Design of Machine Elements – I

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Lecture No - 14

Design for Fasteners – II

dear student let us begin lectures on machine design part one

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this is lecture number fourteen and the topic is design of fasteners this is the continuing part of the lecture on the same topic

now the last class that is in lecture number thirteen we studied how to design a fastener that is a mechanical joint

now in that class we have designed how designed what is known as a knuckle joint that is the fastener is a pin type joint

now ah we are going to study different kinds of joints today ah mostly we are going to concentrate on a type of joint which is which uses a uh mechanical element which is known as cotter

so let us go to the topic proper and let us see what are the different types of cotter joints

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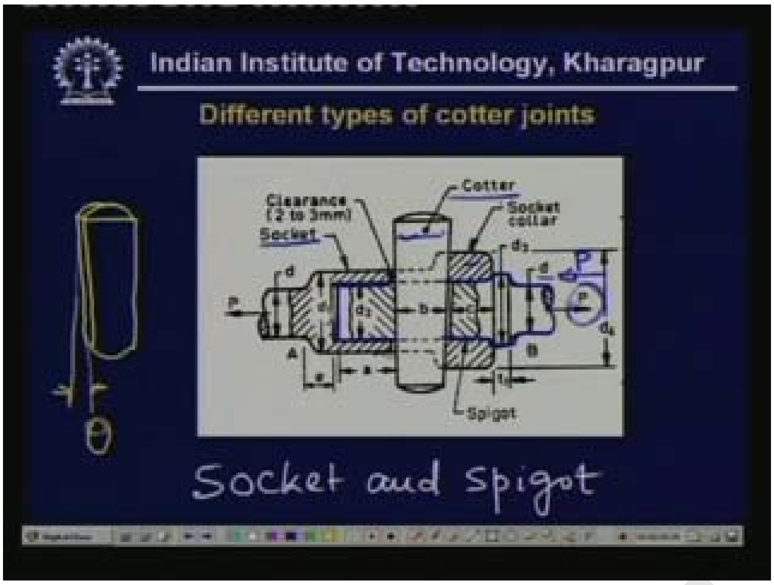

now [Vocalized-Noise] what you see here is one kind of cotter joint and here you see this part there are two parts which are to be joined by means of a cotter

now this is known as a cotter a cotter is like a pin but it has square cross sections if you if you want to draw the cotter then it looks something like this so this is a cotter in three dimensional figure

now you see there is a tapper here so there is an angle taper angle theta this taper angle is usually very small but it provides adequate binding force

so this is a cotter joint now this kind of cotter joint is known as a socket and spigot type cotter joint

so this is a socket and spigot type cotter joint so the spigot is here [Vocalized-Noise] this part is spigot this one

now this is in the form of a ah a rod and [Vocalized-Noise] the other part which is hashed over here so this part is known as a socket as the name implies it has a hole inside through which this spigot ah enters and these two parts are joined together by means of this cotter

so the purpose of this joint is to get um get a ah to bind this two elements uh when they are under tensions as you see here but it can also sustain some compressive force because of this collar a little protrusion as you can see here now if you think of this diameter this diameter is taken to be d where this is different d three which is greater than d

so therefore this collar it provides compressive force when ah compressive stress when a compressive force is given so instead of P if we can give P over here then it develops ah compression so this joint can withstand both tension and compressions

here what you see here a clearance is made between this two part that is this but the socket part and cotter of about two to three millimetre [Vocalized-Noise] so this clearance is required to insert this cotter

now we are going to design this {wawa} (00:04:33) well going to see how to ah use the failure theories for this kind of joints in a great details but for this time being let us see different other kinds of cotter joints

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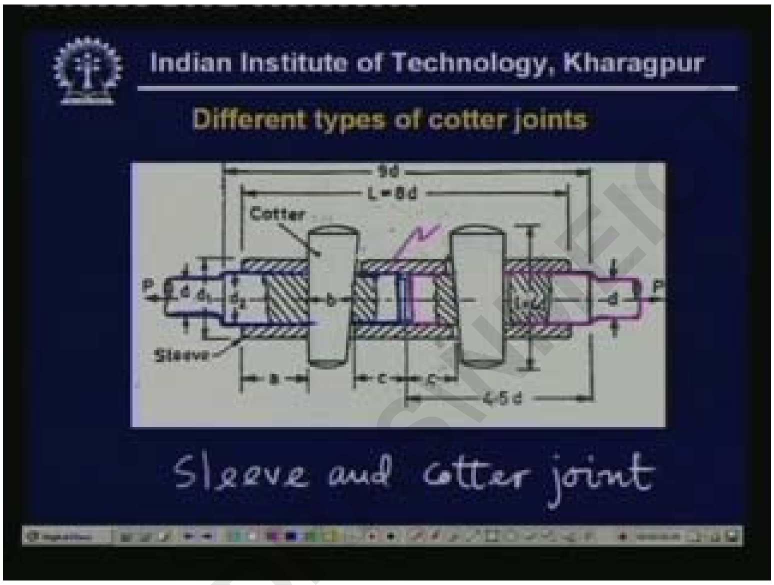

now this was the very simple joint which is known as as a sleeve type cotter joint so this is known as sleeve and cotter joint

what you see here there are two two rods which is here one such is up to this part and another one is here so they are connected together now how the connection is made now it is made uh with the help of a sleeve

now this part is known as sleeve as it is ah mentioned over here this is the sleeve so this is just like a hollow pipe now this two pipes are put inside this hollow pipe and then the hollow pipe and the solid {cylin} (00:05:52) and the solid pipe they are connected together by means of two cotters

now here [Vocalized-Noise] the normal distance between them is if the d is the diameter of each of this pipe connected together then normally four point five d is this length which goes or uh um which is the joint length for each pipes so the end the total distance is nine times d now this is rough and this is normal the standard ah distance used now ah of course the other dimensions are given here but these are uh very important while designing but now we are going to we are not going to design this one ah but different other joints but what you see here there are two cotters and the ah for the for the sleeve and cotter type joint the tappers are in the {dif} (00:06:46) the tapper side are facing each other this is very important and ah this is normally done so

so this is what you see here is a sleeve and cotter joint this is also very important kind of joint

