Design of Machine Elements – I

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Lecture No - 27

Design of Springs

good day today we start our lecture which is lecture number twenty-seven and ah this is the design of springs

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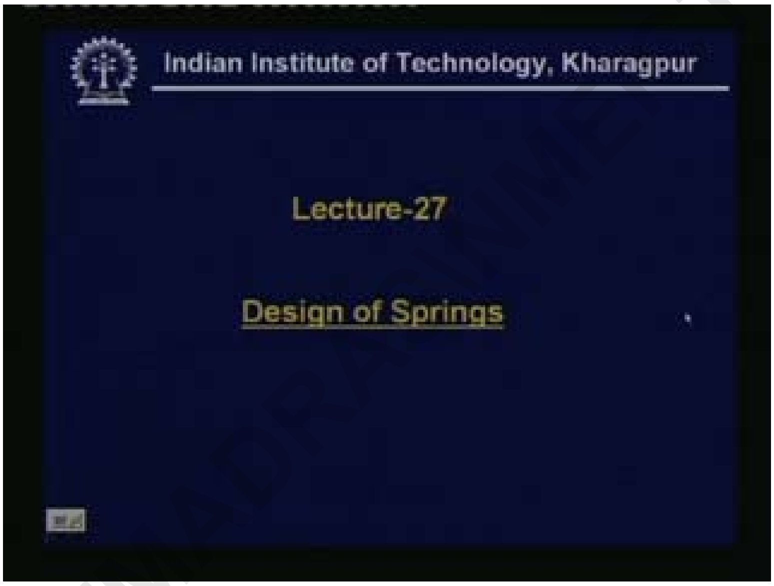

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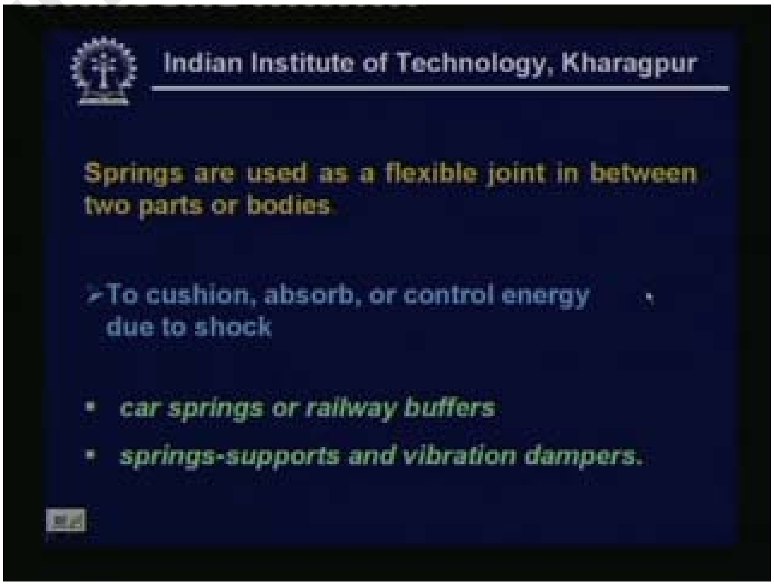

now for the design of springs ah we start with ah how we define basically a spring
all of us know what is spring we have used springs in our everyday life so basically we can say that a springs are used as a flexible joint between two parts of bodies
now here you are having some sort of objectives for the spring what is that one
first of all to cushion absorb or control energy due to shock it's a very common thing what we find out the application of springs in car springs or railway buffers and to control energy due to shock is a well known situations for the springs-supports and vibration dampers
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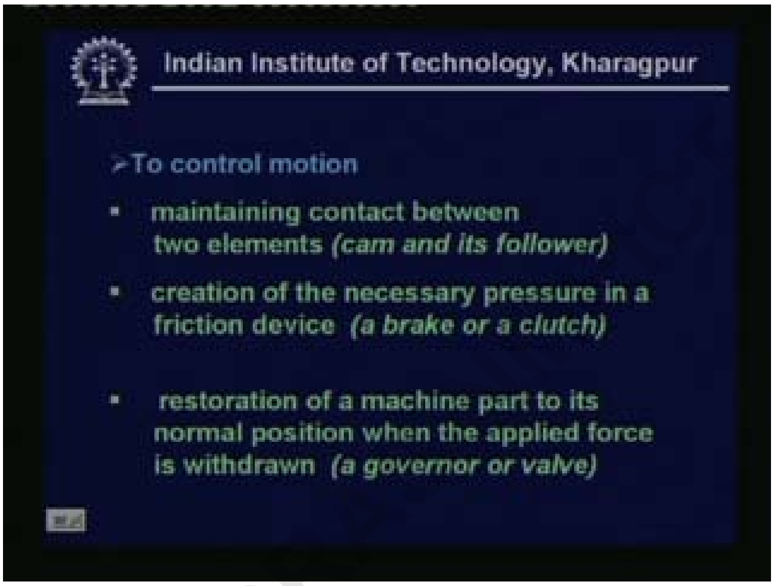

next to control motion
what is is the idea to control motion means maintaining contact between two elements as cam and its followers
you understand that when ah if you just think of the cam and follower arrangements ah widely used in so many applications then we will be finding out the spring is there which always keeps a contact between the cam and the followers thus it controls the motion
now whenever ah if you see someone driving a car he uses a break or a clutch for the car control of the ah car control as far as the motion is concerned and there what we do
we apply the break which again eventually is having ah spring system and the clutch is also having a spring system which engages and disengages ah at it which the mechanism or system of springs or a single springs like that
and another one is the restoration of a machine part to its normal position when the applied force is withdrawn
a typical example you know ah that in turbines ah in in the turbines suppose if we take an example then what we see that whenever you are having to control the speed okay

which is going on increasing or decreasing a governor system is used then which controls the motion or the rotation of the turbine wheels and thus the see the flow through the ah turbine ((veins)) (00:03:55) by the governor mechanism which controls a series of ah say veins for inlet water impingement like that and that is also controlled by springs

and here we use again as {sum} (00:04:10) some sort of control motion and that is also using a spring governor and another example there are some valves actuator valves are also having the spring which can have ah some arrangements for the control motion

