Vibration Control

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Module - 6
Principles of Passive Vibration Control
Lecture - 1
Basics of Passive Vibration Control

Hi, this is Dr. S. P. Harsha from mechanical and industrial department, IIT Roorkee, in the course of Vibration Control, we discussed about the three modules. And in these three modules, mainly these were focused on the vibration generation mechanism, how to design the material for suppression of vibration. Then even you see the vibration isolator features especially and because we know that, when the vibrations are generated from the source, the transmission is also playing a critical role in that.

So, whenever we are designing the entire vibration control system, we need to check it out that, at the end, at the receiver, that the vibrations are being transmitted. What exactly the kind of amplitude and the frequency levels are there, accordingly we can design these vibration control system. So, in the previous module, we discussed about that, what exactly the material feature is, through that at least we can put some kind of damping features there itself.

So, there were various compositions will just came and we know that, from the material aspects you see here, there are various internal resonances are also there. So, it is not that just by taking some kind of good high carbon percentage material or in the metal side particular or even such kind of polymers, which can absorb the vibration, just take it like that. Because, we know that, some internal resonances at the molecular level, even they are just playing a critical role in dislocation of these molecules.

And also at one point of time, the energies are being released from the system, from the material itself and which makes the system unstable. So, we discussed thoroughly about the material design, that what exactly the design considerations should be there, at least at the point of material chosen for that from the damping point of view. Because, there are various other aspects are there in the material side, when some kind of the weight considerations are there, the strength considerations are there, against the typical type of load, against the temperature, against the moisture, various phenomenas are there.

But, from this aspect as well, because we know that, the vibration generation and the transmission is quite rapid according to the material. So, we need to choose the material so that, here we can provide the kind of damping from these materials. So, in this module, our main focus will be there on the passive vibration control, what exactly the mean of the passive vibration control we have already discussed.

Because, there are two main modes or two main mechanism, through which we can control the entire vibration from the machine or the transmission feature through the path towards the outer side, may be it is just towards the environment exposure feature. The one part is the passive, which we can directly applied you see here, some external sources are to be added directly just like the cushion, the rubber or any kind of plastomers features and then we can control the things.

But, which type of the appropriate device should be chosen so that, we can effectively control the noise and the vibration level and we can provide the comfort conditioning towards the production floor people. And then also you see here, we can get the accuracy during any machining operations or any kind of operations at the production floor. Second was the active vibration control, in which we need to provide some kind of electronic forces, in which the direct control can be put at the time of the excitation, not these kind of devices should be provided at that.

We will discuss in detail that, how we can design these active vibration control and the passive vibration control according to the service condition, according to the environmental features and according to what exactly the operating features are there, at which the sound and vibrations are being generated. And we need to control those, right from the source to transmission towards the receiver feature.

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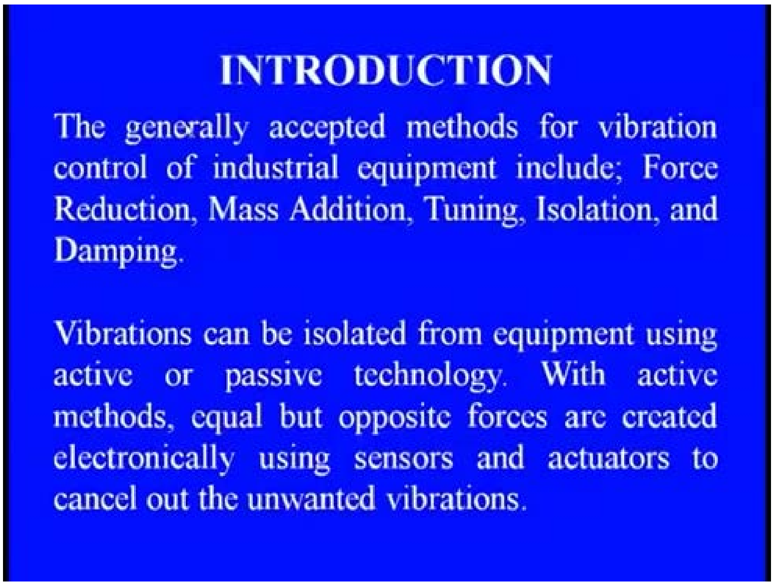

So, now if we are talking about this we know that, the common accepted method for this in any of these industrial equipment devices, where the excitation forces are quite dominating and then we have a huge vibrations and this noise level is. The first thing is coming to our mind that, how it can reduce the force, through which these vibrations are generating. May be it is because of the unbalanced force, may be it is because of the misalignment feature, looseness feature or any external excitations are there or may be the interaction, the nature of forces if the impulsive of any kind, the flow induced.

Then, we need to check it out that, how we can reduce the force, second either can we provide straight damping there itself, can we provide the spring itself or will it be mass, through which we can suppress the vibration. So, these are very common methods, if we are talking to a layman, they can say, why do not we put these things to control that. So, in general way we can say that, vibration can be straightaway isolated from the equipment using these, either the passive technology by adopting some external devices or by active technology, by reducing the force through electronic manner.

And with the active forces like you see we are saying that, the forces which are quite active at the point of contact or at the point of this misalignment feature then we can adopt even the active vibration control by creating electronically, the force using the smart sensor or the actuations with the smart materials even. To cancel out these unwanted forces, which are being coming out through this whatever, the machinery features or the rotating part of the machine. So, either if we are going towards the passive or the active, we need to first see, what is the feasibility and what exactly the kind of excitation level is. And what the entire structure is there, because ultimately the structure is supporting to these vibration features and the sound propagation.

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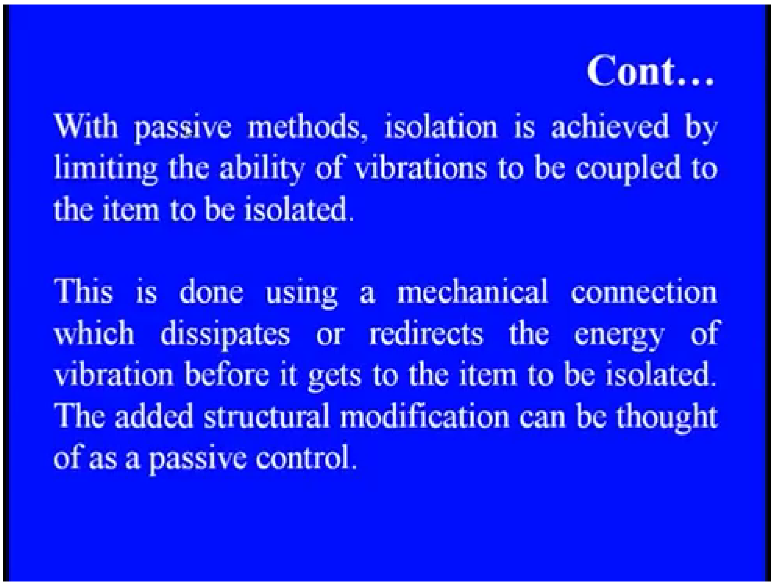

So, with this passive method, the isolation can be straightaway achieved by putting certain isolators, but again you see, the basic limitation is coming is that, what type of isolator we need to provide to cancel out these unwanted forces. So, generally we need to see that, what exactly the connection, which we can provide from the isolator to the excitation so that, whatever the dissipated or the radiated form of the energy is coming out, it can be straightaway absorbed.

So that means, it is a kind of some structural modifications, as we are just going towards the passive control. Because, in that, there is a clear gluing, adding or any kind of fixing of an external device on the surface of vibrations or even we can choose some kind of stiffness feature like the spring stiffness or the high kind of any device, through which the stiffness can be provided to improve the vibration absorption or the released feature or in other way, we can say that, the vibration response through these vibration control processor. So, it is some kind of technique, in which we need to use some kind of the additional device like in the active vibration control technique.

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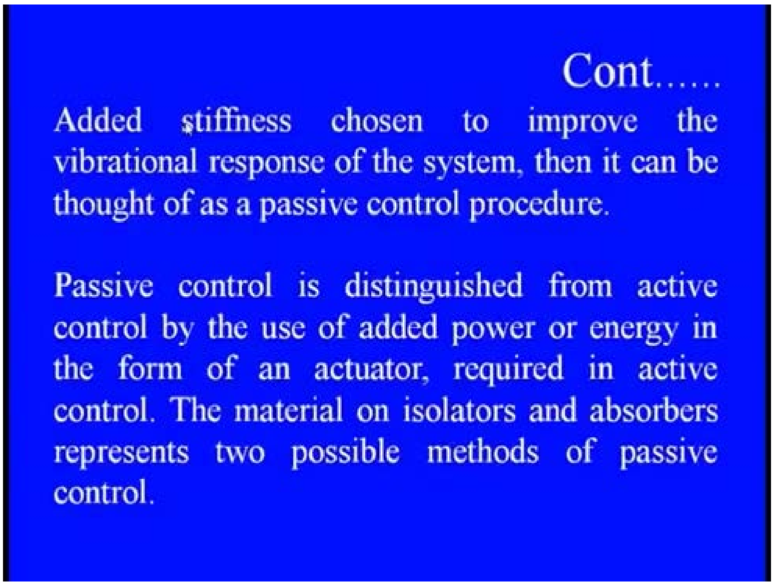

We need to add some kind of power or energy in form of some, we can say the actuator or in some kind of, we can say the sensor and these power is just acting against the generated force or whatever, to cancel out. But, here this is a direct material of the absorber or the isolator, which needs to be put on the surface to absorb the energy or to absorb the vibration from excitation level, from the source or from the receiving path. So, in this chapter, our main feature is the designing part of the absorber or the isolator in the passive manner.