now let let us go to the next type

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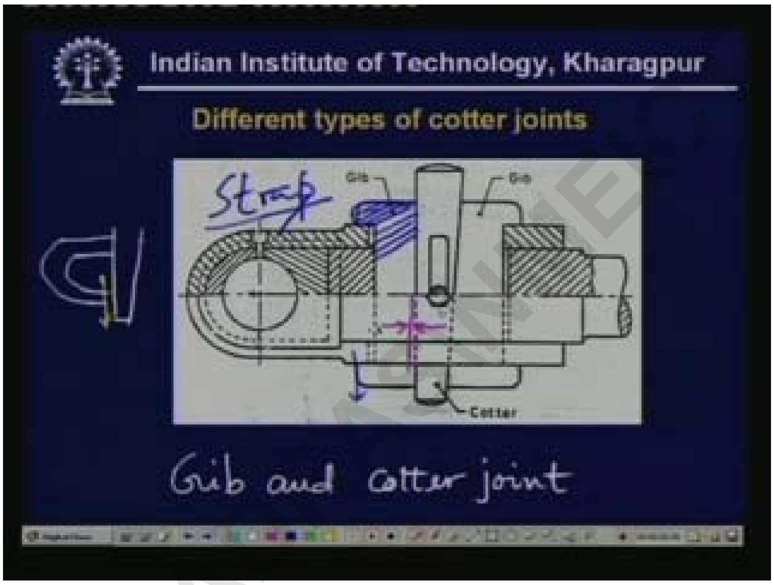

which is a gib this is known as gib and cotter joint

now this type of joint is normally used to connect the uh large end of the connecting rod now there is a strap end so this the outer periphery this one is known as strap this is the strap and when you have this strap then [Vocalized-Noise] without this part which is known as gib

now gib without this part it ah uh this strap tries to open up that is if we have a strip uh if you have a strap like that so if you have a only a strap and a cotter so because of the friction force here the friction developed over this surface this strap tries to open up

so this part without this gib it opens up now in order to resist that we provide what uh an another element which is known as gib

now gib is nothing but a {smi} (00:08:32) mild steel piece which has the same thickness as the cotter but which has this kind of shape now what is the purpose of this shape you can see this strap which normally tries to open up because of the friction force between the strap surface and the ah cotter surface this gib because of it's ah integrated geometry is this see this part ah has some protrusion that is when the strap tries to open up this part withheld that so in in that case the strap is secured against this the connections so this is the purpose of the gib

now there are different kinds of arrangements of gib this is what you see here double gib that is two gib's are put here and gib has also the tapper and the tapper angle is same as that of the cotter as you see here there is no gap between the gib over here and there is no gap so this is the gib surface and this is the cotter surface so there is no gap between the gib and the cotter so gib is ah very useful member in that kind of joint so normally these are the different kinds of joints ah which uses cotter

now we are going to study ah in somewhat details how to design such a joint using cotter

so let us go to design of cotter joint

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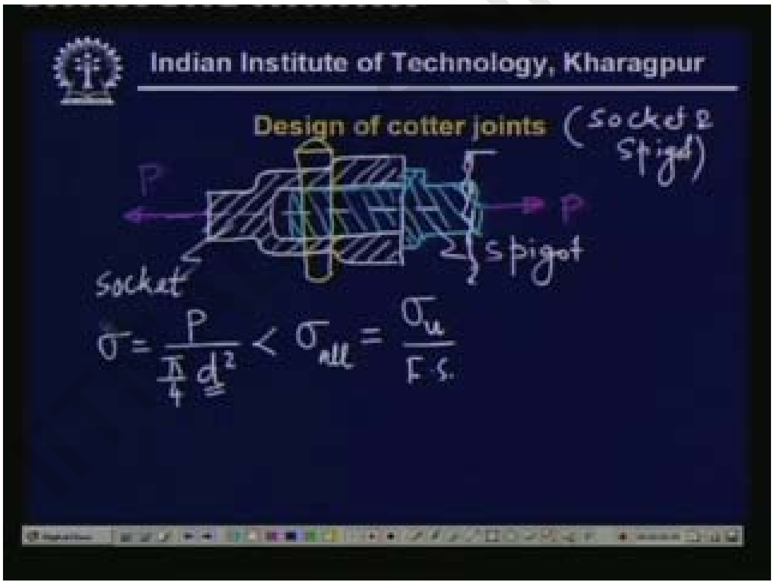

first of all let me draw a cotter joint here we are going to use the socket and spigot type joint

now this spigot this is a socket it has hole inside and we have another component which is known as spigot this part is spigot and through it we insert what is known as a cotter so this is the cotter inserted

now [Vocalized-Noise] when we apply a force P tensile force [Vocalized-Noise] then different parts are subjected to different kinds of stresses so let us analyse one by one first let us take the case of spigot so this part is known as spigot and this is socket so first of all this spigot it will try to tear up now the the most important ah design ah um most important part is this part [Vocalized-Noise] that is the rod end

now as you see the tensile stress developed here is nothing but [Vocalized-Noise] sigma developed when you take a cut over this surface then we get the tensile force tensile stress is P divided by area of cross sections pie by four d square of this must be less than sigma allowable

if uh i can remind you that sigma allowable is nothing but sigma ultimate the ultimate stress divided by the factor of safety [Vocalized-Noise]

now sigma ah from this data we can calculate what is that d so given a force P we first calculate the diameter

now if you remember uh the diagram then all the data umm all the other dimensions are given in terms of this d the ah uh diameter of this of this rod

so this is very important and we will have to find it out ah quite carefully

then what are the other modes of failure you see this now let us consider this spigot now you see the critical section of the spigot is somewhere here if you look from the top the spigot looks like

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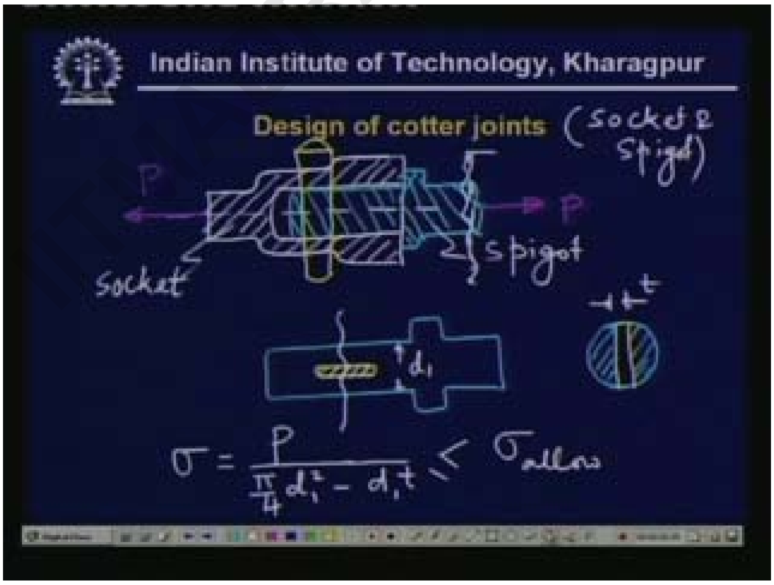

and the cotter is inserted over here this is the cotter insertion point so therefore and this uh this a circular cross sections so therefore the critical cross section will be somewhere here and if you find out the if you draw the cross section then it looks like here through which the cotter pass the cotter passes so this is the critical cross section of the spigot now the tensile stress developed here will be equal to sigma is equal to the normal force is P divided by the total area which is equal to pie by four

now if this diameter is d one if this d one d one square minus and the thickness is let us say t then d one times t

so this is the total area over which P acts so this is the stress and this must be less than equal to sigma allowable [Vocalized-Noise]

so from this data we can find out d one [Vocalized-Noise]

the d one value when found out then we can go for [Vocalized-Noise] some other calculations [Vocalized-Noise]

now the cotter will uh umm rest against this part so therefore there is a chance that a crushing may take place between this spigot and the ah [Vocalized-Noise] and the cotter

so let us calculate that [Vocalized-Noise]

