Tribology

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Lecture No. # 05

Friction Instability

Welcome, to lecture five of video course on tribology. The topic of this lecture is friction instability; it is a very interesting topic, friction causing instability or causing instable system, introducing some sort of disturbance, some sort of a continuous vibration phenomena or Jacque phenomena. We will be studying in this topic detail of why friction instability happens and how we can avoid it.

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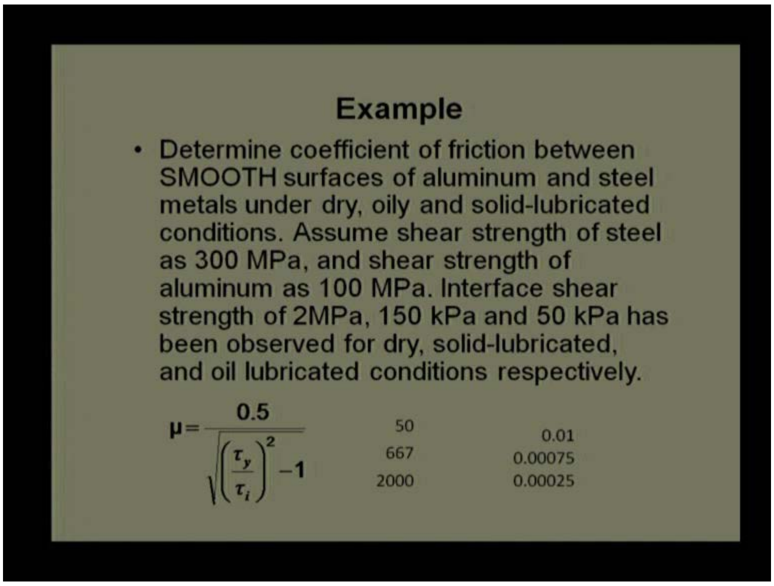

To start with that we will take one example related to our previous lectures. And the example as I have shown in this slide says that determine coefficient of friction between two SMOOTH surfaces. So, when we are using the word SMOOTH surface; that means, surface roughness is negligible or in other word coefficient of friction due to plugging effect will be negligible. We can neglect that; and we can consider oily coefficient of friction due to adhesion or junction growth here. We are define the two surfaces; one is made of aluminums, and another is made of steel; three conditions have been defined the dry oily, and semi solid lubricated; solid lubricated may be in this case. Again, we can say, this is a powdered lubrication molybdenum disulphide or some toughen gridded coating on that.

In addition to this data shear strength of the steel is given as a 300 megapascal, and the shear strength of the aluminums is defined as a 100 megapascal. So, aluminums will govern the behavior of this tribe pair, as we have learnt shear strength of weak material need to be accounted. So, we can say the shear strength of aluminums will be considered that will be 100 megapascal; and shear strength of a steel, which is defined as a 300 megapascal will not be utilized for our expressions. Then in addition to this, we have data relating to interface shear strength, which is a 2 megapascal, 0.150 megapascal, 0.05 megapascal under dry solid lubricated, and oil lubricated condition from this example, it is clear that oil lubricated condition will give minimum shear strength of the interface; and dry contact will give the maximum shear strength of the interface.

So, we can utilize formula, which we derive in previous lecture, that mu due to adhesion or junction growth is equal to 0.5 divide by square root of ratio of shear strength of weaker material to shear strength of interface as we have mentioned in previous lecture. We discussed in previous lecture, that this ratio decides, what will be the coefficient of friction. It is not absolute material shear strength, which decide, but the ratio of interfacial strength to bulk modular, bulk shear strength of material is going to decide, what will be the overall shear, overall coefficient of friction due to junction growth.

If I take this ratio, the tau y by tau i that is 100 megapascal divide by 2 megapascal. So, in that case, I get 50 value; that means, this ratio tau y by tau i for solid (( )) 50, and this ratio for solid lubricated surface is 667 not very different-not very much different in this case, and well for oil lubricated case is turning out to be 2000 using this ratios value. We can find the coefficient of friction, which turn out to be 0.01 for dry case, 0.00075 for solid lubricated case, and 0.00025 for oil lubricated case.

I can interpret these result in three ways; first thing is that dry lubrication gives the high coefficient of friction; and second thing is that getting coefficient of friction equal to point 0.00075 does not mean much it will not really waste much power. So, these are the hypothetical values that interpretation can come that as a coefficient of friction is very low. I can choose even the dry contact if I if I go through overall economic point of view, if I consider the cost of lubrication mechanism of lubrication, and excess rates, which are required for lubrication mechanisms. I can reject second and third options. I can say that 0.01is coefficient of friction is very- very low. We can go tolerate this; we can go ahead with this, but there is a problem, problem is that whenever there is a dry lubrication case. There will be a more variation in a static coefficient of friction, and kinetic coefficient of friction; that will bring or that will induce instability; that is what we are going to describe in today's lecture? We are going to discuss in today's lecture.

