Vibration Control
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Module - 4
Vibration Generation Mechanism
Lecture - 2
Self Excitation Vibration

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. In our previous lecture we discussed about that how we can classify the source through which the excitations are being happen in the machine. We discussed mainly about the unbalanced rotor, because this is a very common cause of vibration. We also discussed about the misalignment.

We know that you see the unbalanced, which is being there you see in the rotor is also due to various reasons. We discussed about the resonant conditions and we discussed about the various other features of the systems characteristics through which the excitations are coming in that. We also discussed about you see the band or the boat shaft and when it is being excited.

How the vibration spectrum is being coming out and then you see if we want to analyze the vibration spectrum say in the time domain or the frequency domain. We can immediately find out that there are more than one exciting frequencies are there. Even in the frequency response function f r f. We can simply see that there are dedicated exciting frequencies according to the defects like in the bearings or in the gears or in the shaft. Even in the shaft you see here the misalignment unbalance.

So, we can analyze various features through the vibration signature. We could easily figure out the source, so that is why you know like noted down the previous lectures the various causes of the vibrations are. Then we discussed about you see that when you see these vibrations are there in the you know like in this mechanism of features. Then how do we analyze these vibrations using the signatures. Then you see once you find out those things then what are the possible other classification, when these two or more defects are being interacted.

So, in the current lecture, now we are going to discuss again you see the vibration generation mechanism under the self excitation. Because, we know that even the system is of the robust design there is no defect there is no unbalance. There is no deterioration or the wear and tear is there of the component through which you see the excitations are coming. Even the machine is inducing the vibration the machine is always creating some kind of noise. This is mainly coming under the self excitation or the self excited vibrations. So, the system, which is under the self excited vibrations begin to vibrate of their own accord in spontaneously.

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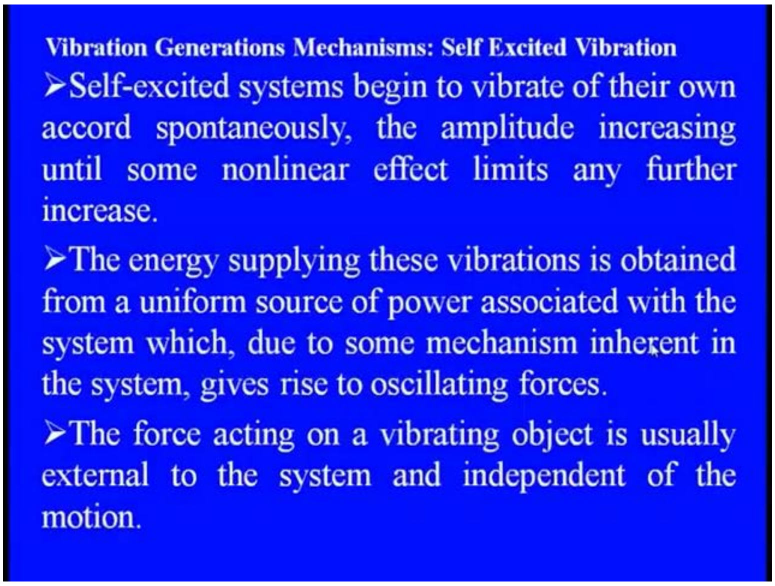

You see the amplitude of these vibration increases until some of the non-linear effect limit is increases further increases. So, that means we can say that when a realistic system is in the rotating feature the nonlinearity is there. The nonlinearity was the nonlinearity in the system may be of various reasons the geometric nonlinearities we are considering. Say you see at the contact reason the point contact line contact, the surface contact the deformation, which simply you know like coming in the restoring forces as a linear, but the real nature of the deformation with the force distribution. The mass distribution all along the component is non-linear.

This thing is coming under the non-linear second feature in the non-linear effect is having the damping nonlinearity. Because, you see the material, which we always assuming the homogenous material, but under you see the real situation the things are not the same. Even under the elasto hydro dynamic lubrication with the viscous damping. We cannot say that at the entire load zone the film thickness of the elasto hydro dynamic lubrication will remains same with the deformation.

Even the mass distribution of the component with these three, like we can say that there is a clear nonlinearity. The boundary conditions when the system starts we know that the transient conditions are there. Because, of these boundary conditions say, because of any eccentric loading or something you see here we have always the nonlinearity. So, the energy supplying by these you see vibration can be easily obtained from the uniform source of power, which is associated with the system.

There is no external excitation, it is only within the system itself. Because, you see due to some mechanism, which are being inherent in the system gives always rise some kind of the oscillating forces. This force acting on the vibrating object is usually like external and independent of the motion. Then we can say that you see here the energy supplying towards the system side is inducing the vibration.

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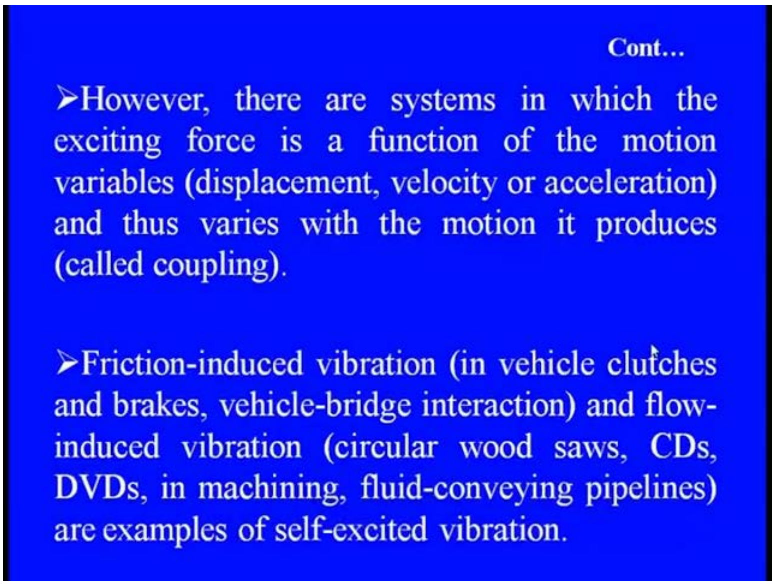

It has you see a single kind of power generation, which is associated with the system only, but there are systems in which you see the exciting force, is a function of motion variables. Like the inertia force, restoring force or damping force, the elements are displacement velocity and acceleration. When these variables are varies with the motion with their you know like coupled part. These things they produces the kind of excitations and even the friction induced vibration.

Sometimes you see like when we know that the vehicle clutches or the breaks. Any kind of you see the vehicle bridge interaction or the vehicle surface interaction. Even the flow induced vibration like any kind of the fluid conveying pipelines. They are the perfect examples of the self excited vibrations like the C D's, D V D's motion. The machining part the circular wood stalls all these are perfectly we can say a representation of the self excited vibrations.

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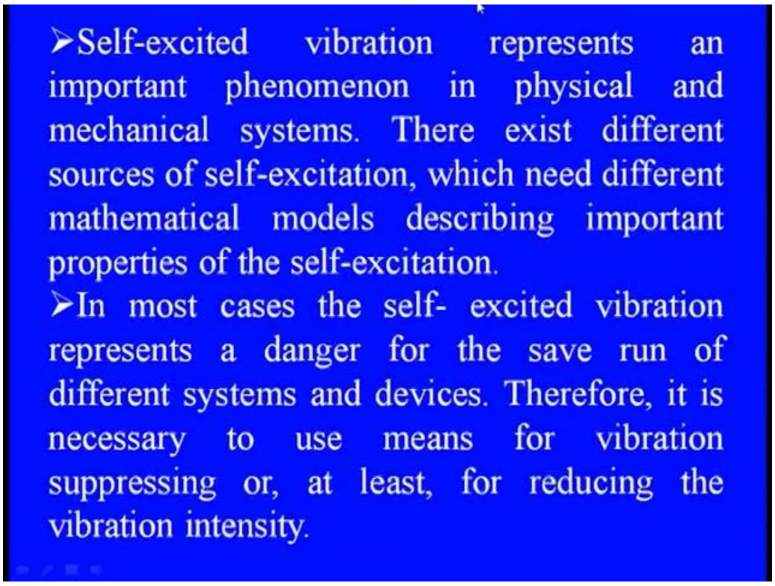

So, self excited vibrations can be can represent an important phenomena, especially in the mechanical system with their own physical interpretations. There exist a clear different source of self excitation, which needs to be clearly understand with the using of mathematical modeling, which can immediately coupled. The inherent property of all the we can say, object along with the other properties through which the self excitations are being inducing.

So, in most of the cases of this self excited vibration. It always represents a danger for save run of different systems and the device. Therefore, it is necessary to use the means of vibration suppression. At least to reduce the vibration intensity when there is no fault or there is no external excitations are being there. The occurrence of this self excited vibration, in any physical system is intimately associated with the stability of equilibrium positions as well.