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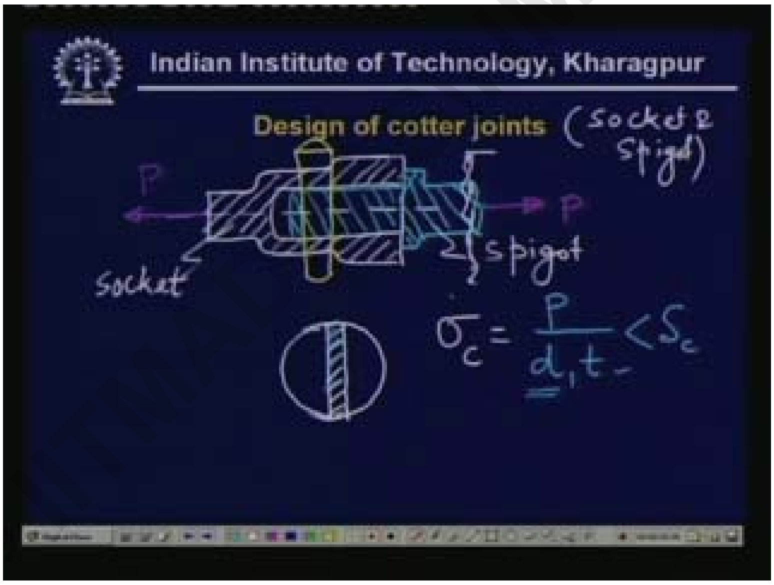

so this is the spigot and that is the surface over which the [Vocalized-Noise] over which the cotter rest so therefore the crushing stress that is [Vocalized-Noise] compressive stress developed is equal to P divided by pie or this total area which is equal to d one times t and that must be less than [Vocalized-Noise] less than Sc that is the compressive strength

if there that exceeds then of course the ah um the failure will take place and this surface will be damaged over here so damaging takes place if the ah sigma c becomes larger than Sc

so in that way we can check for the ah crushing stress we have already ah selected t and determined d one with this we check now failure theories are used not only to determine the design parameters that is to make the dimensions but also to check against failure

so here is the case where we have already determined the uh the proper dimensions and now we are going we are checked against failure and the failure is due to the compressive stress

what are the other modes of failure you see that once the cotter is sub uh once uh we ah give a force P then the cotter may be sheared away

how does it take place let us see what we see here

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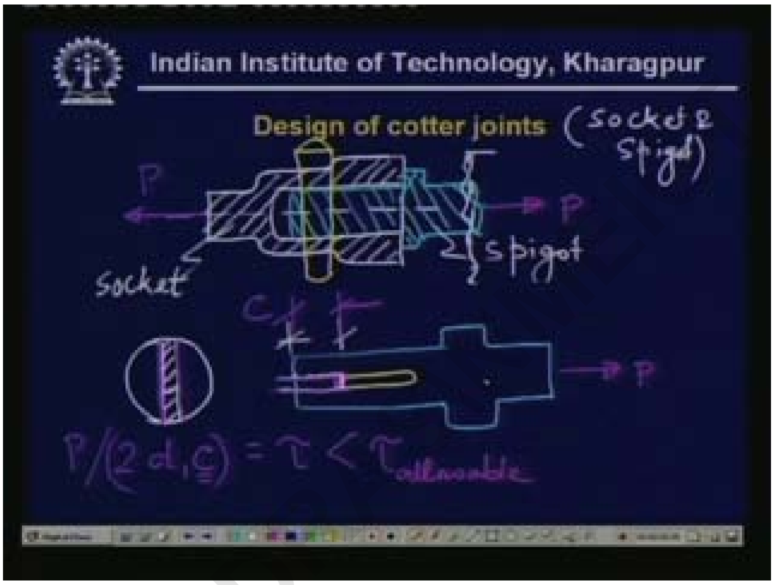

again this is this the spigot and this is the cotter [Vocalized-Noise] now if the force is given here then a large force is developed large stress is developed and that stress may be such that this part gets torn away it is it may fail against this direction

now what is the ah what is the area of cross section as you see the total area of cross section is now this distance times this one

so this is the total area of cross section we have to find out that total area and this is nothing but so it may tear away because of this shear stress will develop here on this surface and the total shear stress is d times d one times this distance if you call this distance C the d one times C will be the uh will be the surface on which the shear stress develop and this is twice of that because there are two surfaces and [Vocalized-Noise] this this is the total area so P divided by that will give you the shear stress and that must be less than tow allowable

if that is not satisfied then this entire part will be sheared away and we have to resist that so from this equation we can determine this value of C now this is how the ah this spigot can fail when subjected to tension now if it is subjected to compression then there may be other ways of failure let us see one

now when when there is compression you can see that there will be a stress developed on this surface

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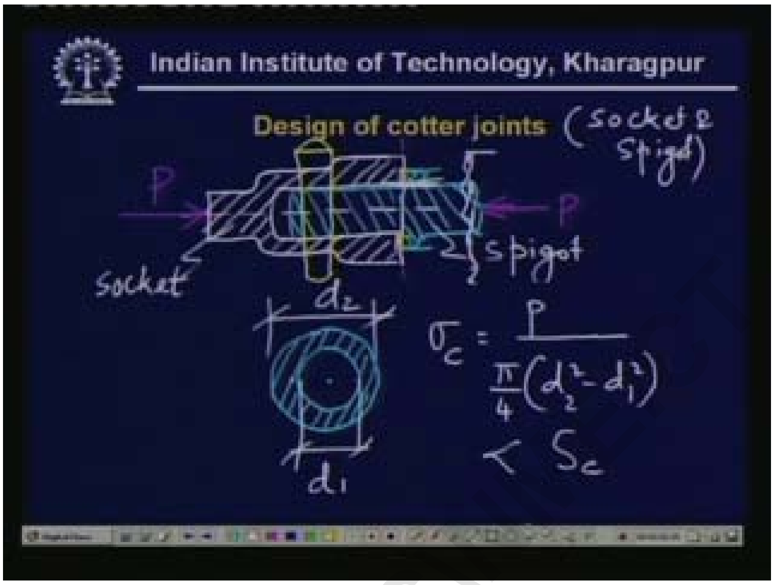

here the stresses will be developed because there is a collar here protrusion so when we give a compressive force now we are of course giving compressive force P and P over here

so now if you if you draw the cross section over here then what you see this spigot this diameter and the inner diameter so this part is subjected to compressive stress\

now what is that {compresi} (00:22:40) value of compressive stress sigma c is nothing but P divided by if the two diameters are let us say here d one this one was d one and if you call this to be d two then pie by four d two square minus d one square this is the compressive stress developed and that must be less than Sc the strength against compressions

so this is ah to be satisfied from this we can design ah the value of d two

what is the other mode of failure as you can see it can shear away even about this part so with this it can be sheared now just see that what is the shearing what is that shear stress developed as you can see the total surface over which the shear occurs