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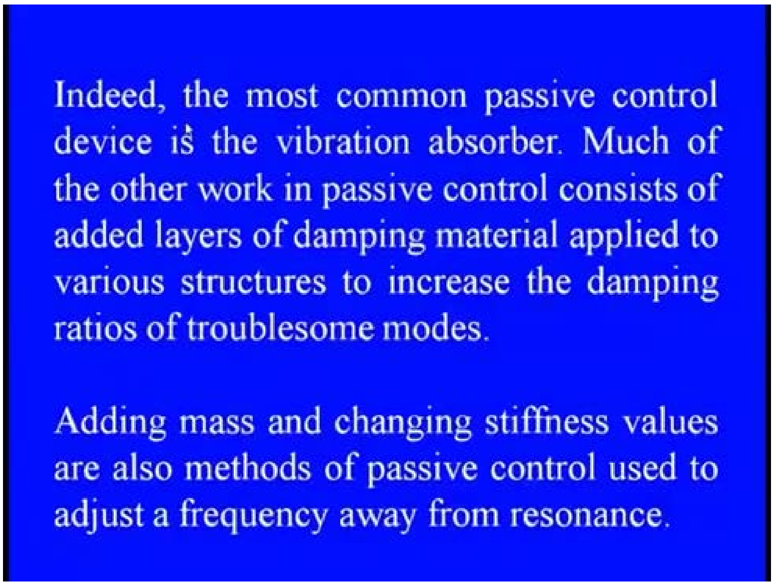

So, most common passive vibration control is absorber, because we need to absorb the amount of energy, which is being creating by the excitation feature. So, most of the work here is being presenting in terms of the damping material, which is associated with these absorber and directly can be applied to the structure, where the excitation features are there, so that we can increase the damping ratio at the various excitation modes or the excitation frequencies.

Sometimes, we can also add the mass or just add the springs to strengthen the stiffness features there. They are also coming under the category of the vibration control, through that we can at least adjust the resonance frequency, so that we can avoid the huge amount of energy or the amplitude excitation at that frequencies.

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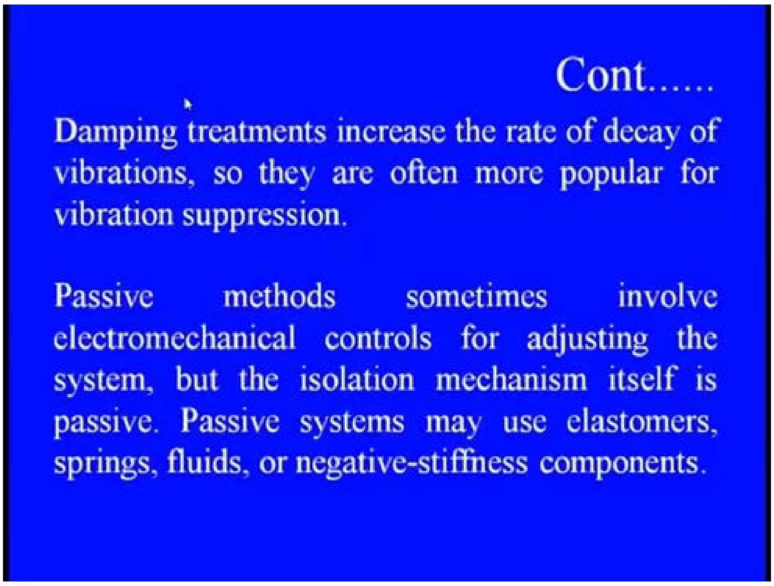

So, the most effective treatment here is the damping treatment, because it increases the rate of decay of vibration and through that, an effective way of vibration control can be adopted. So, passive method sometimes involve even electromechanical controls for this cancellation of the vibration forces, but you see here, in that also the isolation mechanism is also a kind of passive, some straight adopted feature.

So, we can say that, either we are using the elastomers, the rubber or if we are using any kind of fluid material, even we are using the springs, the fluids are sometimes providing the negative stiffness towards the component as well. So, either of that you see here, which we are choosing is coming under the passive control equipment. And then we can straightaway put, that how we can design, either this spring or the elastomers or any kind of rubber, polymers and all this part, and also a fluid or rather we can say, the fluid is nothing but which is just providing the negative stiffness.

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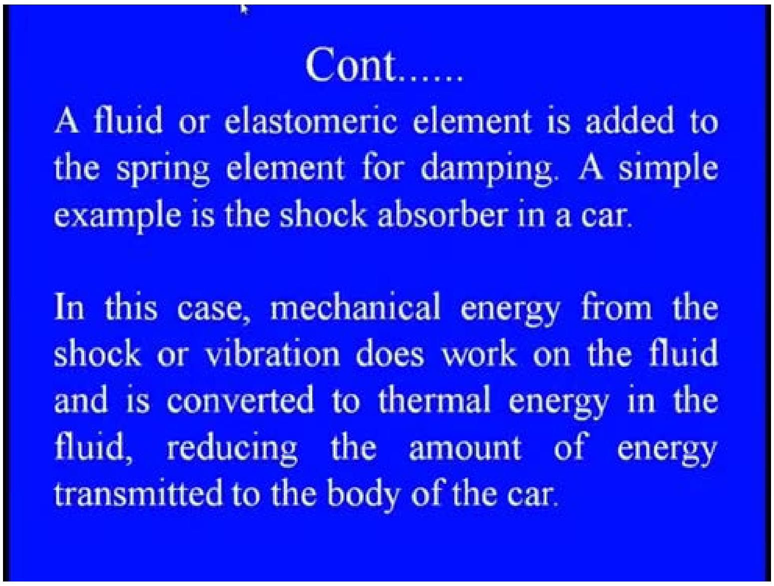

We can say, it is also the elastomeric element, which we can straightaway add to this spring element for providing some kind of the integrated effect of the restoring and the damping forces. Just like nowadays the composition of the spring and the damping feature is always coming together and we are saying that, these are somewhat the advanced elastomers, which can provide a perfect shock absorber in various vehicles.

So, in that, the mechanical energy which is coming from the shock in terms of the impulsive forces or in terms of any abrupt change in the force magnitude or even the cyclic feature of the vibration, can straightaway work on the fluid and is converted the thermal energy into the fluid. So, there is a clear reduction of the amount of energy, which is being transmitted to the body of the vehicle.

So, means that you see here, whatever the fluid or an elastomeric element, which is being chosen in these cases, they are effectively acting just like absorbing the energy, and also the transmission of or the dissipation of energy in such a way that, from the source, the things can, whatever the excitation can be straightaway reduced.

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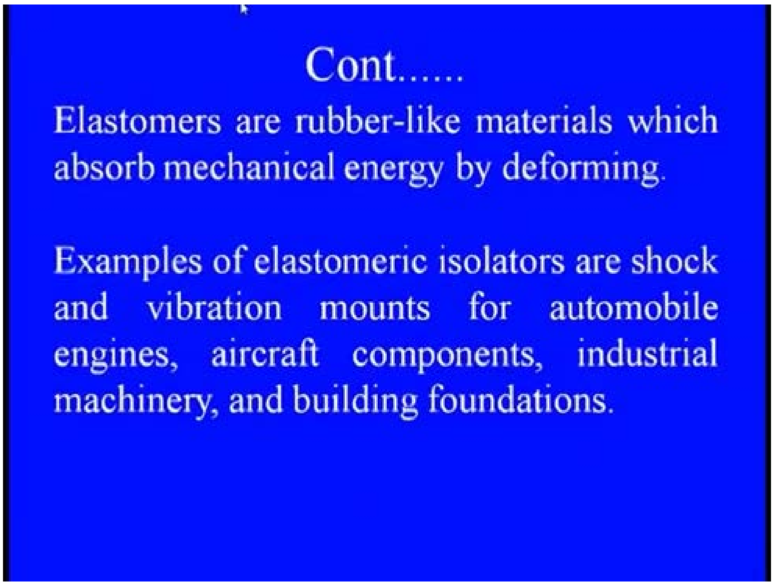

So, in elastomers generally when we are taking about, these are always a damped feature, in which the rubber like materials are there, through which you see, we can absorb the mechanical energy under the force due to the deformation. So, elastomeric isolators are sometimes we are saying that, because of the vehicle at which we are using these elastomeric feature of the element, they are always being used to absorb the shock vibration or the cyclic vibrations.

So, whenever the shock and these cyclic vibrations are being there in any of the vehicle, these elastomeric isolators are just mounted on the automobile engines or even the aircraft components, the heavy industrial rotating machinery. Or even you see nowadays, because of the earthquake, the random vibrations are coming, so even the building foundations, these elastomeric isolators are just perfect replacement for these things. So, we cannot rely straightaway on the damping feature of concrete and say that, that is perfectly ok when the earthquake or these tremors are being coming in this way, the random vibration feature.

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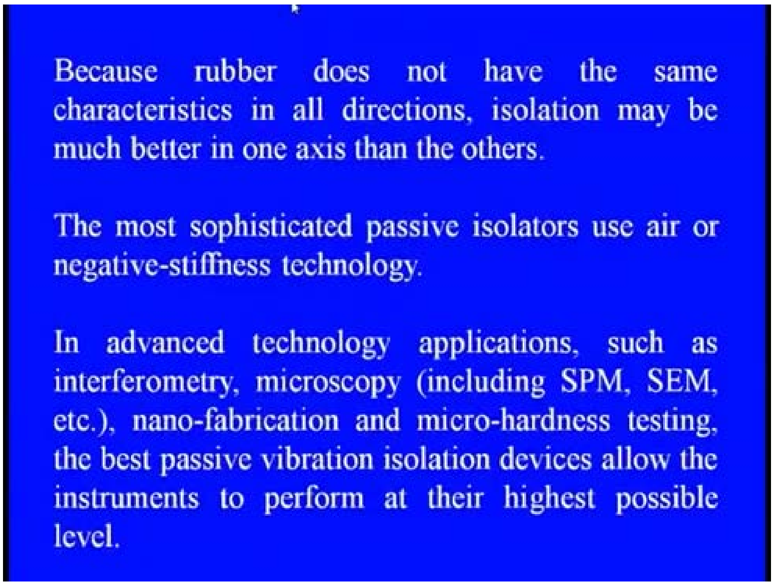

Because, rubber does not, sometimes rubber does provide the energy damping, but it is not having a similar kind of characteristic, that by only putting the rubber you have the entire features, you need to just go with a elastomeric feature of the damping and you need to add in that way. So, you see here, the isolation is having much better in the specific direction, say the vertical direction, the excitation is quite dominant when the vehicles are moving, we need to keep accordingly.