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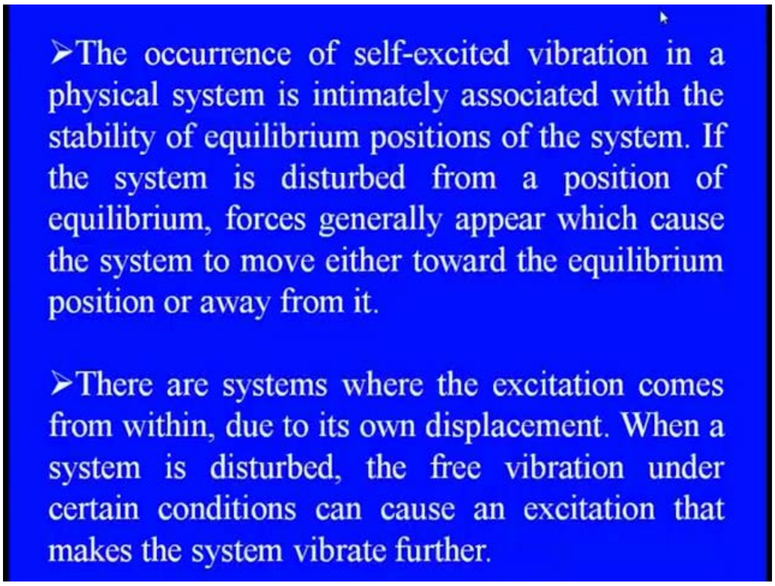

If the system is distributed from the position of equilibrium forces with generally appear. They are causing the system to move either from the, we can say equilibrium position or towards you see the outside away from the equilibrium positions. So, we need to check it out that, what exactly the occurrence of these self excited vibrations are in any physical system. There are various systems where excitations are coming from the inside. Only due to its own displacement or inherent nature, when a system is disturbed the free vibration under these certain conditions can cause the excitations, which makes the system further vibrate and can damage up to the extreme level.

An increase in vibration can cause further increase in excitation. Therefore, we can say that the system can run out of the control with their amplitude. When these system vibration amplitudes are higher the restoring force is goes on increasing and increasing. Because, of the inherent nature and these increased restoring forces are absolutely you know like fighting with the other increasing amplitudes. Until, a balanced feature is not being added to reduce the excitation of vibrations. Then we can say that by putting those control features we can brought down the vibrations towards the limit cycle vibrations.

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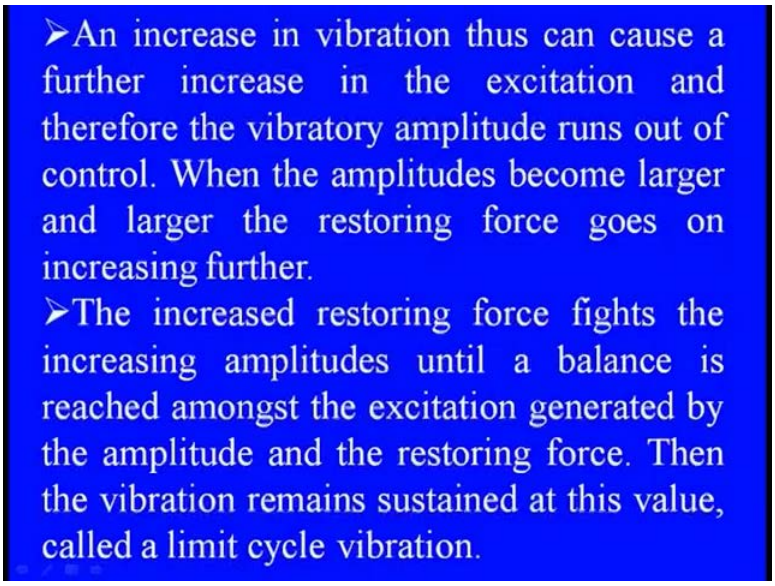

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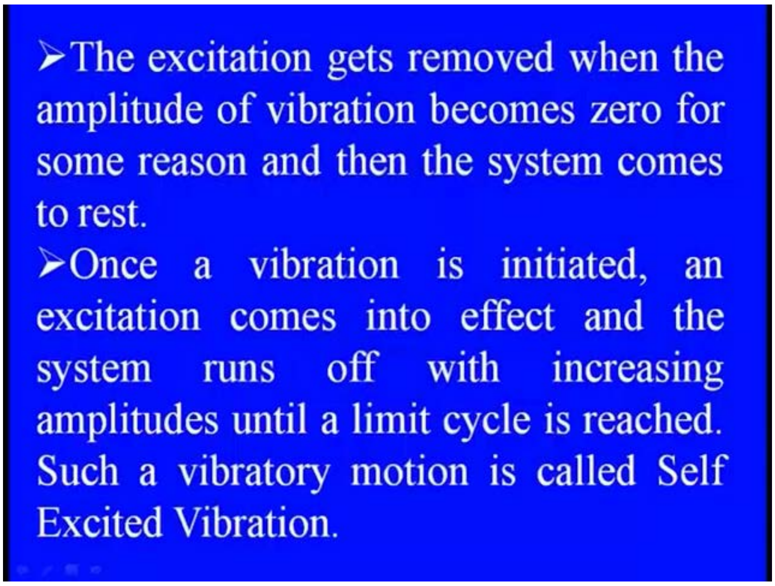

The excitation gets removed when the amplitude of vibration becomes zero. Else we can say that we can simply brought the system towards the equilibrium side. Once the system is just vibrating and that vibration initiated the excitation comes into the effect. The system runs off with the increasing amount of amplitude. Until, the limit cycle is not being reached. So, when such kind of you see the vibrations are being happening. We can brought these kind of vibrations under the self excited vibrations. The function of many machine and devices such as the power picks the drilling sets or any compacting.

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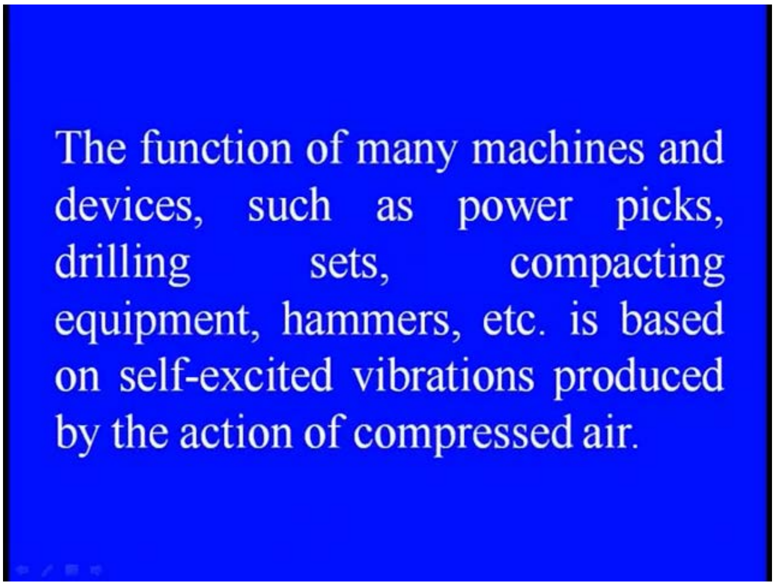

Like the equipment like the hammers or anything they are always based on the self excited vibration. These are being produced by the action of compressed air. Such machine can hardly be expected to operate efficiently without having a thorough understanding of the problems, which are being existed.

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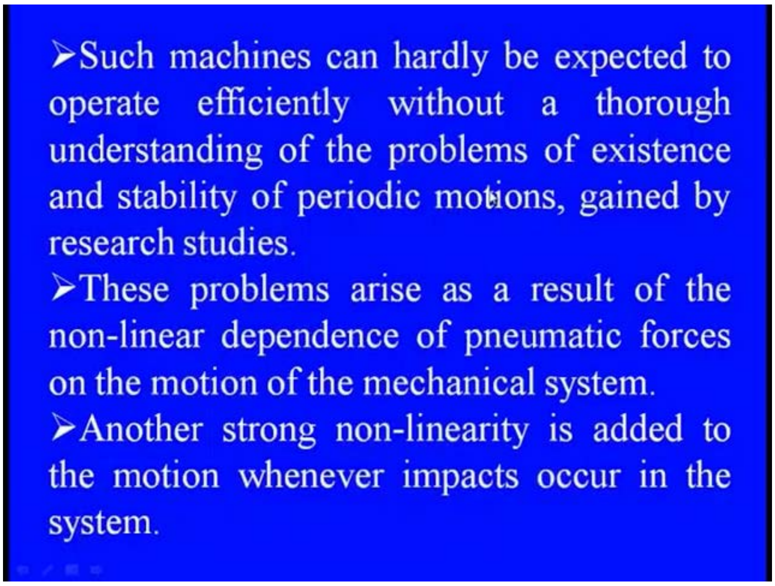

The stability of any periodic motions within the system. Since, we know that there are periodic inputs within the system, but because of the system nonlinearity the output is somewhat different, what we are desiring. It may be periodic it may be quasi periodic it may be harmonic sub or super harmonic. Sometimes, you see because of the nonlinearity of the system. It may be the chaotic one, so these self excited vibrations can cause even the chaotic vibration, which has the irregular features towards that. Then it is very difficult to brought down the entire system towards the equilibrium or the rest side and these problems arises.

As a result of this non-linearity, which is absolutely you see the non-linearity dependence of these pneumatic forces of the motion with the mechanical systems and by strong non-linearity, which is being added to the motion, whenever it impacts with the transient features. So, we know that you see the self excited vibrations can immediately not only cause. You see the oscillation or you see the exciting features, but also it can directly affect the system stability. So, machining and measuring operations are invariably accompanied by these vibrations.

