Vibration Control

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Module - 4
Vibration Generation Mechanism
Lecture - 6
Damping: Models and Measures – II

Hi, this is Dr. S. P. Harsha from mechanical and industrial department, IIT Roorkee. In the course of vibration control, we are discussing about the vibration generation mechanism. And in that, we discussed mainly about the source classification, the unbalanced rotor in the rigid or flexible form or even you see, whatever the external sources are there you see in the various forms like, from the misalignment or any looseness or something, we discussed about.

We also discussed about you see, when the self excited kind of vibrations are there in which you see, the system is robust and there is no defect as such. But also you see here, through some internal resonance or some kind of you see the negative damping effect, the system may be unstable or the huge excitation is there in the system.

In the last lecture, we discussed about the damping model in which we discussed mainly about that, how the damping can be computed particular. Because it is a very, this complex phenomena and it has a significant effect on the vibration generation and the same time you see here, the, to control the vibration excitation, the damping is one of the important term. We discussed mainly for the damping evaluation for single degree of freedom system.

For a continuous systems, in which you see you know like the discrete features of the mass damping and the stiffness are not being featured out. And also we discussed about, the damping in the multi degree of freedom system. In which you see here when the systems are you know like, having more than 2 or 3 degrees of the orientation where, the clear we can say the spaces are there, in which the variations are there. So, the basic mechanism in which the computation of the damping is evaluated we discussed about.

In this lecture also, this is the second part of this vibration generation mechanism, in which the damping models and the measures are there. And in this, we are going to discuss mainly about that, how the effective way to compute the material damping or you see here, what are the basic problems when we are just going for the material or any kind of damping in the beginning, when the new machines are there. And when you see, it is being running for say you know like the years and years then, how we can compute effectively the damping, a complex damping phenomena specially in the vibration generation mechanism.

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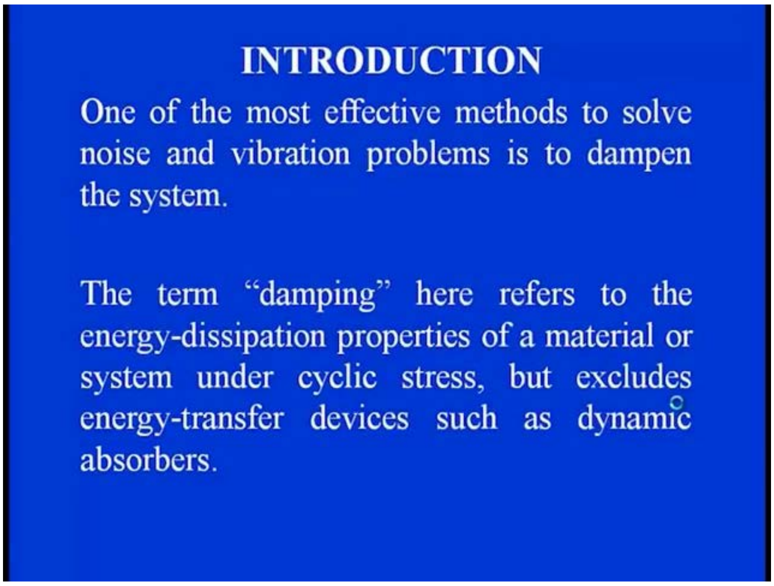

So, one of the most as we discussed you see, one of the most effective method to solve the vibration features or the vibration we can say effect, it just to include the damping part in the system. So, the term damping refers that energy dissipation as we discussed already, that how the energy can be dissipated from the source of excitation. So, here also you see we are trying to refer the similar you see, the energy dissipation property of a material or the system, when it is under the cyclic loading or the stress. And you see, we just want to transfer the energy through various ways like using the absorber, using various of the features of the damping part.

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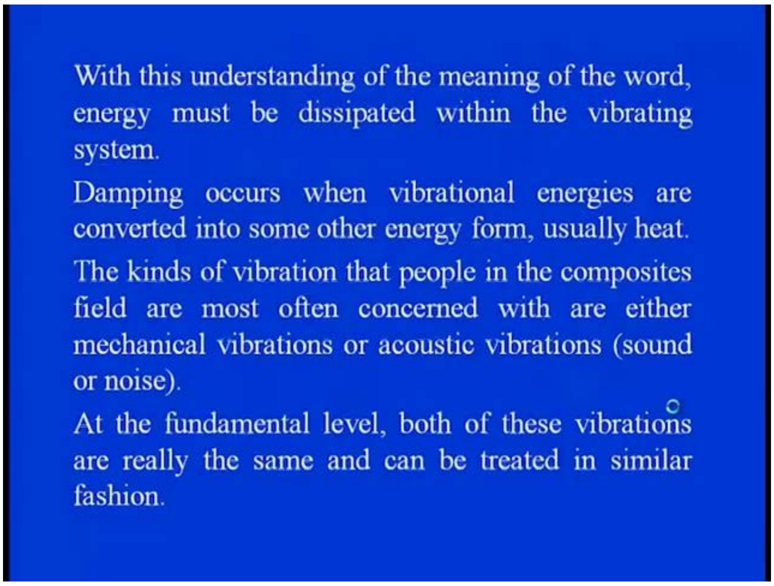

So, with the understanding of the meaning of this damping word, the energy must be dissipated within the vibrating system and this damping occurs when the vibrational energies. Because you see, when the excitations are there the energy is being rapidly transforming. So, these vibrational energies are converted into some other form of the energy and sometimes the basic feature of this energy is coming out, from the source is in the form of heat. And the kind of vibration, the people in composite field are often concerned with either mechanical vibration or acoustic noises or such kinds.

Because, we know that when you have the composite features at the interfacing, we know that there are closed compact features and these molecules are always you see providing some kind of support in the rapid transformation of that. But not exactly like, when we have a single metallic surface.

So, at the fundamental level both these vibrations are really same and can be treated in a similar fashion like, you see either we have a solid plate or in the composite feature. So, if you are talking about the damping even, when we have you seen you know like, in the, in the composite feature say the middle layer or at some layer. You see here, we have a good absorbing feature, absorbing materials are there even after that also, the excitations are always been transmitting through that.

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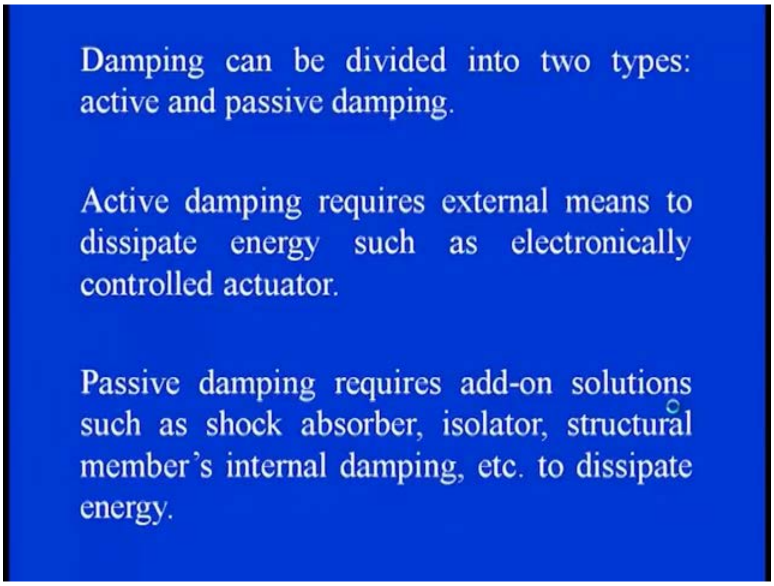

So, if we broadly speaking about the damping, there are two main categories in the damping, the active and the passive damping. The active damping always requires an external means of some kind of source through which, the dissipation energy can be controlled or can be transmitted. Such as electronically controlled actuators or even some kind of the smart structures are there through, which we can control the vibration excitation using these, the smart materials, in which you see some electronic features are there in that.

Second is one of the, we can say, the material to be applied there or some kind of you see we can say, a passive part. So, the passive damping is something which there is a requirement of add-on solutions such as, the shock absorber, some kind of isolators or the structural members, internal damping, which always provides the domain to transfer the dissipation energy, just to dissipate that energy.

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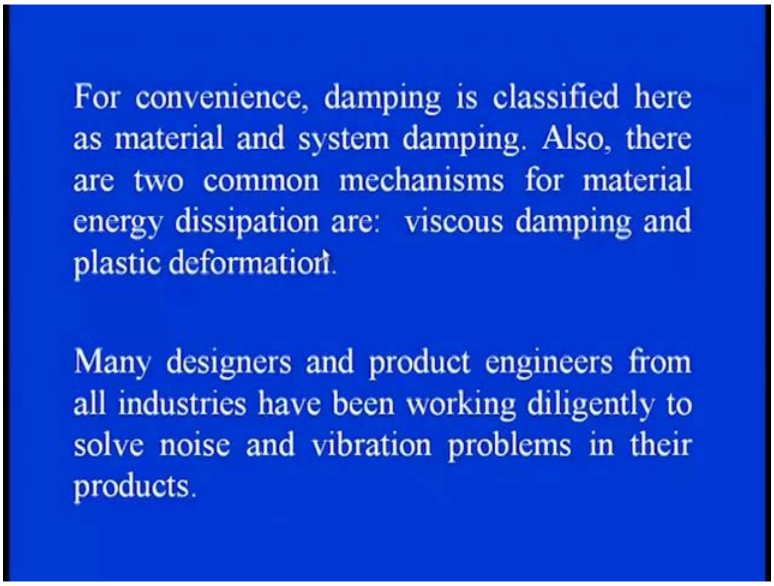

So, for convenience we can simply classified the damping as the material or a system damping. And also, there are two common mechanism for material damping, in which you see the energy dissipations are there, that is the viscous damping and other is the plastic deformation. So, these are the two common mechanism which we are going to focus just to provide that, how material damping is really, actuated on the system.

So, when you are talking broadly about the damping, we know that many engineers and the product designers there, from every kind of industry always being working diligently to solve this vibration problem, for there, for their products. Because, they know that you see here, if we are not able to control the vibration then, the various properties are directly affected by this.