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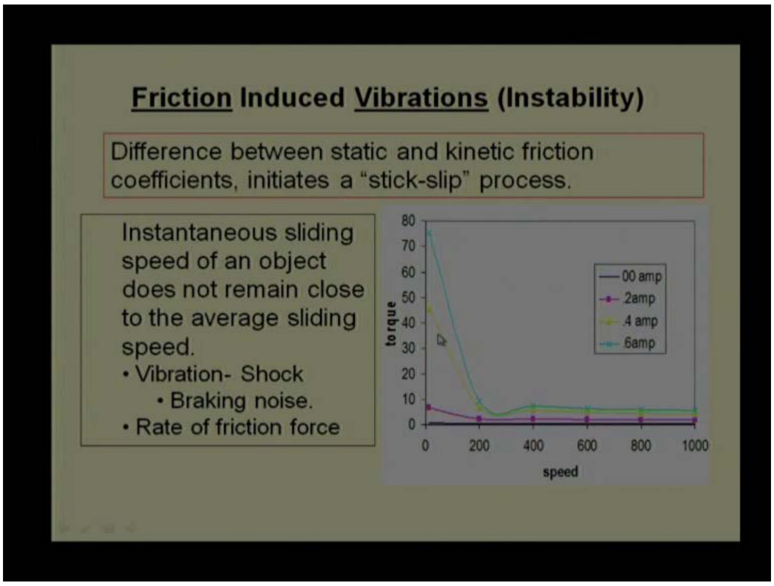

So, I can say friction induced vibration in an instability vibration. We are using the word, this is coming, because of the static, and kinetic friction coefficient or difference between static and kinetic friction coefficients. And this difference is initiating stick slip process, how we are saying that anytime velocity of the object or instantaneous velocity of the object does not remain close to the average velocity; that means, there is a continuous fluctuation in velocity. Sometime, it is moving at the higher speed compared to mean speed sometime the lower speed. And that kind of variation in velocity will introduce vibration phenomena, and if vibration phenomena have some lack in the damping, then instability is bound to come.

This phenomenon often known a shock phenomena, what we are trying to get a feel from that sometime material is in contact, and sometime it is not there. So, there is a continuous jump phenomena, shock phenomena, which is keep going on as one surface moves related to other surface. And this is very-very common in the breaking or we say the brake shoe, and disc brake shoe, and drum, this is a very common phenomena that is why the, what a noise? (( )) get induce, when we apply brake due to variation in velocity. We will suddenly getting slipped; and that is why the noise comes-chirpy noise comes, which is many times intolerable; that is why the we, when design good brakes? We try to keep this in our mind. This kind of noise should not be there or if it is there, it should be very-very low level; we try to design brake, and brake material from that angle that minimum noise should be generated, when we are applying brake, when we are trying to stop vehicle or we are trying to stop wheel.

It largely depend the rate of the friction force at which rate friction force is applied-is it applied very fast is applied gradually; that decides, whether there will be friction instability or not to elaborate this I am just showing a couple of results, which we have done experiments on one brake material, what we use a brake material as magnetorheological liquid as a brake material; good thing about the morphed magnetorheological fluid is it get solidified in just few milli seconds, and due to this solidification coefficient of friction will increase significantly. We say coefficient of friction from 0.1; it can reach to 0.6 in 10 milliseconds, which gives a braking torque or which give the resistance against the movement.

But what is the problem with this. So, when we use use we, when we perform experiment on (( )) brake, what we got at the lower speed coefficient of friction was very high or torque resistance capacity of that brake was very high we can say that here the blue line pink line yellow line and the green line what we are showing here the blue line is for 00 ampere; that means, there is no magnetic field generated in m r brake well at the 0.2 some magnetic field was generated which churn up the liquid converted, liquid (( )) liquid to some semi solid, low shear strength semi solid, when we apply current 0.4 ampere? It turns out to be moderate level, and 0.6 ampere, if it has high and good torque resistant capabilities. We can see the torque capabilities at the 0.6 ampere of the m r brake was almost 0.75 Newton meter at the negligible speed, but as the speed is increasing at the rotational speed, when the brake was applied increases, we are able to see, that there is a continuous decrease in torque or resistant torque offered by the brake; it reaches to the minimum value at some speed in here, it is showed around roughly 250, 260 r p m it shows the minimum value, and after that it reaches to the steady value.

After maybe say, 400 onward fluctuations are negligible. So, it is a problem there is particularly, when operating is speed is nearby 260 may say within the range of from 200 to 300. There is a possibility of friction instability coefficient of friction does not remain stable; it keeps changing from one value to other value; and that is a dangerous that makes lot of noise, which should be avoided as far as possible.

And in this case particularly, if the we are operating at the brake, at a lower; then this speed very high coefficient of friction, and may be quite possible a jerky motion comes and stops vehicle immediately, which is also should be avoided. In other way, we should try to apply this kind of brakes, when the speed of operation is more than 400 r p m lesser than that these brakes are not showing the very good performance; and it need to be supplement with some other brake materials, what we say that observation from this slide is that the coefficient of friction decreases as the velocity increases, but there is a limit it is not continuously keep going down or continuously decreasing it is reaching to one steady state condition, and if I remember kinetic coefficient of friction, and static coefficient of friction.