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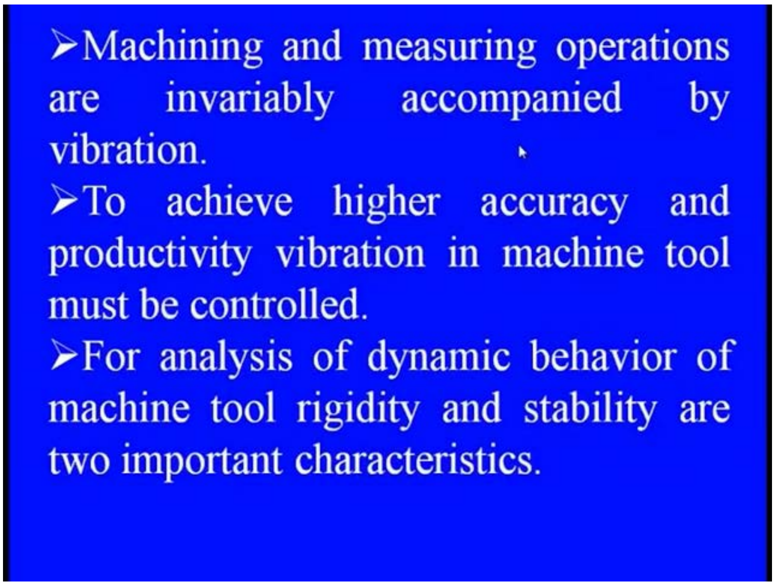

To achieve the higher accuracy in the machining or any measuring part. Even the productivity these vibrations have to controlled. Otherwise, we can have a different geometric deviations during the process. The for analysis of the dynamic behavior of machine tool rigidity and the stability needs to be checked thoroughly, because these are the two important characteristics for analysis of the dynamic behavior. When we are simply see that you see the system is not stable. They are providing more kind of you see the excitation. Then the straight way it is affecting the rigidity and the stability feature of the entire system itself. In the machine tool just like you see in the previous part we discussed the machine tool vibrations can be divided into three basic features.

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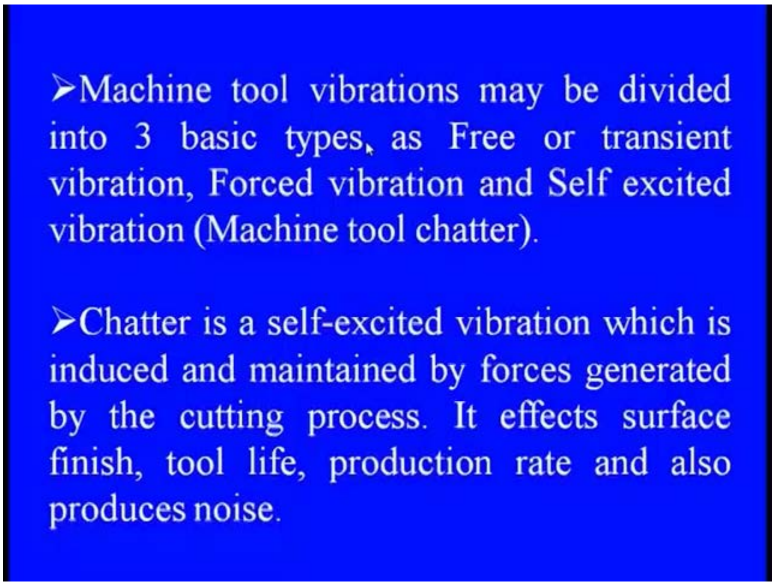

As you see the spindle you know like motion is of always at the higher speed may be upto 20,000, 30,000 R M P. So, they are contributing the huge amount of vibrations into the machine we can broadly classified this vibration into three basic types the forced vibration. The self excited vibrations and the transient vibrations and the self excited vibrations can also termed as the machine tool chatter.

So, chatter is also coming under the self excited vibration, which is simply induced and is being maintained, also by the forces, which are being generated during the cutting operations. This you see the chatter vibration is straight way affecting the surface finish. Even, because we just want the surface finish of the microns levels, which can be only achieved, when you can control this chatter vibration.

So, not only it is affecting the surface features, but also there is a clear effect of this chatter vibration on tool life production rate. Even it is producing the huge amount of noise, that the worker who is continuously working on that having a significant effect on their nerves. Like regular activities and even in their behavior, because the sounds waves are straight way affecting with this. So, the chatter resistance of the machine tool is usually characterized by of maximum stable.

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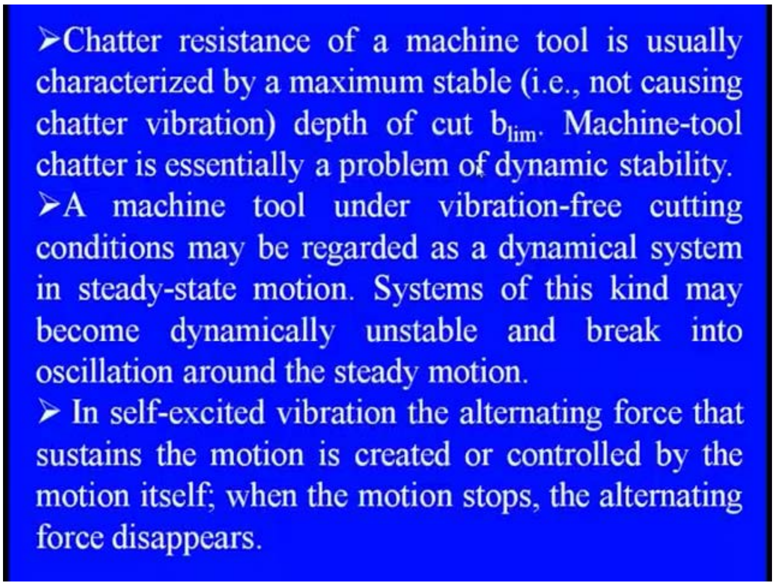

Again, you see in that we are simply looking towards the depth of cut that, how much depth of cut is there accordingly the chatter resistance can be come out. It can be simply we can say the chatter vibrations are. The machine tool chatter is essentially a big problem of the dynamic stability for this machining feature. So, machine tool under the vibration free cutting condition can be termed as the dynamical system of steady state motion. Because, in this case we can at least remove the transient feature of that the system of this kind in which the steady state portions are there.

We can say that it can be immediately go to the dynamic unstable, when the self excited vibration. The chatter vibrations are just increasing with the amplitude. When there is a diverging effect of that. It can be break into the oscillation around a transient. We need to brought down this towards the steady state.

So, in the self excited vibration and alternative force that sustains that sustained the motion is created or controlled by the motion itself. When the motion stops the alternate source, which is being generated to control this oscillation is immediately disappeared. So, in the force vibration the sustaining, we can say alternative force, which is being existed independent of the motion.

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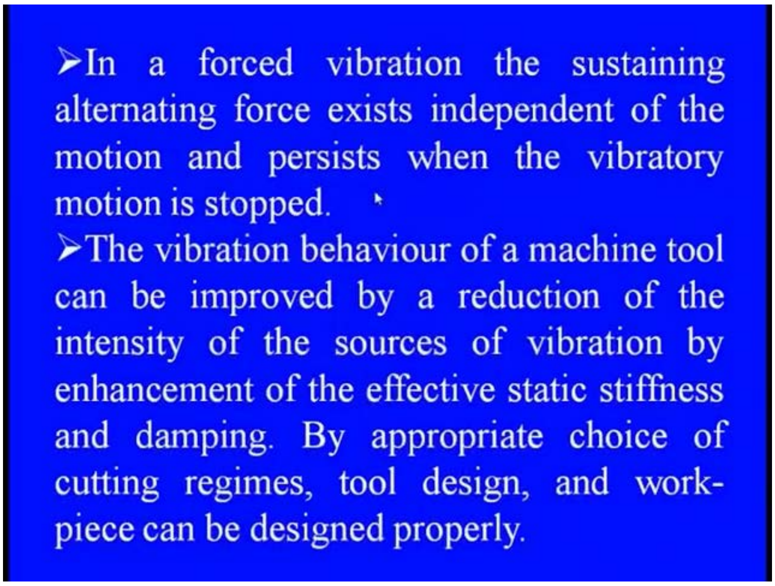

Also, can persist when vibrative motion is stopped having a significant feature for controlling the self excited vibration, the vibration behavior of machine tool can also be improved by reduction of the intensity of the source of vibration by enhancing by effective static stiffness and damping together. So, that you see here we need to check it out the two system parameters. Because, we know that the self excited vibration is the systems inherent property. So, how we can redesign the system parameter specially from the damper side and the stiffness side, so that we can reduce the intensity of the source vibration. We can improve the machine tool feature and by appropriate choice of the cutting regimes the tool design and work piece can be appropriately designed. So, that is you see one of the significant feature of the self excited vibration is.

Abatement of the sources is important mainly for the forced vibration conditions and the stiffness and damping’s are one of the two important features not only in the forced, but also in the chatter or the self excited vibrations. Both, the parameters the stiffness and the damping are important you see here just to brought down the vibration reduction. Importantly when we are talking about the stiffness, it is one of the critical parameter for accuracy of machine tool, because through stiffness we can reduce the structural deformation during the cutting forces. Damping is also the crucial for reducing or decaying the transient feature of acceleration. Once you do that the transient feature of the vibration can be suppressed out.