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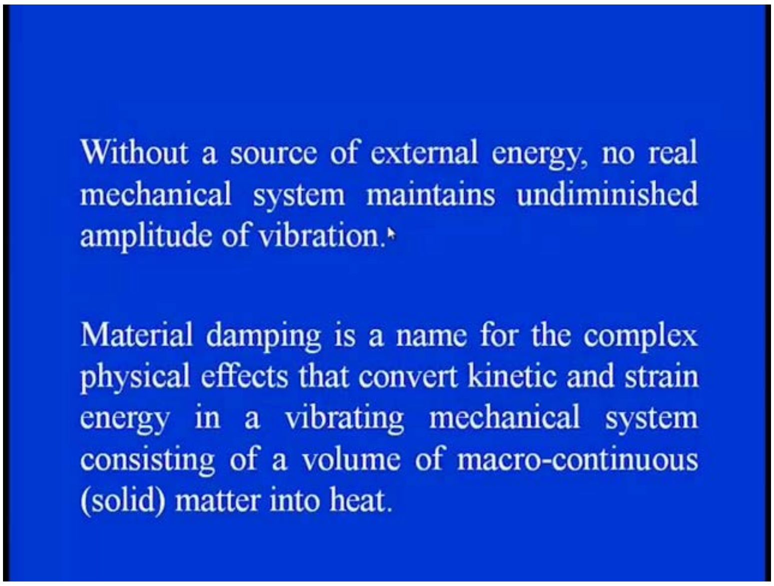

And without a source of this external energy, no real mechanical system maintains undiminished amplitude of vibration. So, this is you see here, the undo effect which is always being there for any kind of whether, the manufacturing feature of the machine or maintenance or any kind of supporting machine as well. And the material is one of the important part, which plays a critical role even in dampen the vibration amplitude, as we discussed.

So, material damping is a name for complex physical effect, which converts the kinetic and strain energy. Because, you see when the molecules are moving the same time they are under deformed condition. And you see in these two conditions, we have the kinetic energy and the strain energy in the vibrating mechanical system, which is consisting of a volume of macro continuous solid or we can say, all these molecules of the matter. And then, they are converting or they are transferring this entire system into the heat. So, this is what you see when you are just talking about some kind of a macro feature of the material damping we need to see that, how the kinetic energy and the strain energy is being transformed and these energies are being converted into the heat at the microns level of the surface.

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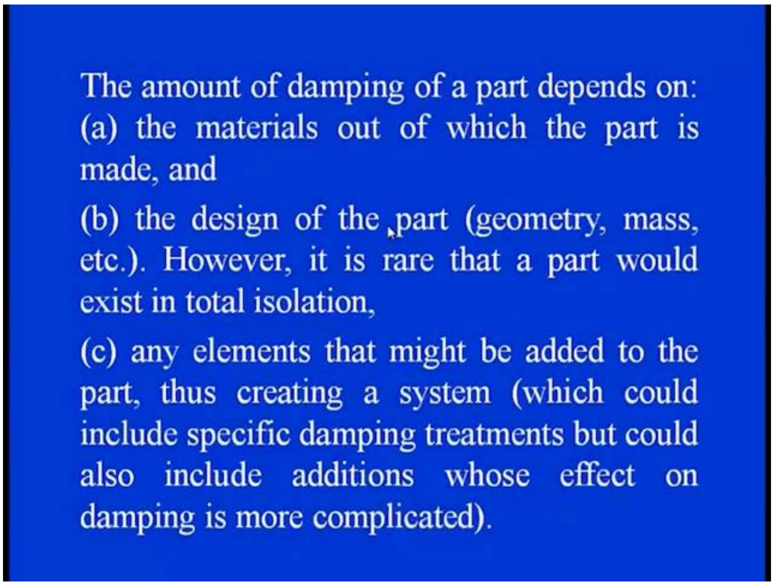

So, the amount of this damping is a part of the entire damping and it depends on the material out of which, that part is to be made, in which you see the object means, the part of that object, what exactly the material is there. Second, for that object part, the design of that part in terms of the geometry because, accordingly you see you know like the distribution of the material is there. Second the mass because, that is also one of the important segment through which we can configure the measure of content and then, accordingly you see all the layers arrangements are there. So, both are the important aspect one, the geometry and second the mass.

So, this design is specifically important. However, it is a rare you know it is a rare part, that we can say that, the absolute isolation is there means, the total isolation can be formed in that. And even the third feature, which you know like, just contributing towards the amount of damping is, any element that might be added to this objective part thus creating a system, which we can say that some of the part through which some more damping can be added by various ways.

So, these you see you know like when we want to dissipate the energy these are the three parts, which can directly you know like we can say, contributing for the amount of damping. So, when we know that the damping, even which is coming out from the material is having somewhat more complex phenomena. And when we just want to see, that you see through the material or the micro structure, when the kinetic and the strain energy is being transformed into heat. Then, how the molecules are really playing you know like, in that transformation of energy. So, these we now we would like to discuss first, that what exactly the damping properties of the materials are?

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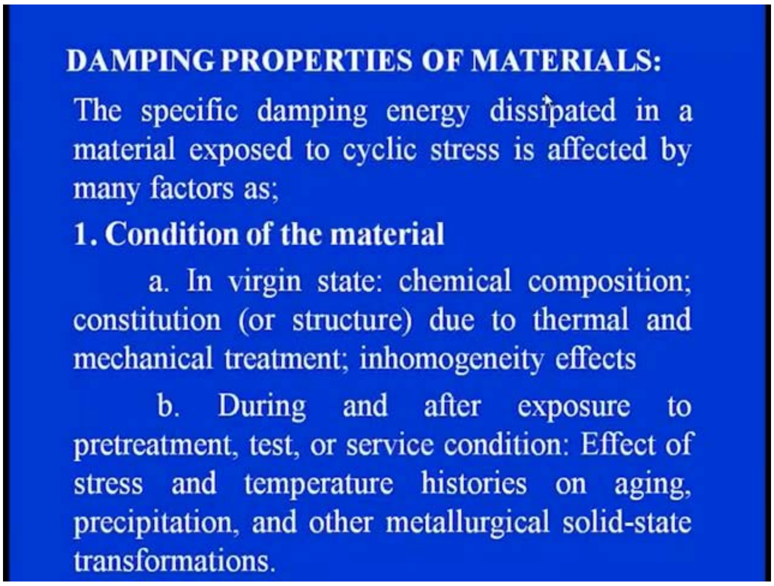

In which you see here first, there are various factors which have directly, we can say we can coupled or which have directly impact of the specific damping energy, which is being dissipated through the material. And you see, you know like when they are exposing under the cyclic stresses, these factors are closely associated in such kind of activities.

The first factor is the condition of material, as I told you in the beginning of my lecture that, when we are buying the new material then, certainly you see all the fibers, which we sometimes you see, we are assuming that the homogeneous material isotropic feature of the material and all blah blah things. They can be absolutely valid, but as we move further with these kinds of all the operations every day, then we cannot retain all the properties of this micro structure, with these fibers, as we are assuming in the beginning way.

So, the condition of material is very important. So, in that first at the virgin state the chemical composition, the constitution that means you see, what the structure is due to the thermal and mechanical treatment, the in homogeneity effects are there. So, it cannot retain in its own structure at, as it has to be because of these heat generation. Second, during and even after the exposure to pretreatment test or even the, whatever the you know like the, operating or the service conditions are.

The effect of this cyclic stress, whatever is the fatigue stress is there, because of this vibration feature and the temperature histories on the aging precipitations. Means, you see when we are just you know like, absorbing such kind of heat, at the easy effect and other metallurgical solid state transformation related to the micro structure of this material is clearly featuring out that, there is a clear change, there is a clear transformation of all these micro structure and the green boundaries and even the green sizes.

And accordingly you see the damping properties, which are being evaluated according to the material itself, is not being same as the things are moving, with the time. So, you see here in these kind of things we need to take care that, what exactly the conditions. And that is why you see, the pretreatments are always being necessary to check it out, you see the microstructure and you see their formation at an appropriate level.

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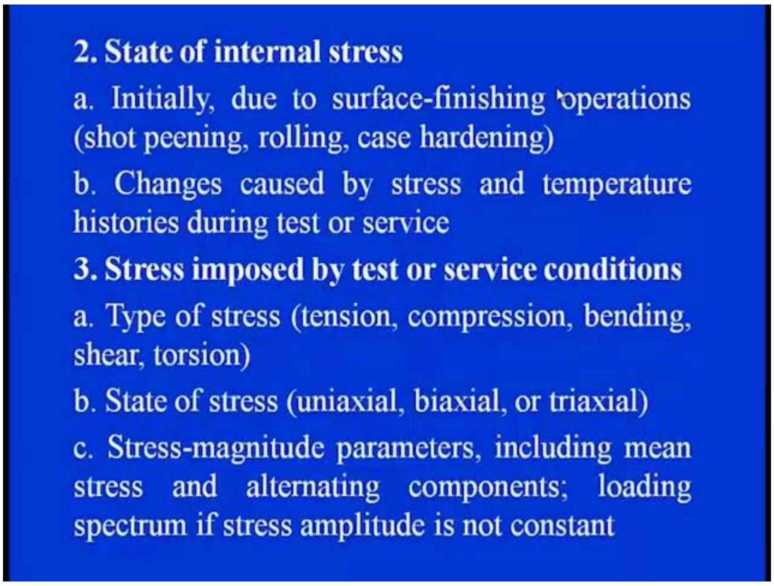

Second factor is the state of internal stresses, as we know that the stress is a internal phenomena and it always being associated with the molecular structures. As we apply the load, we know that this is something the intensity of the internal resistances. And it is being well settled with the entire structure of the material, in the entire feature in, in the internal feature.

So, initially due to the surface finishing operations like, the shot peening rolling or any case hardening. Certainly, you see the internal stresses are being checked out and whatever changes. Which are being caused by the stresses, these all cyclic stresses or the temperature variations during the test or even during the service conditions, straightway affecting the entire structure of the molecule. So, these are the two conditions in which we can say that, the state of internal stresses cannot remain same, after sometime within the material itself. So, certainly it has a clear impact on the material damping.

Third factor is the stress imposed by any service conditions or the test condition like, the various types of loading conditions and the result of these loading conditions, the various types of stresses like the uniaxial stresses, the tensile or the compressive one. The shear stresses or the torsion stresses, the bending stresses, which is nothing but the combination of these two, the tension and the compression. So, when such kind of you see the type of different cyclic or fatigue loading is there or these conditions are there, certainly the material properties is straight way affecting.

Second the state of stress whether, the stress is in the uniaxial, biaxial or triaxial form, as per the tensile nature of this stress or even the stress magnitude parameters like, the mean stress or any alternative components, which are being there due to loading spectrum, if the stress amplitude is not constant. So, these service conditions are always being creating some kind of problems or some kind of we can say, a direct effect is there of these service conditions on the damping feature. So, this is one of the significant factor in the material part, which can straight away affecting the damping property of material.

And in that also, some of the characteristic of stress variation, with respect to the frequency and with respect to their waveform. Whether, we have sinusoidal feature, impulse features you know like, we can say any other part, in which you see, you know like some abrupt changes are there, some non stationary waveforms are being created. So, they have also you see the direct impact on this and in this also, service condition one of the environmental condition like, the temperature variation. The variation not only right from day to night, but also see the moisture conditions along with this.

