Introduction to Mechanical Vibration
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Lecture - 01
Introduction

So welcome to the lecture on fundamental of vibrations. So, this is an introductory lecture. Let us discuss, what is vibration? As from the mechanical engineering aspects, we will discuss the vibration.

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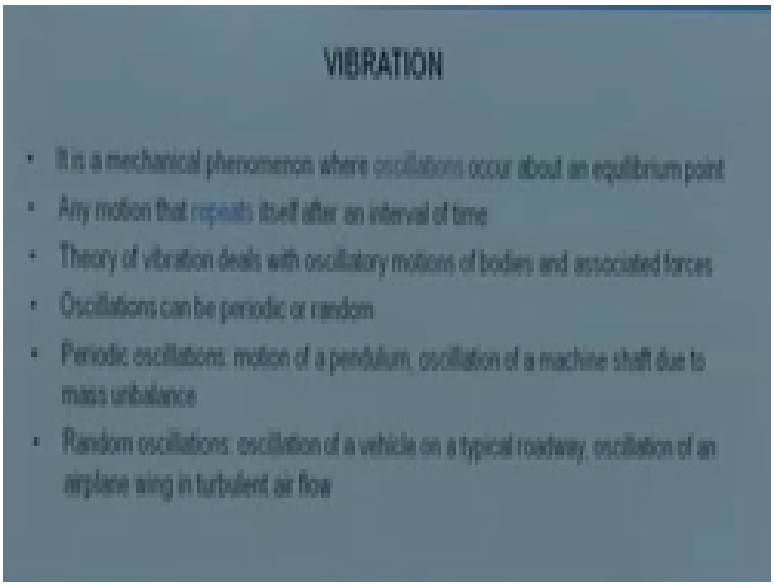

So, in general, vibration is an oscillatory motion and it means that a motion that repeats itself after some interval of time. So, usually mechanical systems or mechanical components, they are subjected to the repetitive motion, I mean they repeat their motions. So, vibration usually occurs in mechanical systems, because they are subjected to some forces and they have disturbed from their equilibrium positions, so they start vibrating.

So, vibration is type of oscillation, a repetitive motion and these oscillations can be periodic as well as random. So, for example periodic, periodic like, if there is a motion of a pendulum. Periodic means it has a fixed interval of time, after which it repeats its motion and when it is random means, there is no any fixed interval, when it will repeat. So, periodic motion is the motion of a pendulum or the motion of a shaft due to unbalanced masses.

However, the random motions, when we have a vehicle that is passing on the road way and due to the road profile, because the road profile is irregular. So, due to the effect of that road profile the motion of the vehicle or automobile, that is random.

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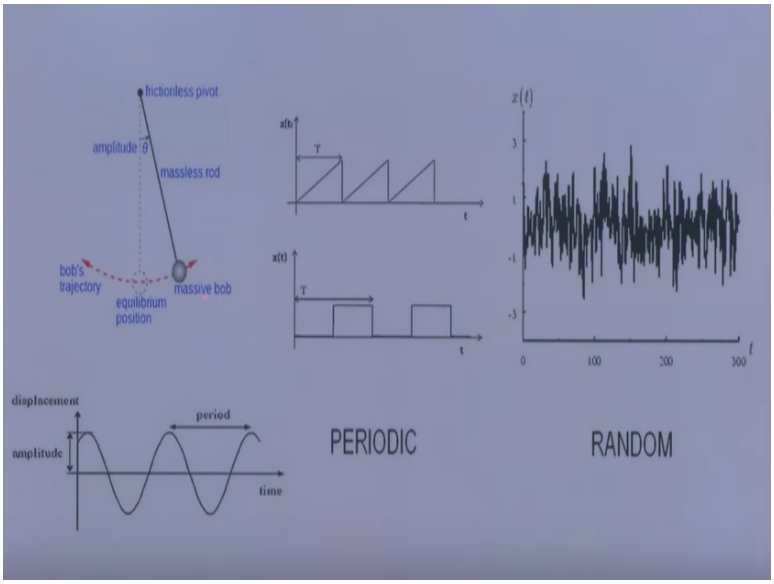

So, here we can see that, so I say that there is a pendulum and it is moving about some equilibrium point. So, equilibrium position is the position at rest. When we leave the pendulum, it will rest in this position. However, when it vibrates, it will vibrate at this position and it may have a theta, this degree of freedom. Similarly, we have here, you can see some profile of the displacement and time plot.