So, the most sophisticated passive isolators, which using air or negative stiffness technology, because in these recent time of technology, we need to go with the interferometry or microscopic like the SPM, SEM, all these nanofabrication and the micro hardness testing. And with these all advanced technology, we can provide a best possible passive vibration isolation device, through which we can go upto the highly level, we can say the high précised level absorption of the vibrations.

Because, in that you see here, we need to design the passive isolator in such a way that, we can use the air as the suspension device. Or even sometimes we can say that, the negative damping as a suspension device along with these elastomeric features of the rubber, through that you see here, we can effectively control the vibration for such a sophisticated system.

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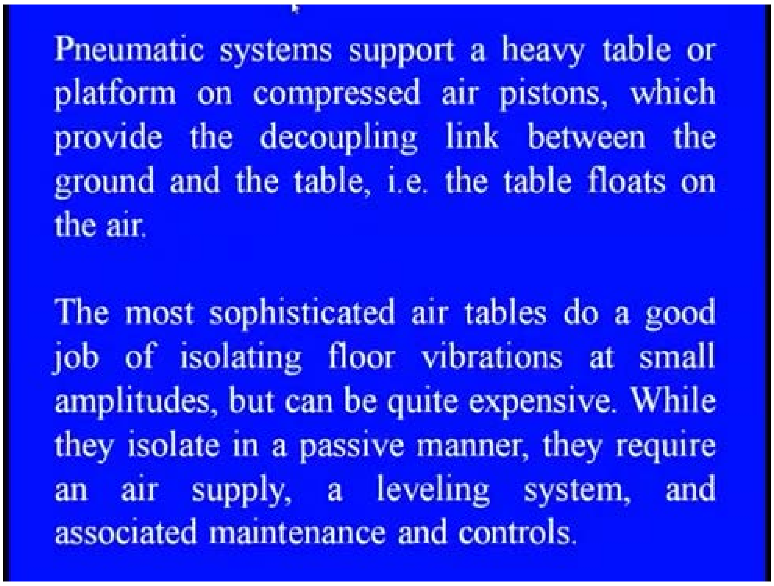

Like you see the pneumatic systems, which are supporting a heavy table or even the platform on any compressed air pistons, and through that you see here, we are just providing a decoupling link between the ground and table, and the entire table if you look at the real mechanism, the entire table is floating on the air only. So, this air is acting as the passive control feature and through that, this entire we can say this suspension is being provided by the air and there is a clear isolation of the table to ground with using of this compressed air.

So, the most sophisticated air tables are always providing a good and the precised operations with just removing the entire vibration through the isolated floor vibrations and even the small amplitude. But, the things are there that, what kind of the operations are being requiring, the precised operation, because this is an one of the expensive method, because we know that, when we are just putting the compressed air, we need to check it out the pressure and the pressure variation in the entire operations there itself.

And also you see here, we need to check it out, what exactly the maintenance features are there to keep the pressure uniform and the same time, the leveling of entire system. So, you see here, the entire control strategy is somewhat expensive for such kind of sophisticated system.

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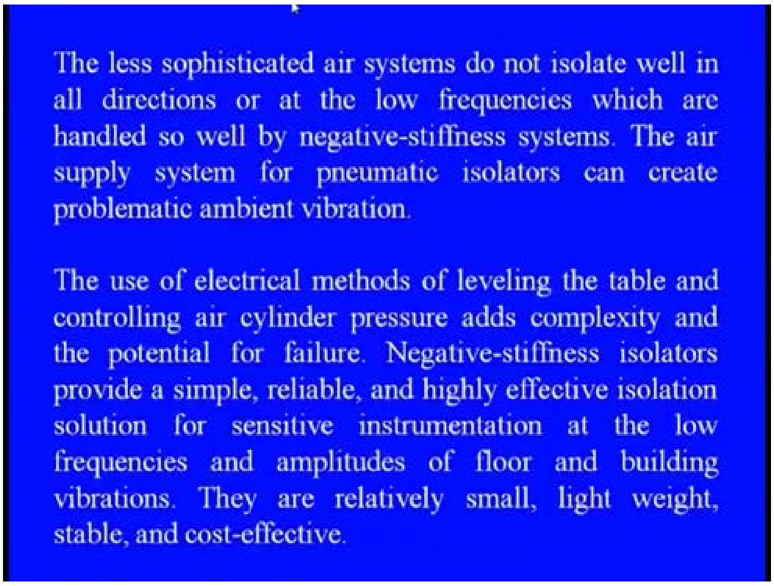

But, the same time you see here, when we are just doing at the low frequency excitations, sometimes this air suspension is not an accurate one. So, we need to go with the other way that is, the negative stiffness features, because the air supply system for the pneumatic isolator can sometimes creating even the ambient vibrations also. So now, we will use even some other electrical methods for the leveling of the table and controlling the cylindrical pressure, just to add somewhat more complexity and the potential of the entire system failure.

But, the negative stiffness isolator, they are providing a simple, a reliable and highly effective isolation solution for the sensitive instrumentation even at the low frequency and low amplitude of the floor and the building vibrations. And also they have a good features that, they are relatively small as compared to the compressed air feature. Also they are having the light weight, they are more stable and as far as the maintenance and the cost feature is concerned, it is perfectly alright with that. So, again we need to check it out that, what kinds of applications are there, on which the vibration generation and reductions are to be featured out.

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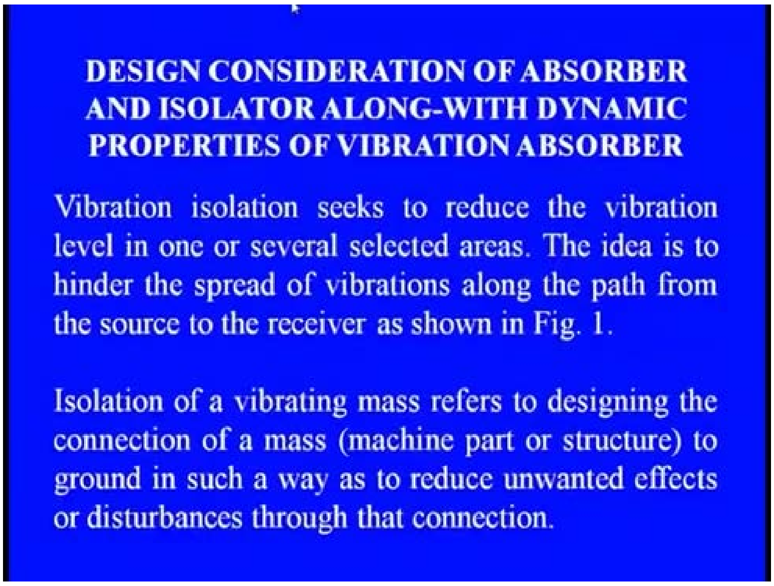

So, the first thing is coming, what is the design consideration of the absorber and the isolator under these all dynamic actions of the vibrations. So, we know that, the vibration isolation means, to reduce the vibration level or the amplitude of vibration in one or several selected areas. So, here we need to hinder the spread of the vibration along the path from the source towards the receiver, as we discussed. So, isolation of vibration means, it is a clear reduction of the amplitude at the source.

At the same time, we cannot always go for the treatment of the source only, we need to treat this entire structure, through that the transmission is quite rapid and it is just going towards the receiver end. So, when we are talking about the vibrating mass and we need to just isolate the vibrating mass. That means, we need to design the connection of the mass or the entire structure or the part of the structure to the ground in such a way that, there is whatever, the untold effects are coming out due to this vibrating masses, we need to reduce or we need to disturb the entire transmission path. So that, through that, we can say, we can absorb the energy or the amplitude in that transmission feature of the excitation.

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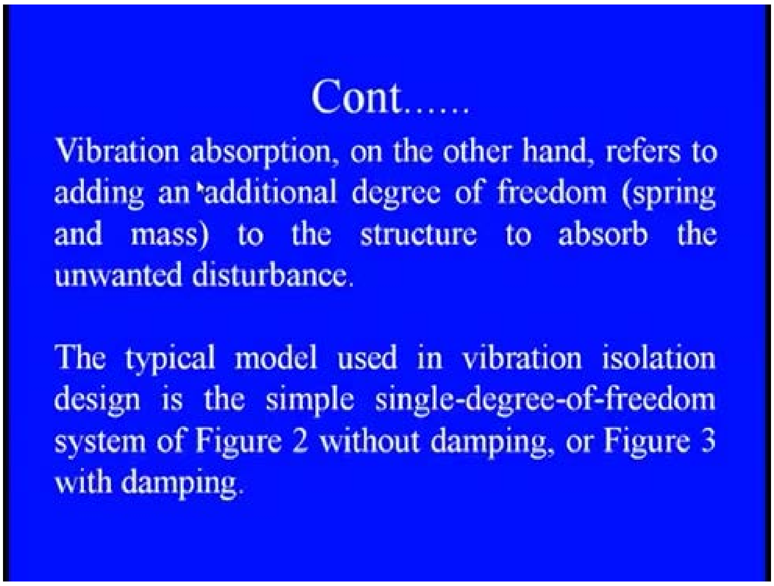

So, vibration absorption on other hand refers to some additional degrees of freedom to be added like in the mass or in the spring to the structure, to absorb these all unwanted disturbance. So, we can say that, when we are using this vibration isolation feature or the design part, we need to go with the, say that if we have a simple single degree of freedom system, we need to go with different kind of features, which is supposed to be added at the point of contact or at the transmission path.