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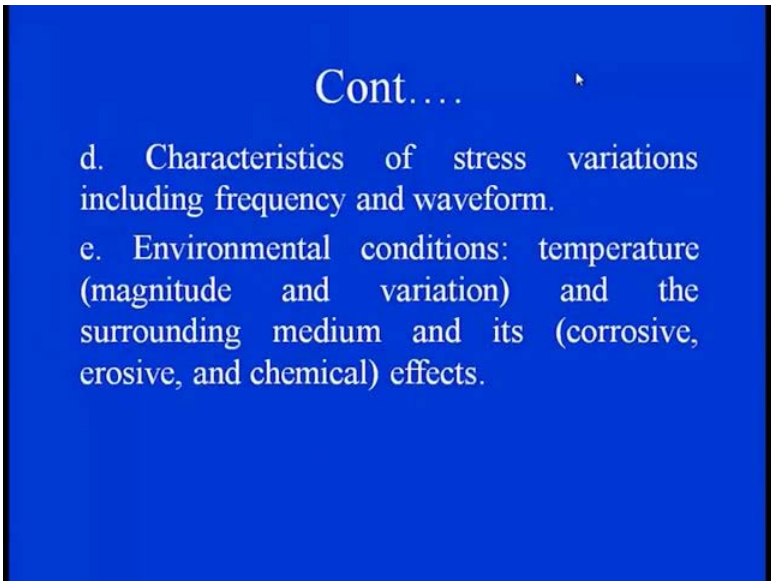

Then, what exactly the surrounding medium is? Like the corrosive, erosive or any chemical effects. So, they have also interacted with the material and the microstructure of this material so that, the entire damping featured are being just different as you know like, we are working with the initial material and with these conditions of the material conditions. So, you see here when we are just looking towards all three factors, we know that in one way or either, these factors have direct impact on the damping of the material.

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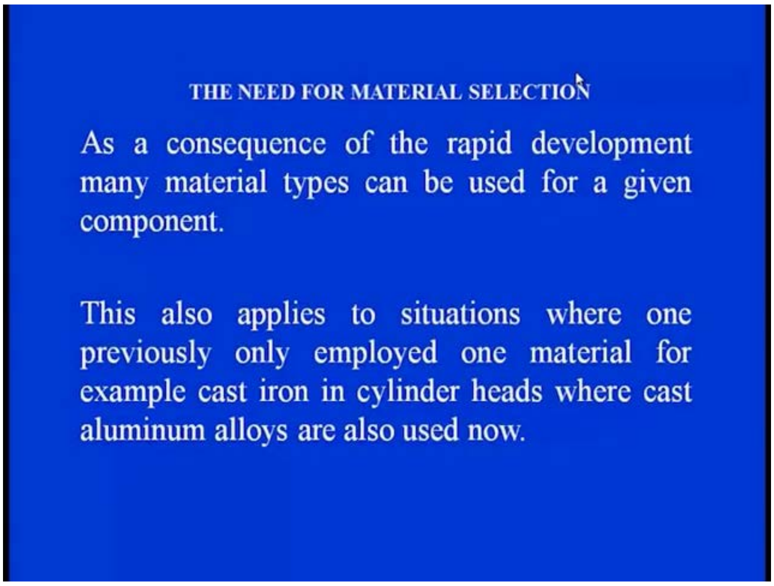

And the need of material selection, is one of the essential feature in this because, as a consequence of the rapid development of various materials means, the metallic feature of that. The composite features of that, the polymer feature of that, the ceramic feature of this. So, there are various you know like we can say, a developments are there not only you see, the refinement of the green structure of the material, during the processes and well adopted you see, you know like, the microstructure feature. But also you see here, the variety of materials are being added to enhance the specific properties of the base material to any matrix or we can say, some kind of the composite things.

So, when we are talking about the composite even we can say that, whether it is the metal matrix composite, the polymer matrix composite or ceramic matrix composite. What is the epoxy material and what is the basic material in that? And you see here, you know like when we just want to reduce the inertia, we know that, we can reduce the mass so that, we can you know like. And the same time you see just, we just want to provide the similar kind of strength and they can also absorb the heat and various things you see. So, we just want to optimize the various parameters and which is the basic need for material selection.

So, when we are talking about all these properties of the material and you know like, the researchers are playing with the material properties with their own constitutions, with their own you see here, with the addition or subtraction of any part of it. The same can also be applied to the situations where, the damping is being a requirement. Like, the basic you see we can say, one of the good example in this is the cast iron cylinder. We know that, when we are going towards the cast iron, it is one of the harder material and the same time it is a good damper as well.

So, the cylinder heads which are being always framed by the cast iron now, it is a straight replacement by the cast aluminium alloys. So, you see here we are getting a similar kind of the physical properties, but the mass which is one of the important we can say, factor for inducing the inertia forces can be straight way reduced so that, we can at least you see automized and we can you know like, economized our fuel feature in the cars. So, what I mean to say that even for any vehicle or such things, these materials are providing very good thing.

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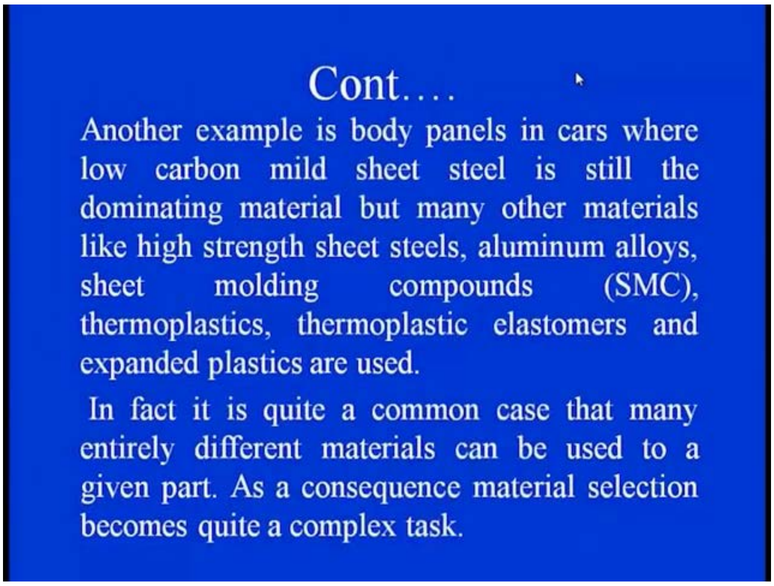

Even we can take next example, like the body panels in the cars where, low carbon mild steel sheet is still dominating material. But many other materials like high strength sheet steels, aluminium alloys, the sheet molding components like you see, you know like in which the SMC materials are there.

The thermoplastics and even though thermoplastic elastomers, which are being you know like sometimes providing a good elastic properties, along with the expended plastic, plastics can also be used in these body panels of the cars. And that is why you see here, in many of the cars you will find that all these materials which I named it, have their own specific applications according to the service condition. And all other conditions, which are being there the surrounding part. So, in fact it is quite common case that, many entire different materials can be used in the given part or some part is being replaced by that.

So, it is very, very complicated to say about a single material that, this is the need of damping and this is the perfect replacement of the material is, because it is a very complex task to figure out the appropriate material, can provide the appropriate damping for whatever the kind of excitations in the systems. So, you see here many researchers still you know like, like you see now a days the graphene sheet. In 2010 you see, you know like the noble prize was there for the graphene sheet, evaluation to the Japanese and the American scientists.

And through this graphene sheet you see here, various carbon nanotubes, the single wall carbon nanotube, multiwall carbon nanotubes, which are been injected to form the various composite materials. And they are not only providing the less weight, but the significant mechanical properties, because of their Young's modulus, because of various other properties are create, a significant as compared to this metallic materials.

So, you see here this is one of the significant feature that you, it is a the feature in the computation of the damping is, it is a really complex task to say, an appropriate way to you know like, that this is what my solution for such kind of problems. Now you see here, in this chapter, but that does not means that you see we cannot discuss about that. Now we are going to check, what exactly the models which can be framed based on the various material property, which can be used as you know like, the damping feature in the material damping.

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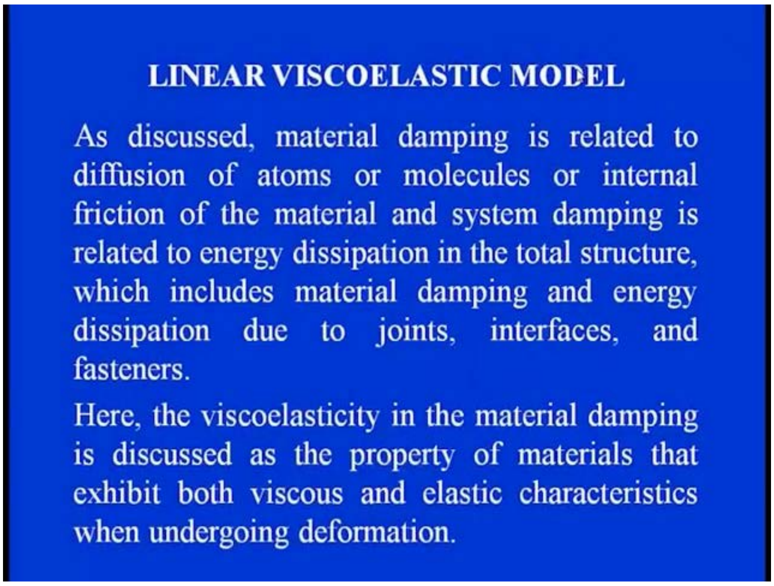

One of the basic thing is, the linear viscoelastic model. So, as we discussed the material damping is related to diffusion of atoms or the molecules or any internal friction of the material. And the system damping is absolutely related to the energy dissipation in the entire structure, when the kinetic and strain energies are being clearly associated with the atoms, through which the diffusion is being occurred or the molecules you see here. And through that, the heat generation and the transformation is there, which in term we can say that the dissipation of energy. So, not only you see it includes the material damping but also, the energy dissipation due to joints, the interfaces or the fasteners, straight way coupled with these internal feature of the material.

So, the viscoelastic in the material damping is nothing but the property of material, which exhibits the viscous and the elastic character of the material, when it is undergoing certain deformations. And that is how you see here, the kinetic and the strain energy because, the localized deformations are there and because of the, this energy transformation, the molecules which are under, you see the load condition or the stresses they are being deformed.

And then, because of this deformation the strains are being formed and because of that you see here, the energy is being you know like, taken out you know like, from the source. So, in the viscoelastic we are going to focus on the two aspects of it. First, the viscous feature of that, and second the elastic character of the material itself, under the loading condition.

