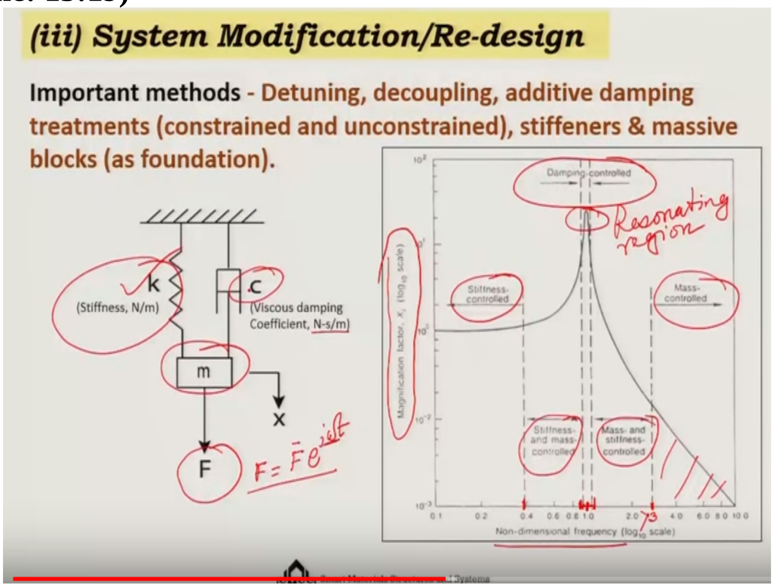
In fact that is dissipating the entire energy so that is the strategy that this woodpecker take in terms of the spongy bone so that the vibration gets isolated and the vibration does not travel from the beak side to the brain matter. So we have seen how this woodpecker have been able to you know absorb the shock work as a beautiful shock absorber the entire structure is designed in such a manner that there is a good isolation of vibration that is possible in the system.

(Refer Slide Time: 15:11)



Now let us go to another way of vibration control. This time we will talk about system redesign. Let us see how we can do this system redesign for controlling the vibration.

(Refer Slide Time: 15:19)



I earlier told you that any system vibrating system generally has 3 parameters the mass M, so this is the single degree of freedom system. The stiffness K and which is measured in terms of Newton per metre and the damping constant let us say the viscous damping C then the viscous damping coefficient is Newton second per metre. So this is the single degree of freedom system which has the 3 parameters stiffness mass and damping.

If you really look at the first of all the response of the system is subjected to a harmonic force F and let us say F is the harmonic force something like F bar e to the power of j omega t. So that the harmonic excitation giving to this single degree of freedom system and if you plot the non dimensional frequency versus the magnification factor which is the ratio of amplitude of the system and what will you find is that up to about 0.4 so the at the peak frequency the non dimensional frequency is unity.

So after 0.4 you would see that the response of the system or so to say the magnification factor is purely controlled by the stiffness, stiffness factor. We have to keep this point in our mind. Later on i will derive this to you right now we will keep this point in our mind. So that means until and unless excitation frequency omega reaches a level where it is more than 40 percent of the natural frequency the vibration control by stiffness itself.

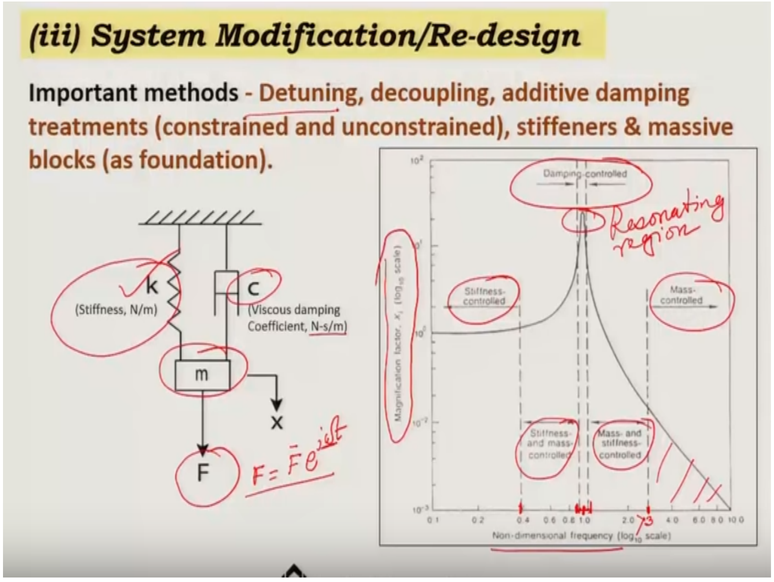
So we have to modify the system property i will not touch the mass i will not touch the viscous damping coefficient i will only modify the stiffness of the system.