So, we can see here this triangular profile, it means this motion is going to repeat, this triangle is going to repeat itself, after a fixed interval of time. So, this time is fixed. So, this is the time that is fixed and therefore it is periodic. Similarly, here this profile, this motion is going to fix and that repeats after this fixed time and that therefore it is periodic motion. Similarly, here, we have a repetition of this wave profile, it repeats from here and then again it starts repeating its motion.

These are periodic but if you see this motion, there is no any fixed time interval, when it will repeat itself. It is random motion. So, for example, there is the wind forces and therefore the vibration of a tower due to this wind forces. So, these are the random vibration signals.

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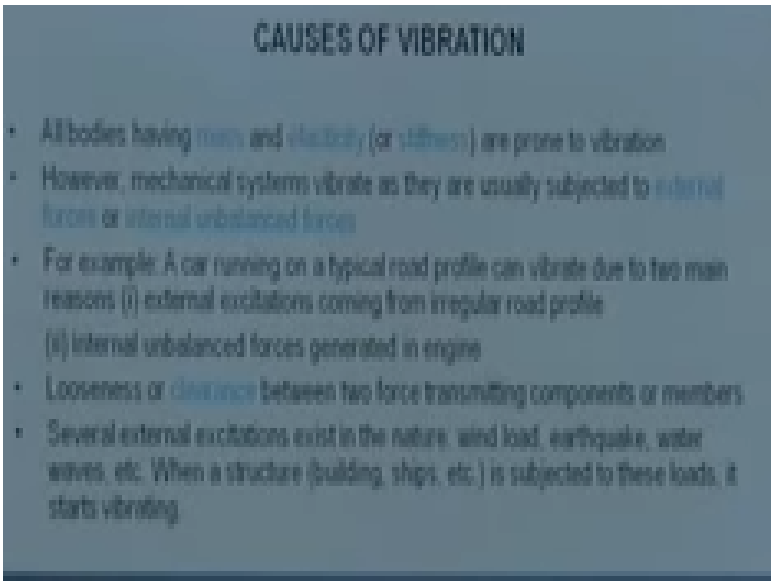

So, now the next question is why mechanical system vibrates? Why there is vibration of mechanical systems? Why do not they are static? So, as we know that every mechanical system has some mass and stiffness. So, any system that has some mass and stiffness that is prone to vibrations. Moreover, the mechanical systems, they are subjected to external forces as well as some forces that are generated inside the system.

For example, if there is some internal combustion engine, there are some unbalanced forces that are generated inside the system and due to the effect of those forces, the system will vibrate. And there are several external excitation forces, for example there are earthquakes, there are wind, there are water waves, so for example, there is a boat or ship in the water, in the sea or in the canal or river, due to the waves, because waves are external force and when they are applied on a system that has some stiffness and every mechanical system has some stiffness and mass.

And whenever that forces are applied on the system, they make them vibrate. In mechanical systems, there are some looseness between, because there are connections between the two members and when there is some weak connections, loose connections, so that can cause vibrations.

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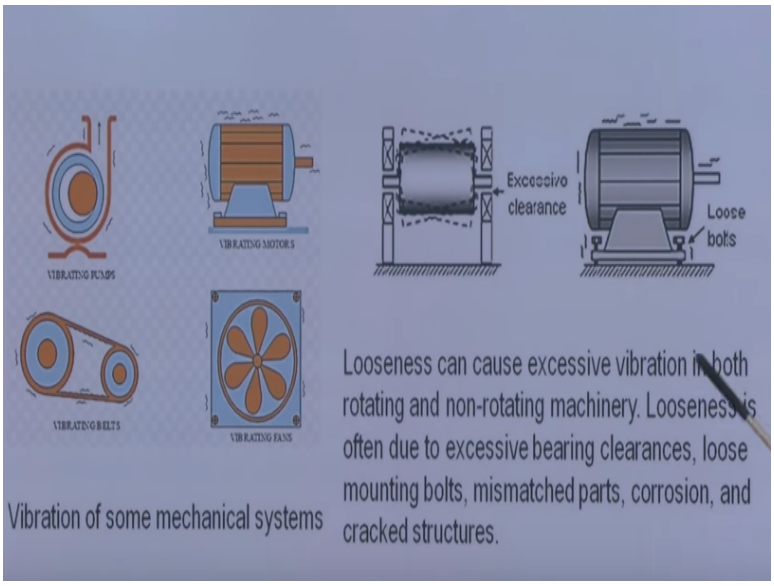

For example, we can see here, so here are some clearance, so this is the bearings and the shaft, if there is more clearance or here are the bolts that are supporting this motor that are connecting to the support of this motor. If they are loose or more clearance is there, there will be more vibrations. And there are some mechanical systems, like vibrating pumps, vibrating motors, belts and pulley drives, then vibrates the fan.