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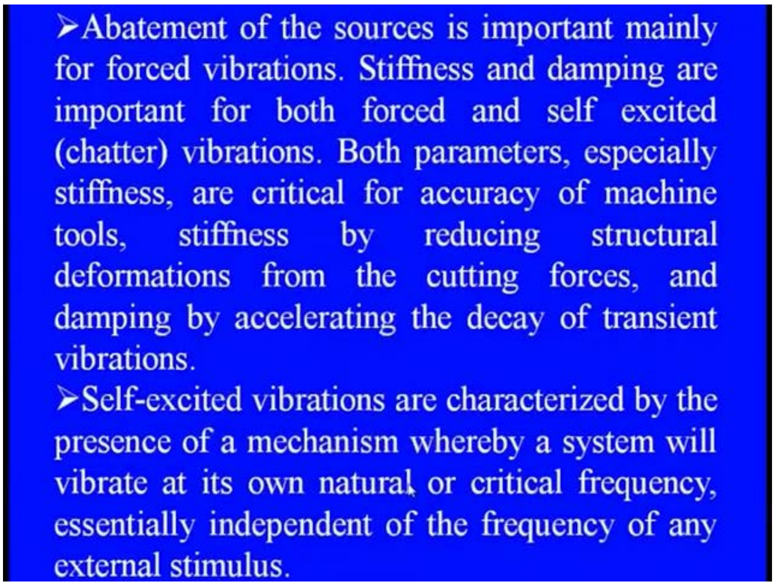

So, how these two parameters are acted it can immediately sensed out that, you know like if we have the damping. Then certainly you see the acceleration the transient feature can be decayed. If we have the stiffness the structural deformation during the cutting operations or the cutting forces can be brought down. So, self excited vibrations can be characterized by the presence of a mechanism whereby a system will vibrate at it is own natural. We can say inherent or we can say the critical frequencies, which is essentially independent of the frequency of any external a stimulus.

So, you see here you know like when we are trying to understand the physical significance of self excited vibration. We need to first characterize the physical system. We need to check it out that what are the, you know like the inherent parts or the main components are there through which these vibrations can be generated. Then we need to design the spring or the damper in such a way that we can suppress these vibration at it is own level.

So, when we are trying to term this in mathematical terms the motion is described by unstable homogenous solution to the homogenous equation of motion, is something coming under the self excited vibration. In the contradiction in case of forced or the resonant vibrations the frequency of isolation is depending on the frequency of forcing function, which is being externally applied. Like you see we know that the shaft rotational speed is one of the important feature. What are the exciting frequencies are there when they are just you know like, broughting down the particular integral solution of the equations is showing the forced vibration solution.

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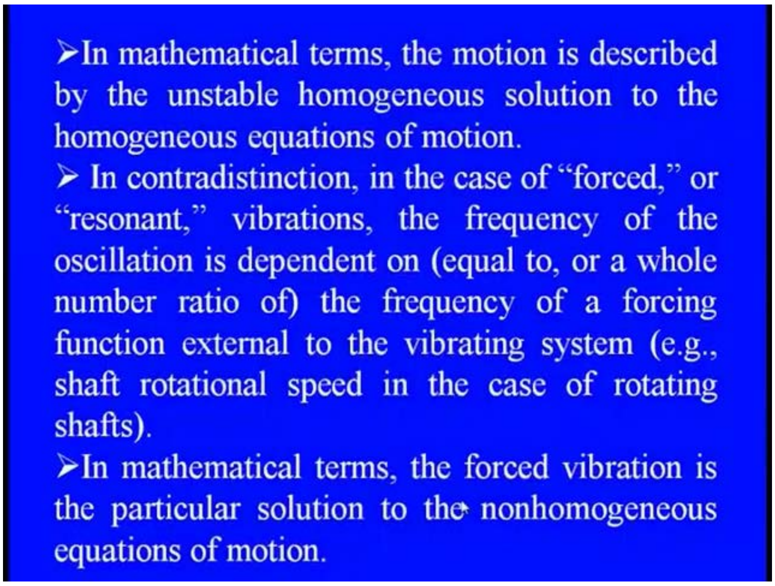

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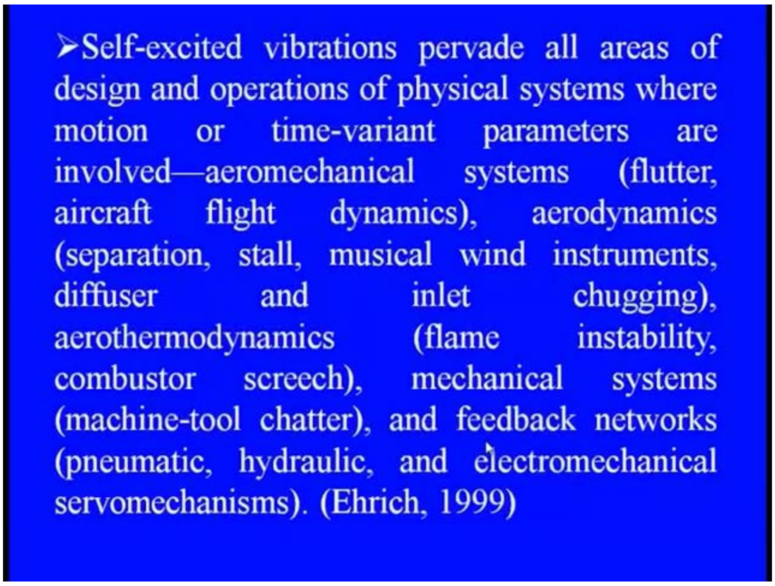

So, in mathematical terms we can say that the forced vibration is the particular solution to the non-homogeneous equation of motion, but here the motion is described by unstable homogenous solution to homogenous equation of motion. So, here there is a clear bifurcation in terms of the solving method one is a particle solution to non-homogenous equation of motion. One is the unstable homogenous solution to homogenous equation of motion. So, you see here the equation if motion is here in the self-excited vibration is homogenous, but the solution is unstable homogenous solution.

So, self-excited vibration pervade all areas of design, it is not an very specific thing it is just you see spread it out in that all areas of design and operations of physical system. Where, the motion or time variant parameters are absolutely involved how we can see various examples like the aeromechanical systems. Where, the flutter or aero craft you see you know like the flight dynamics are there the aerodynamics straight way even in which you see the separation the stall musical. Any kind of you see the wind diffuser or even the inlet chugging operations are there. These are all you see the aerodynamic forces, which are being generated. They are inducing the vibrations even the aerodynamic part the fluid or the flame instability the combustion is screech.

Even in the mechanical system as we discussed the machine tool chatter the even the feedback networks, where the sun damping is being applied. There the pneumatic hydraulic or any electromechanical servomechanism. These are all the variety of we can say the applications, where the self excited vibrations are coming, due to its inherent nature. This is being you know like analyzed by in its own paper in a very significant way. So, if you want to understand the basic mechanism of self excited vibrations. The mechanism just shows that in rotating machinery.

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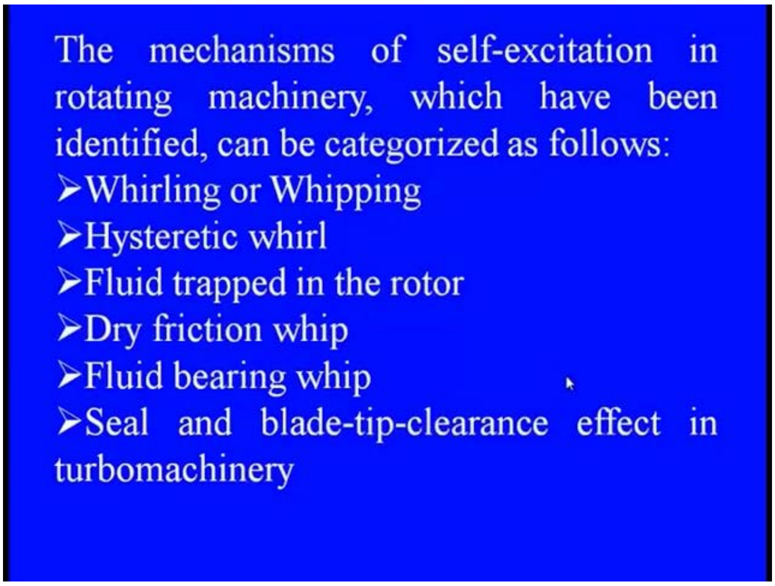

There are various categorizations of this self excited vibrations are like the whirling or whipping the hysteresis whirl. Even the fluid, which is being trapped in the rotor and creating the self excited vibrations. Even the dry friction whip fluid bearing whip and even the seal or any blade tip clearance effect. Because, when the clearance is there though you see we know that the clearance is being provided just to flow of the fluid. Even for any thermal expansion during the operation, but this clearance is also creating some kind of self excited vibration not only in the bearings not only in the gears, but also in various component of the turbo machinery.