Beyond that from 0.4 to somewhere very close to unity generally up to the point it is controlled by both stiffness and mass in both the sides. And between the half of the points that is this region it is actually the resonating region where it is damping controlled so the resonating region between the 2 half of the points always is actually damping controlled.

And once again beyond the value of about 3 or so greater than 3 this region onwards there is a the response is actually is mass controlled so that is also actually interesting if it is a very high frequency excitation beyond the peak frequency in that case neither stiffness nor the damping will actually help us in the terms of controlling the vibration.

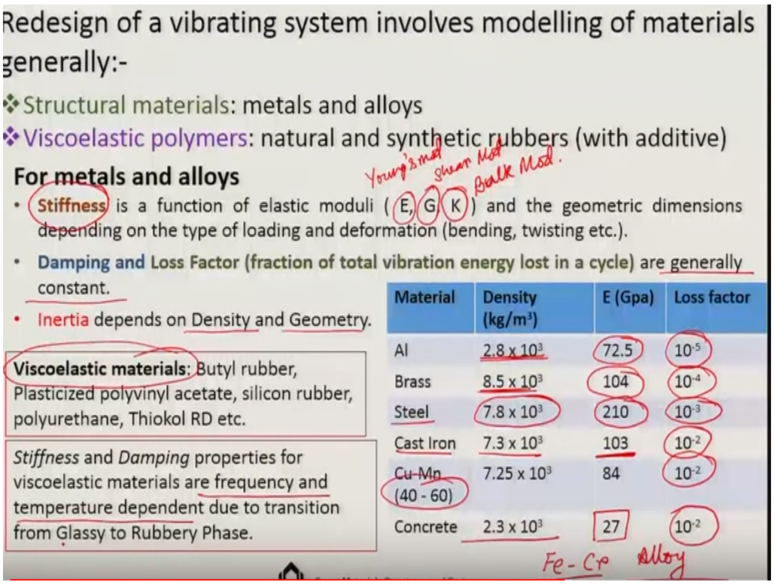
But only the mass of the system will help us in terms of controlling the vibration. So wherever we go for system modification we have to keep this point in mind that at what point of frequency excitation we are talking about if it is small then it is stiffness if it close to resonance then it is damping if it is beyond a certain point then it is mass

(Refer Slide Time: 19:01)



In between we have positions where we have mass and stiffness controlled now to do that to implement that there are certain strategies that one can do like detuning decoupling or lets spent of additive damping treatments which can be constrained or unconstrained then stiffeners and massive blocks such as foundations or you know water tanks etc. So these are all various strategies of system modification but the basic facts we have to keep in our mind now let us see that you know how we can.

(Refer Slide Time: 19:39)



Do these in terms of structural materials are in terms of viscoelastic polymers so structural materials like metals and alloys stiffness of course you can change and how you can do it if you change the modulus of the elasticity or the sheer modulus or the bulk modulus. So these are the 3 things right. So this is the elastic modulus or young's modulus. And then G is our sheer modulus, and k is our bulk modulus So by actually you know changing eg, or you can get a change in terms of the stiffness for the metals.

You can also change the damping and the loss factor by choosing the suitable material and for the metals once if you choose this material generally remains constant. Right. That means it is not a function of the most important thing the temperature. Because the temperature is the one parameter in which one that fix particularly the polymer sand the viscoelastic materials.

The other thing is of course in a high frequency region etc wherever the mass controls the response then you can actually control the density and the geometry of the system. So to give you an some kind of a idea like aluminium it has the lowest density in terms of a damping material that is used. But its loss factor is very low. If you consider brass it has actually higher density and its loss factor is also very low. No wonder that is why brass is used in terms of musical strings.

Where it does not have you know high loss factor that is why it is used. And in terms of modulus of elasticity Aluminium's modulus of elasticity is 72.5 degree giga pascal whereas brass is about 104 so it is slightly stiffer than the aluminum. If I go to steel, then the density is will be higher than aluminium about 7800 kg per cube. Modulus of elasticity is about 2 times high so that there is gain in terms of stiffness and also you will gain terms of the loss factor because this is of the order of 10 to the power of minus 3. So which means in comparison to the aluminium you will hundred times more energy dissipation if you consider steel.