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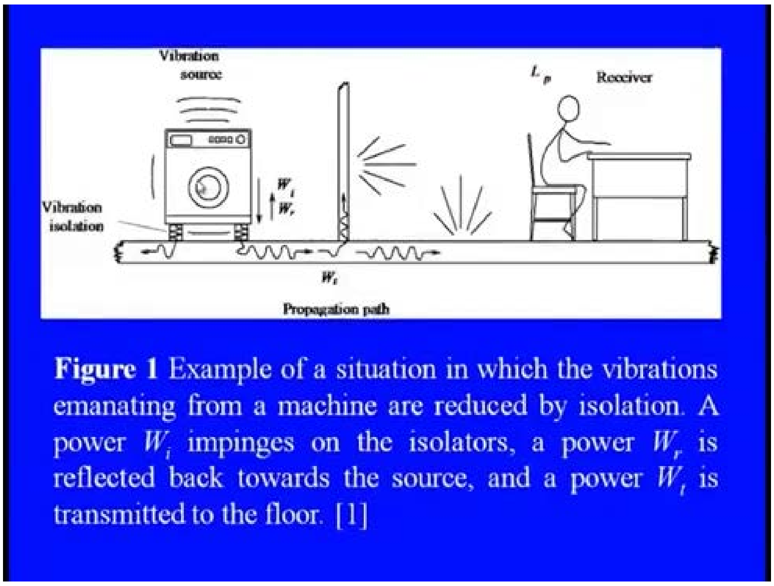

Figure 1 Example of a situation in which the vibrations emanating from a machine are reduced by isolation. A power W_i impinges on the isolators, a power W_r is reflected back towards the source, and a power W_t is transmitted to the floor. [1]

So, we can see in this diagram, it is pretty clear that, we have a situation where the vibration is just generating from the machine and we need to reduce, the same time we need to design such a system that, the transmission should be proper. And also you see here, the absorption feature should be there so that, at the receiver end, the things are not so dominating. So, we can see that, these power which is being transmitted, first of all we need to provide the isolation exactly from the source to the ground in between.

So, you see here, through this isolator feature, some part is being absorbed and just repulsive way towards the source, some part of the energy is transmitted through the ground. And even by putting some kind of obstruction in the path, even it can also provide some media, through that the vibration transmission can be featured out. So, ultimately when it is reaching to the receiver, the path of this vibration transmission is so deviated that, whatever the vibration frequency and amplitude and the sound level, the sound power level or the energy is almost reduced by various ways.

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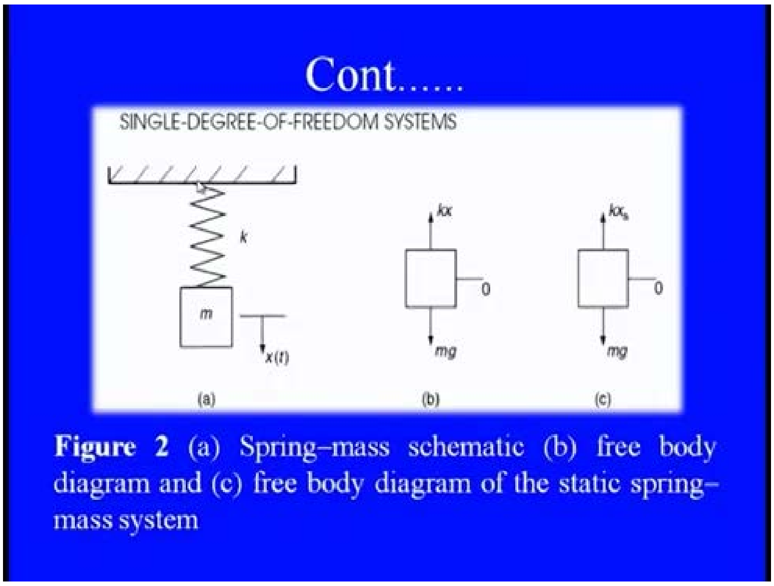

So, when we are trying to keep this single degree of freedom system we know that, we have a simple spring mass system, in which all the forces are being balanced out by the inertia, whatever the inertia vibrating mass and the restoring forces due to this one.

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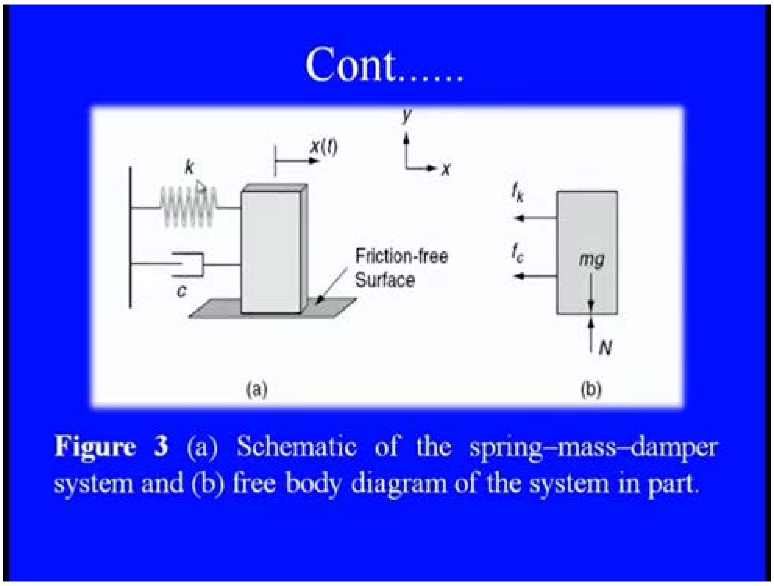

Or else even you see here, when we are providing the damping, the forces which are being balanced out of the inertia forces are through that, the damping or the restoring forces. So, the meaning is very simple that, we need to provide not only the frictional feature as you can see on the surface, the frictional feature like the coulomb damping, the dry damping, the viscous damping is there, the material damping is there. And with the same time, we need to provide the spring to just control the oscillatory feature of that with the energy absorption.

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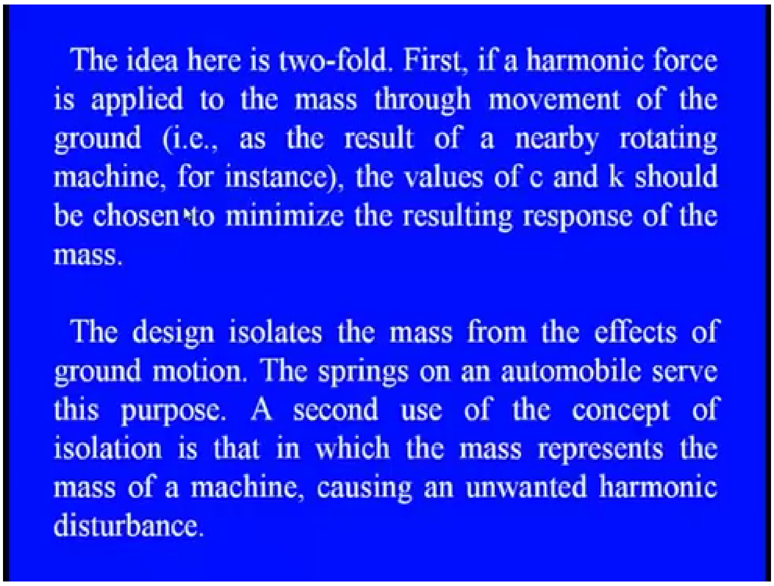

So, the idea here is of two fold, first if the harmonic force is applied towards the mass, through that the movement of the ground or the vibrating masses are being there, as a result that the nearby things are being disturbed. The value of the damping and the stiffness should be chosen in such a way that, it can effectively minimize the resulting response of the vibrating mass.

And the design which is being provided through the design of isolator, which is being provided through the external system on the vibrating mass in such a way that, it can straightaway absorb or disturb the transmission path to the ground motion. So, rather we are saying that, it is a spring on an automobile or even the elastomers on the any of these exciting surfaces are just serving the same purpose.

And the same time, when we are saying that, isolation needs to be there, we need to see that, how the mass is being there. Whether the entire system is exciting or the part of the system is exciting, whether the gear is creating the noise or the vibration, or the bearing is creating this noise and vibration or the entire arrangement of rotor bearing and the gear, which are under the rotating feature, are creating this thing. So, we need to check it out that, this unwanted harmonic disturbances are being created at what point. And then what exactly the transmission features are there through this robust connection of this entire mechanism, so then accordingly we can choose this one.

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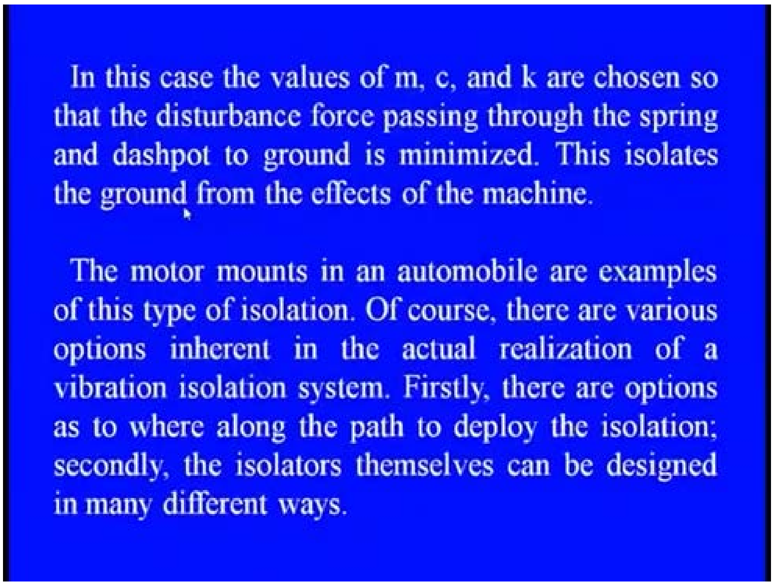

So, if we are talking in this case, we can straightaway put the value of mass damper and the stiffness in such a way that, whatever the disturbing forces which are being coming out from any source, we can choose the damper, we can choose the mass and we can choose the stiffness, just to diminishes this entire vibration generation at that point. Because, ultimately our main feature is not only to control the excitation vibration, but also you see here, we need to isolate this propagation path also.