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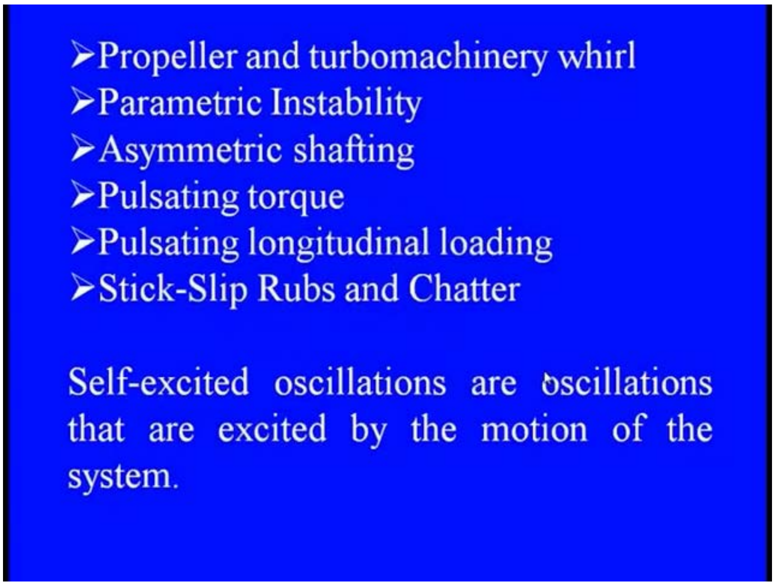

Even we know that the propeller or the turbo machinery whirl during the whirl action. One of the important parameter, which is being analyzed in the self excited vibrations are the parametric instabilities, because sometimes when we define the parameter according to the critical design of the system. We know that the parameters are always under the dynamic action, when they are crossing the range. They are exciting the system in a huge way even asymmetric shafting the pulsating torque can produce this. Even we can say that the stick slip rubs or chatter these.

All you know like factors we can say that the, these factors are coming under the category of self excited vibration. These vibrations are nothing but the oscillation that are excited by the motion of the motion of the system and being. Like we can say transmitted fastly due to the inherent nature of the system is. Like, we can see the example here.

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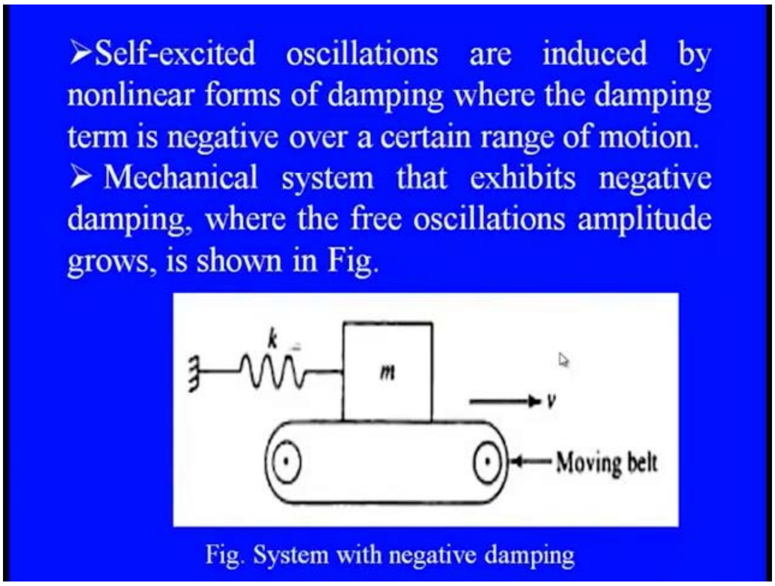

Fig. System with negative damping

The self excited oscillations are induced by the non-linear forms of damping, where the damping term is a negative or certain range of motion. When these mechanical systems that exhibit the negative damping. It clearly shows that the self excited vibrations are there. Even the system instabilities are there, because we know that the damping positive means whatever the function, which is being defined for the damping. It has to execute that, but instead of the dissipation of the energy. If the energy is being supplied to the system by the damping can be termed as the negative damping. When such things are happening means when the energy is being supplied by you. See one of the important parameter then it makes the system unstable.

So, you can see that the example means we have a moving belt and all, which you see the you know like we can say that. We have the mass and because of this velocity of the moving belt there is you see instead of having, like the vibration suppression of the mass the energy is being supplied by the damping material of the belt to the mass. So, here we can say that the system will suddenly make an unstable effort. Because, of this negative damping and this is one of the universal criteria. That is why like we can say whenever we are designing the damping. We need to find out that it should not be over damped system. So, that you know like the energy is being supplied due to you know like high viscosity to the system. This makes the system unstable.

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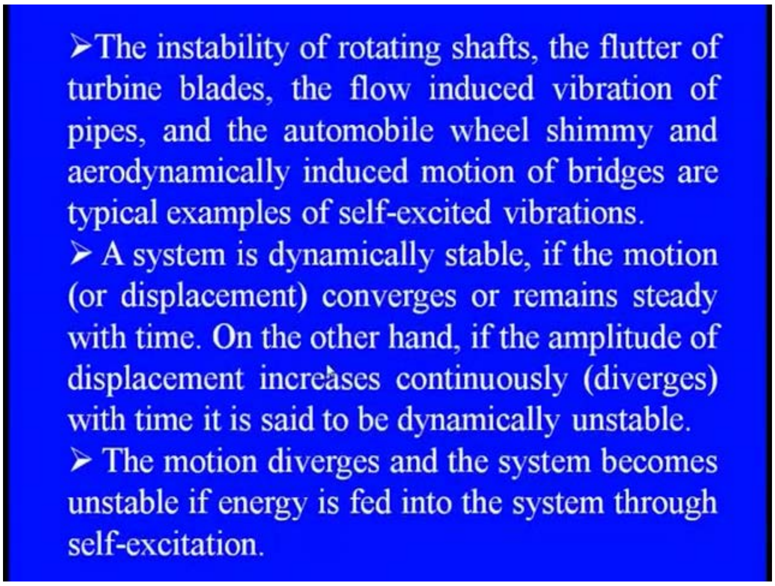

Then the instability of rotating shaft or the flutter of the turbine blades or the flow induced vibration in the pipes or in a, we can say automatic wheel shimmery. They are all a typical example of self excited vibrations, because in these cases the system can go up to the instability features. Because, of these energy supplied towards the system. Because, we know that if the energy is minimum of the system the system is stable, but here we have a different kind of system set up.

So, a system is dynamically stable, now we can categorize even if the motion displacement or anything converges. Even remain steady with the time, but if the amplitude of the displacement increases. We are saying that if the diverging effect is there of the amplitude. Even the system energy with the time the system is dynamically unstable. When this energy is being supplied certainly there is an exciting feature. The energy is coming for further excitation how we can make the system stable. So, the motion, which is diverges and the system becomes unstable the energy is directly feeded into the system as we discussed.

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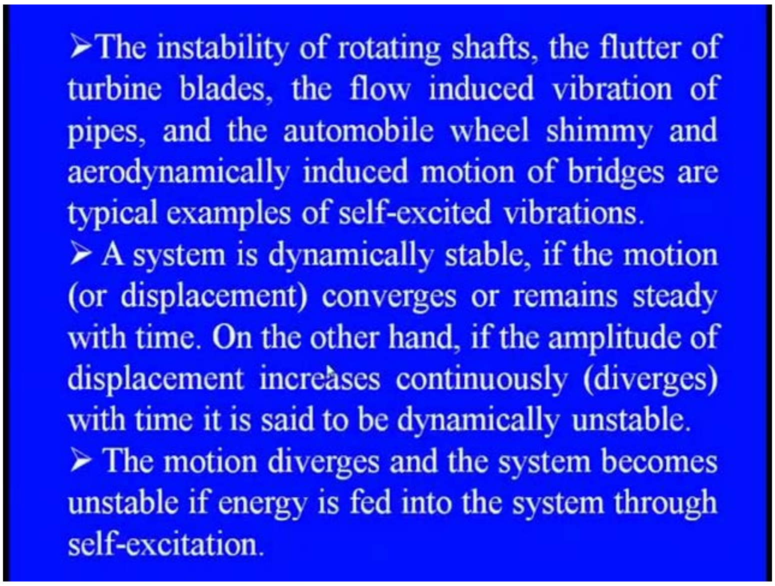

That is why you see here the self excited vibration is always creating some kind of un stability in the system itself. So, let us talk about the mass spring damper system. As you can see on your screen in that the force balance equation is this according to the Newton’s law. We discussed already these things.

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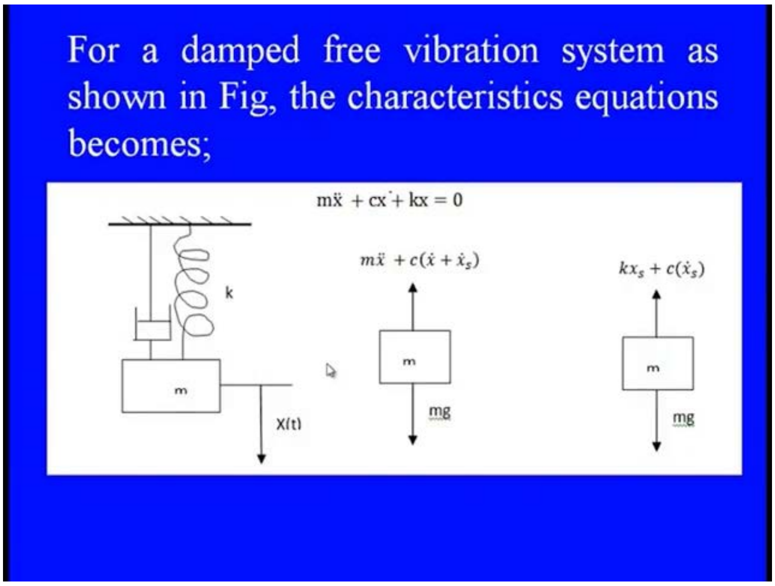

So, we have now the equation of motion n x double dot plus c x dot plus k x equals to 0. Now, if we are substituting the basic displacement as the input feature X of t equals to a e to the power lambda t.