We say that static coefficient of friction; we can calculate at the first point that a just the start, and kinetic coefficient of friction, when it comes reach to the steady state condition. But the difference in that coefficient of friction is almost 6 to 8 times. We may say that coefficient of friction at static level is supposed 0.8, and kinetic coefficient of friction turn out to be 0.1, and whenever there is a large difference between the static coefficient of friction, and kinetic coefficient of friction. There is a possibility of friction instability. We will derive mathematical equation, and try to find out, how this variation is affecting the result.

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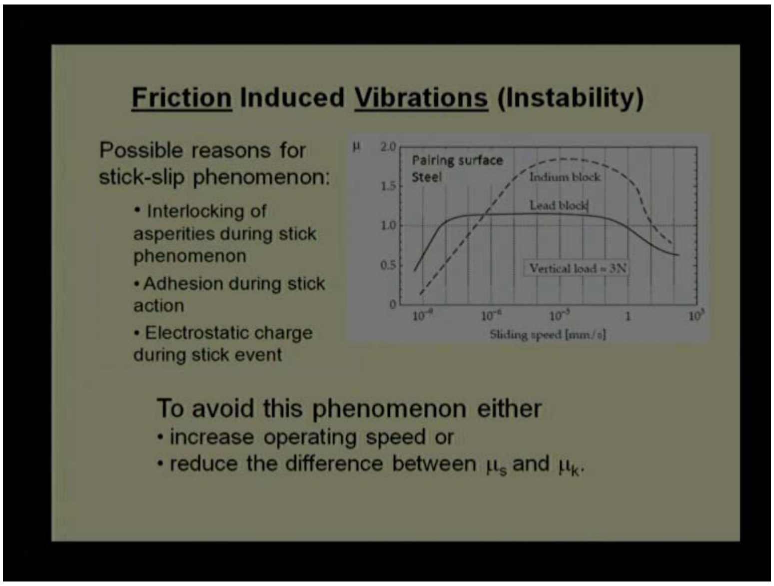

But before coming to that I have a some more example available from the literature. So, this there these figure shows, coefficient of friction variation. We say that even the sliding is speed increase with increasing sliding speed; the coefficient of friction is increasing, which is amazing. We never feel that during the experiment that it happens, but it turn out to be this is a micro or nana level study, which was performed on the laid block versus steel, and indium block versus steel shows that, when you are pushing one block on other block. Even though applied force is lesser than static friction force, there will be some micro slip, that is why the speed is shown here in 10 power minus 9 millimeter per second, which is very low negligible it cannot be detected by naked eyes.

In that case, the coefficient of friction is continuously increasing ideally. We believe that the coefficient remain stationary or static value or the static, because we are not able to detect this low velocity in common experiment, which we perform in the lab, and after certain speed it reaches to static condition, and after that there is a decrease. So, this micro sliding really, if it is required in micro machines. We need to consider the how velocity is affecting coefficient of friction. And these are just opposite coulomb said clearly coefficient of friction does not depend on the sliding speed, but this kind of micro experiments. They are my experiment, which perform on micro skill; they clearly show that coefficient of friction depends on velocity; and of course, we know static coefficient of friction and kinetic coefficient of friction. We are taking only 2.0 value, but there will be some gradual change; it cannot that static coefficient of friction is 0.5 and suddenly it reaches to 0.2, it will not be (( )) it will be some linear curve or some parabolic, and some exponential curve, which need to be accounted, when we talk about friction instability, when we want to operate the machine in that zone or in that domain.

Now, why this kind of phenomena really happens couple of hypothesis are there we say that interlocking of asperities during stick phenomenon. If the operating speed is low, what will happen? We push block asperities are in contact after some resistant block will start sliding, it will climb up on the some asperities, but after that again it come down; then there will be lesser coefficient of friction. Then again some asperities will come, again will climb up, and coefficient of friction again will vary.

So, if we apply once force after that we do not apply force. We may be push block it will not climb up, it reaches to static condition. And we leave it the block will not stop, there it will move down to some value. And then slowly, it will come to stationary another one, what we are saying that, what we are applying force, and it is overcoming static coefficient of friction or static force. Then it will be having lesser kinetic force plus some inertia plus some velocity to that block. We will come to that, when we study or when we describe our mathematical relation.

A similar phenomena will occur, when there is adhesion or adhesive components or wear two components are getting valid at asperities, we push it, and leave it, what will happen? The junction will be broken or sheared, and after some again they will be formed, and last is that electro static chargers; there is a molecular attraction. And they may not be making cold junction, but they have attraction force that will be broken. Again reformed gain broken, and again formed these three mechanisms can describe, why stick slip phenomenon happens, if we are trying to operate machine in very low speed domain. If we are operating machine at very high speed domain, some other instability comes. Then in that case, friction instability does not come, but the lower speed operation friction instability is dominating, and we need to clear; it we need to avoid it either using active control system or some lubrication mechanism.