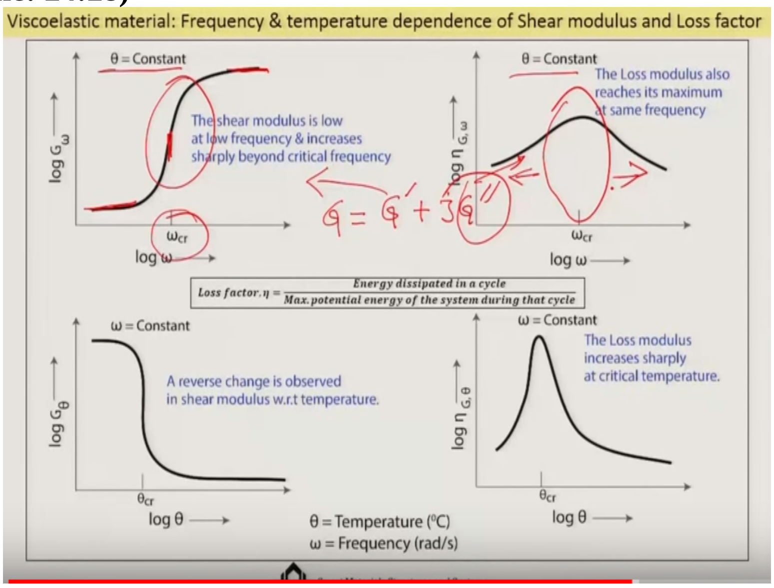
If you can go for cast Iron, you will get a little bit of weight advantage. It is about 7300 kg per meter cube. Its modulus of elasticity will come down which means the k the stiffness will come down but the loss factor is ten times better than the steel Its about ten to per minus 2. If you go for copper manganese 40 60 ratio of an alloy you get nearly the same kind of the thing better part from the cast iron is that cast iron is more breakable but this is better more ductile than that.

If you can use concrete, then the density is about the same level of the aluminium. Modulus of the elasticity is not very high and the loss factor you will get of the same level as the cast Iron or copper- manganese alloy. So we can see that metals up to a certain extend it can be used in terms of damping material and also in terms of particularly in terms of the high stiffness because most of the metals have high modulus of elasticity.

In fact, one of the metals which is used today is an alloy of Iron and chromium It is called fe-cr alloy ok. which is having a much better loss factor. Now in comparisons to these if you to enhance the loss factor for that you have to go to viscoelastic material. But the only problem in viscoelastic material is that their property will not even fix. They are frequency and temperature dependent.

Due to their change in the configuration from glassy to rubbery phase. So if you want to gain in terms of the loss factor stiffness, of course will not gain much because modulus of elasticity is not very high. But if you want to gain in terms of the loss elastic factor, you have to loose in terms of this temperature dependence and frequency dependence of the property.

(Refer Slide Time: 24:28)



If I look at it that how it changes you would see that if temperature remains constant which is teta equals to constant in the top 2 cases. The you know there are 2 modular retain here . One is shear modulus the real modulus also and the other one is the loss modulus. So the elastic modulus G I will later on explain the details of it is divided into 2 part. G prime and G double prime ok. So G prime you know will approximately varying this manner whereas the G double prime which is the loss modulus will vary in this manner.

So what you will see is that when the frequency of excitation is low in that case the shear modulus is low and as the frequency of excitation is increasing at a particular point there is a sharp jam that would be initiated and then at a high frequency the shear modulus will be quite high. Now that is particularly the real part of the shear modulus Why is it so. So it means that this polymer actually a pretty damn is the excitation frequency goes beyond a particular range which is known as omega critical and the critical you know frequency for the particular polymeric material.