So, these rotary systems, they may have some eccentric masses, they have some unbalanced masses. And due to that unbalance, they may have some vibrations.

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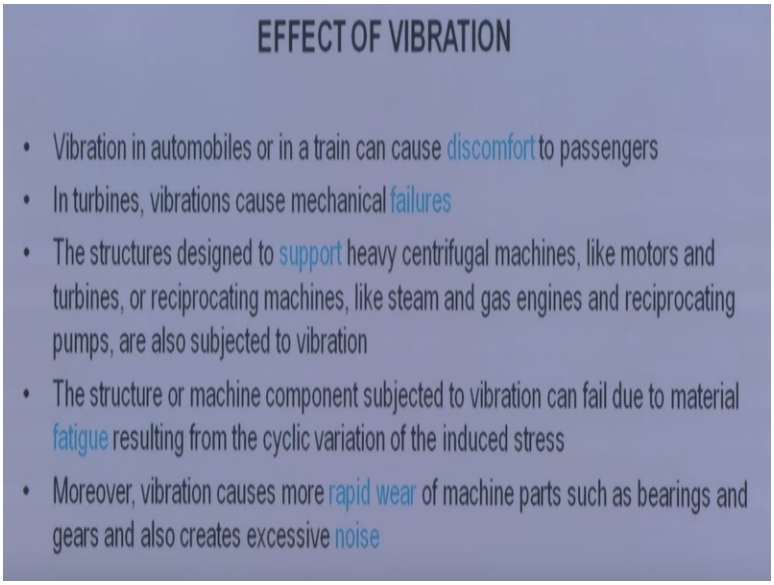

So, what is the effect of vibration? Now, we have defined vibration, we have defined the causes of vibration, now, we are to know what is the effect of vibration? The effect is positive or negative? So, in general, in mechanical systems, in several applications, we avoid or we do not want vibrations. For example, if we are in a train, we are in automobiles, we are in bus and we do not want vibrations because the vibration causes discomfort to the passengers.

If we have some turbines, there are plates and rotors, the vibration can cause fatigue and failure of the turbine plates, turbine rotors, components and if there is some machine that is on some support and there is some vibration of the machine, the vibration will transmit from that machine to the support and usually the support are on the floor and so, the floor can vibrate. And the people on the floor can feel that vibration.

And they can feel uneasiness of the vibration due to vibration. Moreover, due to the vibration there could be rapid wear of certain components like bearings and gears and due to that there could be generation of noise also. So, we can see that in mechanical systems usually we are avoiding the vibration because vibration is going to have some harmful effects.

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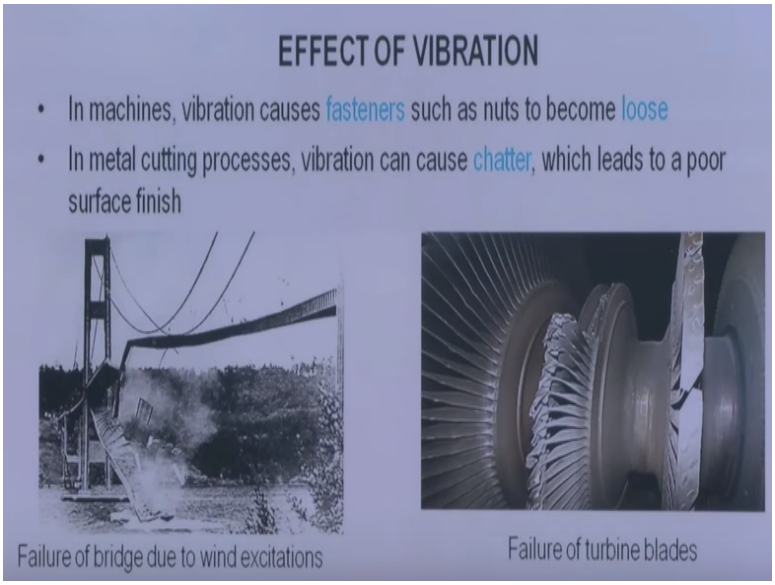

So, we can see here, a vibration can make the fasteners loose and if there is some vibration in the machine of the, for example, if it is cutting lathe machine, ok, so the tool can chatter and due to the vibration of the tool, we cannot achieve the required surface finish on the product. That is

machined. So, here we can see the two examples, so one is this bridge and that is failed one due to that is collapsed due to the wind excitations.