We say that, to avoid this phenomenon either increase operating speed; that means, if I want to operate a machine at the 100 r p m. I should redesign in a such a manner, that the speed is going beyond 100 r p m. or maybe is reaching to r p m to 150 or 175. Then we need to redesign the system in such a manner. New design is avoiding the friction instability in other sense, and other way is that try to reduce mu s, and mu k. We may be, you make or you choose a tribe pair, which have a lower difference between a static coefficient of friction, and kinetic coefficient of friction change the material or introduce some lubricant, because in introduction of lubricant of force; lubrication will reduce this coefficient of friction, and difference between the steady coefficient of friction, and kinetic coefficient of friction.

I can give very typical example of general bearing, when the general bearing are particularly under radial load operates. In fully developed condition coefficient of friction is very-very low may be say 0.001, but when during a stop, and start, if there are no friction modifier available. Then starting coefficient of friction will be very high, it may be in 0.1, 0.15. So, difference in static coefficient of friction is a 0.1 or maybe says ranging between 0.1 to 1.15, while we are coming to the fully developed hydrodynamic bearing or fully developed general bearing coefficient of friction is reduced to 0.001. It is a huge difference, when static coefficient of friction, and kinetic coefficient of friction. And if you want to operate really that general bearing or hydrodynamic bearing at lower speed operation surely there will a contact no contact contact no contact contact no contact. There will be jump phenomena, there will be continuous variation in the position of the shaft.

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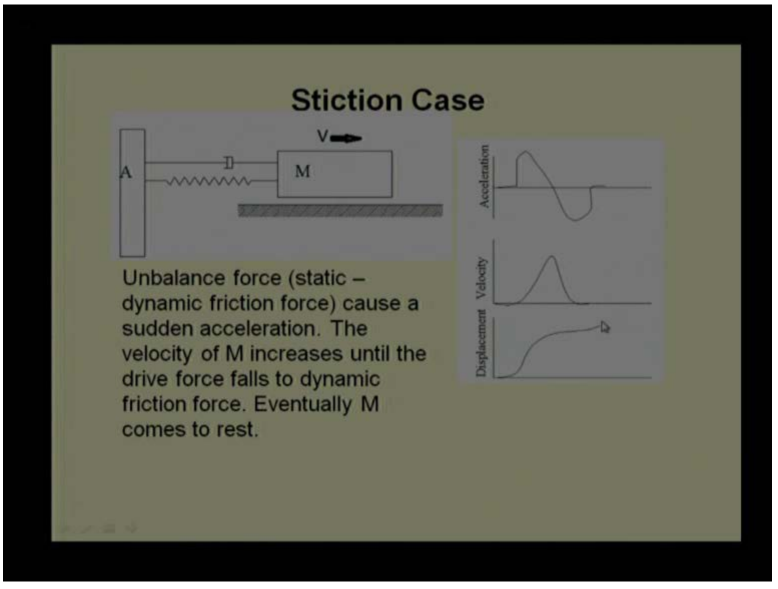

So, we try to avoid it to give a slightly more detail about this. We will take a one example, we say assume, there is an assembly. And there is a block has a mass m artificially. We are assuming there is some sort of viscous damper, and there is a some spring stiffness spring, and damper are connected to the assembly or in the other word, when we are pushing this block related to the stationary surface. This force will be constraint due to the stiffness, and damping force, which is a very common machine alignment or we may say almost all kind of machine alignment have this kind of a stiffness in damping, coefficient damping coefficient can be very low, can be very high; it depends on, how the system is arranged. We are talking about the viscous damping. We can replace for simplicity, when the coulomb damping expressions will remain same or it can be interpreted in that way.

Now, we are saying that unbalance will come, if there is a difference between a static coefficient of friction, and dynamic coefficient of friction or kinetic coefficient of friction, what will happen? There will be a balanced force; we have supplied friction force equal to the static force, which is really required to start sliding of the block. Once sliding start, then friction resistance is coming down is reduced. This will give as unbalanced force; that unbalanced force will initiate acceleration will induce acceleration in the block as there is acceleration naturally velocity will increase till balanced force is nullified.

Once, it happens again there is again, there is a possibility of sticky, and that is why the we say the eventually block, m will come to the rest or mass m will come to the rest, if I plot displacement velocity, and acceleration diagrams, what we get, we can see that displacement is coming increasing to a certain value, where the equilibrium force is forcing block to be at some position away from its initial position, and see the velocity. We are able to see the velocity reaches to a peak value, and then drops back well acceleration start building, I am just taking this point as a initial push given to the knock, and after that, when it is started sliding. Then acceleration is going up to a certain level; and then again decreasing going to the negative side, and finally coming to the rest.

So, this kind of behavior is observed, when we push block related to one surface, and stop or stop supplying force. We give force equal to force required to start sliding the block, and as we have attached one viscous damper, and stiffness. We can say overall behavior of the stick slip behavior of the system depends on the system stiffness, and system damping, and the difference between force required for sliding, and force required for continuous sliding. So, overall performance will depend on this.