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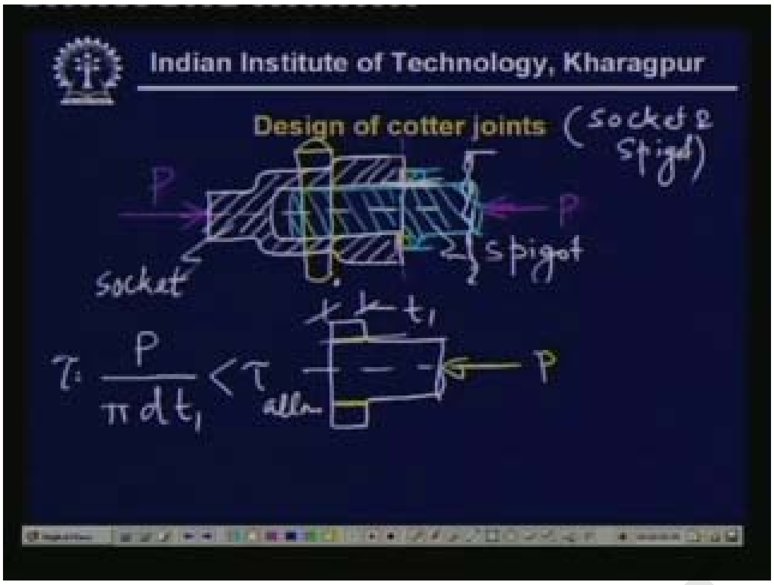

now this is the collar and the shear takes place over here if the force is too large we have P over here so the shear occurs over here so what is the total surface now this is cylindrical so therefore the total surface area is nothing but pie d and this diameter which is equal to which is equal to d pie d times this thickness t one

this is the total surface and when this is uh um when P is divided by that quantity we get the total shearing stress and this must be less than t tow allowable so tow is equal to there

if this is not satisfied then this part will be broken and this only occurs when there is compressive force if instead of compressive force we have a tensile force then of course uh here no stress is developed it only just touches or there may be uh um uh contact loss but whenever we have a compressive stress there will be this two parts will be in contact and in that case we can have compressive stress

so this is how a spigot may fail under various circumstances the first kind as i said this is tearing the second is crushing against cotter the third one is shearing of the spigot uh because of the stress developed between cotter and contact stress developed between cotter {co} (00:25:50) cotter and the spigot and in uh um in the case when the compressive stress is {giv} (00:25:57) compressive force is given then there are two other kinds of failure one is the crushing of the spigot collar against the socket collar and the shear of spigot collar so this is how a spigot will normally fail

now let us look at the situations of socket

the analysis is very very similar to that of spigot now the socket [Vocalized-Noise]

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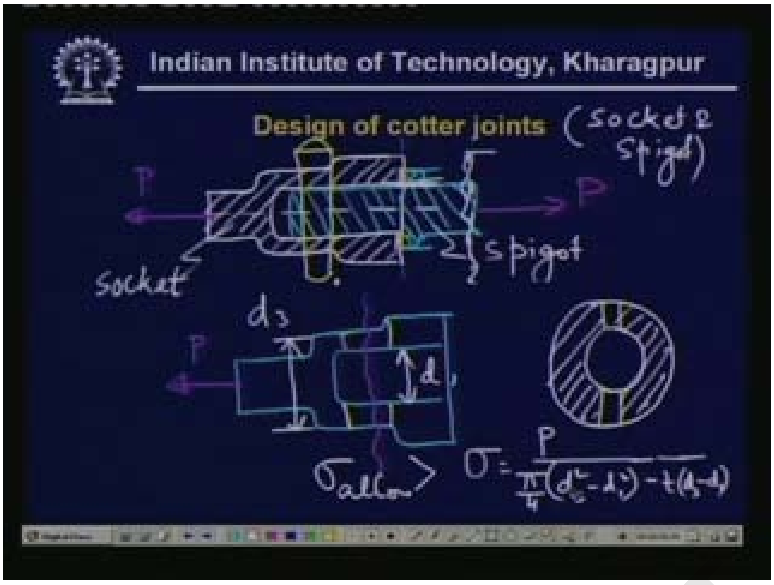

if we draw the socket part so this is the socket and we have a cotter [Vocalized-Noise] passing through here

now again it is subjected to tensile force as you can see here so this is subjected to tensile force so when this is subjected to tensile force then of course the [Vocalized-Noise] socket can tear and the critical cross section will be somewhere here as you can guess and you have seen for the spigot if you draw the cross section this is hollow remember and the cotter passes

so this part is subjected to tension and therefore sigma is equal to P divided by the total area the area is if this is d one inner diameter is d one and the outer diameter let us say d three then pie by four d three square minus d one square minus this much which is equal to d three minus d one times t t into d three minus d one

so this is the sigma and this must be less than so this sigma must be less than sigma allowable

this condition has to be satisfied now with this we can find out the value of d three this is ah failure against tension that is tensile failure

we have other kinds of failure just like spigot let me uh describe the spigot or ah the socket will fail against against crushing

so if we find out there will be the crushing force developed that is the compressive stress will be developed on this surface