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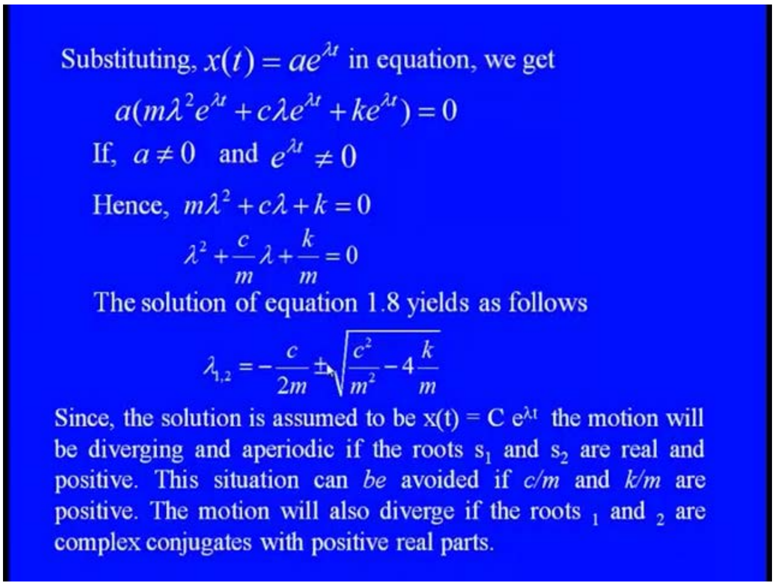

When we are keeping all the things we know that the characteristic roots of the equation. This is characteristic equation is just giving you the Eigen values of that. In other term we can say that these are nothing but our natural frequency. Since, the solution which is assumed to be X of t, which is you know like, because it is a harmonic part.

So, c into e to the power lambda t the motion will be diverging and showing the a periodic nature only. When the roots are real and positive and how the roots could be positive. You can see that the lambda one lambda 1, 2 are nothing but minus c by 2 m plus minus square root of c square by m square plus minus 4 k by m, when the roots are real and positive when you have the damping negative. When the damping is negative minus c by 2 m will show the positive feature. That means you see here from somewhere means from the damping or any other we know feature the energy is being feeded by the self excited vibration to the system. That makes the system diverging feature on unstable or the a periodic part.

This situation can be immediately avoided if the c by m and k by m are positive. We can say the motion will be diverging if the roots are of complex conjugate with the real parts as well. So, what I mean to say that we need to check it out that these things means we are saying that the positive damping positive stiffness. That is what these features are when they are acting with their with their own properties to absorb the energy or to suppress the entire oscillation. We can say that we can brought down the system towards the stable feature or equilibrium feature. You see whatever the solution features are being coming out it is absolutely under steady state phenomena.

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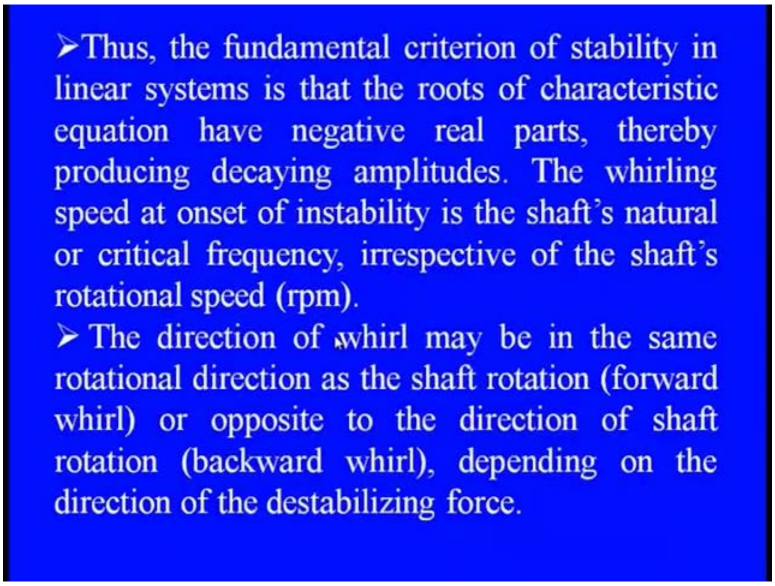

So, thus the fundamental criteria of the stability in the linear system are the roots of characteristic equation should have the negative real parts. So, that we can produce the decaying amplitude, because we know that when we are just trying to draw this with the damping effect, we have oscillatory decaying exponential feature, and the sinusoidal features are there. That is only possible when you have the real roots negative the whirling speed at the beginning of onset of a stability is the shaft natural or the critical frequency irrespective of whatever the speeds are.

So, the direction of the whirl in this whirling speed may be of the same as the rotational directions of the shaft rotations are. We can say it may be opposite to the direction of shaft rotation, when you have the backward whirl. So, the forward whirl and backward whirl are absolutely depending on the direction of these stabilizing force in the whirl action of the shaft. So, this is what you see the fundamental criteria, which we can simply see.

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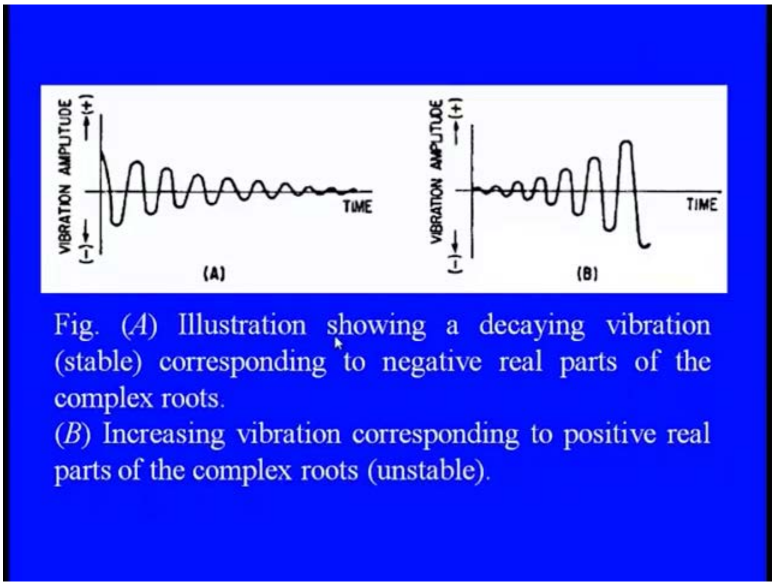

In this diagram you can see that we have the vibration amplitude one in which you see there is a clear decaying of vibration is showing the stability features in that, because we have the real parts in the negative way of any complex roots, but while in the other end. You see that there is a clear diverging or a periodic effect is coming, because we have the real parts are positive of the complex roots. They are showing the negative either c by m or k by m with the energy feeded to the system, which makes the system unstable.

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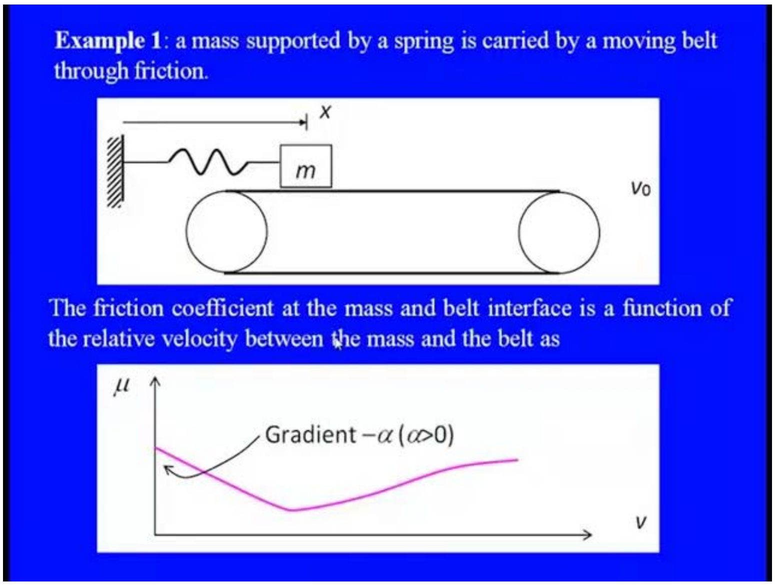

So, we can have you see the examples of that say the mass is supported by the spring is carried out by the moving belt through the friction. This friction coefficient, which is absolutely in between the mass and the belt, interfacing is a function of relative velocity, with respect to mass and the belt. So, you can see that the friction coefficient and the relative velocity you can fight simply the gradient. Then you can see that initially when the speed when the velocity is low the friction coefficient is just going down. After certain time it is now increasing. So, when the friction coefficients are increasing it produces the heat. You can make the equations there itself, like m x double dot plus k x.