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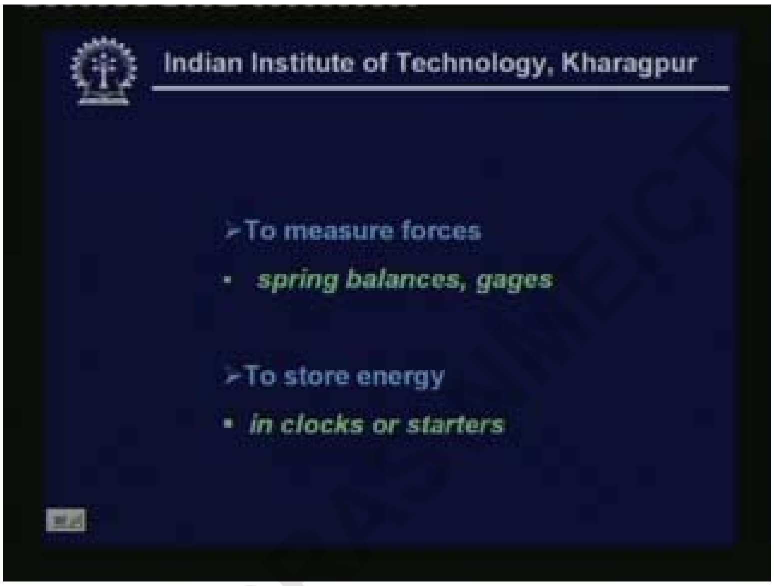

and the very common use of the spring you can see the measure to measure forces that is the spring balances and gages what you utilize as a spring and to store energy ah in clocks and or or the starters

however ah we do not find much of the winding clocks now a days but still you must have seen the clock ah the spiral type of springs which first you wind it to coil and then gradually it recoils ah and to stored the energy is recoiled and this phenomena also you can also see in the toys used by the children

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now in the lecture design of springs we will consider two aspects one is the design of Helical springs another is the design of Leaf springs

these two springs are very widely used in actual practice or actual fields in so many cases and some of the examples just now what i have stated

so we start our lecture ah with the design of helical springs

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now we will start with the commonly used spring materials one of the very important thing is the choice of the spring material so that the purpose for which the spring is made is actually performed nicely

now in this case normally if you are having the springs of very small diameter and the wire diameters are also {sma} (00:06:28) small then the springs are normally manufactured by by a cold drawn process through a mantle however for the very large springs having also large coil diameters and wire diameters ah one has to go for manufactured by a hot processes it means after heating the wire and then using an proper mantle to wind the coils

now [Noise] coming back to our discussion on the spring materials we see here that the common spring steel which is called the hard-drawn wire is the cheapest among all and it is normally used for low stress ah conditions and static loads

the material [Noise] is not suitable for subzero temperatures or temperatures above one degree centigrade this is a very common cheap type of springs what we can use in everyday life

next comes the oil tempered wire it is a cold drawn wire but after that it is quenched tempered ah ah and it is again a general purpose steel

however it is not suitable for fatigue or sudden loads also at subzero temperatures and also at temperatures which are above one eighty degree {cent} (00:08:03) centigrade

when you go for very high stress conditions then alloy steels one of this is a Chrome Vanadium steel is ah used

it can be used at a moderately higher temperature around two hundred twenty degree Celsius and this has got a very good fatigue resistance and long endurance for shock and impact loads

another one is also the Chrome Silicon this material also we uses for highly stressed springs and it offers excellent service for long life shock loading and temperature ah relatively higher than chrome vanadium that is around two hundred and fifty degree Celsius

so these two type of steels are as you can see are used for the fatigue conditions

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music wire this is the most used wire for small springs it is the toughest and has the highest tensile strength and can withstand repeated loading at high stress values

however it cannot be used at subzero temperatures or at temperatures above one eighty degree centigrade but ah [Noise] you see that normally when you talk about the springs ah you will be the finding out that music wire comes out a very common choice because of the reasons just stated

now the other one is the Phosphor Bronze or Spring Brass these are also wide used and ah it has good corrosion resistance and electrical conductivity that's the reason for the electrical contacts and other things you use this type of {ss} (00:10:05) spring materials

spring brass has a property that it can be used also at subzero temperatures

now there are [Vocalized-Noise] several other ah spring materials like ah stainless steel also ah and some more alloying elements

however in this particular one the ah names of those materials are given which are very common in everyday practice [Vocalized-Noise]

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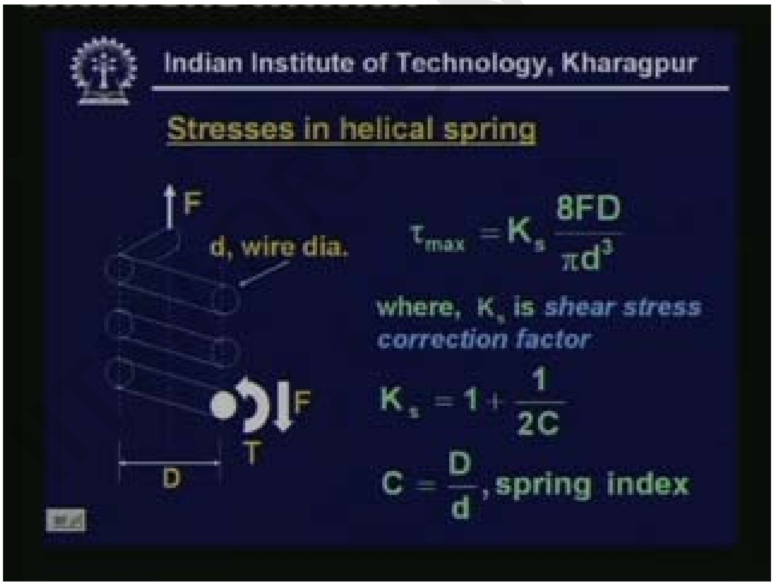

now [Vocalized-Noise] let us come down to the the stresses what occur in helical spring

now to look at the helical spring situation let us look at a the figure first

this is a schematic representation of a {sche} (00:11:14) ah ah spring so this is the coil cross-sections okay now these are the coil cross-sections so if you look this coil is actually owned in this fashion and this bold one what you can see these are all outlines of the coil okay these are the coil these are going like this another one is like this so (( )) (00:11:50) so forth

now this is a cut section means and from the entire coil somewhere you make a cut and that is the reason it is given in a shaded way now if you look at a free body diagram then what we will be getting we just concentrate on this particular zone then what you see is that if we look for this one then obviously at a cut section you are having a vertical equilibrium will give you the force the directly this force which is a shear force coming in these direction and the cut section the torque which will be coming over here is in this direction and there is no horizontal force coming into picture because there is externally there is no horizontal force present

so ah just {fro} (00:12:52) from our for our fundamental ideas of the free body diagram you can see that this is a situation ah any section of a spring is experiencing that is simply a torque and a force this is the shear force