So that the vibration or the sound level should not reach to the ground or surrounding for the kind of disturbance, so the motor which is mounted on, say in automobile just requiring such kind of the spring and the damper to isolate the things. And there are the various other, we can say options are there, which can be adopted not only with just putting the mass and the damper and can be controlled out. The options are, when the path, when it is just transmitting through that, what are the equipments which are coming in between that, means what exactly the actual path of that, and secondary, how we can just isolate the entire source in such a way that, it is not even transmitting the other machinery part through their excitations.

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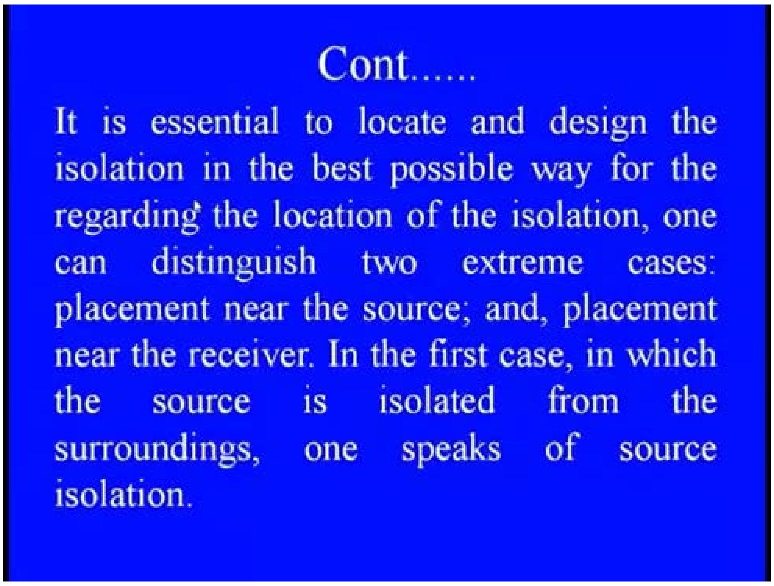

So, that is why it is very important to locate and design the isolation in the best possible way for regarding the optimum location of the isolator. Because, through that, we can put in such a way that, it is not transmitting through this solid media and disturb the other equipment as well. So, there are two extreme cases, which we can take here, first the placement near the source and the placement near the receiver.

So, in first case, when we are keeping the absorber or the isolator just near the source, we need to check it out that, what exactly the isolation features are to be requiring. Because ultimately, the huge amount of excitation force or excitation energies are being there near the source. So, source isolation is somewhat more specific and you see here, it needs a typical kind of the properties at that point, while when we are designing.

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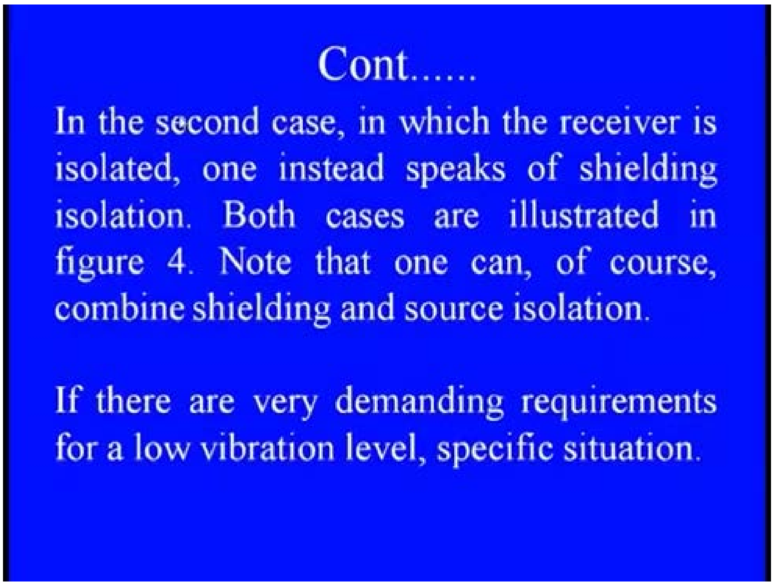

The second case in which the receiver is being isolated, one need to go towards the shielding isolation, and the shielding isolation is straightaway absorbing whatever the transmission or the acoustic radiations are coming in terms of energy in such a way that, there is a abrupt absorptions are there before it is reaching to the receiver end. So, you see here, either we are going, in either way they are very demanding, especially when we are just going for higher or the lower exciting features in that.

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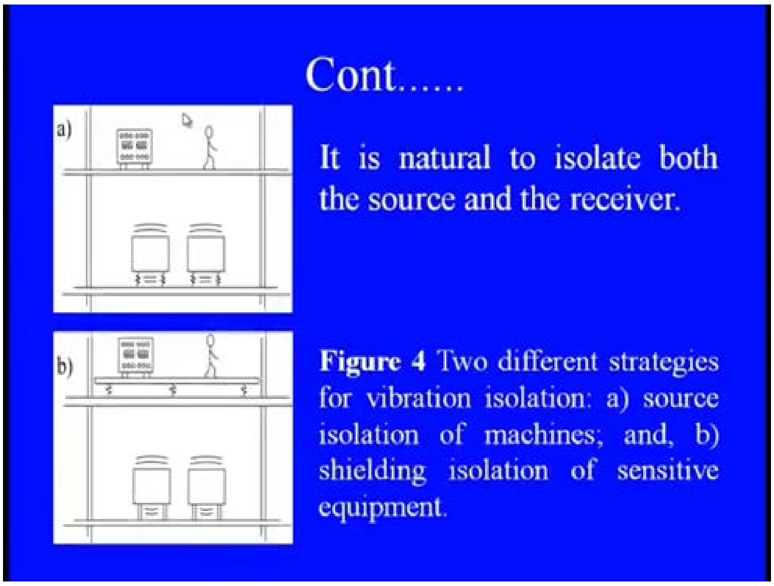

So, as you can see on the screen, there are two main examples are there, first when we are just going with the source isolation. So, you can see that, in the first floor when the machines are being operating the rotating machine, they are inducing the vibration and we need to strike on the root cause of that that means, the source. So, when we are striking on the source, there is a clear you see, the elastomers which are being provided just below the machine and can you see here, we can straightaway isolate or we can deviate the path of this excitation.

And the second is you see here, when we are just looking that, no it is not feasible sometimes, but even after that, the things are being transmitting in such a faster way at the low frequency excitation. Then we need to just put some kind of isolators at the receiver end, you can see that the springs are being provided. So that, whatever through the structural transmission, whatever the vibration level is coming, that can be even rather absorbed at this point, through the shielding of the entire equipment, the shielding isolation.

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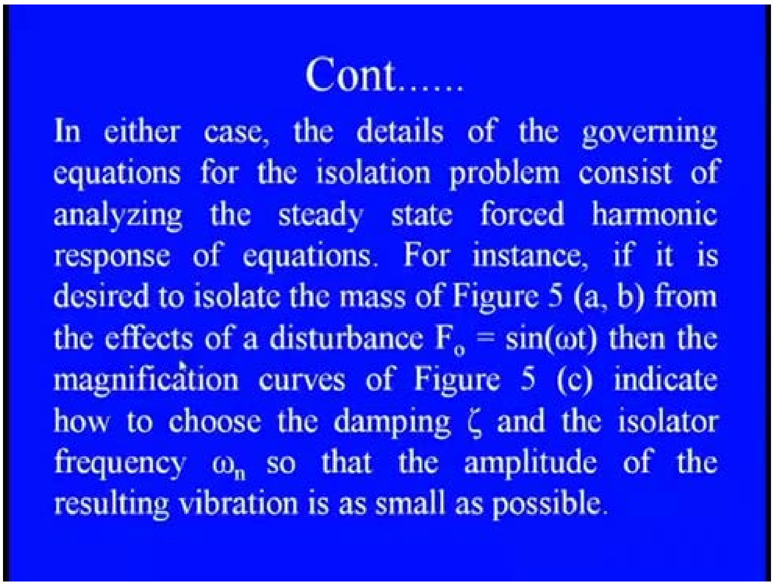

So, either case you see here, when we are just talking about the harmonic excitations we know that, the kind of disturbance which are being coming in the forces that is, F 0 sine omega t. And then we can indicate that, whatever the kind of excitation features are coming and when we are keeping the spring or the damping, how we can design this. Because, we know that, when we are choosing the damping, we need to check it out that, what is the damping ratio, which simply gives the relation between the applied damping and the critical damping and the critical damping is the inherent feature of the system is. And then second thing is coming, whether we are trying to isolate the low frequency vibration or high frequency vibrations. Or even you see, because we just want to avoid the resonant conditions in these cases.

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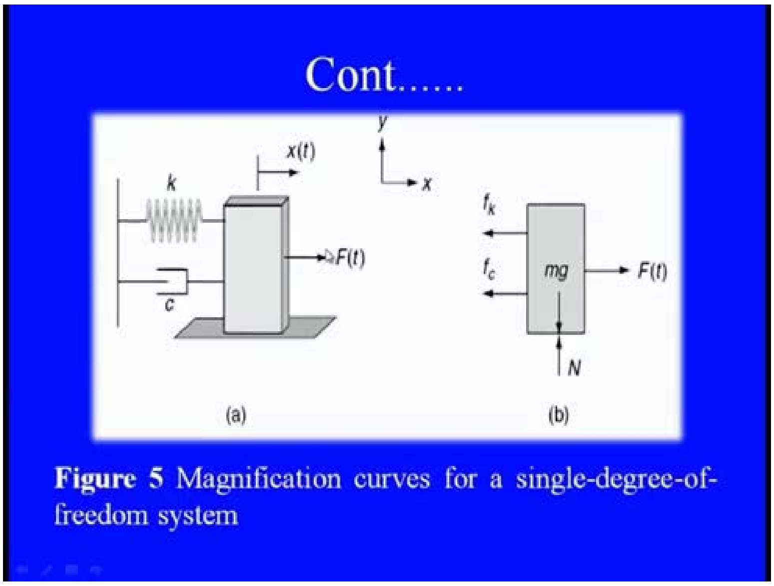

So, when we are just looking towards that, we can see that, this is what you see, the forcing frequency F of t, F 0 sine omega t. So, this is my forcing frequency, which just gives, which just supplies rather we can say, the force or the energy at certain frequency part. And when the entire system with the mass stiffness and the damping, when these are being excited then what exactly the excited features are there from this machine. So, we have the systems inherent frequency, the exciting frequency and the forcing frequencies are there.