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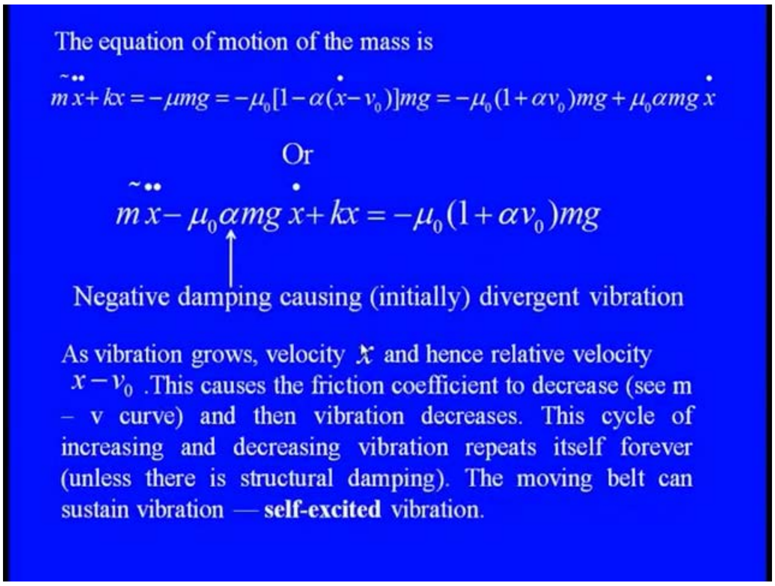

These are the two inertia force and restoring forces, which makes an equal to the friction forces mu into m g. Whatever the gravitational or the weight is there of that. Even we can add the other features of the movement of the belt with the masses. Like plus alpha, which is nothing but the coefficient absolutely based on the material property into x dot minus v 0 m g. Else even we can say that it is equals to minus mu 1 plus a v 0 m g plus mu times of alpha m g x dot. So, in all we can say that what we have we have two main things one the frictional coefficient. One is alpha the frictional coefficient the alpha is nothing but equals to your damping, which is coming out due to the material property of your belt.

So, when we are trying to resolve these things we have the inertia forces, which are being balanced by the restoring force the frictional force. The damping forces, which is mainly due to that and here the damping, which is nothing but equals to the which is always like coming along with the frictional coefficient is nothing but equal to the mu 0 alpha m g into velocity. This alpha is nothing but the negative damping, which simply causing the diverging figure or unstable figure in the vibrations.

So, as the vibration goes beyond certain level means a when you see it is increasing the velocity. Even the relative velocity x dot minus v 0 will increases, this cause the friction coefficient to decrease. Then vibration decreases this cycle of increasing and decreasing vibration repeat itself forever. The moving belt can sustain vibration is always having a self excited vibrations are. So, this is one of the significant criteria there, if we are going towards the another example.

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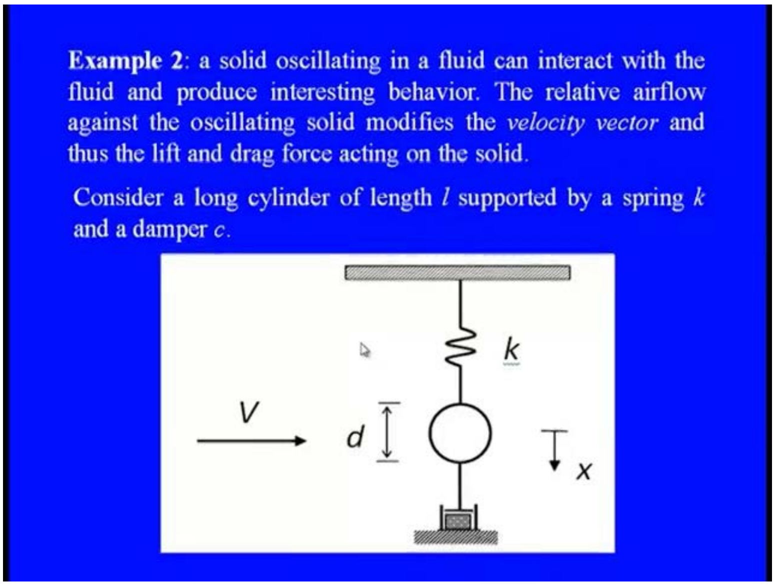

We have a solid oscillating in the fluid and can interact with the fluid and can produce the intersecting behavior with that. We can see the relative aero foil motion against the oscillating solid bodies motion and we can say that the velocity vector can be simply brought down their itself. So, we have a clear drag force the velocity is moving and you see here the mass, which is being you know like oscillating at that point. Thus the lift and drag forces are being absolutely acted on this solid. Now, you see you can see on the diagram there are you see the spring. The damper is being attached to there and the velocity vector is just going into that direction.

Now, if you are considering the long cylinder length say l which is being supported by the spring on one end and damper. On other end and the total you know like we can say the diameter of this solid is d. Then we can simply find out that how these forces are being surrounded on that. So, the equation of motion is as simple, because we have three main components.

The mass with the inertia force the damping see with the damping force and stiffness with the restoring force. Then it is equals to what are the forces, which are being coming due to the velocity v are termed as the lift forces. So, f of t is nothing but equals to half rho v square d l c 1, where you see the rho is the density v is the velocity is coming, all other features are with the dimensional details.

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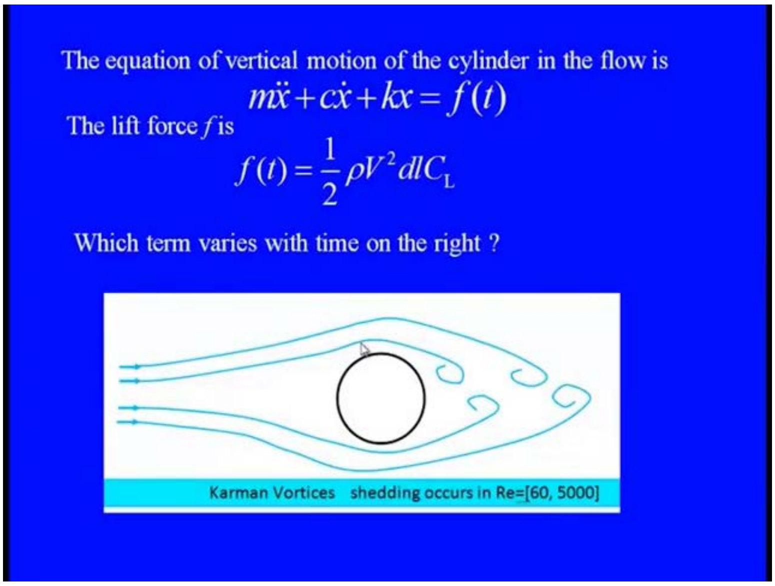

So, the term which is varying with the force whatever the lift force f of t is now. You can see that this is you know like the Karman vortices are there. They are absolutely moving at certain reynold numbers. So, you can see on the solid these forces the vertex motions are there. The forces are being generated all along the circumferences of these ball. So, due to the vibration of the cylinder the solid feature the lift coefficient is no longer constant certainly, because the shedding of the vertices.

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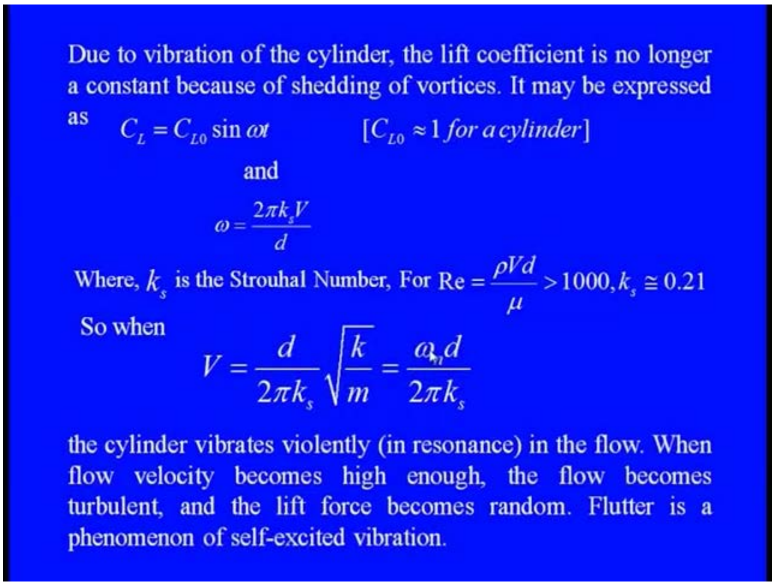

When we are saying that this c l is not a constant figure it is being you know like the pulsating feature, we have c l is nothing but equals to some constant into sign of omega t. You see the this c 10 or whatever the coefficient is absolutely depending on what is the shape of the solid is we can say omega, which is nothing but the exciting frequency is nothing but equals to 2 pi k the stiffness of that into whatever the displacement divided by d. Where k is nothing but equals to the Strouhal number and we can say the Reynold number, which is being there as the ratio of inertia force and damping force. We can simply brought down up to say 1000 for a laminar flow and k can be simply brought for this case when you have the laminar flow is 0.21.

So, we can simply say that the velocity v is nothing but equals to d by 2 pi k square root of omega this k by m, which is nothing but the natural frequency. Or else we can say that the velocity is nothing but the natural frequency into d divided by 2 pi k. So, the cylinder, which is vibrating can also becomes you know like vibrate in the violent feature or in the resonant condition in the flow.

When you have the clear exciting frequencies the forcing frequency by v and the natural frequencies are coinciding. When the flow velocity becomes even higher than this then the flow becomes turbulent in this case. The lift flow whatever the lift is coming whatever the lift is coming to the system is being in the random part and this randomness. Because, of you see the turbulent flow of the air, which is causing, you see the entire random vibration in that is coming under the flutter feature in this. Flutter is a perfect phenomena of the self excited vibrations. So, you can see that this is what you see a rigid wing, which is attached to that in the another feature we have a clear velocity V a.