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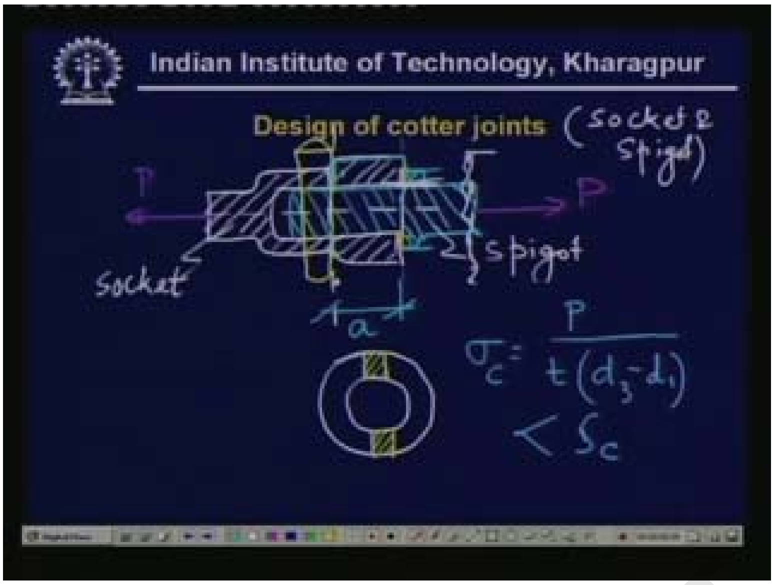

so if you find out if you draw the uh the cross section area of this surface what you find out that this part this part is subjected to to a contact force P

so therefore the contact stress developed is sigma c will be equal to P divided by this total area which is equal to t times d three minus d one so this is t times d three minus d one

so this is sigma c and that must be less than Sc the compressive stress otherwise this surface will be ruptured or it will be uh trashed and that is that is to say this surface will be damaged and the joint may fail

the other kind of failure is again ah shearing of the spigot of the socket collar that is this part is known as the socket collar this one and if the distance is taken to be a then the total ah surface over which the shear stress developed is nothing but let us find out the the shear stress remember we are dealing with the shear stress on that surface that is

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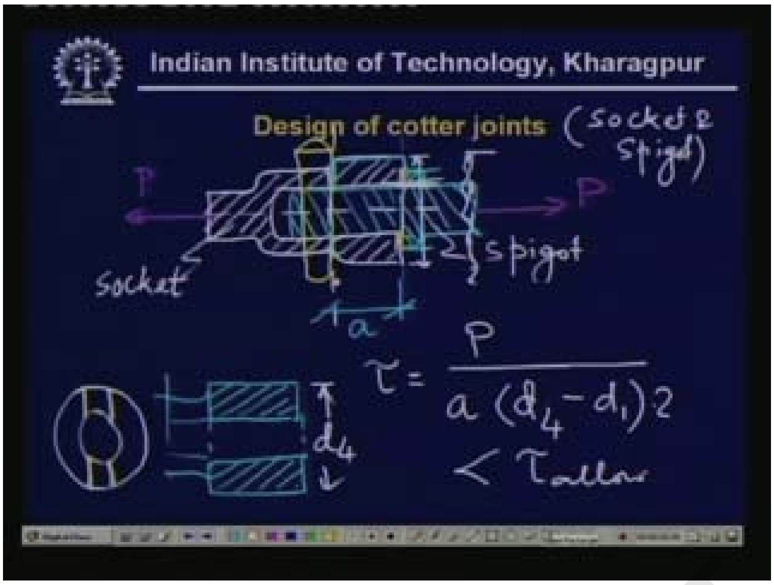

this is the spigot collar and this entire surface so this part is subjected to the shear shear stress and the shear stress is nothing but tow will be equal to P divided by this total area which is equal to this distance a times this part that is if you draw the cross section it becomes

so this length this four lengths together times this distance a and that is equal to a times the outer diameter which is let us say we take this to be d four

so the outer diameter d out or let us say d four minus this part d one and twice of that the factor two comes because there are two surfaces so therefore this is the shear stress developed and that must be less than tow allowable from this we can calculate the d four or if we have already calculated then we can check against the shearing of the ah socket collar

so this is these are the ways in which the socket fails the socket fails then in three ways one is the tensile failure the second is the ah compressive failure that is the crushing of the the ah socket collar against the cotter or the shear of the socket collar because of excessive ah shear stress developed

so this is how the spigot and the socket is designed now comes the most important thing that is the cotter

now let me draw the free body diagram of the cotter

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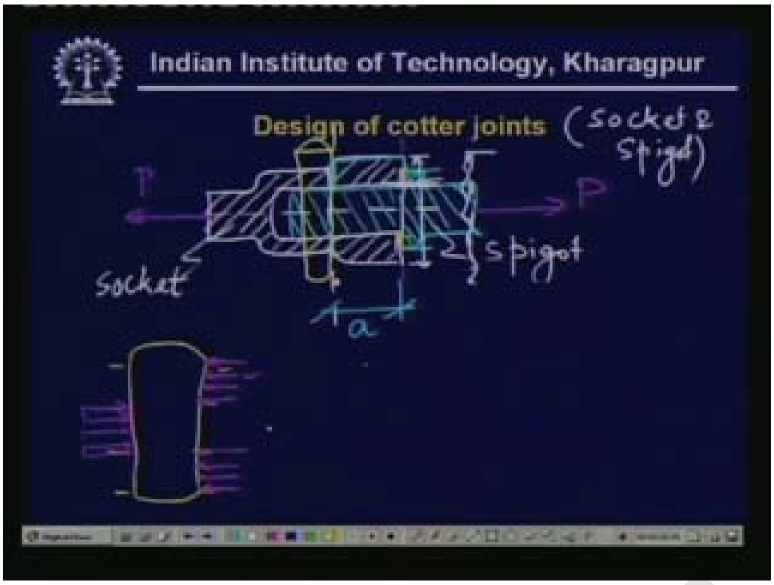

cotter this is the cotter and this part there are three parts again this part is [Vocalized-Noise] here

so this is going to the to the to the socket this part is going to the socket and we have compressive stress so here we have compressive from this side here we have compressive stress from this side and then again here compressive stress that side then what is the distributions the distribution is (( )) (00:35:46) not known we have to make some guess

so in most of the design hand book the normal distribution taken is triangular over this surface and rectangular over over that surface

so if you draw the uh free body diagram with that assumptions then the free body diagram looks like the following