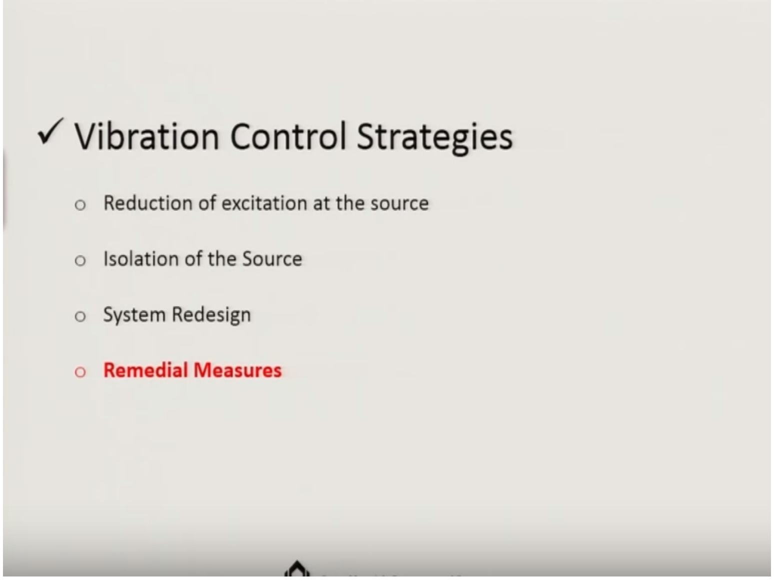
In fact, it will have since it will not be able to dissipate energy much beyond that level so what you will see is that around this region of omega critical you will see that the loss modulus that is G double prime would increase suddenly. But before this and after this that means if an excitation frequency is much lower than the omega critical or much higher than the omega critical then at a constant temperature you will see that the loss modulus is not very high.

So what it means that at the glass transition temperature which actually is same in terms of the kind of the mobilisation of the change of the polymeric material that happens at close to that particular frequency but around that frequency level ok and the glass transition temperature and this critical frequency are actually have an equi balance between the 2, but around that level this chain mobilisation occurs so the loss factor increases enormously.

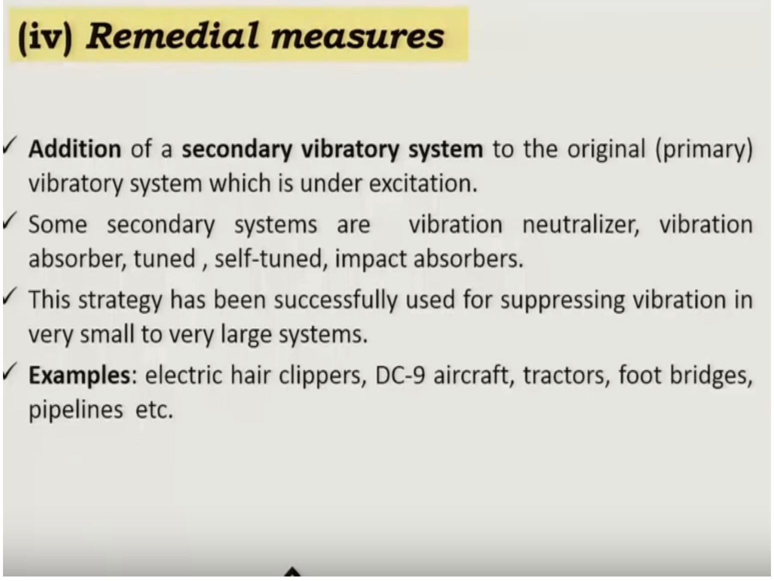
But before and after it will not be very high. Now if you change the temperature you would see a similar picture in the sense that increase of temperature is equivalent to decreases of omega. So as the omega decreases and the temperature increases you will get a similar picture. That means at low temperature you will see that it has a high shear modulus but as the temperature increases the shear modulus becomes quite normal.

Which means the stiffness is changing in terms of the loss factor of the damping at low temperature once again the damping is not very high but beyond a particular temperature the glass transition happens and the chain mobilisation occurs, so you will get a good loss factor here and after that temperature once again the loss factor drops down. So this property we have to keep in our mind in terms of the modifying the system parameter.

(Refer Slide Time: 28:20)



(Refer Slide Time: 28:21)