As I said that the structure or systems, they are subjected to wind loads and due to that they can vibrate and that vibration can lead because the theory of vibration is very vast and you will understand that in certain condition this vibration can lead to the failure of this phase and here in turbine blades, there could be the failure after wind blades due to the fatigue that can be due to the vibration.

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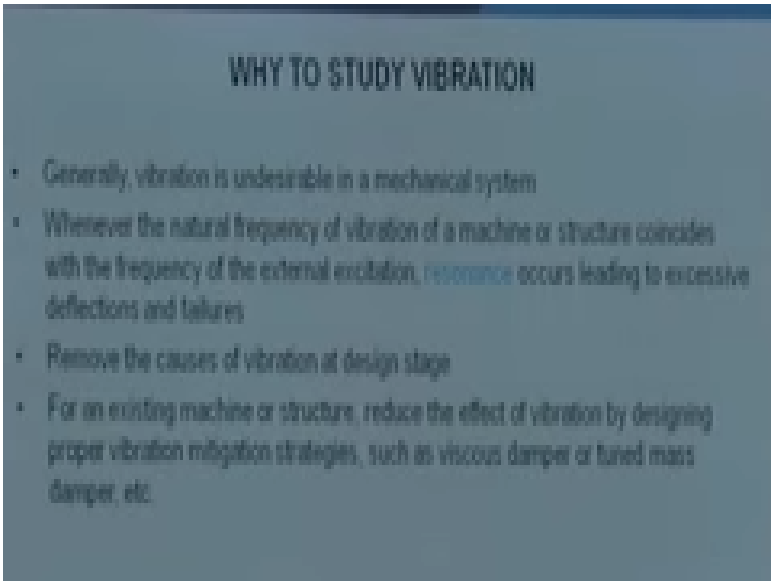

So, as a mechanical engineer, why should you study the vibration? As we saw the examples and we find that the vibration in mechanical systems is undesirable, we do not want vibrations and every mechanical system has some natural frequencies. And if the force that is applied on the system and the frequency of that force coincides with the natural frequency of the system, there is the resonance condition and in this condition, the vibration amplitude of the system is quite large and the system can break and fail.

And as a mechanical engineer, we should study to avoid this circumstances in any machine and therefore we should study the vibration. We should study it, why because we can identify and remove the causes of vibration in the designing stage or we can identify in the early stage if there

is some problem of vibration. We can identify, we can know why it is and we can rectify the vibration causes.

Nowadays, if a system is existing and there is vibration problem and there is no any possibility to change the design of the system, then we can design some devices that are known as dampers or vibration mitigation measures. So, we should study the vibration, so that we can design the proper vibration mitigation strategy for a system in order to reduce the vibration, for example, if we have the train motion and there is a vibration and there is primary and secondary suspension systems that are responsible for the reduction of the vibrations.

So we can design these suspensions properly, so that we can reduce the vibration. There are enough regions for you as a mechanical engineer to study the vibration.

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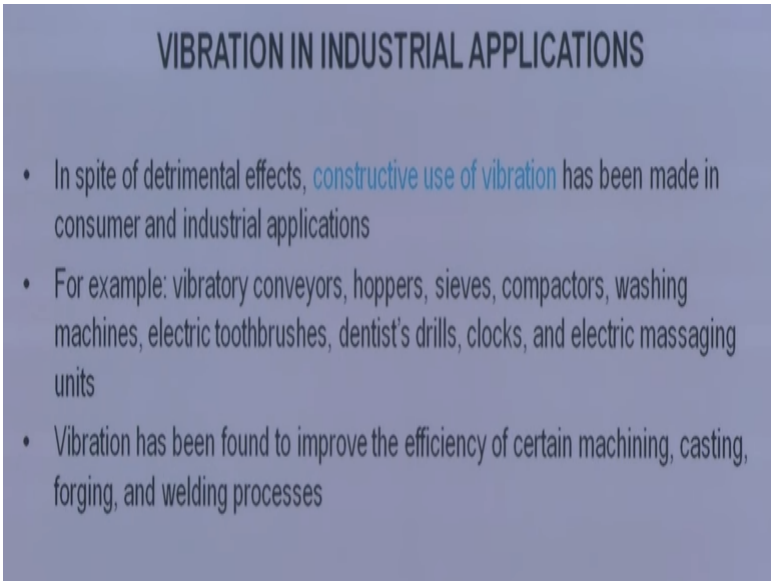

Of course vibration, we saw that they are undesirable. However, some idea of vibration is used in positive sense in some industrial application, for example, if we have vibratory conveyors, we have hoppers, sieves, washing machines, they function and they use the concept of vibration. And vibration can be used in some machining processes to improve the products to improve the efficiency of the operation.