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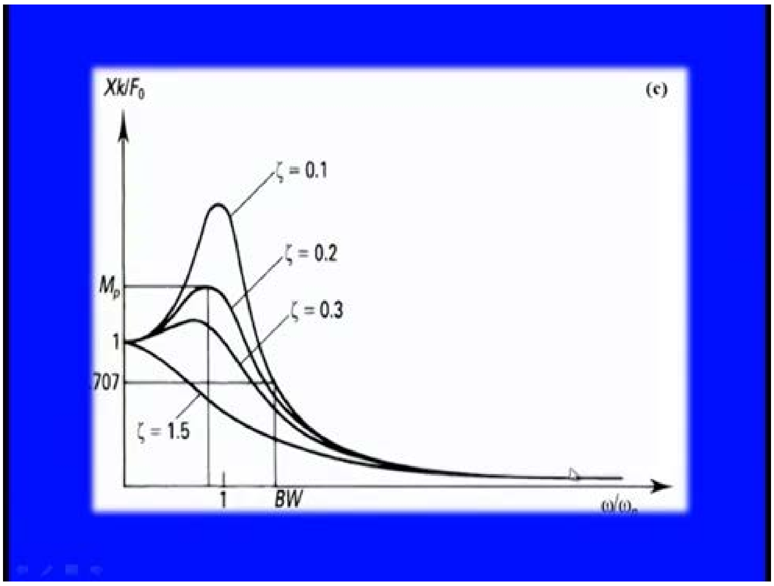

So, when we are just trying to find out the relation between whatever the transmission features means, you see X by F 0, the transmission ratio and you see here, with the frequency ratio, the natural frequency and the forcing frequencies. We can simply find that, when we have the less damping coefficient that means, the damping which we are providing is quite less, as compared to the critical damping feature of the system. Then we know that, the kind of excitation, the kind of transmission is such a high, you see that zeta equals to 0.1, it is almost the maximum.

But, as we increase the damping properties, there itself you see the excitation source then we know that, it clearly suppress the vibration amplitude by absorbing the energy or by dissipation of the energy itself. So, you see here, this zeta 0.2, zeta point 0.3 or even when we are trying to reach at zeta equals to 1, this is a critical damped feature, through which we can effectively suppress the vibration at the minimum time.

But, again you see here, we cannot go for the higher damping value just like blindly, because we need to see that, whether we want an effective solution at the minimum time or just we want to just delay those things. So, you see here, when the zeta is 1.5 you can see that, the responses are just going and the steady state response is just diminishing or just going to the end in a very long time.

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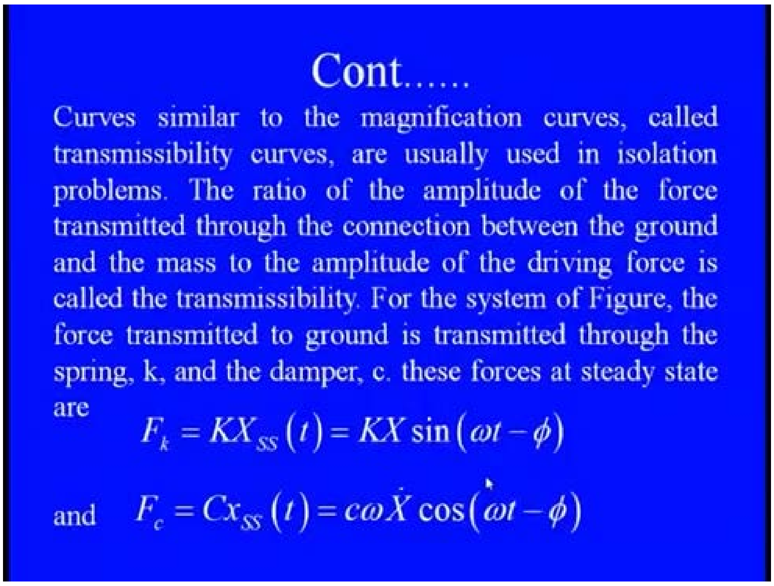

So, you see here with these concept, we need to check it out that, what exactly the ratio of the amplitude and the first transmission that in terms of the transmission ratio should be there and what exactly the exciting frequencies levels are there. So that, we can make a proper balance and we can get, and how we can make the proper balance, by choosing a appropriate value of the damping and the stiffness. So that, whatever the vibrating masses are there, can be effectively controlled.

So now, we can talk even in terms of the force balance equations that you see, whatever the forces which are being there at the spring level. These are the restoring forces and the restoring forces are nothing but K into X ss or we can say that, whatever the variations are there, these are all the harmonic variations and it is just varying with the stiffness feature of the entire system. So, K X sine omega t minus phi and whatever the damping features are being there, that can also be evaluated based on the velocity and the available damping in the sinusoidal feature.

So, we have c into omega X dot cos omega t minus phi, so this is what you see the differences. When we are talking about the restoring force, they are just showing the independent feature of the frequency. While you see, when we are talking about this damping forces, there is a clear dependence on, not only on the amplitude, whatever you see c or X dot is there, but also you see here, it is depending on the omega, the frequency dependency part. So, we need to check it out that how, means what level of the frequencies are there, whether we are just going for the low frequency or the high frequency excitations.

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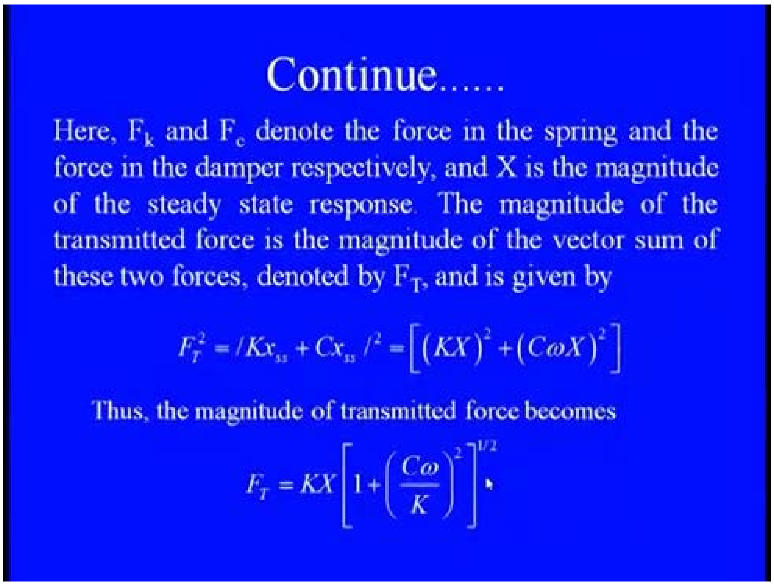

So, these two forces which are being coming out from the spring and the damper, can be straightaway create an steady state feature of the solution. And the magnitude, which we can say that, in terms of the transmitted force is always being there from the outside displacement with the inside force excitation. So, when we are talking about these magnitude of the transmission force then we can straightaway go for the algebraic summation of these two forces and it is simply the K X, which is being there you see through the restoring and C X, which is there for this damping forces.

So, when we are talking about this, the magnitude of the transmitted force through these two equipments are nothing but equals to K X 1 plus C omega by K, the square and since we are just going with the resultant one, so it is the square root of that. So, we can straightaway get the transmission that you see, what exactly the transmissions are. They are through the entire system, in terms of the transmissibility ratio and this transmissibility ratio is always being depending upon the two main key features, what the damping ratios are. Because, accordingly you see here, the entire system is working for the absorption of the energy or just to reduction of the vibration amplitude. And second is, what is the ratio in between the exciting frequency and means, the natural frequency and the external force excitation frequencies that means the frequency ratio.

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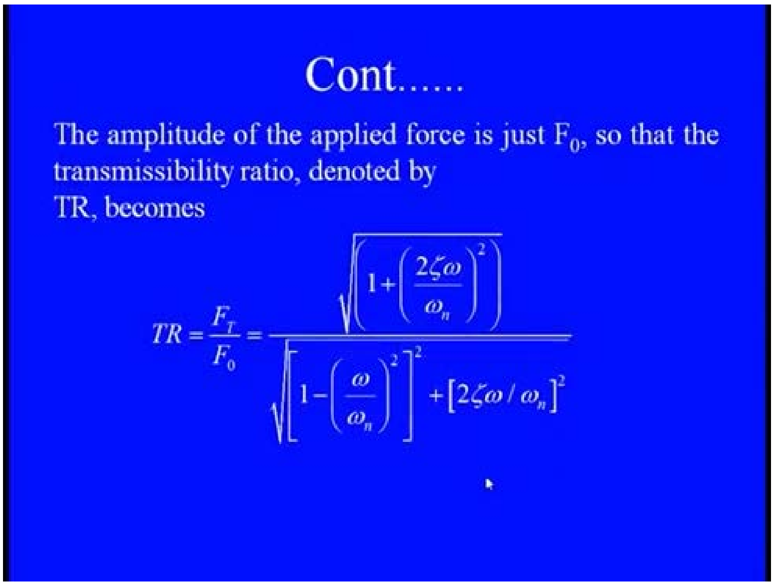

So, you can see that, it is absolutely wearing within the transmission 1 plus 2 zeta omega by omega n square divided by you see here, 1 minus omega by omega n whole square plus 2 zeta omega by omega n square. So, this is what you see the dependency feature of the transmissibility ratio on the two main ratios, the damping ratio and the frequency ratios.