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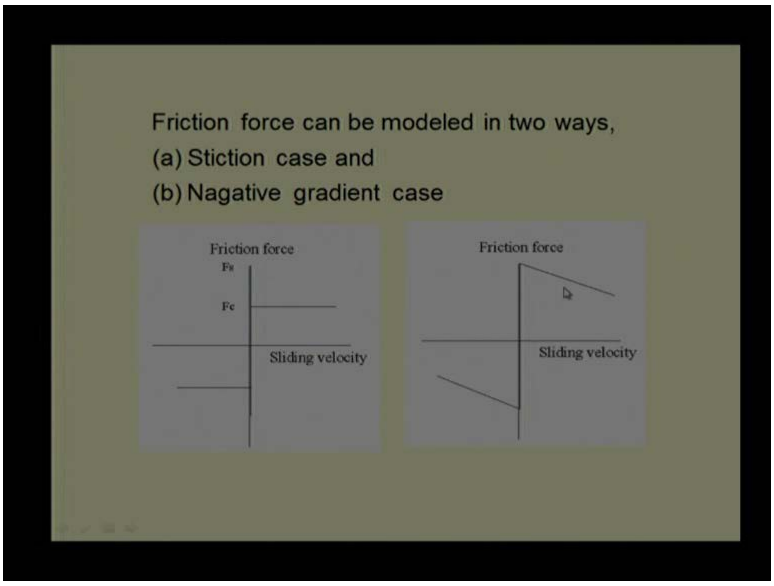

Now, to elaborate this kind of behavior, we can take simple example of a very simple example. In this case, there we are saying there x direction is the sliding speed, and y direction. There is a friction force F s, and F c is shown over here; F s is the static coefficient of friction, F s is a static friction force; F c is a force required for sliding or continuous sliding or when block is started sliding.

We can consider two cases; it is the first case, when we are assuming a ideal case initially, there is a high static coefficient static coefficient of friction, that makes high friction force. And then subsequently, there is lesser friction force. So, that is why there is a abrupt change; we have supply more; then it comes to the 0 and not 0, it equals to F c and that continues, this is a ideal case, and that is why we are saying that this is the only satiation immediately the junction are broken, and the block starts sliding, while we can consider the other case, where static force is initially F s, and reaching slowly to the kinetic friction force; that means, there is a linear profile it is not immediate, it is a linearly varying from initially high value to some sort of F c value. And there is a decrease, and we do a reverse operation, and the same thing is going to happen, we when we do a reverse side loading, we can consider this case, this is a ideal case; it will does not show any problem, but we can consider this case, which will show under, which condition system will be instable or friction will induce instability to consider this in right manner.

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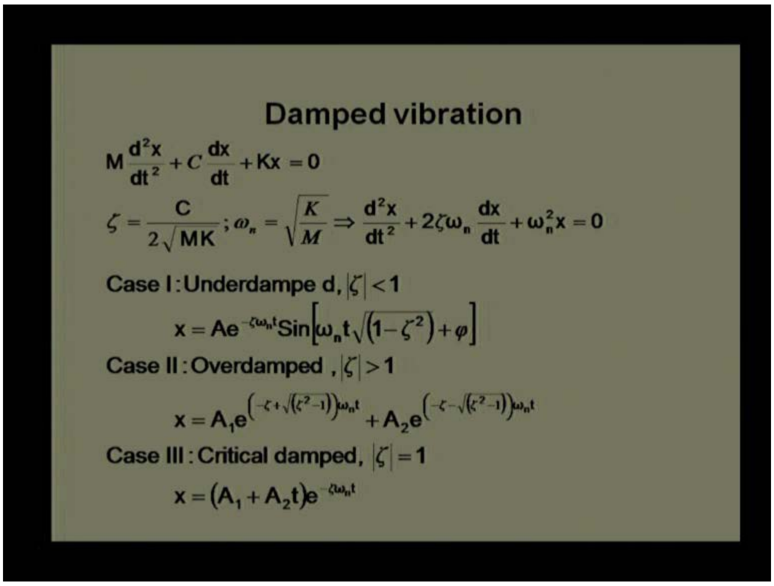

We will start with a common equation, which we generally use for the damper vibration. We know this is a second order equation or partial differential equation can be said, but here we are using only X, we are taking only the one direction. So, it can be converted into differential equation; M is the mass; C is the damping force by enlarge viscous damping force, and K is the system stiffness or stiffness, which attaching the block. We can non-dimensionalise it. So, that we can interpret in a much better manner, we say there is a damping factor, which is the ratio of damping coefficient divided by critical damping natural frequency is the ratio square ratio of the K by M that stiffness by mass, when we use this expression, we can rearrange this first equation to this equation.

Now, we know the solutions are available for this kind of equation. And they are categorized in three categories; case one, case two, case three based on what is the value of zeta, if zeta lesser than 1, that is known as the under damped system, and solution or for X is generally in terms of t is giving as some constant exponential decay in the magnitude. And then in trigonometry terms, we can write in terms of sine plus coos or here, we have written some phase angle so that we can express either in sine or in coos term.