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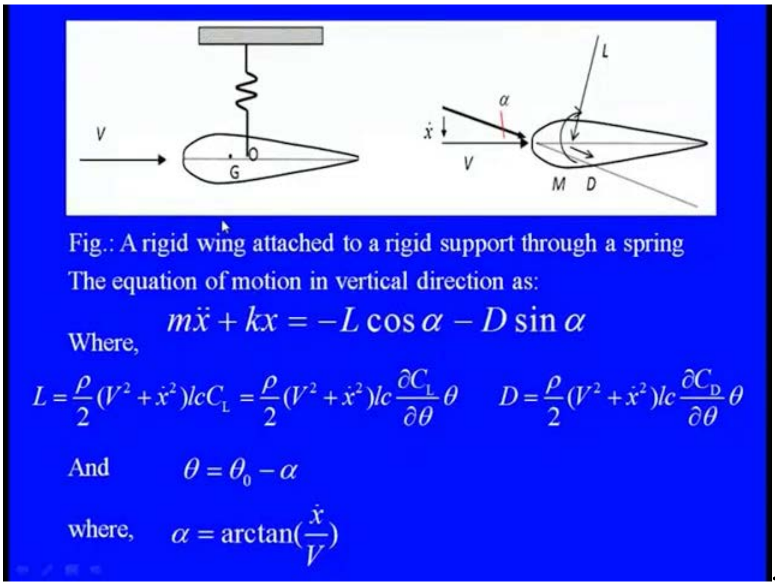

When it is a attacked to this there are you see you know like this absolutely attack the rigid wing attack is there to a rigid support, the springs are being there just to support that the vertical motion. So, we can write even for this equation you see we have a straight way the spring, which is being hanged out on the wall. It is being you know like controlled that entire thing. When you see the velocity the air velocity is dragged into that there is a clear inclination motion.

We can have the equation of motion m x double dot plus k x equals to minus l cos alpha minus d sin alpha. According to the resolution of these two components and we can write the equations in that you see l equals to rho by 2 v square plus x square. We can say it is nothing but equals to rho by 2 v square plus x square l c rho c by rho theta and d which is you know like nothing but you see the energy formations in the Laplacian transformation.

This d is equals to rho by 2 v square plus x square into l c rho c d by rho theta. Where you see we can say that the theta, which is like the you know like the balanced angle is theta 0 minus alpha or alpha is nothing but equals to tan inverse of velocity x dot divided by v. So, when we are broughting these down we can simply you know like get the equation of motion m x double dot plus rho by 2, this v l C d C 1 by d theta and all.

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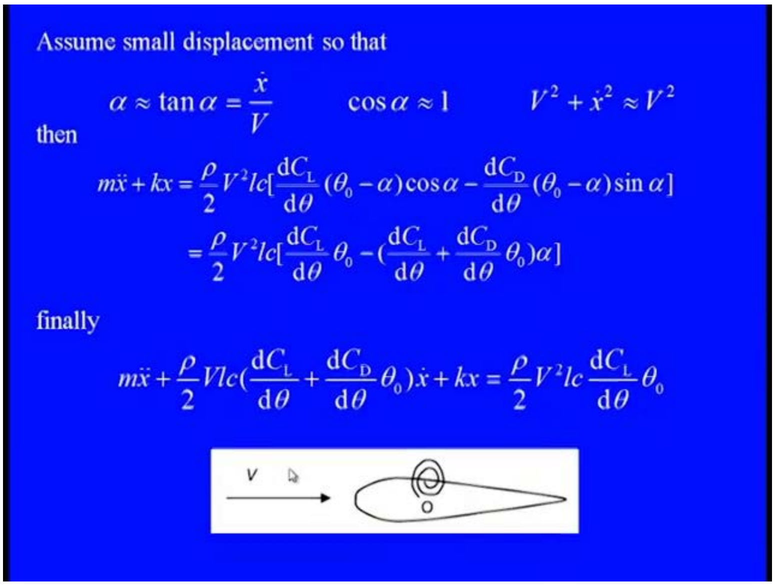

We can say that finally, the equation the balanced equation for these you know like the aerofoil motion, which is even being hanged with the say spring controlled is nothing but equals to m x double dot equals to rho v square l C by 2 d C 1 by d theta 0. Where, we have a clear interaction of the inertia forces along with whatever the here motions are. So, when we are doing these things we can say that there is clear torsional feature of the vibration.

When the center of gravity and aerodynamic centers are being even coinciding, when such things are happening we can simply get the equation of motion with M e square. This I you know like this is nothing but equals to the inertia force the moment of inertia mass moment of inertia. We have M e omega square plus you see whatever the stiffness features are being coming as k minus rho v square l C by 2 d C 1 by d theta.

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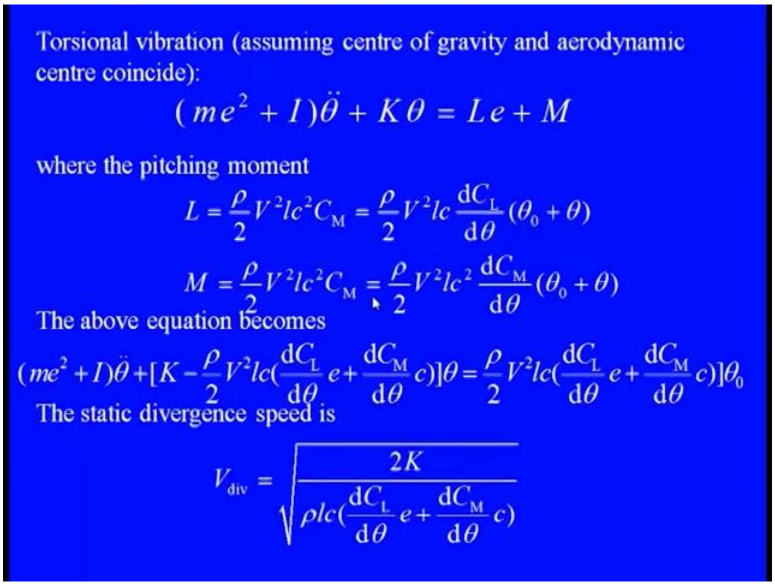

Also, you see here we can simply brought down the entire like the dynamic features with the static diverging speed v diverging is nothing but equals to square root of 2 k divided by the rho l C d C 1 by d, d theta or d C m by d d theta. So, when we are broughting down these things. We know that the symmetric profile of the aerofoil with this diverging velocity will be absolutely depending on the K. Also with that d C d C l by d theta.

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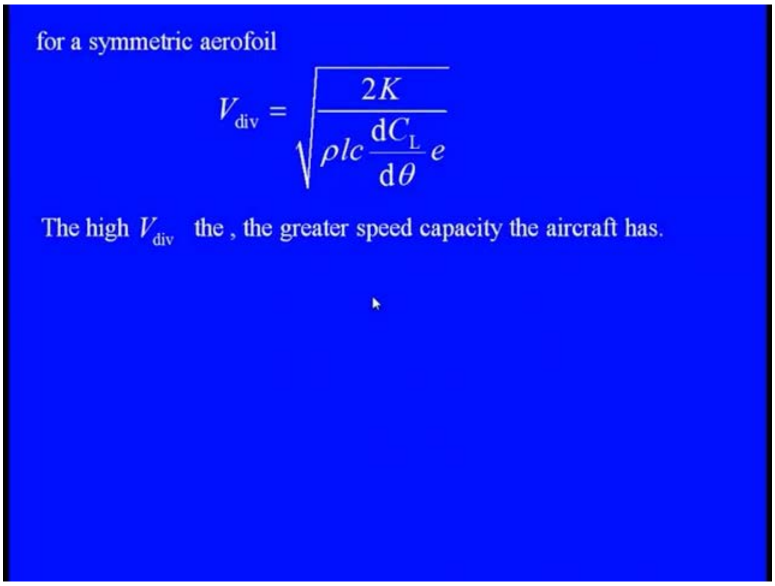

So, when we have the diverging velocity high the speed capacity will be more of the aircraft. Then it becomes the system is more diverging and it becomes the system unstable. So, here we can simply say that even if you want the stable aerofoil motion. We can simply choose these system parameters with the k rho. You see the d c 0 in such a way that we can brought down the self excited vibration, which is simply showing the flutter vibrations of the aerofoil motions.

So, in this lecture we mainly discussed about the vibration generation due to self excited vibration. This self excited vibration though it look likes that pretty simple that like, because of the inherent nature of the system. Some system parameter the parametric excitations are there, but it contributes even up to the unstability of the system by feeding some kind of energy to the system.

So, when we are designing those things we need to calculate the self excited vibration, because this is something. You see the non homogenous solution and we need to just brought down to the homogenous solution of the equations. It is absolutely different than the forced vibrations in terms of the solution itself. So, in the next class we are going to discuss about the vibration generation mechanism, but the flow induced that, when you see even the fluid interaction is there, as we discussed already the various mechanism of the fluid induced vibration f I V here. Now, we need to check it out we need to computationally check it out, rather that how you see when the fluid is just moving towards that, that how a mechanism is working towards the vibration generation. We will certainly take various example to understand the physical significance of such vibrations are.

Thank you.