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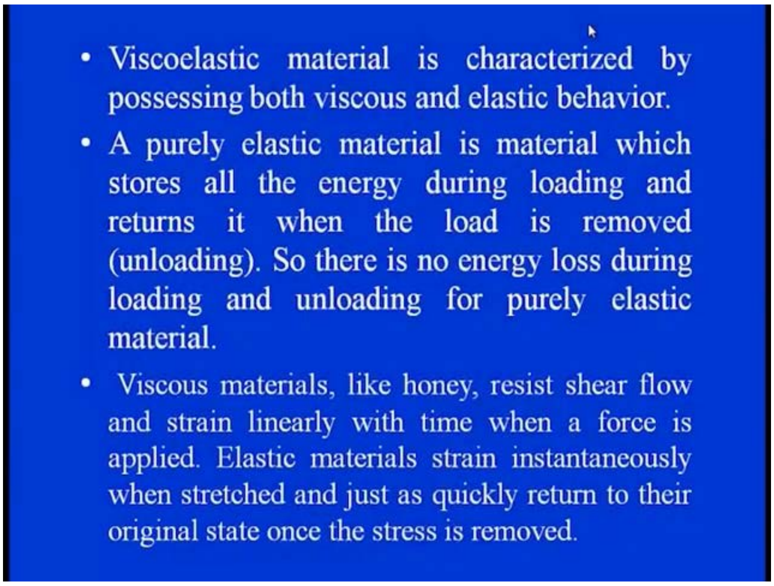

So, we can say that the viscoelastic feature of the material can be characterized by possessing both the viscous and elastic behavior. And we need to check it out both simultaneously, at the point of application. So, when we are trying to characterize these, we can say that a purely elastic material is nothing but which stores all the energies, during the loading condition. And you see here, it releases the entire energy when the load is being removed like unloading conditions. So, it is like you see the spring or any elastic feature, in which we are always assuming that the stress is proportional strain or the force is proportional deformation or Hooke’s law or something like that, which has the linear propagation in releasing and absorbing the energy, just like the spring is.

So, there is no loss of energy during the loading and unloading condition, when we are talking about purely elastic behavior of the material. And the same time, when we were trying to add the viscosity because, it is a viscous and elastic material, property in the viscoelasticity. So, viscous material like honey, like any kind of you see you know like, the fluid resistance feature, it just shows the resistance which is nothing but in the shear natures. So, resist a shear flow and the strain linearly with the time.

So, you see here these materials are always showing the resistance against the flow and the same time you see here, the strains which are being you know like, drawing there itself, which always a you know like, we can say very linearly with the time, when the force is being applied there. So, you can see that the elastic materials, the elastic materials, in which the strain is being there, when they are stretched. And just like you know like, we can say that, when they are coming back to these original situations, there is a clear means if the unloading condition, there is a clear linearity in that.

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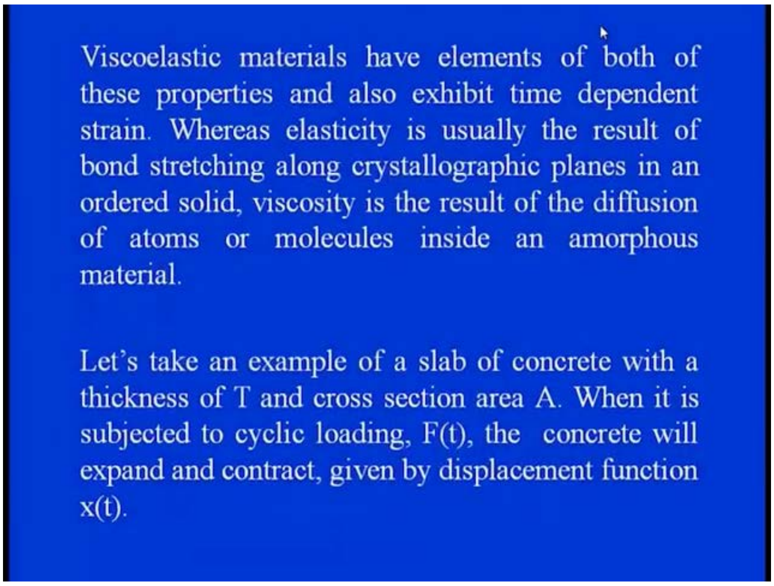

Now you see here, we need to coupled both the features together, in which the viscosity which is nothing but acting as a frictional factor in the solid like you see. And the same time you see here, the elastic feature of those molecules can be coupled together, to provide a perfect feature of the viscoelastic material.

So, we can say that these materials, the viscoelastic materials have the elements of both these properties and they are exhibiting the time dependent strains. This is one of the important feature, remember that they are showing both the properties the viscoelastic materials, in which you see the molecules which are containing all that part. But they are always showing the strain, the deformation with the time dependent part. Whereas, the elasticity is usually the result of the bond stretching, along the crystallographic planes, in an order of the solid formation and the viscosity is the result of diffusion of the atoms or the molecules, in an amorphous material.

So, you see here this is what the inter facial structure of these viscoelastic material, that we have the elasticity which is mainly, we can say due to the bond stretching along the crystallographic plane. And we have the viscosity, which is mainly due to the diffusion of the atoms or the molecules in an amorphous material. And these are you know like two, you know like we can say the two different properties coupled together and form a real property of the viscoelastic material, which always shows the time dependent strain.

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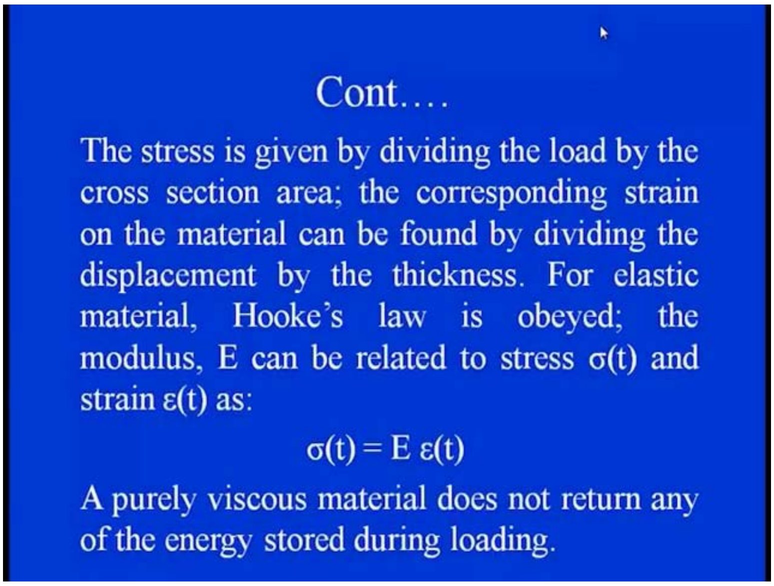

So, now we would like to compute this thing. Now we are taking one say, we have the concrete slab whose dimensional features like the thickness is t and the area is A. And when you see we are simply applying the cyclic loading to featured out you see, you know like the vibration part and that cyclic loading part is F of t then, we can say that the concrete will expand or you know like, we can say contract. Due to this cyclic force, A is x of t.

So, when this displacement is like that, we can say that the stress is, which is nothing but equals to load per unit cross sectional area. And they are corresponding strain, in which you see, we know that whatever the deviation is there, in terms of the displacement by the thickness. We can simply put, since it is a elastic behavior in these materials so, we can say the Hooke's law is very well valid. So, the stress which is a time dependent part sigma of t is proportional to the strain, which is also you see the time dependent phenomena, as we discussed already for the viscoelastic material.

So, the sigma of t is proportional to epsilon of t or when we are, when we are making equal then we have the Young's modulus of elasticity. so, when we are talking about purely viscous material then, certainly we know that a purely viscous material does not return of, does not return any of the energy stored during the loading condition. So, this is what you see you know like, one of the feature of these material is, because of the combination of these two.

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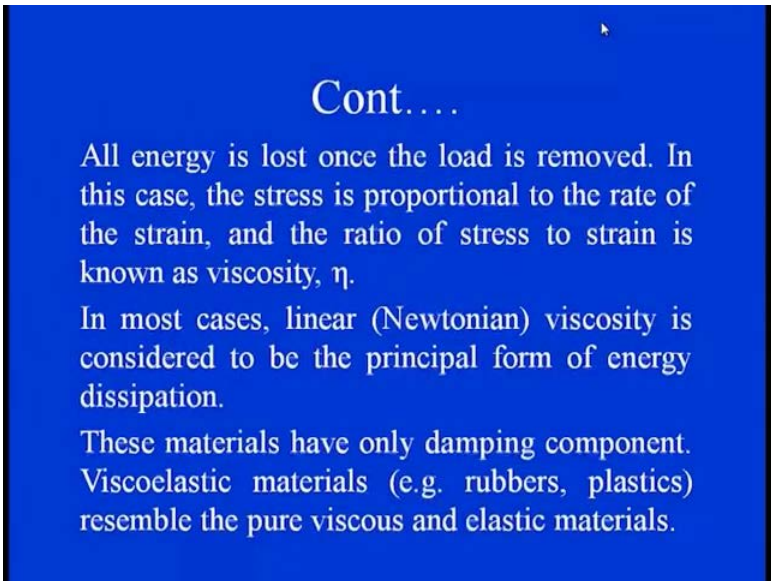

And all the energy, which is lost once the load is removed, then we need to framed that you see here, how the energy is being lost or how the viscosity is playing a critical role in forming of that. So, in this case the stress as we discussed here, the stress is proportional to the rate of strain and the ratio of the stress and strain, which we are generally saying that the viscosity eta.

Then, we need to find out that how the relations are being setup at the molecular structure, because of the crystallography or the other features of this. Then we can, first of all we need to check it out linearity so, we can say a linear viscosity or the Newtonian feature of the fluid, in which the Newtonian viscosity is there, is simply considered to be a form of the principle, form of the energy dissipation.

So, these materials have only damping component in which, the damping is coming out at the molecular level. So, viscoelastic materials like the rubber plastic or any kind of that, always resemble the pure viscous and elastic materials, in which you see here, both the kind of mechanisms are playing together and forming the entire feature of the damping.

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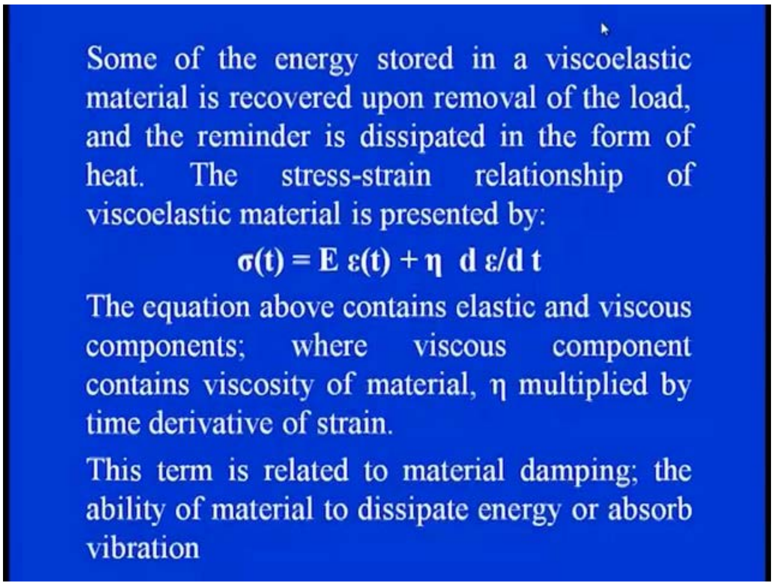

So, some of the energy which is stored in the viscoelastic material is recovered, upon the removal of the load at the reminder is the dissipation of the energy. And it can be you know like, transferred in term of we can say like, dissipation in term of the heat. Now, we can add this feature in the stress strain relation, for the viscoelastic material that is sigma of t, which was earlier you see as the elastic material feature is E into epsilon t.