now you know whenever there is a shear force you know that there will be an associated some amount of bending moment but you do not see any bending moment over here

that is an we just try to analyze yourself the reason i am telling it's because simply it is a curved one as because it is an curved one then that's the reason there is no bending moment appearing in the free body diagram of this particular cut section of a spring

now as you have learnt earlier that the stresses that will be generated due to the torsion as well as the direct shear can be can be computed using the simple equations and we can superimpose the stresses that is occurring due to the torsion and direct shear and thus we will be getting the final expression

i have written here the final expression as tau max as Ks eight F D phi d cube

let us see that how we get the simple relationship

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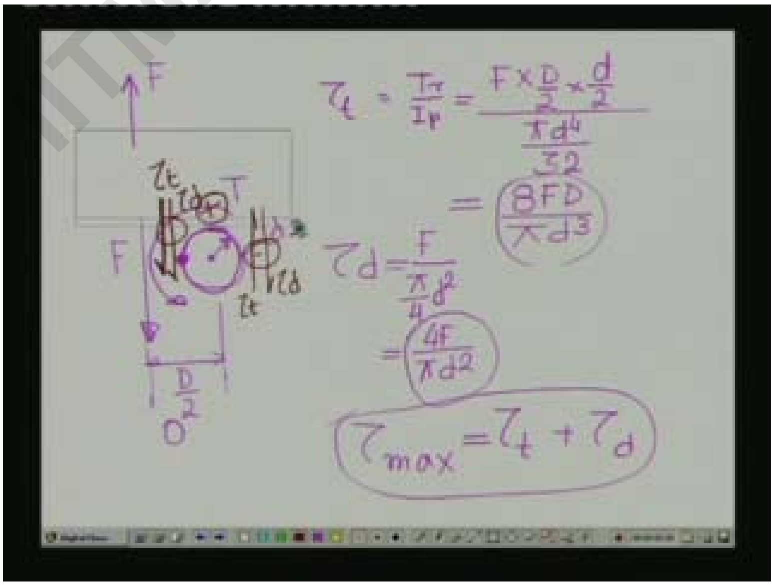

now as you have seen i am not drawing the entire one entire picture i am not drawing and just look into this one so if we have a cut section and we are having an torsion T and a direct shear F that is acting into this direction so what is the shear stress due to torsion

tau T that we know from our fundamental ideas that Tr by Ip we know all the notations okay the standard notations we are using

what is the torque that is acting here that we have seen from the free body diagram this is the F and this happens to be the radius of the coil or the total one

well just one second it's better that i give the notations as is in the earlier figure so this distance comes out to be D by two

so if you replace one after other then what you get

you get T this T magnitude of T comes out to be F into D by two what is coming out to be this small r

small r means here from here it is a small r so at this location we are giving it is as d by two okay where d stands for the diameter of the coil this has got the diameter

i am sorry diameter of the coiled wire divided by Ip so that gives you the phi d to the power four by thirty-two

so if we simplify then what comes out to be eight F D by phi d cube

it is the force due to tau direct how you get it

his tau direct will be coming out to be the total load by area

so total load is F and this comes out to be phi by four d square so that means it comes out to be comes out to be equals to just one second four F by phi d square

so we get one stress due to the direct one and another one we are getting due to the torsion one

so what is the next stress that is acting on to the spring at any point it will be the summation of this one and this one

now one thing i just would i like to mention here see we have taken the average stress although we know that there is an distribution of the stress direct shear stress but here we have taken this just as an average stress

so if we try to put another notation as tau max then what we note down

we note down that it should be the summation of tau T and tau d but at the point where it should show up the maximum

if we look into this one then you can see that at this location the direction of this is the {di} (00:18:34) direction of the tau T this tau T so if i just give another one ah just one second if i give this as tau T this as tau direct

d that stands for tau direct then here we are getting an summation effect however if you look at this you can see the shear stress will be here and here this is tau T and this is tau d so it is a minus of this one so you take this one minus that one will give you the value

so obviously when we consider the value tau max then we find that it will be summation of tau T plus tau d and this comes out to be the tau {max} (00:19:33) maximum means tau maximum (( )) (00:19:35) it represents a maximum shear stress that is occurring

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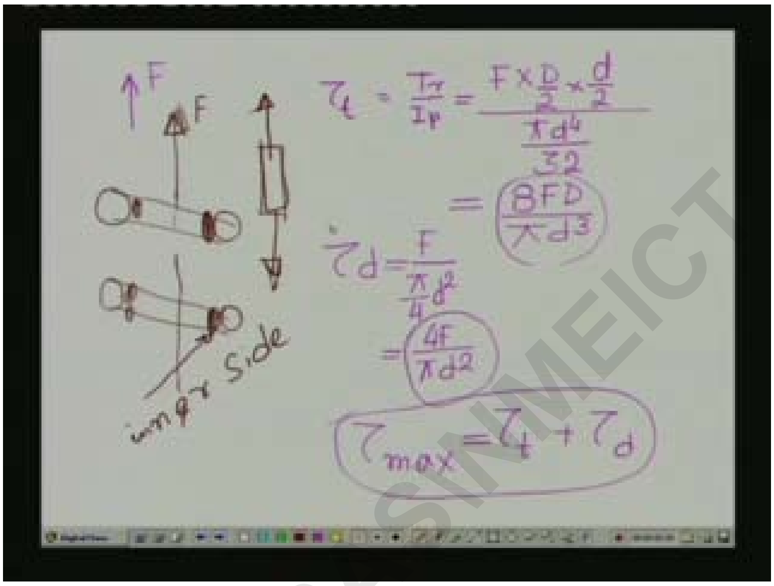

and you can see this maximum shear stress is occurring if we ah look to this particular spring ah as a whole i am just ah giving you {th} (00:19:52) the idea just here one second okay

so if you look to this one that means a series of springs like that what we have drawn earlier okay so what it is giving this is a spring acted up on the force F at this zone we are always getting similarly if you look at this one we will be always getting in the inner side

so the inner side this is the inner side of the spring which always gets heavily loaded so the spring failure is expected always to have from the inner side of the spring and that actually really happens

now you might be questioning that i have taken an example where the spring is in tensile mood means you are you are actually pulling the spring if this is a spring then you are pulling the spring like this so this is what you are getting a spring