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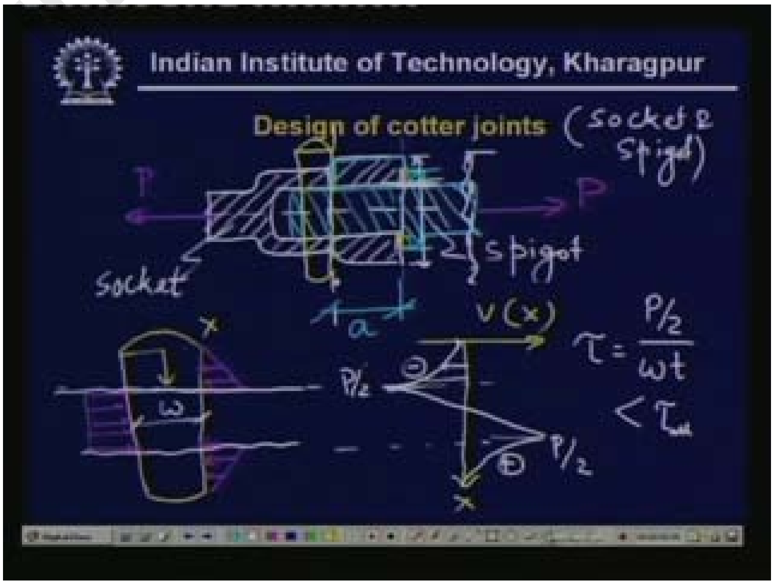

so up to this part we have a triangular distribution and also here triangular distribution over this part we have rectangular distribution

now [Vocalized-Noise] if this is the case then this cotter pin will cotter will be subjected to both shear and bending moment

so let me draw the shear force diagram if you draw the shear force diagram then it looks like so this is v x if you measure x from this length and v is the shear force positive over here and this is x then the shear force diagram will be taken to be approximately

so a large negative shear force thus this is part is negative this is positive so we see the maximum shear force is here and that is what is expected this part is subjected to shear so in in the case of excessive force what may happen the the cotter may gets damaged on this two surfaces

so we have to find out the shear stress the shear stress is now tow will be equal to the shear force is nothing but P by two over here if you calculate then this is P by two that the maximum P by two and this is P by two so therefore P by two divided by the area area is equal to the mean uh width that is if you take w as the mean width then w times t [Vocalized-Noise]

so this will be the tow and this must be less than tow allowable or tow maximum

that is once we have decided for t we can find out the required value of w that is the width of the cotter

then this cotter is not only subjected to shear ah stress but also bending moment now we have to draw the bending moment diagram the bending moment diagram if you draw it carefully

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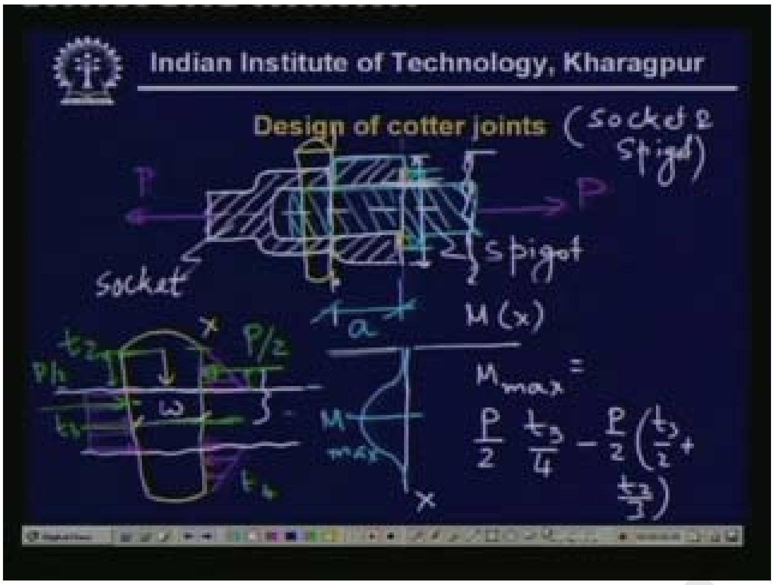

the bending moment diagram is so this is m x x over here so the bending moment diagram is almost look like that of course not zero over here

so bending moment is maximum near the mid point what is the value of the bending moment here m max

m max [Vocalized-Noise] okay if P is taken to be the instead of P here distributed we have P by two acting at one third distance away from this point that is if this length is let us say t two if this is t three and if this is t four

now t three is nothing but d one t two is nothing but the difference between the socket ah um socket outer diameter and the d one and similarly t four is nothing but t four is equal to t two so in that case we can calculate the total bending moment over on this sections

now once you calculate the total bending moment we have left it unfinished so we have P by two acting over here hence the bending moment at this point is P by two times t three by t three by two is equal to P by two times t three by two and P by two minus P by two times i am sorry this is t three by two and this distance is mid way so this will be t three by four instead

so this is t three by four and P by two this distance which is equal to t three by two plus one third of so this is M max

we {calcu} (00:41:55) we have calculated M max now we have to calculate the bending stress the bending stress is given by the known formula that is

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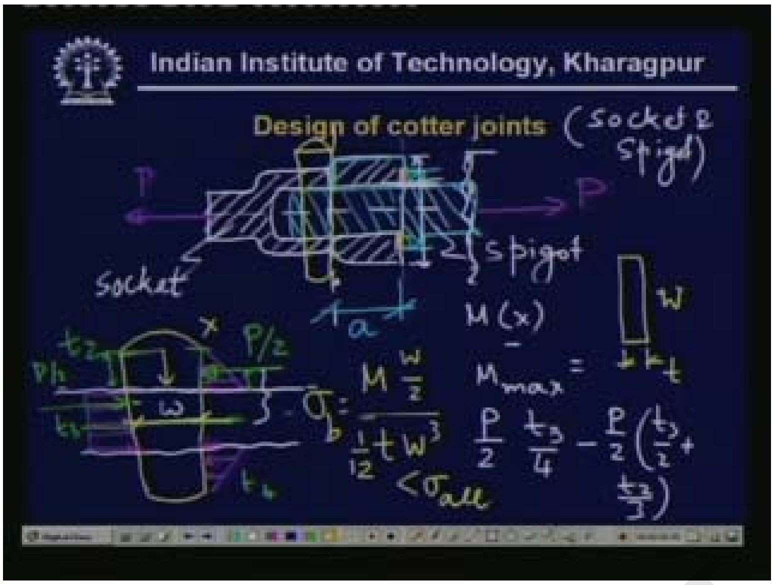

sigma b is M the maximum stress will be on the top fibre which is equal to w by two M y by I I is equal to one twelve then t ah b h cube w t cube so this is the ah this is the value of of sigma b may be wrong here so this is this is the cross section you see the cross section if you take the cross section it looks like this is t and this is w so we have b h cube that is t w cube so this is the sigma {bhi} (00:43:21) b definitely if w is quite large then the value of sigma b is less nevertheless we have to check against the failure

now the bending stress is tensile or compressive depending upon which surface you are looking at now this must be less than sigma allowable when we have both compressive uh both uh um bending stress and the shear stress then will have to calculate also the maximum principle stress

now in this case this is quite complicated but the principle is that once we have combined kind of stress then will have to calculate just {bef} (00:44:02) like