Case two is over damped with zeta is greater than 1. Here, we can see exponentially both the terms are going to be negative side. So, this will be continuous decay, this will be continuous decay, and the third case, when zeta is equal to 1 that is a boundary case. We are able to see that this will take a one period time to stop the vibration, if we disturb one any block, any system, any component, it will come to the rest after one period, one complete cycle, while in case of the over damped it does not, it shows that there is a possible that it will be damped immediately without taking much time or it may take a slightly longer time or magnitude may be slightly longer time depending on overall characteristics, while in the first case shows that clearly that there is a senatorial term, there is a periodic term; that means, it will keep getting some oscillation, but at lesser, and lesser magnitude. There will be reduction in amplitude of initial disturbance, but it will continue over a number of cycles. We generally use a logarithmic decrement expression to find out, what is going to this system.

Now, in this case particularly zeta is important parameter for us shows that always zeta is positive. We are not consider here zeta as a negative, we are not consider negative damping at all, but there is a possibility of negative damping even though physics does not permit us to say, what is a negative damping, how heat generation, how energy generation will happen without any input, but mathematically we can interpret it, and we can show, why the friction instability occurs.

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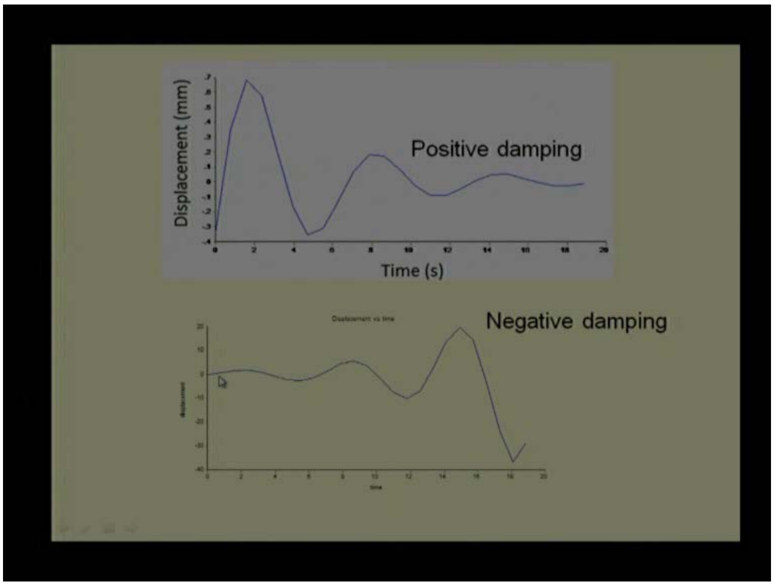

Just to elaborate that what I am saying that, there are two cases; one case is a positive damping; there is another case the negative damping, and in both the case the displacement is shown in the vertical axis y axis, and time is shown on horizontal axis, when the damping is positive. We can see even the amplitude is initially high and of course, in both the cases, we are considering under damp, when the zeta is lesser than 1, and in this case zeta is lesser than 0. So, positive damping zeta is lesser than 1, either under damp condition the coefficient displacement goes on maximum value comes back to a minimum value in the negative side, and opposite side. Then next cycle, it goes again to high value, but lower than first cycle damping, we are assuming this is a natural damping it is not forced damping system; and it keeps going on and finally, it reaches to some stationary condition, if it is 0 is a initial condition; it will reach to 0 condition, while coming to the negative damping, even though it start from the 0; it reaches to the some X value.

Then in next cycle, this value increases, and subsequently this value keep on increasing till a final lock between the components occurs or impact between two component occurs or shock between two components occurs, which will make a lot of noise, which will reduce the life of component, and may cause a fracture of the component. We say that cast iron shaft or cast iron in block is there, and we are using some ceramic component against the cast iron. We experience the negative damping naturally cast iron will break or ceramic block will break, because they have low fracture toughness, and failure will occur. So, that is why we should avoid this kind of negative damping as far as possible otherwise we need to redesign a system.

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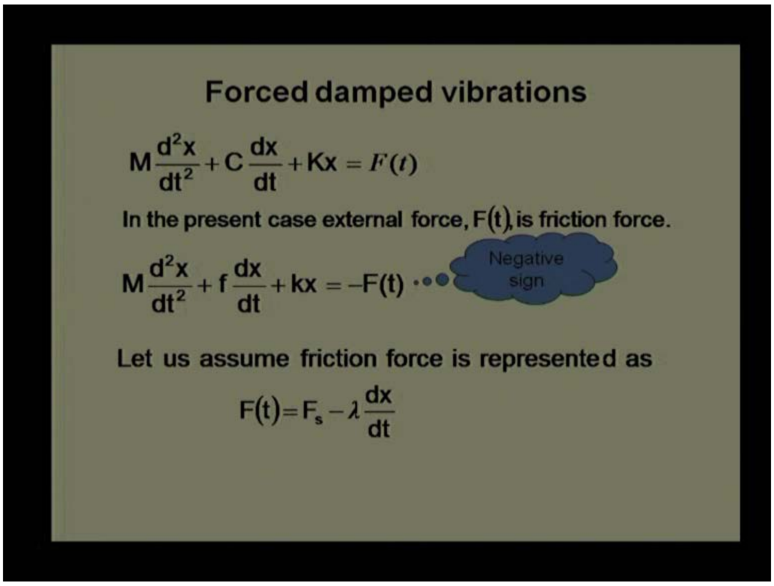

So, that this can be avoided to consider this further in detail. Let us, take a forced damped vibration case, this is same as we have described in earlier case except the last term, the right hand side term, which shows the external force as a function of time or this force is varying with the time. Here, we are constrained to consider F as a friction force, when we consider friction force naturally negative term will negative sign need to be included in this case, this is not to making the motion; it is resisting the motion or we know the friction force resists the motion, that is why the negative sign is been introduced over here. And we need to find out the expression for F of how the friction force is varying with the time.