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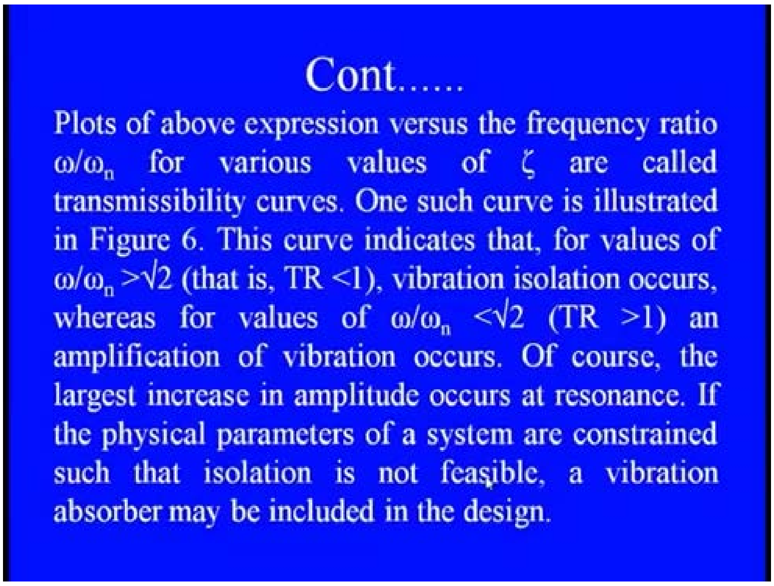

So, we can say that, the transmissibility curve can be straightaway drawn based on the characteristic feature of these two ratios. So, when we can say that, when omega by omega, the frequency ratio is greater than 0.2, the square root of 2 or we can say 0.776. So, when we are talking about the one feature of that, that we have the excitation feature in between the forcing and the natural frequency is greater than some value. That means, the vibration isolation is an effective way, because you see ultimately, we are trying to reduce and it is being effectively done.

Whereas, when we are saying that, no omega by omega n is less than that, where you see the transmissibility is just increased in that means, it is immediately transmitted that, where you see the amplification has been done by these vibrations. That means, the effectiveness of the isolator based on you see here, the mobility is not an effective part. So, we need to rechoose that, we need to rechoose the physical parameter of the system so that, the isolation should be an effective part or the absorber should be there in such a way that, it can at least minimize the transmission.

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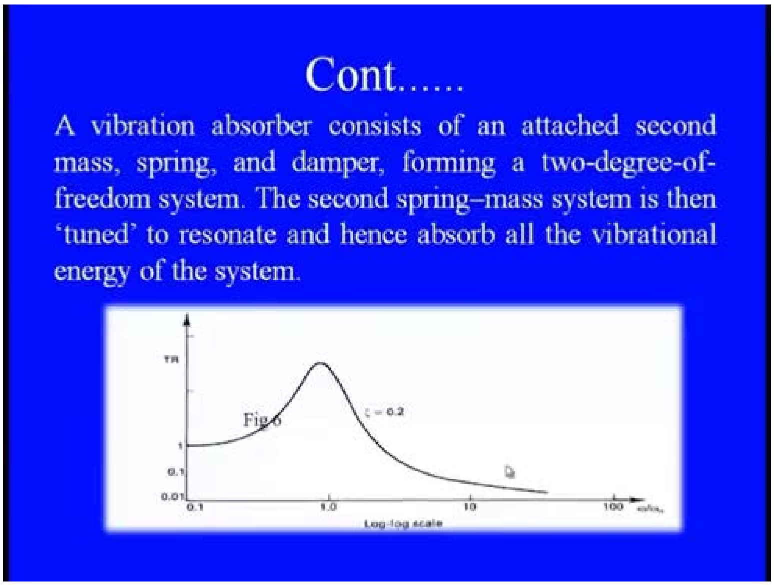

So, you can see in this diagram, it is clearly showing that, the vibration excitation in this part is just varying in this way in such a way that, at some point where the resonance occurs, you have a maximum energy part. So, there you see here, we need to absorb the amount of excitation energy or the amplitude in such a way that, it should come to the harmonic feature and it is being ending in an effective way.

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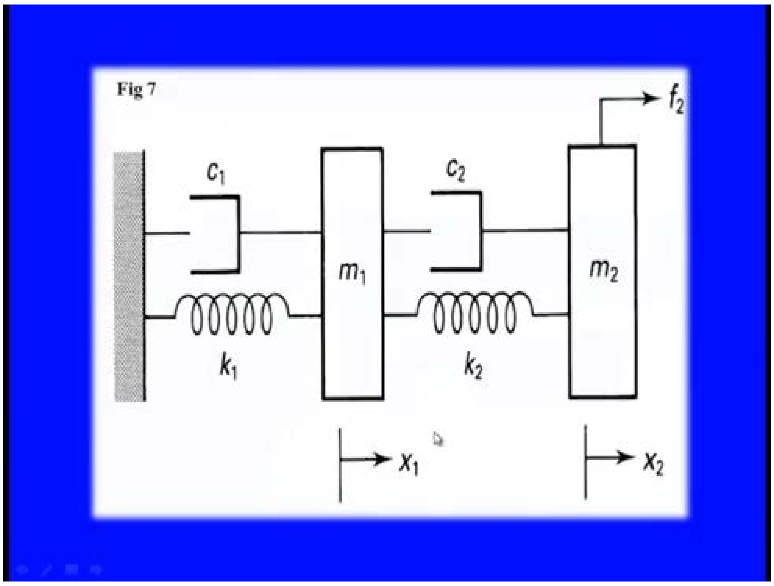

So, if you are talking about say two system, say mass m 1 and m 2 and the forces being excited at m 2 part. And also these entire system is featured with the damper and the spring part then we can say that, how we can choose these things.

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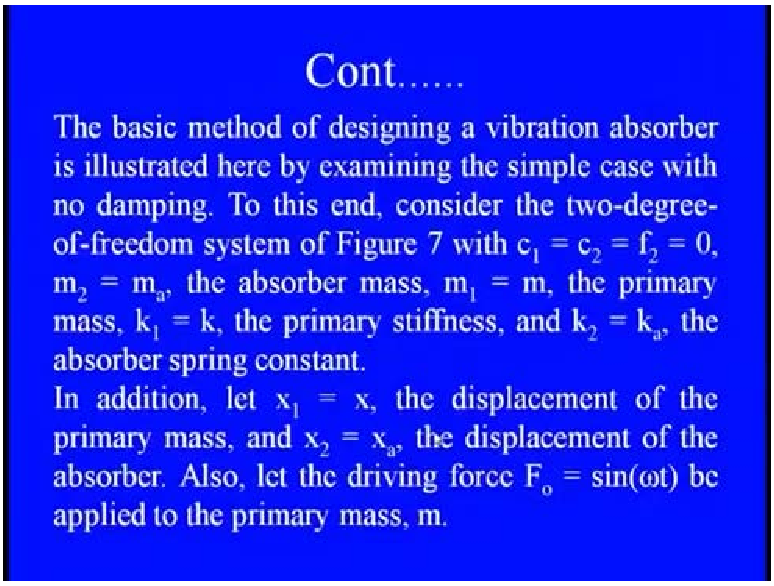

So, in this, the basic method for designing the vibration absorber in such a way that, we need to first go with the two degree of freedom system, we need to put the equations of motion for that, that what exactly the force balance conditions are there in that, and say if you are saying that the damping. What are the damping, which is being there on that particular part and the mass absorber, they are just putting the vibrating features in the entire system.

In their designing you see here, when we are just choosing those values, we need to see that, what kind of the displacement parts are being coming out when even we are not disturbing the mass m 1 or only mass m 2 is being disturbed or when we are just putting the force on the premier mass m 1 and not on the secondary mass then how the displacements are being there. And accordingly, we can choose the absorber at mass m 1 m 2 or the source, from where these displacements are being created.

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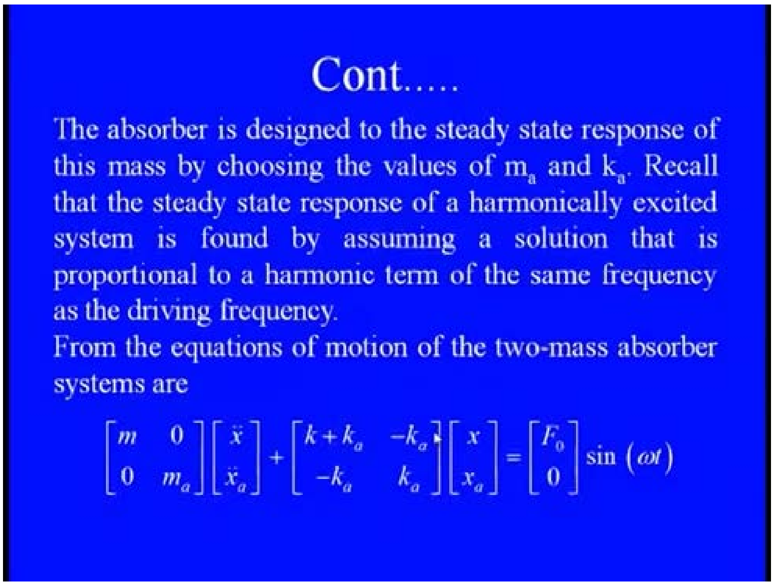

So, this you see here, we can straightaway go to the equation of motion, because we know that, it is a two degrees of freedom. So, the matrix part is being featured out, so m 1 m 2, this is mass matrix with the inertia forces with the acceleration. The restoring forces with the symmetric feature of the, we can say our spring part and whatever the force, which is being excited at one mass, say if at m 1 or m 2. So, right now, we are saying that, say at m 1 we have the sinusoidal harmonic excitation F 0 sine omega t.