Now, since the viscosity is also one of the important feature, in the viscoelastic material. So, sigma of t is nothing but equals to E into epsilon of t plus eta, the rate of strain d epsilon by d t. And this equation consist of both the feature elastic and viscous feature, in which you say the viscosity is coming in terms of eta and elasticity is coming in terms of E Young's modulus. So, we can say that, this is absolutely showing viscous elastic material damping where, the ability of the material is to absorb the energy and to dissipate the energy together. So, this is one of the unique features of that.

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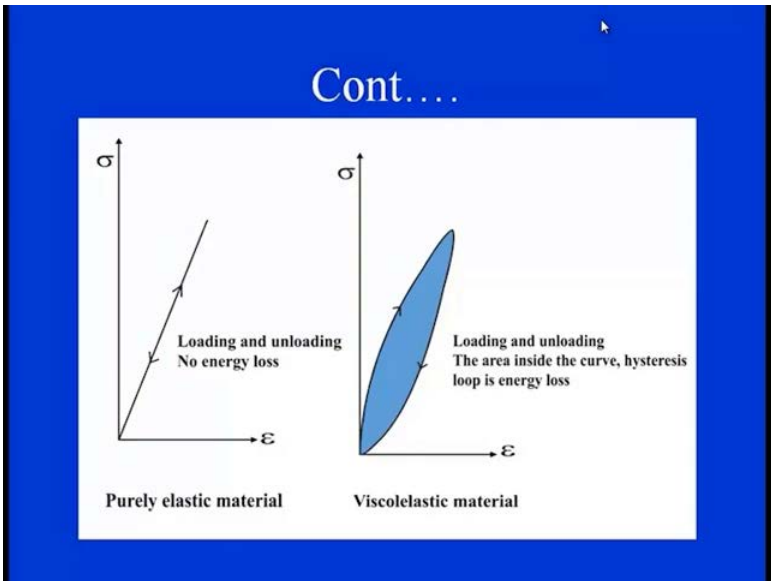

As you can see on the screen that, when we are talking about purely elastic material the stress is proportional to strain as we discussed already. So, loading and unloading conditions are pretty straight way, no storage of energy, no loss of energy rather. But when we are talking about the viscoelastic material, the area you see, this is perfect area where you see, there is a clear loss of the energy. We are saying that this is the hysteresis loop. Because, you see some of the energy is being remained, even the unloading conditions are there and that is the beauty of the viscosity. So, entire energy is not being dissipated in terms of heat.

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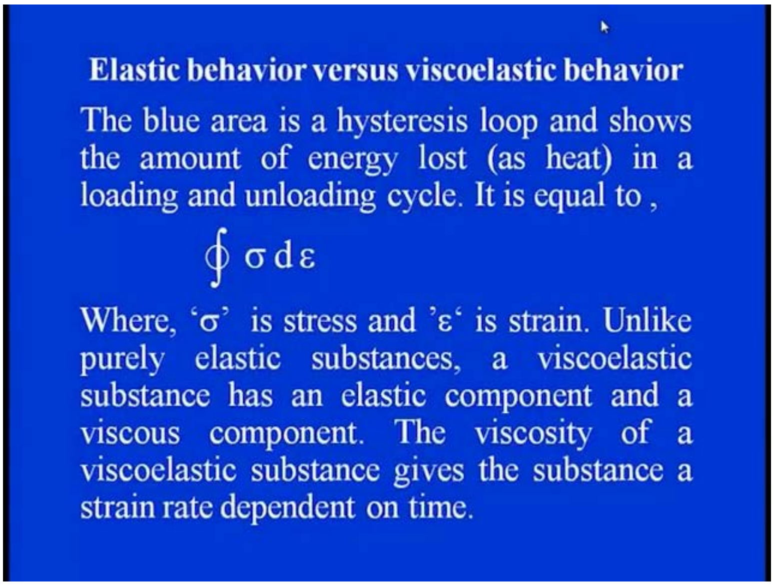

So, when we are talking about the elastic behavior versus viscoelastic behavior, then you see here in this graph, it was purely a blue diagram, the blue area you see which I was showing nothing but the hysteresis loop. And the hysteresis loop is nothing but is the amount of energy loss or whatever you see, the heat or any form in loading and unloading condition. And we can say that, this is nothing but equals to the cyclic integral of sigma into the, whatever the rate of change of the strain.

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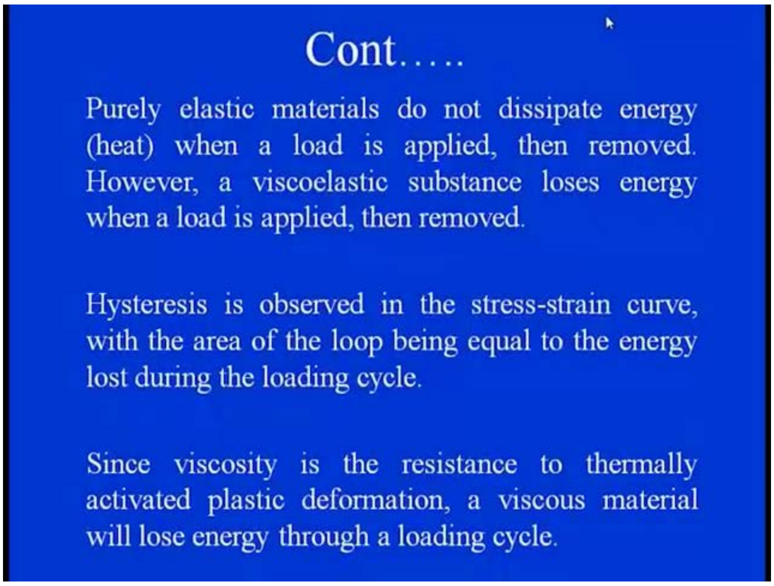

So, sigma into del E so, we can say that whatever the change in the strain into sigma is giving for the entire cycle is giving that, how much energy is being lost during loading, unloading condition. So, like you see the elastic substances, viscoelastic substance has an elastic component and the, this viscous component and this viscosity is basically responsible for having such kind of this energy loss. And this always gives the substance of a strain rate dependent on the time.

So, we can say that, you know like when we are talking about pure elastic, know, you know like the energy dissipation is there, in such kind of things, when loading unloading conditions are there. So, hysteresis is clearly observed in the stress strain curve and this area is giving the amount of loss of energy. And since viscosity is the resistance to this thermally activated plastic deformation, a viscous material will always loss the energy, in every loading cycle.

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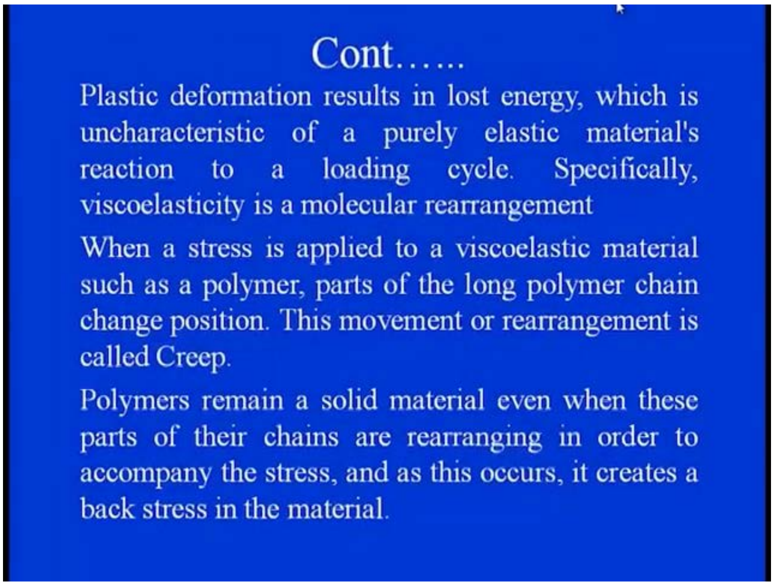

And this plastic deformation results in the loss of energy, which can you see, you know like characterize that, when you have a purely elastic material. And when you have you see, the plastic deformation in the viscous feature of the material, in every cycle there is a molecular rearrangement, in such kind of devices. Because, the heat is being you know like added to, these materials in every cycle. And when the stress is being there or the force is applied to the viscoelastic material, like the polymer or ceramic anything you see here. The part of long polymer chain is just changes its position and this movement or the rearrangement, during every cycle along with the heat is called the creep.

So, this is you see the creep is the molecular phenomena and because of this plastic deformation or because of this viscosity feature, the inherent feature of the material provides these kind of the energy loss. And because of this energy loss or the heat associated with this material in every cycle, creating the creep part. And this is the rearrangement of all the molecules in the polymer chain or something.

So, polymer remain a solid material even when these part of the chains are rearranging, in order to accompany the stresses and as this occurs continuously, it creates a back stress in the material. So, sometimes we are saying that, even this is the pre stressed feature of that because, you see here all these stresses are closely coupled with the materials, as in every cycle this is being happening in the polymers.

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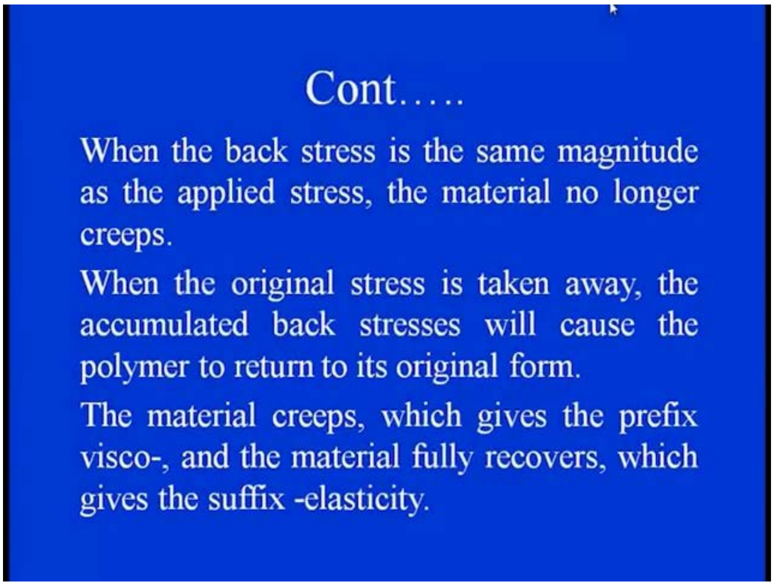

So, when the back stress is now, it is continuously increasing. So, when the back stress is the same magnitude as the applied stress, he material is no longer creep. And when these original stresses is being taken away, the accumulated back stresses will cause polymer to return into the original form. So, the material creeps which gives the prefix visco and the material fully recovers, gives the suffix elasticity. Again, the material creep is always giving the prefix to this visco, viscoelastic material, the visco and the material, which fully recovers after that is giving the suffix feature of the elasticity. So, we have the viscoelasticity in composition of the creep and the elastic feature of the material is.