We initially consider two cases, when the friction force was immediate changing from one position to another position changing from F s to F c. In this case, we are assuming that, there is a some sort of linear profile; it changes gradually; it is not immediately happening from F s to F c to accept that profile. We can say F t is a function of F s is a stationary force or the force required for the just to initiating slide minus some lambda some parameter, and velocity, which is reasonably good for us to understand from this angle. We know that as the velocity is increasing or velocity is decreasing, how coefficient of, how the friction force will vary. And once, we know that, we can find out whether there will be any effect of this force on vibration phenomena of system or not that will be helpful to us.

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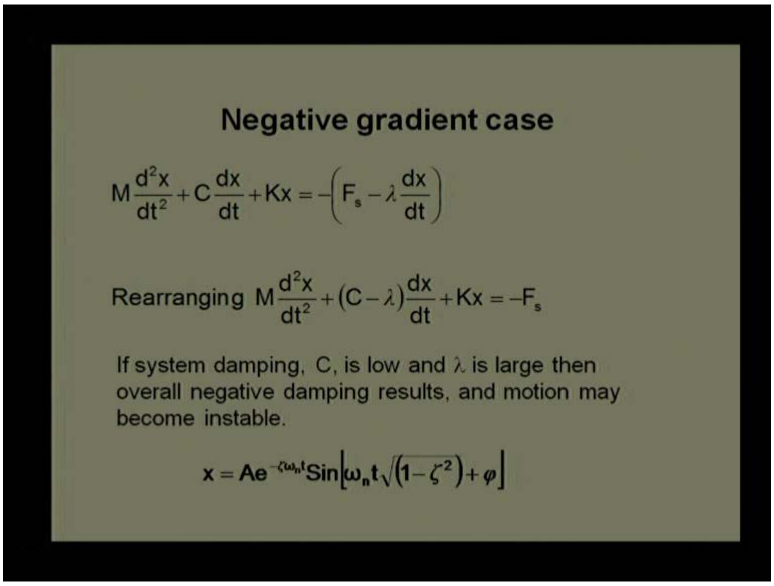

Now, we introduce this or we say that in this equation. We instead of writing F t force function of (( )) as a function of t time, we have written F s minus lambda d x by d t. We can rearrange this equation keeping F s on the right hand side, and clubbing d x term with d x term, we say the c minus lambda d x by d t. So, this will give us the equation. Now, we can find out the answers for this; here m is a block to be moved against the stationary surface; this is the acceleration term, which if initially disturbed, how long this term will remain, and what will be the magnitude of that. And we assume the initial disturbance force or disturbing force is F s or may be continuously, we applying of this force F s, what will happen during the what kind of motion will occur, and how result will affect.

Here, stiffness is also countered many times, we find difficulty in estimating the stiffness. So, what we do, we write equation, we find out the solution, and based on some parameter, some fraction. We can use the scaling factor or the correction factor like alpha, beta, gamma; introduce those factor to get continuous or other results in other words; we do first theoretical calculations or evaluate the expression try to match with the experimental results find out some correlation parameters, and as subsequent to that we try to get the results matching for the subsequent experiments; that means, first few experiments will give us those parameters, and subsequent to that whatever we do experimentally, we should be able to estimate directly from the expression that it will the or ultimately that is going to reduce the number of experiments, it is going to help us.

So, in this case is that, if the system damping is slow think about it. The system damping C is the lesser than lambda; there is a possibility, the system damping is lesser than lambda many times; we do not have damping available or materials are not able to damp vibration, and decrement in friction force is significant; that means, lambda is much larger than C. So, in that case what will happen is this will turn out to be negative, if is this turn out to be negative; that is going to initiate sliding or in this is going to initiate instability or introduce instability in sliding operation.

So, if I revise or think over back to the expression, what we are going to get is X equal to some constant e power zeta omega, and has a natural frequency in time. We are trying to find out, what will be the effect on the magnitude with time, and this is a periodic term that is a sine term with a some phase angle zeta. Here, we are assuming lesser than 1, it may over an expression. Now, if this zeta is decided based on this C minus lambda divide by 2 square root 2 under square m into k m is not going to change k is not going to change C is not going to change; this is only the lambda, which decides, and that is depending on, how static coefficient of friction is getting or converging to the kinetic coefficient of friction.