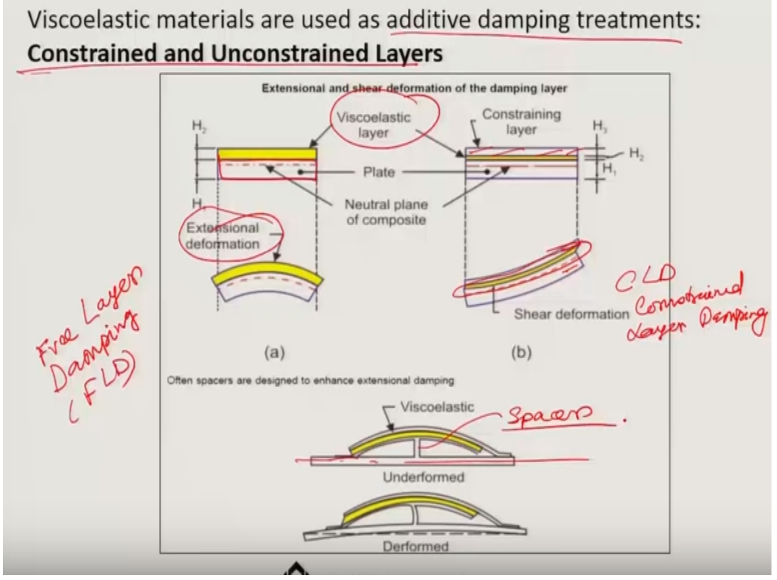


Finally, I will come to the case of vibration control strategy in terms of the remedial measures. So let us see some of the examples of it. Now when we are talking about remedial measures we are actually telling that you know in terms of isolators you have already tried and is not giving you a good result system modification in term of change of mass change of stiffness change of damping you have tried it but it is not giving good results then the thing.

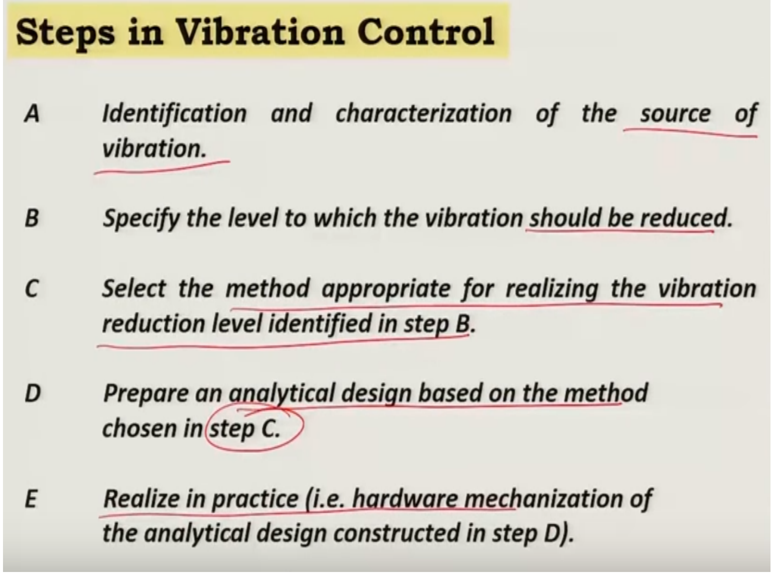
You can try is to add a secondary vibrating system to the original vibrating system which is under excitation. Such secondary vibrations systems are called vibration neutraliser, vibration absorber. You know tuned self tuned impact absorbers. There are many names of it. IF you remember I have shown in this course in the introduction of this course is talked (())(29:27) bridge damper which is a kind of a secondary vibrating system.

This strategy has been very successfully used for electric air(())(29:29) discine aircraft tractors foot bridges pipelines etc. So that is about the use of the remedial measures of a system.

(Refer Slide Time: 29:31)



(Refer Slide Time: 29:30)



Next you know if you think of other viscoelastic materials that can be used for system modification you can go for additive damping treatments like constraint and non-constraint as so you can have a viscoelastic layer you can have just above a plate as freely air. We call it as the freely air damping.

So this is also known as free layer damping or FLD, as you can see that here the loss is taking place mostly because during the extensional deformation in the viscoelastic material. The energy takes place. On the other hand, if you put a constraining layer on the top of the viscoelastic material then there will be a unequal shear between the 2 layers and that will create a lot of shear in the viscoelastic material and that is known as the CLD of the constraint layer damping.

One can actually show the in most of the cases constantly damping works better than the failure damping. 2 sometimes you know make it even better you can actually keep it farther away from the neutral axis by giving a spacer. So this is one of the strategy that is taken such that its effects get even far the magnifier. But this is what you know we do in terms of adding layer but you may also think of it as a system modification.

So what are the systems in the vibration control? The first step is identification and characterization of the source of vibration. You have to keep this point in our mind. Then we have to specify the level in which to be reduced See we may say ok you may bring down the vibration to 0 but that makes no sense.

All engineering design talks about some kind of a quantification. So that level based on what system we are talking about is to be first of all defined. Then at step C we will talk about the method which will be appropriate for realising the vibration reduction level which is identified in step B. And then we have to prepare an analytical design based on the method which is chosen in step C.

And finally we have to realise in practice. Ok. So that is what say in the last part in terms of the vibration control. So this is the overall steps that we have to take in terms of the vibration control.