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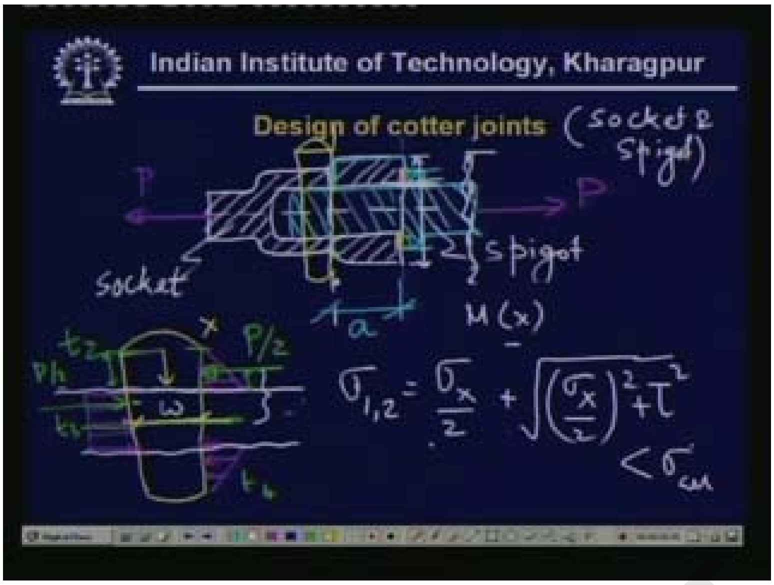

always the sigma one two which is equal to sigma x divided by two plus under root sigma x by two square divided by tow square

at each point we will have to calculate this value of sigma one two and that must be less than sigma allowable

now this the failure when the material is brittle in nature but if the material is ah not ah brittle but ductile then we have other theories of failure as you know the {thi} (00:44:42) the material may fail because the shear stress may reach maximum value

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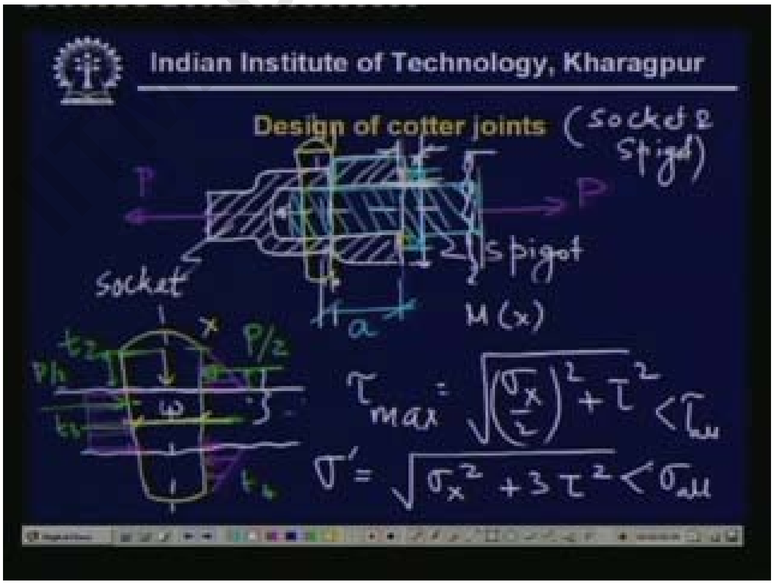

so in that case tow max is equal to under root sigma x by two square plus tow square sometimes we use Von-mises stress then we find out equivalent normal stress which is equal to sigma x square plus thrice tow square

so in that case the in the former case this is this value will be lesser than tow allowable and in that case this value is lesser than sigma allowable

now this is how the cotter has to be designed so roughly we have now ah completed the entire design procedure

we have found out the um the different modes of failure of different elements first the spigot the spigot may fail against tension now tension failure may be in the rod or somewhere here where the cotter is inserted within the ah or into the spigot

there may be the shear failure of the spigot part because of excessive contact stress developed in the cotter so the cotter may just shear ah or the spigot ah because of the excessive stress may get sheared away and the cotter may start moving towards this direction

then the other mode of failure is the crushing mode that is the bearing stress developed between the spigot and the cotter may be excessive and the spigot surface may get damaged

if the force is now compressive then there are two other types of failure that is the collar may get crashed the collar when it is subjected to compressions will develop a bearing stress because of the contact between the ah socket collar and the spigot collar and this contact stress if it is too large then the failure may take place

the other kind of failure is the shear failure where the spigot because of the high bearing stress between the spigot and the socket then the spigot collar may just get crashed so this part will be just sheared away so this is one type of failure

the socket may fail against ah again due to ah various reasons one is the tensile failure which happens near the critical region which is the place where the cotter is inserted in the socket the socket collar may fail because of the large compressive stress developed between the collar and the ah and the cotter

also the socket collar may get sheared away so these are the three types of failure present for the socket

the cotter on the other hand may fail because of shear as well as because of bending stress

so when when the joint ah is to be secured then we will have to design such a way that the failure ah failure of the cotter should not take place in that case we will have to consider both the bending stress developed as well as the shear stress developed so this is how a cotter joint is designed

now [Vocalized-Noise] in this lecture we have learnt how to design a cotter joint in the last lecture we have learnt how to design a pin joint now let us come further to the pin joints

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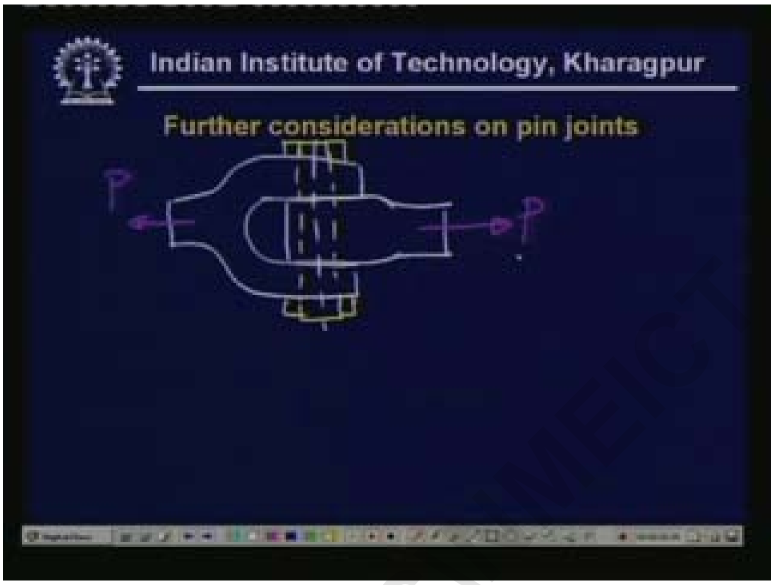

let us see in the knuckle joint we have used see knuckle joint was something like this where a pin is inserted over here

now in that case the collar so in that case this was subjected to tension

now this is the joint where two members are restrained against the tensile force sometimes this pin is also used when you want to fix two shafts when a twisting moment is applied so this is a different pin arrangement let me draw it