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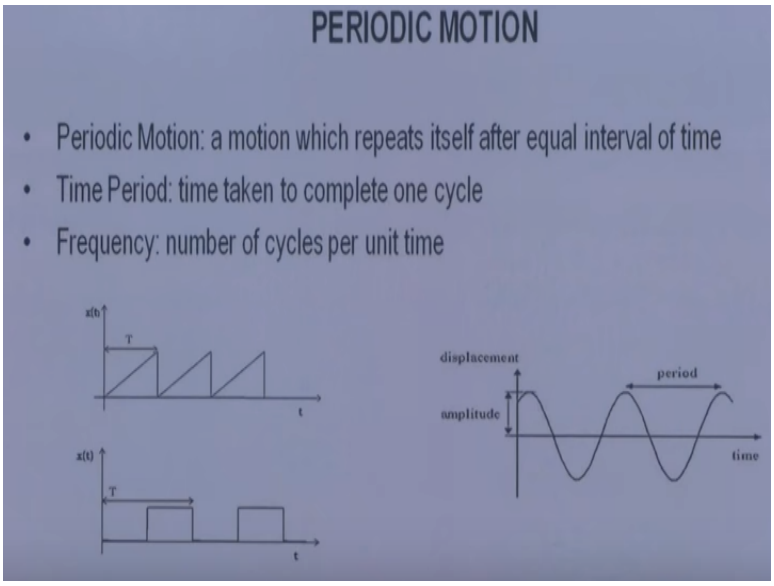

So, we have studied some basics, now again, we come back to the periodic motion. Because, we said that vibration is a repetitive motion and that repetition can be periodic or random. So again, we come to periodic motion and I said that periodic motion is a motion that repeats itself after a fixed interval of time. And we can see that that fixed interval is known as time period and reciprocal of that is known as frequency. And frequency is the number of cycles per unit of time.

So, here we can see, this is the time period. Because that motion is going to repeat itself after T, here it is the time period, because this complete motion, this is going to repeat itself and here this is the time period, because, it is going to repeat itself. Now, we discuss a case of, that of periodic motion that is simple harmonic motion. So, of course simple harmonic motion is a periodic motion also because it also repeats itself after a fixed interval of time.

However, there is some additional features. That additional features are that the acceleration is always proportional to the distance from the mean position. The acceleration is proportional to the distance from the mean position and it is always directed to the mean position. So, a simple harmonic motion can be defined as a motion when a particle is moving on a circle, the perpendicular on a diameter. So a particle is moving on a circle with a constant angular velocity.

So, if we draw a perpendicular on a diameter and we observe the motion of that perpendicular that motion is simple harmonic motion.

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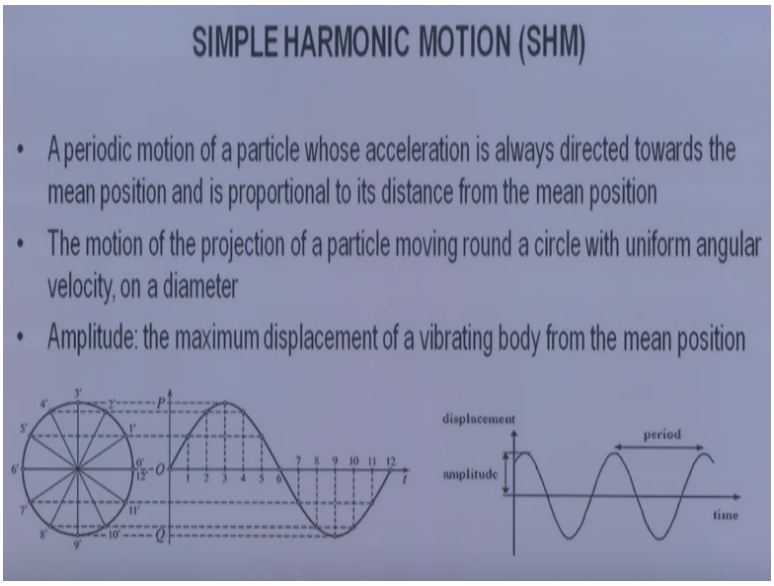

For example, here we can see, this is a simple harmonic motion and that comes because here we have a particle, if it is moving on a circle, we draw a perpendicular here or here, so we see we draw perpendicular and so the perpendicular is moving in this way.