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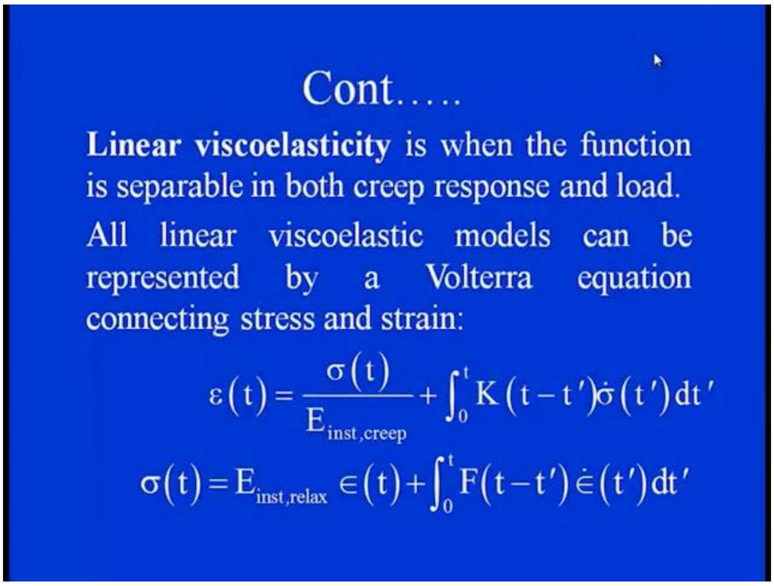

So, we can say that the linear viscoelasticity is nothing but the function of separable in both creep response and the loading conditions. And all linear viscoelastic elastic models can now be represent by, the volterra equations which is straight way connecting the stress and strain, along with this propagation in that. So, epsilon t is nothing but you see here the time dependent strain is equals to sigma of t divided by E, the E due to this creep part, particular at the instantaneous feature plus. So, this is one part because of the elastic nature, plus all the integration of this variation along with the thickness of that. So, we can say the K into t minus t dash into sigma of you know like, t into d t.

So, you see here we have when, the stiffness variation is there along the variation with the thickness at the small small segment, t minus t dash is a small segment difference into sigma t dash. Means, at that particular segment or the, we can say the small part, what is the stress component, the rate of stress is this. Or else, we can say that, the sigma of t is nothing but equals to the Young's modulus, instantaneous when the relaxing is there into epsilon t the strain at that point plus, whatever the forces which are basically creating this you know like, inducing the stress at that point.

So, the cyclic order 0 to t f of t minus delta t the force at that particular segment, epsilon dot t dash into d t. So, you know like for this volterra equation is clearly showing that, how the stress and strain can be calculated for the linear viscoelastic feature of the material. And these models are clearly showing the elastic and the viscosity features together, when the force transmission is there or else we can say that, the energy transformation is there you know like, which can create the dissipation and the heat phenomena together.

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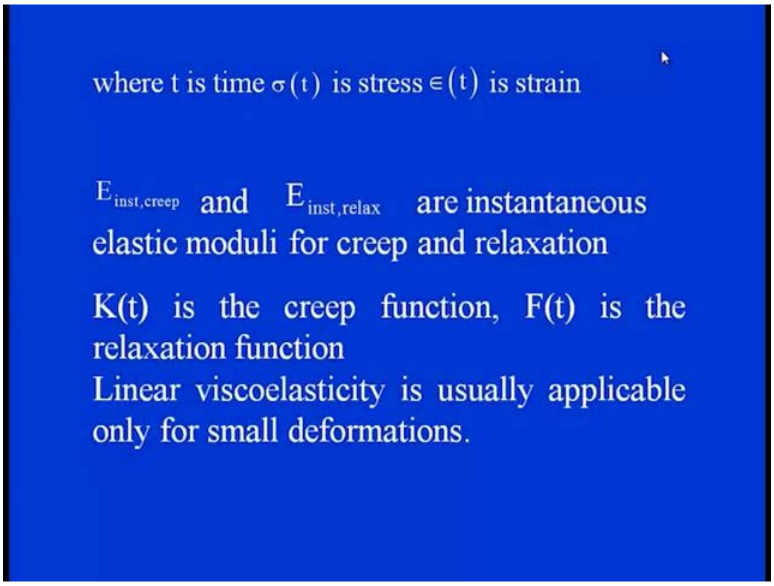

So, since we know that the stress and strain in the viscoelastic materials are the time dependent part. So, we can say the E instantaneous creep and instantaneous we can say the relax are nothing but the phenomena related to the creep part and the elastic part of the viscoelastic material. And we know that, when we are talking about these material, the K part which we were showing in that was the creep function and we know that, when they are just being derived, during the relaxation or during the, this one, the f of t is basically a relaxation feature associated with the stress and strain.

But again you see here since we know that, we applied these things to the small segment and then we are assuming that, this propagation is linear when we apply to the cyclic integral. So, this is one of the big assumptions that the linear viscosity is always being adoptable and applicable only for the small deformation where, we can sustain the linearity or the elastic feature of the propagation along with the viscosity. Because, this is one of the drawback that we are, when we are going with the, you know like the elastic feature and the, the, the viscosity feature. Then, it is hard to remain the linearity in the viscoelastic material property. So, we need to check it out these things. So, in other way when we are not assuming these things, we need to check it out what exactly the nonlinearity impact in the viscoelastic part.

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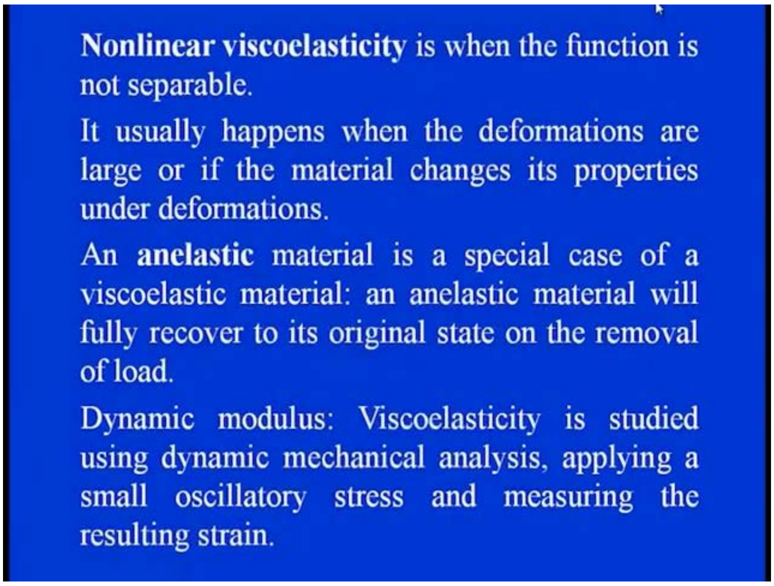

So, non-linear viscoelastic, viscoelasticity is when the function is not separable. Because, sometimes you see here the things are not as straight with the viscosity and the elastic feature and which is always being happening, when the deformation just crosses its limit or the deformations are large. Or even if the material changes its property under this deformation like, an unelastic material, which is always you see a special case of viscoelastic material. Because, it is fully recovered to its original state, on the removal of load and you see here, the viscous effect is playing a critical role in this kind of thing. And in that also you see here, one of the featured parts is the dynamic modulus.

So, viscoelastic property of the material or the viscoelasticity of the material property is always being studied under, the dynamic mechanical analysis, when we know that the cyclic loading or oscillatory feature of the loading is being applied. And the oscillatory stresses which has a small we see you know like, the, this small amplitude is always being there and resultant into the strain feature in that. So, we need to check it out you see here that, what exactly the, any, the inelastic material property and the dynamic modulus's are there in that.

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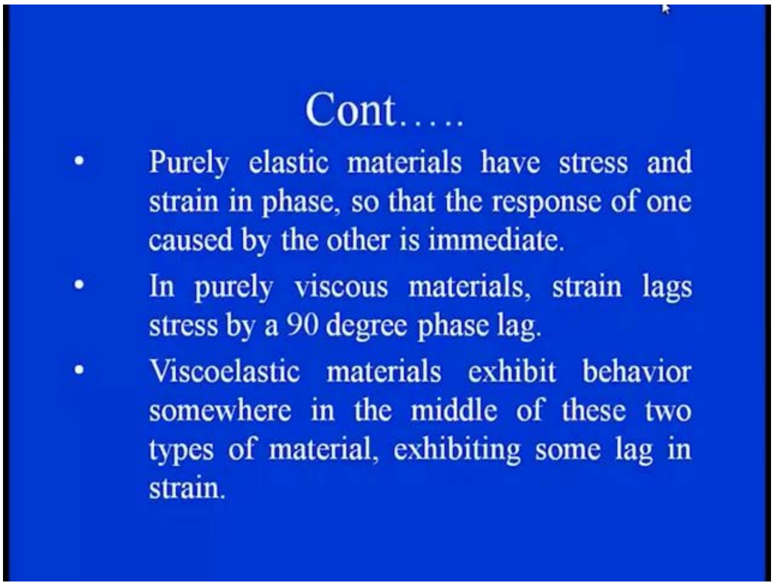

So, when we are talking about the purely elastic feature, we know that the stress and strains are in same phase and the responses of you know like this, is quite rapid and in the linear way. In purely viscous material, the strain is always lagging to the stresses, please remember when the viscous feature is being added to the material property, the strains are always being lagged to the stress by 90 degree with the phase angle. So, in the viscoelastic material we have the elastic material property with no phase difference, we have the viscous properties with the 90 degree phase difference between the stress and strain.

So, viscoelastic material exhibit the behavior somewhere in the adjustment of that, the middle way. When both the types of properties are you know like, creating their dominant features in that. So, we have some time you see you know like in between say, we can say, you know like, 40 to 50 degree you know like, the phase difference and even sometimes less, the phase difference between the stress and strain, because of the elastic and the visco and this viscous property of that.