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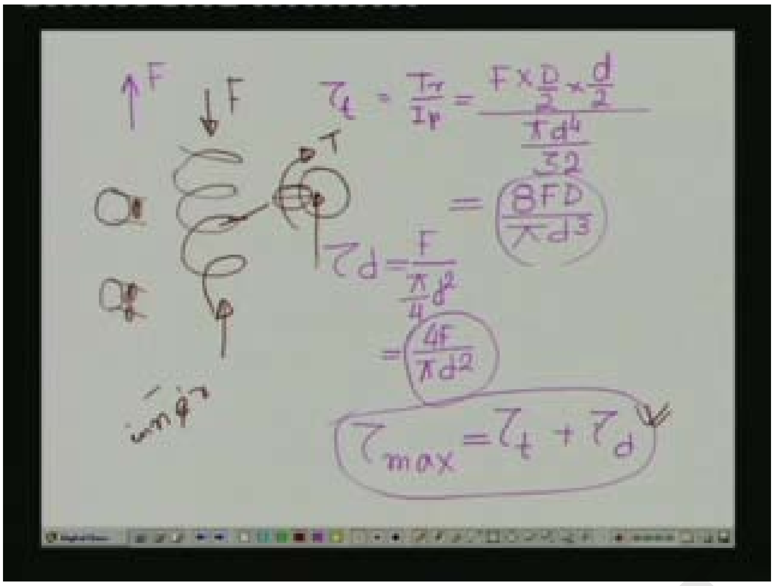

now what i mean to say is that at the spring at the spring was in compressive mode then and then also you see the inner side of the spring

so that means if you make a cut section here just a cut then you draw the cut section then what will happen to the free body diagram ah load will go like this one and the torque from the free body diagram will be like this

see again you will be finding out this inner side is mostly stressed that means what is the idea i am just trying to define you i mean explain you is that irrespective of the spring being in compressive mode or in an tensile mode you will be finding that maximum {sha} (00:22:18) shear stress is occurring at the inner side of the spring

so thereby the chances of failure ah the failure starts always from the inner side

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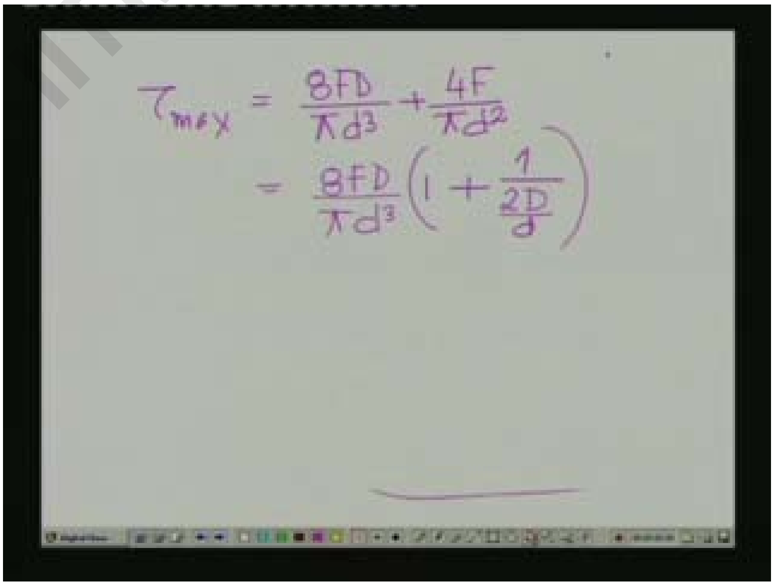

coming back to this equation what we have derived tau max equals to tau t plus tau d if we look into the entire form then what we have seen that we have seen like this that that tau max comes out to be how much eight FD ((plus)) (00:23:05) phi d cube plus four F by phi d square it's alright

eight FD by phi d cube plus four FD ah four F by phi d square so this one if we take common eight FD by phi d cube what we get one plus

what is this thing coming out to be one plus one by two into two into capital D by small d that is what you will be getting over here

now this one i suppose i am correct ah if you take this common that means this is eight means you divide by two so if you are going to taking common d so d comes at the bottom and one d comes at the top which comes over here

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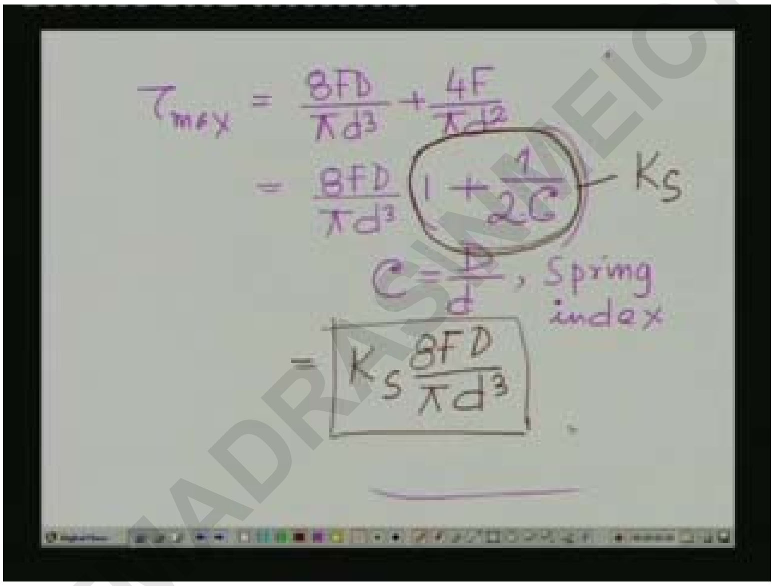

well so if it is like this then we represent a normally i am just without writing i am just erasing this portion okay we write down this normally by an word two multiplied by capital C so what you get that C stands for capital D by small d and this has got a name called spring index okay

now you can see that higher the value of the C lower the effect of this one by two C will come into picture the mostly predominantly it will be coming as the torsional stress

now this one including this particular one is again this entire situation means what i mean to say this entire group of one plus one by two C is written as a value Ks

so thereby we get an expression like Ks into eight FD by phi d cube as a tau max occurring into a spring