If there is a huge variation, the static coefficient of friction is maybe say 0.3, 0.4, and kinetic coefficient of friction turn out to be 0.05 or 0.1; there is a huge difference naturally, there will be a good value of finite value of the lambda, which may be more than or greater than this C, that is going to introduce instability, that is a major problem for us. So, we should look it in that, and we try to avoid at least, if we are able to see this expression. If we are able to find out C of the system using model analysis or some other technique. And we are able to estimate the behavior of friction pair, where static friction force is been plotted with velocity, and we find that there is a large variation, and whatever the operating domain; we have operating speed; we have or we require if in that case lambda is very high, then we should avoid it.

So, with this I believe that you are getting a feel of how coefficient of friction is important for us or why we want to keep this gap to a minimum value. So, that results are favorable to us, and we can avoid instability as mentioned clearly in our earlier slides that, if the zeta value is lesser than 1; then there will be periodic motion; and this zeta value turn out to be negative as was indicated in the earlier slides; then there will be a instability, and there will a knock; and there will be some noise generation; and that will cause some problem to us.

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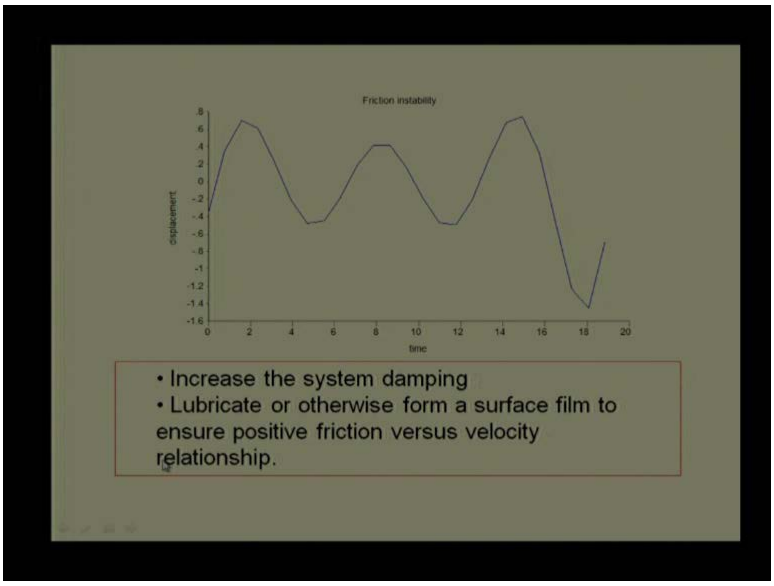

Now, this is what we are showing over here if I take a very small variation in C, and lambda. I am assuming that lambda is almost reaching to the C value slightly more than the C value. Then we see the friction instability here it is going up first coming down, and may be this data is missing here that is why the straight line is coming over here. So, if I get a intermediate data some data will come somewhere here, that will increase magnitude to some level, and that shows that first displacement is certain unit may say that 0.65, 0.64, and if this missing data is can be collected back it will go slightly more than that, and further slightly more than that.

So, magnitude is changing slowly- slowly, and before that we all the operation are able to overcome this. Then system will remain stable; then system will not make much noise, but if we are not able to control on that; then system is going to make lot of noise is going to hamper the operation or loose is main function. So, we can say that increase the system damping is one of the possible solution, increase the value of C itself, if we do not have much control or the friction or friction pair are not able to provide lubricant, because of one reason or because of other reason that many times, we are able to give a lubricant machine related to textile operation. Because we know the textile will get affected with a lubricant and it should be avoided.

However, if it is possible that we can lubricate the surfaces; then it will be always preferable go ahead with lubrication; and ensure that friction force difference between static coefficient of friction, and kinetic coefficient of friction is decreased; this is the reason why, when we are mentioning about, I have given example of hydrodynamic bearing, in hydrodynamic bearing, I have mentioned that at stop coefficient of friction may be very low 0.1 to 0.15, and when we are operating it at the fully developed condition coefficient to friction may be 0.001; it is a huge difference, if we operate that machine at a very low speed naturally. We are going to face problem, there will be more wear, there will be more knocking of the shaft versus shaft over the bearing surface.

But if we are able to provide some other mean to separate shaft, and bearing initially, which happens many times. We use hydrostatic lubrication mechanism; we provide lubricant to separate two surfaces. And then, start shaft rotation otherwise, there is more possibility of failure or more possibility of knocking more possibility of noise to avoid that, we do that sometime may be in an hydrodynamic bearing. We use a magnetic negotiation mechanism that we use a permanent magnet at the start or with the shaft surface is going to touch the bearing surface. We use magnet piece there or maybe say some shot are may be 30 degree to 60 degree to (( )) at the shaft slightly up. So, that there is no contact, and when the shaft is start rotating it will develop a full film lubrication mechanism, and coefficient of friction will be almost same 0.001 at the starting 0.001 at the later operation or may be slightly more than that.

So, these kinds of mechanisms are important, when we understand, what is really happening in a system, we can avoid it. So, I have given a couple of examples on how to avoid friction instability in a bearings similarly, we will detail this kind of topic, and when we will design brake system, how to design a brake system, and how to avoid the squalling or noising or slipping slippage of brake shoe against the disk.

So, we will continue with, we will stop over here on the friction topic. We will be starting a new topic on the next turn; that will be the wear phenomena or wear mechanisms; this will be different operations. Thank you for your attention.