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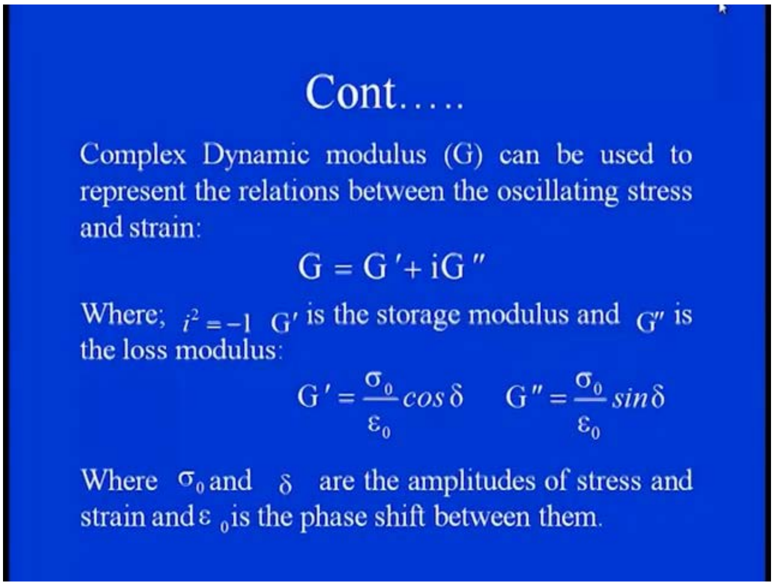

So, now you will see the, when we are talking about this we know that the complex dynamic modulus, with this viscoelastic property can now be represent using the oscillatory stress and strain feature. So, when I am saying that my dynamic modulus is G so, it has two component now, the G dash and iota G double dash where, G dash is the storage modulus and G double dash is the loss modulus. We can compute both, based on the phase and the phase differences.

So, when we are talking about the G dash, which is the storage material it is nothing but equals to sigma 0 by epsilon 0 cos delta and G double dash which is nothing but the loss modulus is also sigma 0 by epsilon 0 sin delta sigma 0. And we see, we can say epsilon the sigma 0 is the amplitude of the stress and cos delta or sin delta, the delta is nothing but the strain feature with the epsilon sorry, sigma 0 and epsilon 0 are the amplitude of the stress and strain. And the delta, which is cos delta or sin delta is clearly showing that, there is a phase difference exist for the viscoelastic material, because of this complex dynamic modulus.

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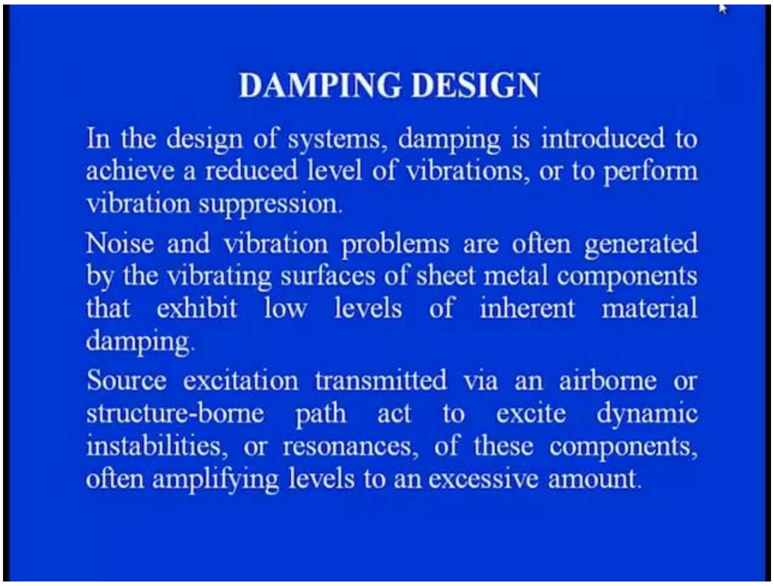

So, this is the basic we can say mechanism available with the damping feature of the viscoelastic material. So, when we are trying to design to damping, we know that the damping is basically therefore, reduction of the vibration excitation. We need to suppress the vibration and this is often we will find that, the sheet material which is always being there is you know like, as an, we can say the part of the product design is providing the transmission, a good domain of the transmission of the vibrations, because of the low level of inherent material damping.

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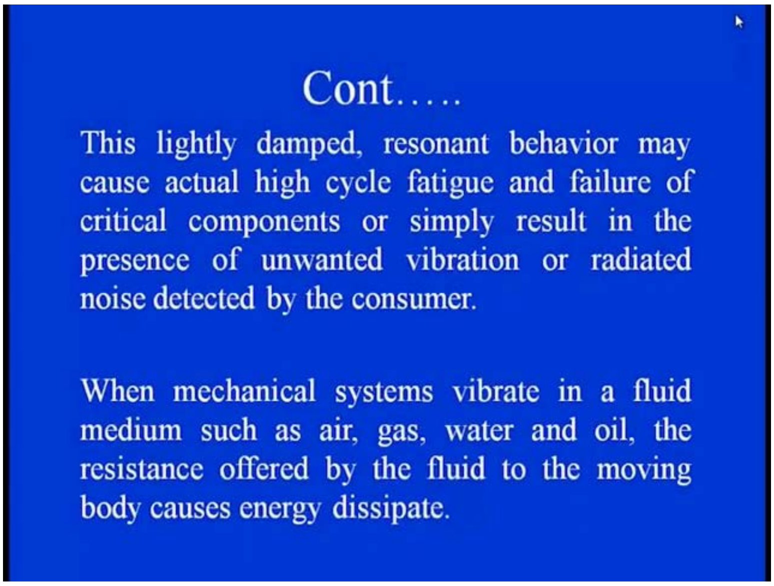

And the source excitation which is transmitted by airborne or the structure borne path, is clearly you know like act as an exciting feature in the dynamic instability, sometime or the resonances rather I should say, of these components. And you see here it will simply enhance the vibration excitation to the excessive amount of the energy level.

Because this lightly damped or the resonant behavior may cause, actual high cycle fatigue and the failure of these components. Or we can say that you see, it simply in the result of the presence of unwanted vibrations or we can say it is just providing the domain for the radiation of the noise, which can be detected, which can be detected easily by the receiver.

So, as we have seen that the large plates are always being wink under the high cycle fatigue or failure because of these, internal features. So, when the mechanical system is under vibratory condition, even under the fluid medium also, like the air gas or any oil. The resistance offered by the fluid to the moving body, is always causing the energy dissipation.

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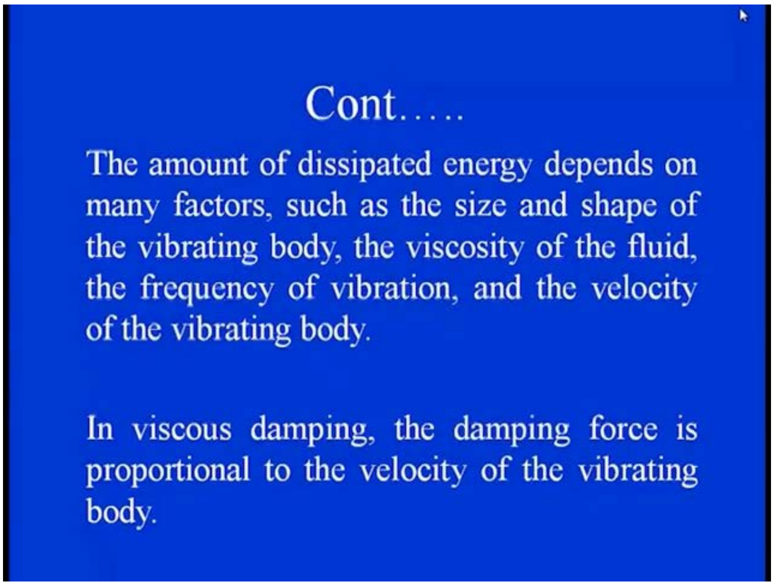

And the amount of this energy dissipation is absolutely depending on the various factors like the size and the shape of the vibrating body. The important feature which is a transmitting media is the viscosity of the fluids. Third is the frequency, At what frequency? What is the number of cycles, which are coming out in a unit time? And second you see here, how much velocity is there or the amplitude of that velocity of the vibrating body. So, in viscous damping we can say that since the damping force is absolutely functioning of the velocity. So, we need to check it out that what exactly the velocity of the vibrating body is.

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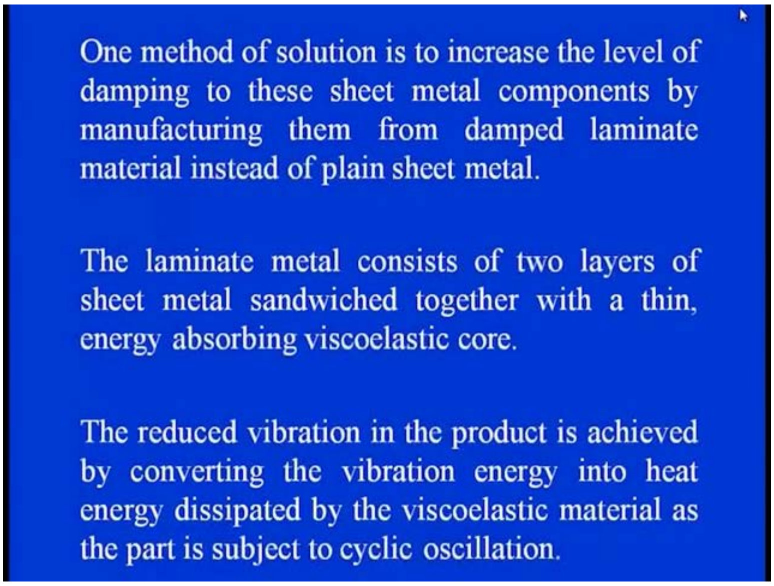

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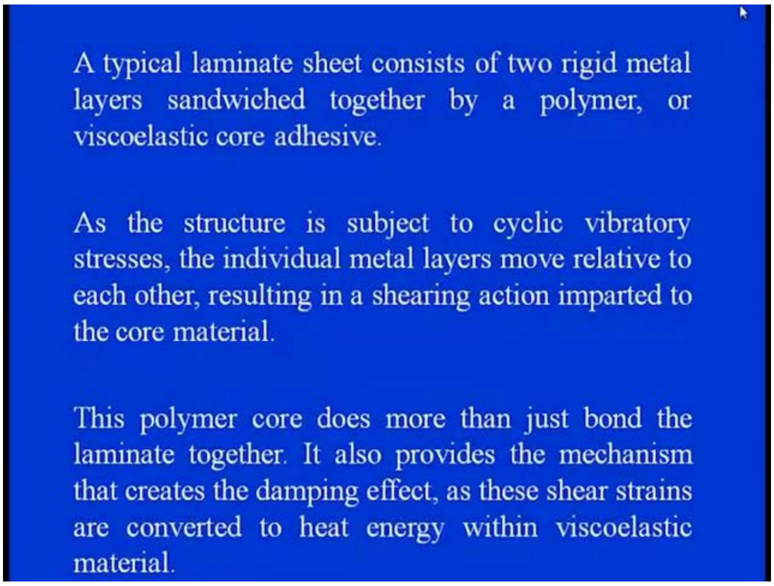

So, one method for solving such kind of problem is to increase the level of damping, either to these sheet material or the, an, any component of that or else we can simply put the damped the laminated material, instead of the sheet plate. The laminate, the laminated material can be having the multiple layers or even to the two layers of sheet metal, which is being sandwiched by a thin energy absorbing this viscoelastic material. And through that, we can reduce the vibration by converting the vibration energy into the heat energy, which is being dissipated by the viscoelastic material.