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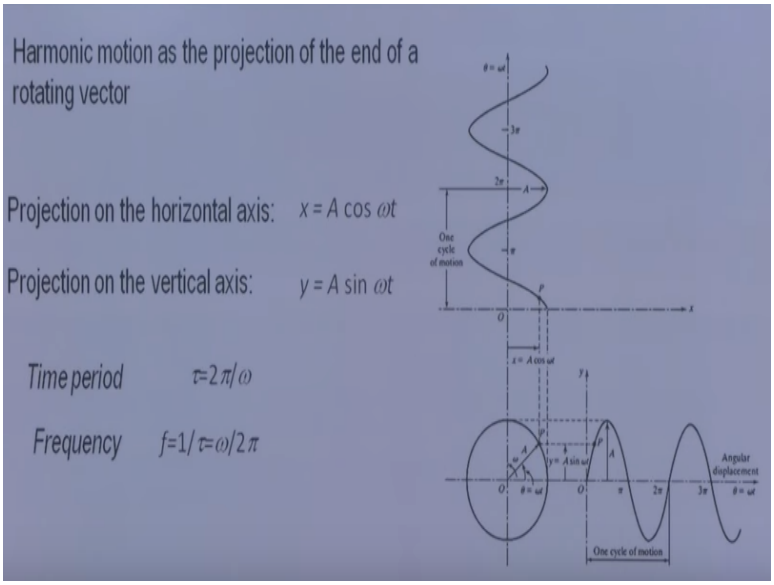

And we can see here more clearly. So, we have here the circle, the point P that is moving here, so if we draw, so we can have here.

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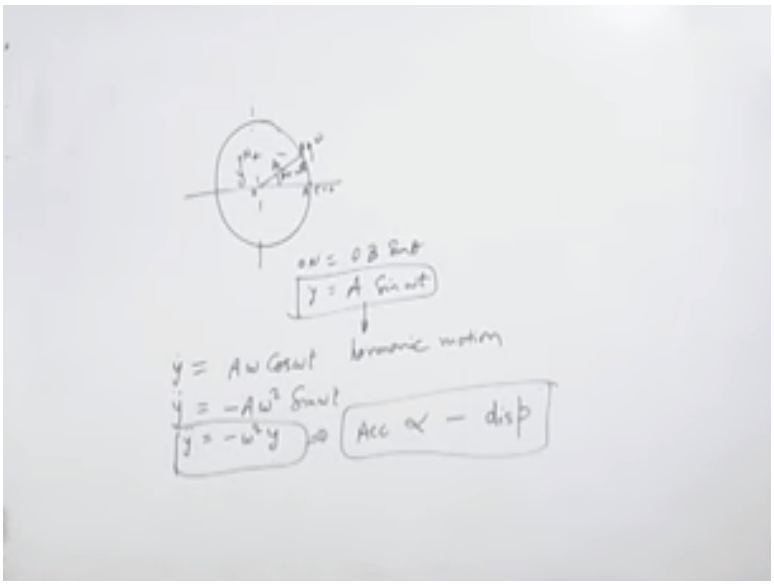

So, this is a circle and a point P that is moving here with omega and constant velocity. This is theta = omega t, this is t = zero. So, if we draw a perpendicular here, so this is, if it is O and this is A this is B this is N. So, ON = OB Sin theta and OB is the radius R, so that is R and theta is omega t, so R sin omega t. If you say this is y, then y = R Sin omega t. And this is a harmonic motion, simple harmonic motion.

So, we can say if it is, this is A, then this is A, so A Sin omega t. Now, if we differentiate y dot that is Mu omega into Cos omega t and y double dot = A omega square Sin omega t minus. So, we can say = minus omega square into A Sin omega t is y, so y. So, this is what the acceleration is proportional to the displacement and with minus sign. So, that is the property of the simple harmonic motion.

So the time period is 2 pi by omega and frequency is omega by 2 pi, where omega is angular frequency.