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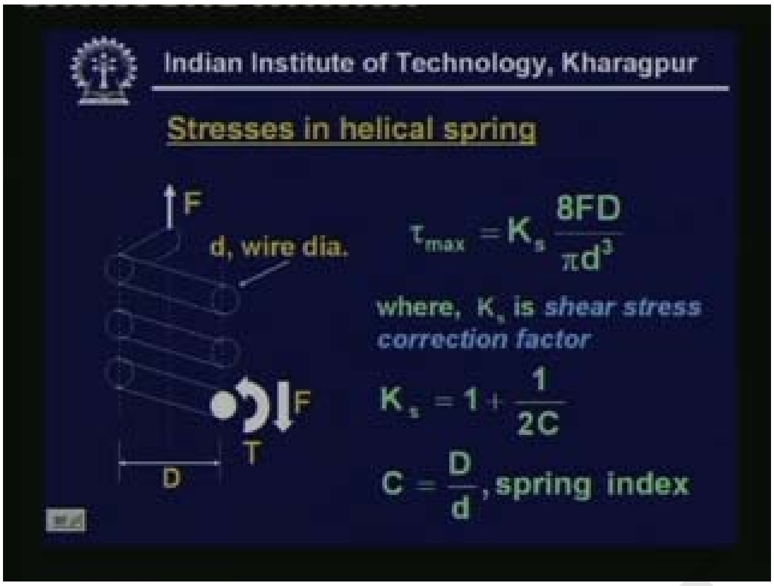

so let us go down to the earlier slide so we can see so this is what it has been written that tau max is equal to Ks by eight FD by phi d cube where you where this Ks is called shear stress correction factor and as i told you that Ks is given by the expression one plus one by two and where C is the D by d that is called as spring index so this is the equation for maximum shear stress occurring in a spring

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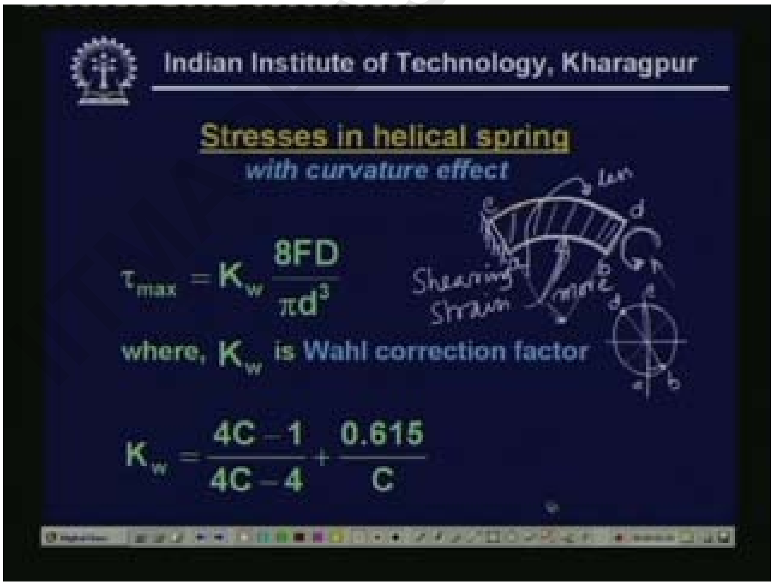

however this particular one this expression is sometimes again written as in the form Kw eight FD phi d cube we can see we have replaced the Ks by Kw

what is this one here this Kw is the Wahl correction factor and named after an researcher who did a lot of work on the spring A.M.Wahl and that is the Wahl correction factor and

this correction factor is given by this expression four C minus one by four C minus four plus zero point six one five by C now this is what you just see the heading the stresses in the helical spring with curvature effect

as a matter of fact ah it should be like this that means that this particular Kw the Wahl correction factor includes both the curvature effect and the shear stress correction factor together

so i mean what you what is the idea of Kw Kw or the total K if we consider this Wahl ah Wahl correction factor then it contains whatever it just telling that the curvature effect as well as the direct shear effect

now ah one should know that i am telling every time curvature effect what is basically an curvature effect

see ah this way we can define a curvature effect or try to explain a curvature effect

so if we if we look ah spring one small section okay so this is facing an circular so this is the center of the spring and therefore the load as we have drawn suppose it is you are just pulling from the center this is one spring what you have just cut out and just represented it

now suppose we just hold this section and you just give a rotation alright you give a rotation i think if we look from this side the rotation confirms with the direction what we have just given in the earlier slide

so if we give a rotation then what will happen with respect to this phase there will be an rotation of this phase

now suppose we we point out this one a and b and this is c and d

well with respect to this one if we rotate then the point b will be rotating with respect to what we just trying to say at a very beginning suppose just an view something like that c and c point is there so after rotation suppose the d has come down over here

this is the point d and this was a and this b has come down over here okay

so we can see the rotation for this two the top {surf} (00:30:21) top phase point d with respect to c and the in the down phase b with respect to a is having the same thing because that is the assumption while we have taken ah you remember in doing the simple torsion problems

however you see the length of the fiber this length of the fiber is smaller compared to this length of the fiber

so what will be the shearing strain the shearing strain will be more so here we understand this if we write this as an shearing strain

this location will be what

more and at this location it will be less that means here that is the what we consider as an curvature effect

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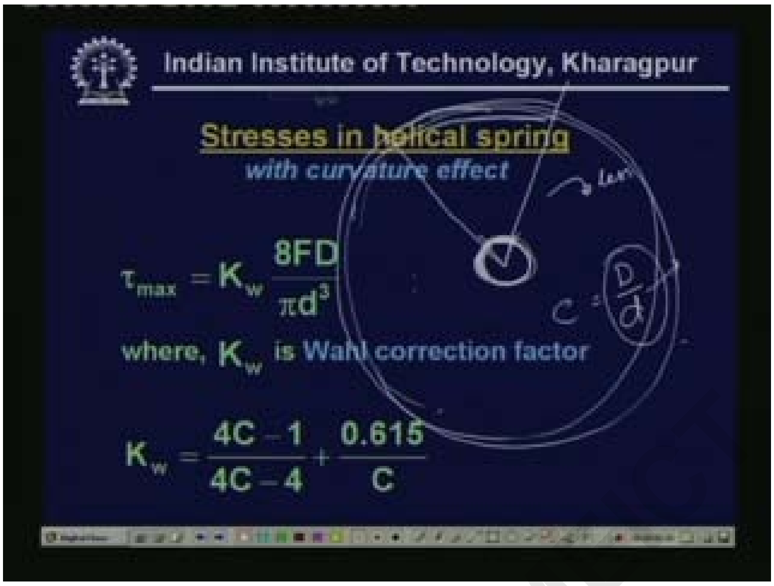

now you you you understand that what will be happening suppose we are having ah we are having a small spring okay of the same diameter of the wire then you can see onto this zone the curvature effect is more

the same wire if we make a large one okay then you can see for the same thing if we extend it this curvature effect will be less

so obviously that means what is happening the ratio of d that means C equals to what is this D by d the more and more the spring index that more and more the spring index then what will be having lesser the curvature effect

so normally for the heavy coils or or well one of the examples that means if you {hav} (00:32:24) if you see that ah train coach is that mean the suspensions which uses a helical spring in the railway carriages

you will be seeing that it has made of a very large diameter wire relatively the coil diameters are small

so in those cases what will happen is this curvature factors will be predominantly high so that is what we understand by the curvature effect

however as i told you that the effect of curvature and the effect of direct shear together you get this value of Kw

so it is customary that instead of writing Ks into eight FD by phi d cube

we will write down this Ks as Kw so that the effect of curvature is taken into consideration so this is the basic equation what we use for the stresses arising in a helical spring whether it is in compression mode or it is in tensile mode