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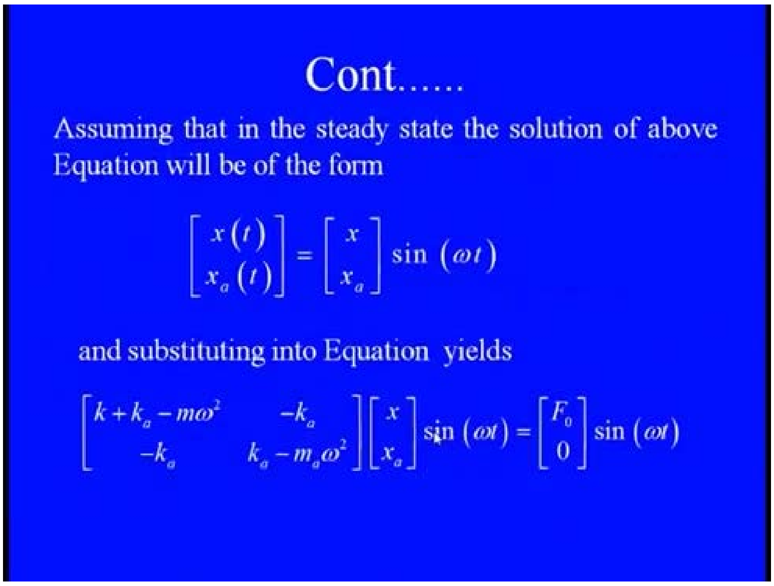

And when we are putting these things, we know that the entire steady state solution can be assumed along with the particular integral solution of the ordinary differential equations. So, we can say, we have x and x of a with this x omega t and x 0 omega t and when we are substituting these harmonic solution, at which we can say sometimes the homogeneous solution of the steady state feature. When we are keeping that, we know that, this minus m omega square plus k into x is giving us F sine omega t. So, this is what our solution, we can get even though Eigen values or the Eigen vectors for such systems.

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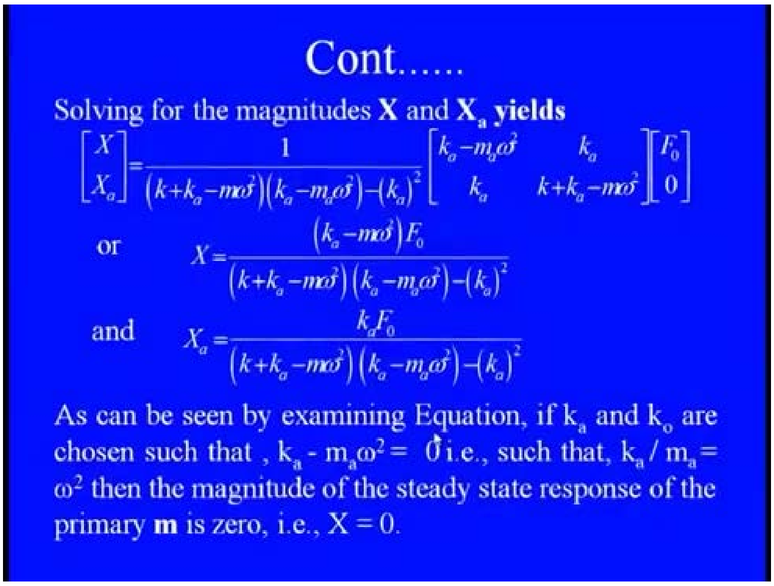

So, when we are dealing these things we know that, we have a clear amplification ratio in terms of, rather we can say the mode shape. So, this is nothing but equals to absolutely dependence on the stiffness k plus k a minus m omega square. In the same time you see here, whatever you see the feature are coming in the denominator side like k minus m omega square and minus k a square.

So, this is the integration between the stiffness and the mass matrices in such a way that, we can get, how much the amplifications are there or how much, we can say the displacements are there right from x to x a. So, when we are talking about the final displacement x, it is nothing but equals to the k a minus m omega square, which is being adopted there into whatever the force excitation, which is being input divided by k plus k a minus m omega square, the inertia feature and into k a minus m omega square.

So, this k plus k a and the minus m omega square are being featured out in such a way that, we can simply control the displacements of the entire excitations. So, we can see that, even the k a or k r is just to be chosen in such a way that, the k a minus m omega square should be 0 or else we can say that, the k a by m a should be equals to omega square. In other way we can say that, if we want to get the steady state response for the primary mass m, it can be 0 only when x equals to 0 or else when it is being excited at square root of k by m.

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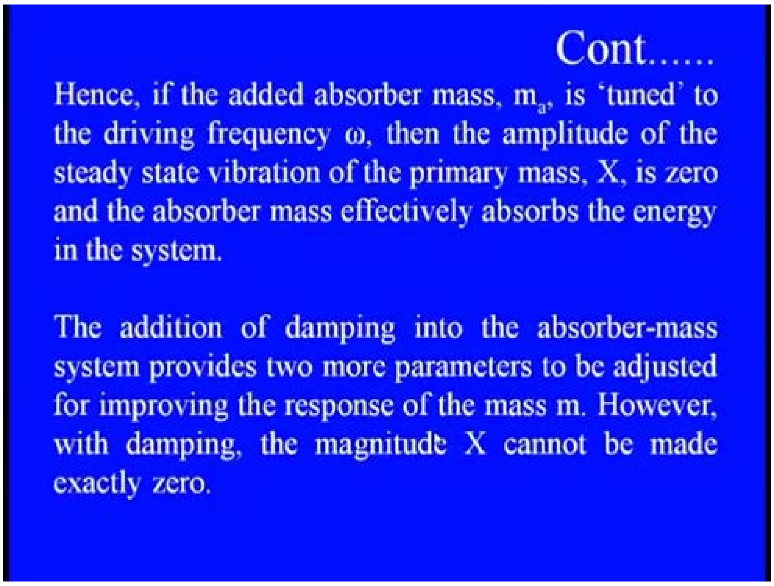

So, if any added mass, which is being m a was there you see here, is absolutely tuned to the driving frequency omega, obviously you see the amplitude of the steady state response of the primary mass is supposed to be 0. Because, the entire energy is being absorbed by this added mass at the tuned frequency and the absorber mass is effectively applied to the entire source, where it is being required. So, that is what you see, one of the system is when we know that, the system is exciting at the higher harmonics mode, the added mass in terms of the absorber feature is an effective part. Because, you see we know that, the fly wheel feature, which we are just applying there, is one of the effective way in absorbing the entire shaft vibrations.

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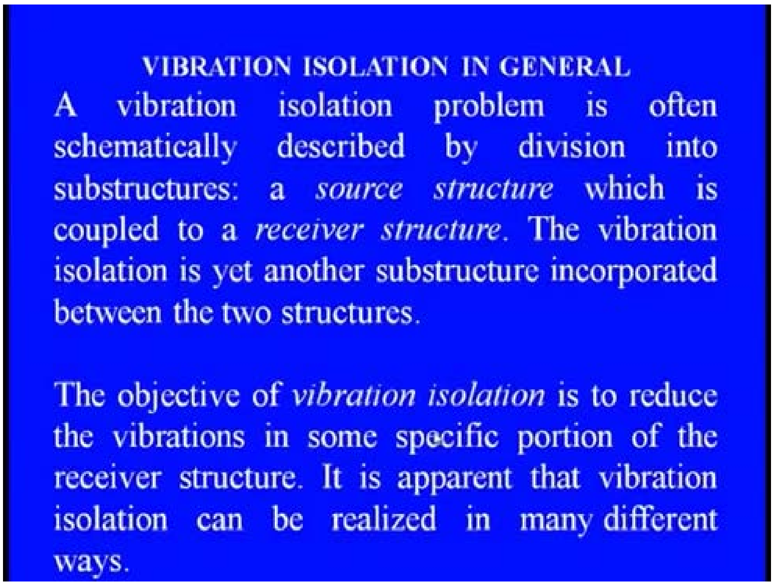

So, we can say that, in general when we are talking about the vibration isolation, we need to see that, what exactly the source, what is the transmission path, through which the vibration transmission is there and what is the receiver, at which the noise level and the vibration excitations is coming. So, the objective of the vibration isolation is just to reduce in a various specific part or the entire structure by adopting the mass, the spring and the damping appropriately. So, you see here, the entire magnitude of these vibration is being reflected by the excitation frequency and the amplitude in such a way that, we need to design our isolator in this way.

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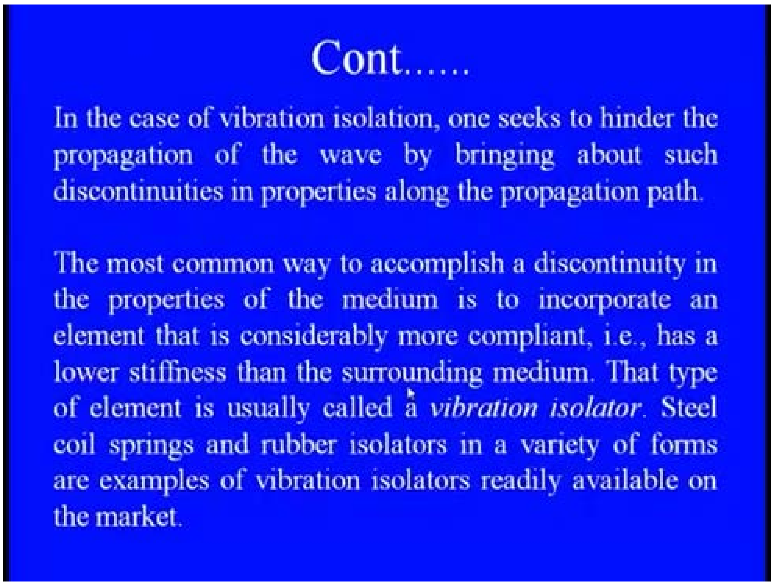

So, the most common way to accomplish; these things by providing the discontinuity or by providing the reduction at the source by appropriately choosing, these vibration isolators. So, we can say, rather the steel coil spring and the rubber isolators, both are being effective, we can say the media, through which we can achieve this much accuracy of the vibration control. So, in this lecture, we discussed about the basic framework of the vibration isolator and the absorber, say in which conditions we need to choose the mass as the vibration absorber, the isolator or the damper.

Even the elastomeric dampers, through which you see we can provide the integrated part of the spring and the damper as well. So, in the next lecture, we are going to discuss about the real application in all these, whether we are talking about the vehicle or we are talking about the industrial machinery, that what are the real feature of the isolator? And where we need to apply, what is the optimum location, where we can straightaway strike out the vibration isolation feature.

Thank you.