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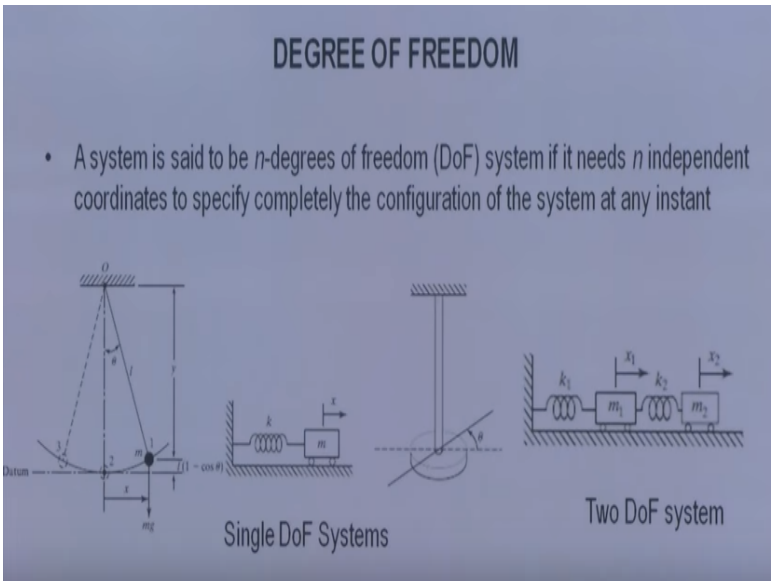

Now, we have degree of freedom. So, a system is set to have n degree of freedom, if it needs n independent coordinates to specify, completes its configuration at any instant of time. So, for example, here we have this pendulum and this pendulum, although this is x and this is y, but they can be represented in terms of theta, so theta is the only degree of freedom that can express its position of this mass attaining strength of time.

Here this is single degree of freedom system, because it needs one degree of freedom, mass that is moving in x direction. This is angular degree of freedom because only the rotation. Here we have two masses moving in x direction, so each mass needs one degree of freedom. So, this is the two degree of freedom system, the system needs two degree of freedom.

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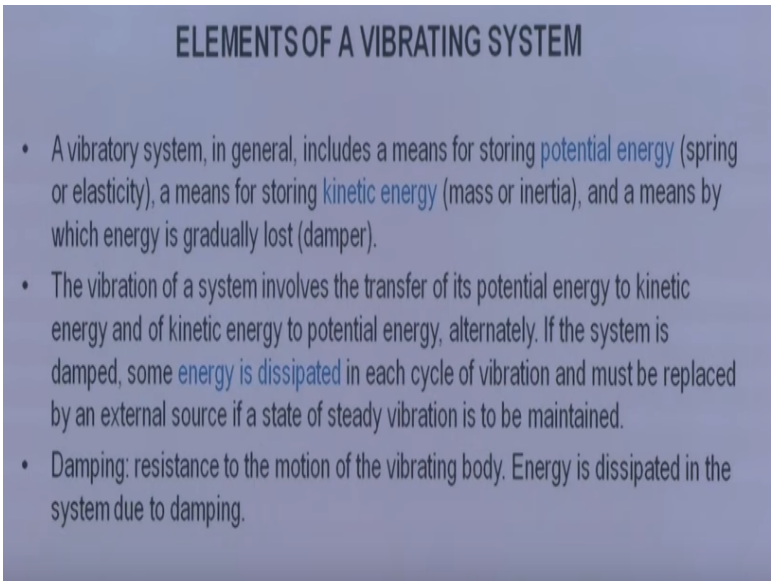

So, vibrating system, what are the elements of vibrating system? So, vibrating system, as I said that mechanical system that is prone to vibration, if it has mass and stiffness. So, the function of mass is to store the kinetic energy and the function of spring is to store the potential energy. And during vibration there is the exchange of these two energies, however there is another element that is called damping element. So, the damping element, it dissipates the energy.

So, if a system wants to maintain its vibration it needs some external force, so that its vibration could be retained, otherwise due to the effect of damping the vibration amplitude will decay with the time. So, the damping is the resistance to the motion of the vibrating subject and it dissipates the energy. So, there are basically three elements of mechanical system that is mass, stiffness or a spring and damper.

So, vibration is classified in two types. Of course, the classification can be made in several ways, but here the free vibration and forced vibration, they are mainly classified because they are different types of vibrations. So, what is free vibration? So, free vibration it says, it means there is no force, so if we disturb a system by pulling it of a small amount, and we leave it, then the system will start vibrating and that is known as free vibration.

And that frequency of that vibration is the natural frequency of the vibration. However, if there is some external force applied on the system and the system is vibrating due to the effect of the,

under the effect of that force that is forced vibration. And in the long run or in the steady stage, the system will vibrate with the same frequency as of the external force.