This you know like, the laminated sorry, the laminated chip plate can be again you see at, as not only the absorbing feature of the vibration excitation, but also see here it can remove the heat features of that. So, we can say that these sandwiches can be framed with the polymer or viscoelastic or any you know like the, core cohesives. And this polymer core does more than you see just, the bond laminated together, but also it provide the mechanism that creates the damping effect as the shear strains are being converted into the heat energy, within the elastic material. Now we can even use that, you see the same equations which we are using for various you know like the simple mass damper and the elastic systems.

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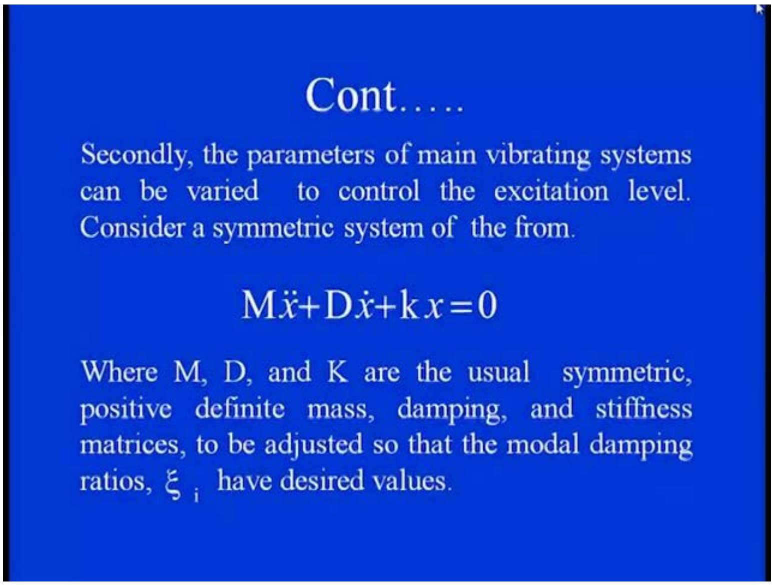

So, we have M x double dot plus D x dot plus k x equals to 0 where, we can say that all the damping stiffness and the mass matrices are being there. And we can get, the model damping ratios you know like, using these what the you know like, the damping is available and what is the critical damping which is to be required for this.

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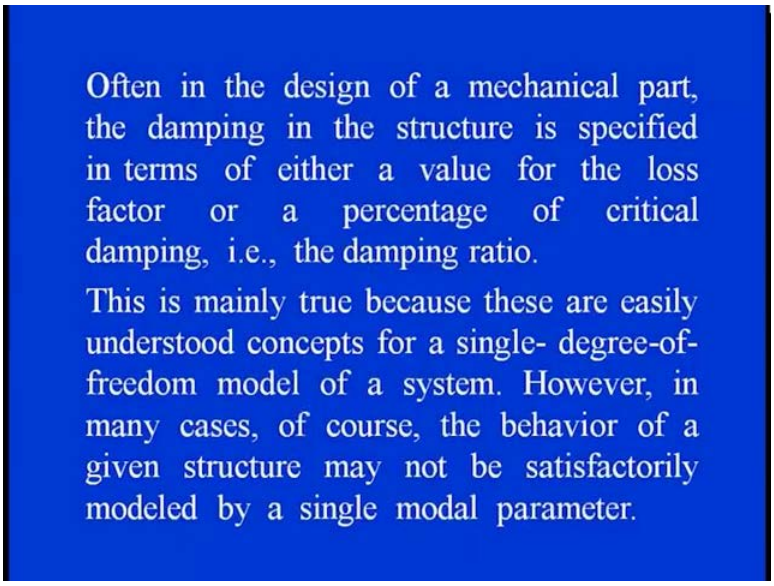

So, when we are saying that you see the elasticity is being there, we need to understand that whether we are talking about a single degree of freedom system or you see the continuous system or multi degree of freedom system, when the damping is being designed.

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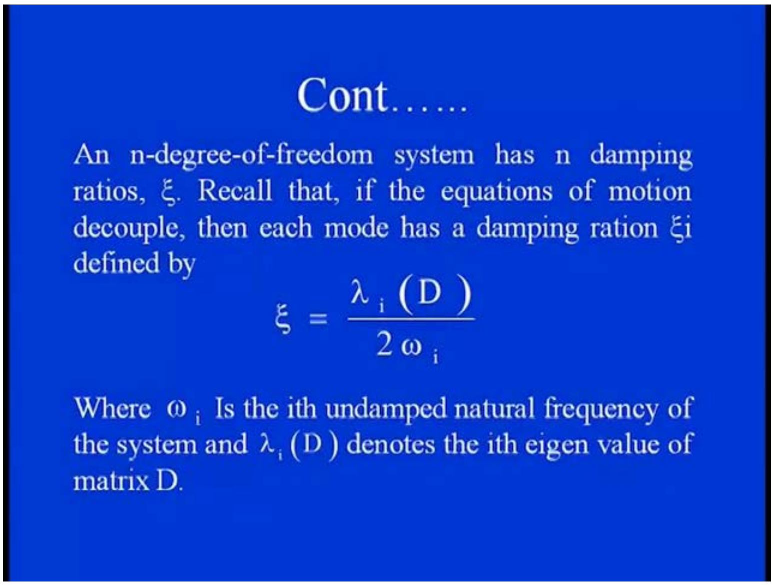

And for n degree of m n degree of freedom system we can simply get the damping ratio for all, which is nothing but equals to say lambda i which is nothing but the Eigen value of the matrix D. So, lambda i of D into 2 omega i and 2 omega and omega i is nothing but the undamped natural frequency of the system. So, we can get you see you know like, the damping ratio for such kind of things and we can like, coupled this thing along with the Eigen value of the damping matrix and also this undamped natural frequency.

So, it can be straight way related you see here, not only with the damping ratio available but also, you see here what exactly the natural frequencies are there undamped. And what exactly you see here the characteristic root or we can say the Eigen value of the matrix D is.

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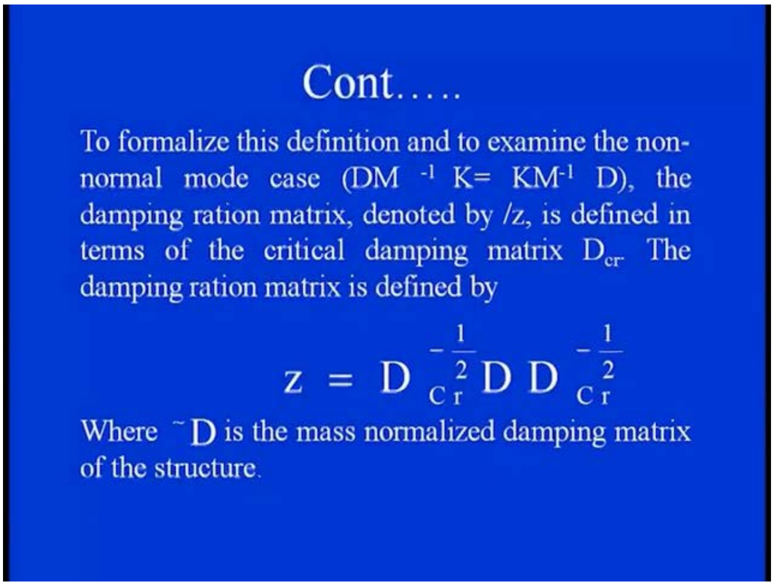

And to formalize this we can say that, the normal mode in sometimes you see, you know like the, the normal mode and non-normal modes are there in this. So, in non-normal mode the matrix like D the damping matrix into inverse of mass matrix. And when you multiply with the stiffness matrix, is clearly giving K M inverse D and these you see the damping ratio matrices, can be simply shown by z which is nothing but equals to D critical to power half, D into D critical to the power minus half. And that can be straight way we can say normalized, using these normalization of the mass and other matrices along with the normalized damping matrix of the structure.

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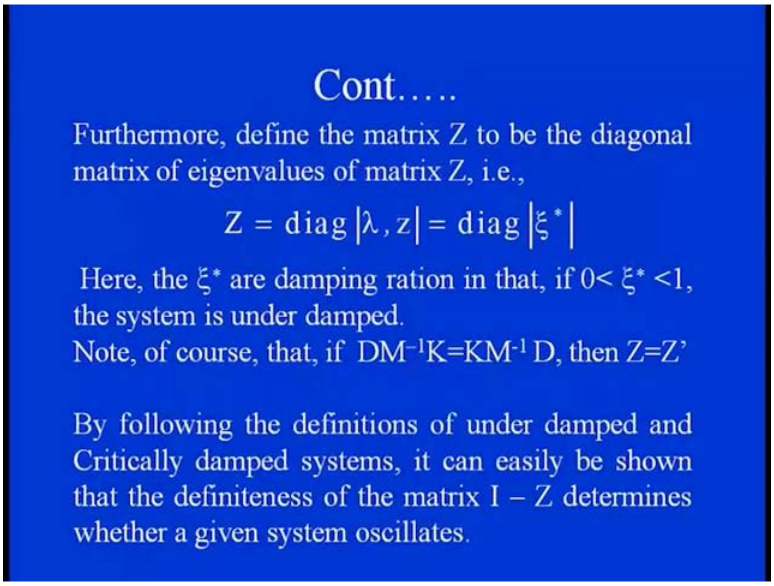

And then, can we you know like easily find out the Eigen value by simply putting the diagonal feature of that. So, diagonal of either we can say lambda comma z or diagonal zeta star can be simply given the dampen ratio whether, the system is under damping, critical damping. Or we can say the over damping system, by putting you see 0 and 1 value together, we can say that for higher order of the system the D, the damping matrix, the mass matrix and the stiffness matrix is absolutely given by stiffness inverse mass and dampen together. And by following the definition of under damping and critical damping system, we could easily figure out these things.

So, we can say that, these you know like, the definitions of the matrices i minus z which was you see, know like nothing but the Eigen values matrix of you know like, these complexity of desired part, can straight way find out that, how much you see the system oscillation is there. So, in this chapter we mainly discuss about the internal mechanism of the damping, how we can formulate that. It is not that you see, what are the you know like, the coefficient which can directly impact not only on the material properties of the damping. But also you see here, what is the need in the formulation of the damping, when we are talking about a solid material, when we are talking about the viscoelastic material and when we are talking about you see a multi degree of freedom system.

So, what are the critical features that was discussed in this, in this lecture. So, you see here in the entire this module, which was basically for the vibration generation and the oscillation. What are the insertions losses when we were discussing about the, you know like, the isolators or what are you know like the various generation system are there. How the vibration of the sound can be controlled, using that, using in a, you know like, the impedance features and all other mobility and everything you see which we discussed in that. Now in the next lecture, we would like to put the numerical feature of all these you see the conceptual part. So, the next lecture will be absolutely related to the numerical problems of all these module 2.

Thank you.