so let us consider one shaft

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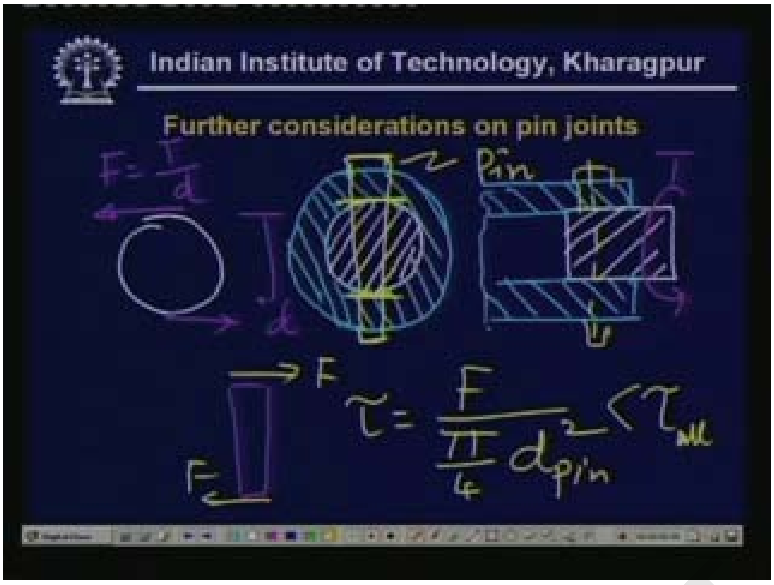

and we want to connect so this is one shaft and we connect it to the other shaft so this is another shaft so this is another shaft and this two are connected by means of a pin

so we insert a pin normally here for this joint we have a very little tapered pin

so this is the pin inserted and this shaft let me draw that one shaft is here and another shaft so this is one shaft and another shaft let us say hollow shaft and this is the pin

now what will be the failure the failure will be against here the shear so if you draw the free body diagram of this part then we have a force over here if we apply torque then the force developed is F is equal to T divided by d where d being the diameter

so in the pin if you draw the free body diagram of this pin there will be this force F and F here so the stress developed is F divided by pie by four d pin square

so this is how here in this case the pin diameter is selected this must be less than tow max or tow allowable

so this is the case where pin is subjected to pure shear we shall ah study different kinds of ah key arrangement where a ah torque twisting moment is transferred from one shaft to the other shaft in the next class but this is also done by means of pin arrangement as i have discussed over here

so in the next class we are going to study how to {joi} (00:53:07) how to join two shafts when a twisting moment is transferred from one shaft to the other shaft

so this is done by means of keys and splines so the next lecture will be devoted on keys and splines

in this lecture we conclude ah with this pin joints and cotter joints so we have learnt how to design a cotter joint and how to design a knuckle joint in this two lectures

we have all we have uh discussed in details how to join different elements so from now onwards we are not going to ah make some detailed analysis leaving something to the uh students something to you to ah fill up the blanks and we are going to just give the outlines of the design procedures

so this is the end of today's lecture thank you very much

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dear student let us begin lectures on machine design part one

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this is lecture number fifteen and the topic is design of keys and splines

now in last lectures we have ah known how to design a common types of fasteners namely the knuckle joints or ah the cotter joints

now in those joints mainly the purpose was to transmit tensile or compressive force from one member to the other but there are cases and many cases in a machine where we have to transmit torque from one shaft to another shaft which are coincide {co} (00:54:54) uh um which ah have the centre line the same

so [Vocalized-Noise] ah these are very common things and we have to design a fasteners such that the torque can be transmitted from one member to the other quite efficiently

so we are now going to start discussions on keys and splines so these are the ah again one kinds of fasteners that is the non permanent type of joints where at the torque can be {transmer} (00:55:24) transmitted from one shaft to the other shaft

so these are very important things and the design is quite difficult exact design exact analysis is quite difficult but we are going to design ah give some guidelines of the design

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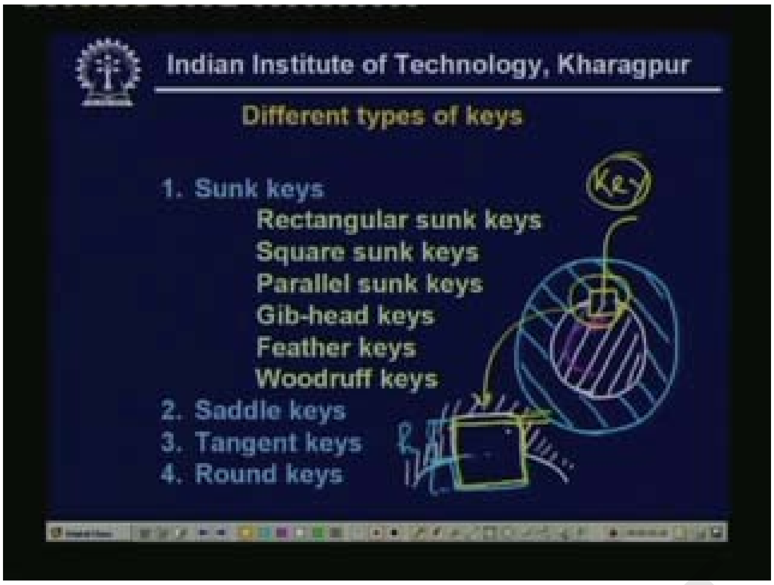

now let us now first come to the basic types of keys

so we are going to uh divide the lectures into two parts one is the design of keys and another is design of splines

in some books you will find splines are ah taken to be {membe} (00:56:00) one kind of keys but for our ah discussion we are keeping them separate

so let us see what are the different types of keys

now the purpose of the keys as i said is to transmit torque from one shaft to the other shaft that is if we have a shaft over here then this is one shaft

let us think of another shaft which is concentric so these are two shafts where the torque has to be transmitted from this shaft from the inner shaft to the outer shaft

the means of doing so is by using the keys now the keys are a small ah small piece of ah some material which is the same as that of the shaft material where ah this are normally rectangular in cross sections

so here we see that what we do we cut two slots in the ah in the shaft in both the shafts and then insert one small piece which is known as the keys so here we have cut one key way and this is key

if you if you draw it in further details then what you see is that let us draw the outer shaft the outer shaft here we can get so this is that part of the outer shaft where this key slot is cut the inner shaft again we have another this is the inner shaft where another slot is cut normally these two heights are equal if the total height is h then this is h by two h by two and so this is the slot for key and we insert a key over here now there is a small clearance a tolerance this is because of the machine fittings

so this is a tolerance very small tolerance that's also depends on the keys the dimensions of the keys but there there is some tolerance and so this is ah so this is how the key looks like in a key slot

now this part which is the corner of the keys this part