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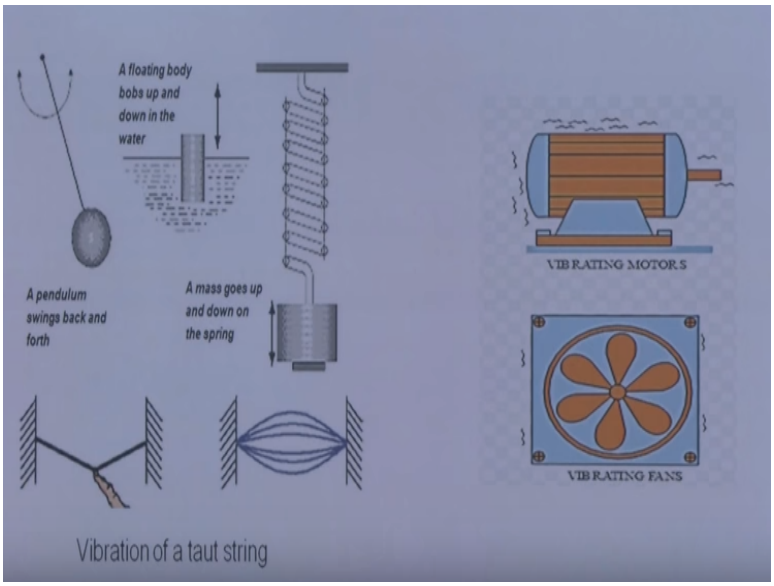

So, here are some examples of the free vibration, I mean we disturb this woof in the water and it will come up and down. This pendulum, we disturb, we pull it little theta, then we leave it, then it will start vibrating and it will vibrate with its natural frequency. There is some string. If we pull a string, it will beat and if we leave it, it will vibrate. These are all examples of free vibrations. However, here are some motors and fans, they are subjected to some unbalanced forces and so they vibrate under those forces. And they are forced vibration case.

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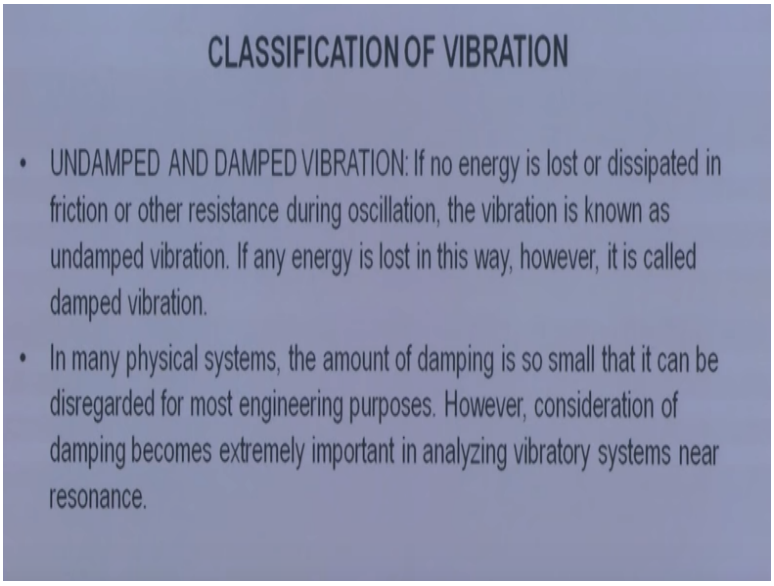

Now, there is also another type of classification known as undamped and damped vibration. So, undamped means there is no damping or damping is zero. There is only mass and stiffness component and so there is no loss of energy in the system, however damp vibration, there is damping elements, so there will be the loss of dissipation energy. As we said that at resonance condition, the vibration is very excessive of a system.

Therefore, to reduce that large amplitude vibration, we need damping to bring that amplitude in some lower range. So, the role of damping is quite important. Then there are some linear and nonlinear vibrations. So, linear vibration means this behavior of dampers, spring, that is linear. They behave in a linear way and the differential equation that is formed, that is a linear differential equation.

However, if stiffness is nonlinear or damping is nonlinear, so the differential equations will be unknown in your differential equation and these vibrations are termed as nonlinear vibrations. So, in case of linear vibration the principle of super position holds and we can take advantage of that, therefore the linear systems are simpler analysis than the nonlinear systems. So, this is all about the introduction on the vibrations. I thank you for attending this lecture and see you in the next lecture.