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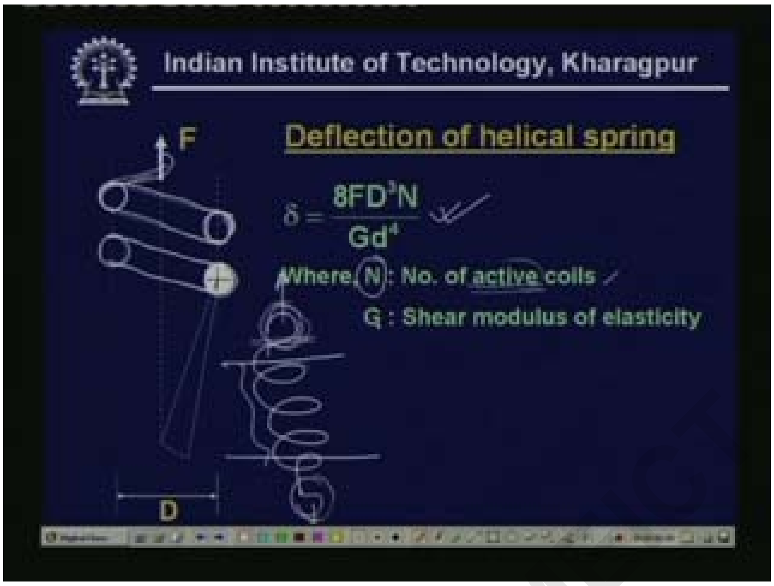

so once we have learnt this one then let us try to find out what is the deflection of a helical spring

now in the same manner you can see we have taken up a schematic view of the spring

so these are the spring coils okay

i hope you are the same figure and this is the cross section of the cut and it is acted upon by the same force downwards means that the spring is in tensile in nature

now while we compute the deflection of the helical spring just by simple geometry we can find out that deflection of a helical spring will be given by on this particular formula this eight FD cube by N divided by Gd to the power four where N is the number of active coils

now again the question comes what is the word active means

ah basically you know ah we will be dealing with this particular term active coil after ah just after these lectures ah this discussions ah but still just to give an idea

suppose this spring the F cannot just hang on to the space it has to have some material contact

suppose it is an spring then normally you will see the spring i mean something like this ah

a spring will have okay and then you have hooks so that means these hooks where you have to put these loads

now this sort of situations okay just that means putting an hook etcetera these are although a part of a spring but it do not contribute actually to the spring deflection of springs stresses it {ha} (00:36:06) it has to be taken care of in a different manner so suppose we consider that this is the zone this is the zone normally where we are having all the coils which contribute to the deflection of stresses then these many coils are what we mean by the active coils

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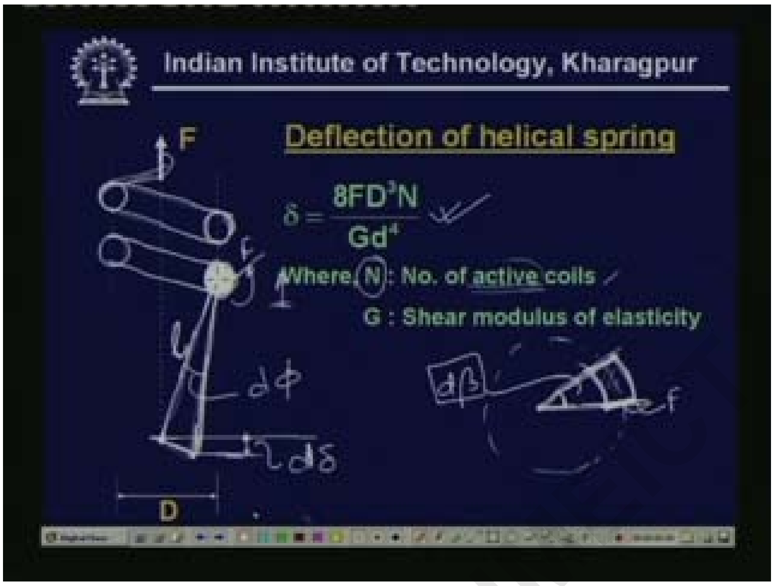

well now the G i need not explain once again you know the G is a shear modulus of elasticity how we actually try to find out this deflection of an helical spring from the geometry

you see ah just a situation before the application of the F what is happening

we have taken an cut and we arbitrarily draw a line from this point to this point and let us denote that the length of this line is l okay some length l of this line

you apply the force F here and also somewhere in the down and what we will be getting that means this spring will just extend and what will happen to this phase

you see from the earlier free body diagram that it it will experience a torque like that so if it is experiencing a torque like that means with respect to just the earlier section you understand what i mean to the just earlier section

it means i am just trying to put it like this okay

now this is the coil means it is the entire coil and this is the phase what we are considering here that means this is the phase F and this is the phase F

so with respect to the center if we draw two phases and this is a situation alright and now let us consider this angle to be something like say d beta

so here this angle ah well we take a very small angle as a matter of fact it will be better just let us take a very small angle and write down this angle till something the d beta okay this the angle

then let us imagine that with respect to the small length segment all other all other means all other springs are somewhat a rigid that means all the springs are rigid only on to the entire spring you are having a rotation with of this phase with respect to this only
we are considering this small length of the spring to be active one means actually responding to the torsional force and that is actually rotating all other spring coils means entire spring coils that you are having the entire thing is rigid only that small portion is active where you can have a rotation like this
so from this particular rotation if we come down to this particular figure then what will happen the length l just due to the rotation like that this line l will travel somewhere over here this is the line it will come over here
now what you are getting that this line has come over here and this angle let us call this angle as small angle d phi
then what is the deflection see this has come over here so if we consider a just an horizontal line through this one then this distance is delta delta ah well i should not put it delta ah say it is it is coming out to be d delta will it be alright i think because it is under a small element length so let us put this one as d delta that means what is this d delta
this d delta has come out due to the rotation of this phase or this phase with respect to ah another phase which is very close to this one only obtaining a small angle delta beta
so we know that to find out the deflection of the helical spring
we have to find out this value of the small displacement that is created due to the [Vocalized-Noise] rotation of a a segment of a small segment of the spring
so that means we have to compute the d delta and then if we can compute d delta then immediately we can compute the delta considering the effect of all other coils for the entire spring so how we can take up
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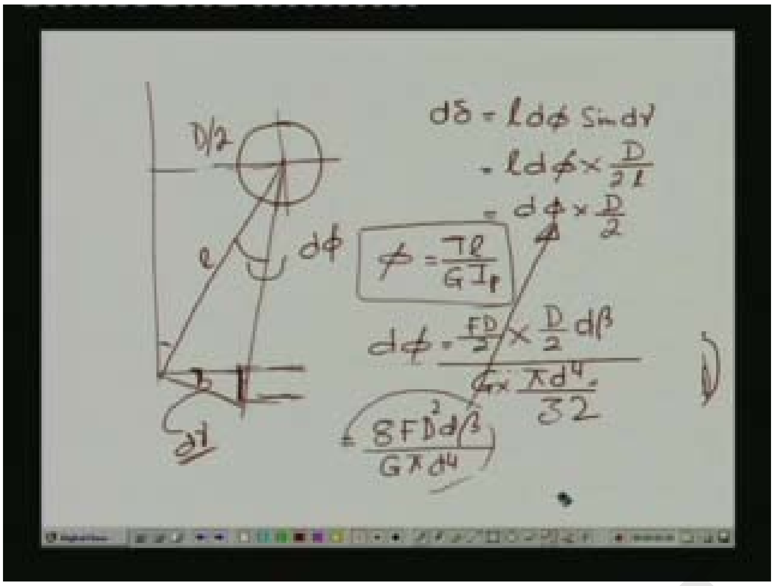

we can take up in this situation let us come down over here you just have an idea

we know ah if we if we if we concentrate on this particular figure this is the central line

the line was like this it was l it came down over here then you are having so this is coming over here

ah well well this is the line so you get a line like this and we are interested to find out this component this is this is the portion we would like to find out

how we can find out this line

suppose this angle this particular angle ah let us say hm d gamma

what is this line

then we can see this d delta equals to this is the thing and what is this length

we had denoted this angle as delta phi so it is this length is ld phi so this one by this one is the sin of this angle that means it is coming out to be ld phi sin d gamma and that comes out to be ld phi

sin d gamma what we can find out

the sin this is the same thing and if you consider how much this is D by two so that comes out to be into D by two divided by l say that is the sin gamma so this comes out to be d phi into D by two

what is basically we want to find out is the value of d phi

how we can get the value of d phi

let us go down to the basic concept of the phi we know

it was Tl by Gip okay it was the fundamental equation for the shaft rotation we did it earlier

so taking the help of this equation we find out that the small angle d phi will be created by what torque as usual F into D by two and multiplied by l what is this l

you remember that we consider this as the segment a spring segment of this length okay

so this was angle angle d beta

what is this one

so this l or here l will be replaced by a dl a small elemental length and this length we can find out in which way

this distance is D by two and this is rd theta means D by two into delta beta this is this length

got it so you substitute this one with D by two into delta beta G what is the value of ip

phi d to the power four by thirty-two

so ah (( )) (00:46:39) please excuse me i have just drawn the entire one this is the d phi G into phi d to the power four by thirty-two

let us simplify this expression then we get this value of d phi and that comes out to be equals to eight into F D square delta beta by G phi d to the power four

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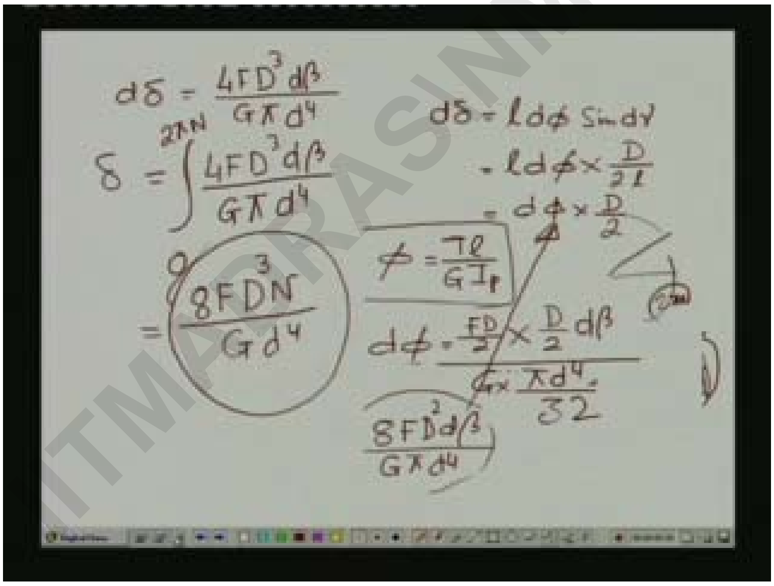

this value again we substitute over here okay

so if we substitute here then what we get

we will be getting an expression i think this is no more required we can erase this portion okay

so this one d delta comes out to be how much

we are substituting this one so two two cancels so four F what D cube d into dt cube delta beta by G phi d to the power four alright so what we will be getting the value of delta integral zero to this was only for a small segment of the coil and now we integrate for the entire two phi is one coil and number of coils for entire angle

this is a delta beta angle so we go by one is two phi we go by number of coils then it is two phi N so if we integrate it and it is coming out to be four FD cube and d beta divided by G phi d to the power four that comes out to be how much

two into phi phi

phi and phi we will cancel off so this delta beta will be simply beta and this two phi N we will be substituted so you understand this will be coming out to be two eight F D cube remaining as it is

two phi N this phi this phi cancels and remains two gets multiplied by four with eight so this is N divided by G d to the power four

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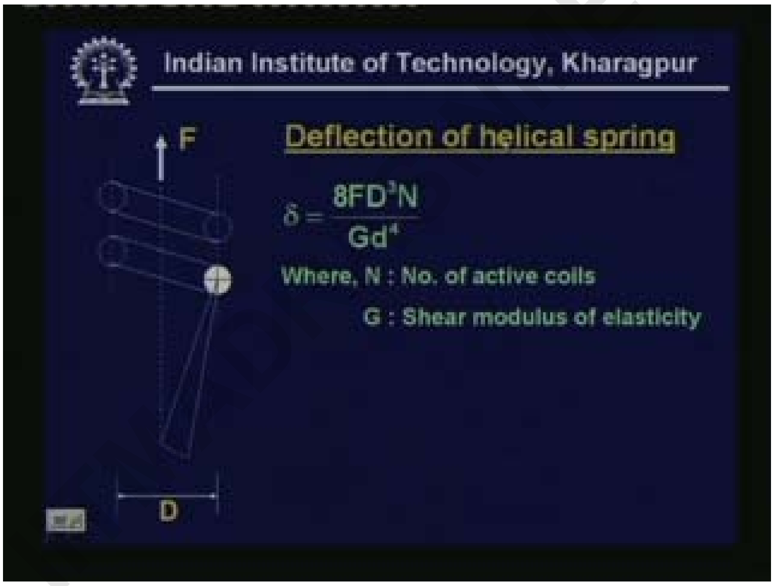

so you can see so we go down to this one and that precisely we see that delta equals to delta equals to eight FD cube into number of active coils divided by G d to the power four

so we find a very simple relationship to find out the deflection of the helical spring

now ah basically what we require in this case the stresses that is arising into the coil so that you can take the proper material or the dimension of the coil and where the sphinx parameters are its length its diameter of the wire diameter of the coil and the desired deflection what is coming into picture

so this will give you the total deflection of helical spring as well as the stresses so this once we find out then we can have the design conditions

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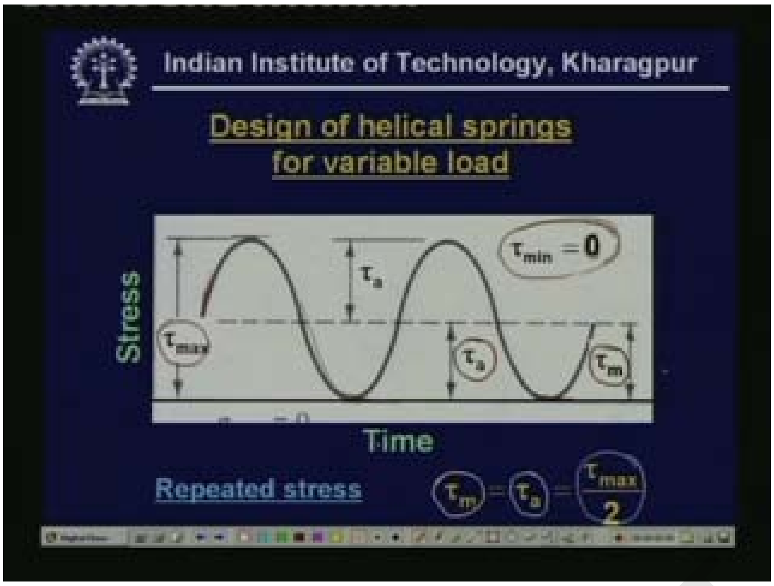

now let us go to another aspects of the spring design which is coming out to be the design of helical springs for variable load

now normally what we have seen the stresses what is coming into picture and the deflections ah everything is just what we calculated right now ah will be meant mostly meant for a static loading conditions

well the basic stress equation remains same ah however ah the deflection of the spring is universal it can be for a variable load or the static load it doesn't matter but anyway the stresses what we have derived that equation is is a condition whether loads are static in nature but as a factor of as a matter of fact you know that ah spring applications comes heavily in the conditions where the loads are not a static loading or a constant loading but it is an variable load

say as for an car for example you will be having the rear suspensions of the modern car which has normally ah coiled springs will be always subjected to a fluctuating load depending upon the road conditions it could go very severe also

so we have to modify the concept of the the design or the concept of analysis of stress on to the coil that is coming due to such type of variable loading well ah you see ah one of the figures

what is represented over here is something like this and you see this is called a repeated stress and this is a total stress and time

you can see one important feature is ah the stress is actually going in this manner the stress is going to some maximum value and then it is coming down to a zero value that means this tau min is zero here once we call about the load we understand that this load is causing a shear stress in the spring because primarily the springs will be subjected to shear stresses only

so what you can see is that the stress which is coming up that is the tau max and the tau min which essentially comes out to be zero and this we call as an repeated stress

so obviously we know ah from our earlier lesson what is this one

this is called as stress amplitude and this is called the mean stress or the average stress whatever may be

so in this case you can see the as because the tau {min} (00:54:15) tau minimum is zero so the this particular mean stress is same as this particular stress amplitude and

which is nothing but the tau {vac} (00:54:30) tau max divided by two means half of the maximum stress that is occurring in the spring

what for this figure has been given

this figure has a significance

see whenever we talked about the variable load design in the earlier lecture then you remember that one of the situation which is important is the material property and

in that time whenever we consider a variable load design in addition to the material properties like weak point and ultimate strength

we require another material property that is called endurance limit

that means the value of the material when it is undergoing a variable load or a fatigue situation we consider a endurance limit

i do not elaborate on the endurance limit because already we have done a lot on the endurance limit

now normally at that {loca} (00:55:42) at that particular situation you have seen that the {endural} (00:55:48) endurance limit of material was obtained by a cyclic loading situation that means some specimen was repeatedly loaded for complete (( )) (00:56:00) reversal of the stresses that means the specimen was rotating having an concentrated load at the middle that gave rise to a continuous stress repetitions of cyclic in nature means completely reversed nature

in the same manner when we consider the design of a spring then we know that spring is primarily acted upon by what the shear stresses

so in case of variable load design condition what material property we require

we require an endurance limit of the spring material when it is undergoing a pulsating type of shear loading situation in that case what is being done that if you if we if we just can visualize the experiment like this

suppose it is an torsion bar then what you are considering that you are considering the torsion bar to be loaded to the maximum and the zero loaded to the maximum and then we get zero okay

so that is what is being done in the case of the material testing

why such situation comes into picture because if we consider a case of compressive spring or a tensile spring then the situation is like that

say for an example first let us consider a compression spring what ah what will happen a compression spring in actual operation that if a compression spring is there in between my this is two plates then it will go down to the maximum and then come down to the zero

you cannot go to the reverse direction because then the spring will get loosened in contact you will just fall out

so what will happen the spring will at the most will be compressed totally to a maximum limit then come down to zero

zero is the limit beyond which if it goes like that then the spring will just fall from its seat

so that's the reason what is happening the maximum what you can attain in case of the compressive spring is maximum load to zero load

so that's the reason we consider a typical experiment of that nature so what {wes} (00:58:33)

we see that in the next class we will continue our discussion which is very interesting for the design of the springs when it is subjected to a variable load

thank you