Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 46
Rolling Process part-2

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So hello and welcome to this manufacturing process technology part 2, Module 46.

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We were talking and discussing about the rolling example where we had arrived at this formulation here.

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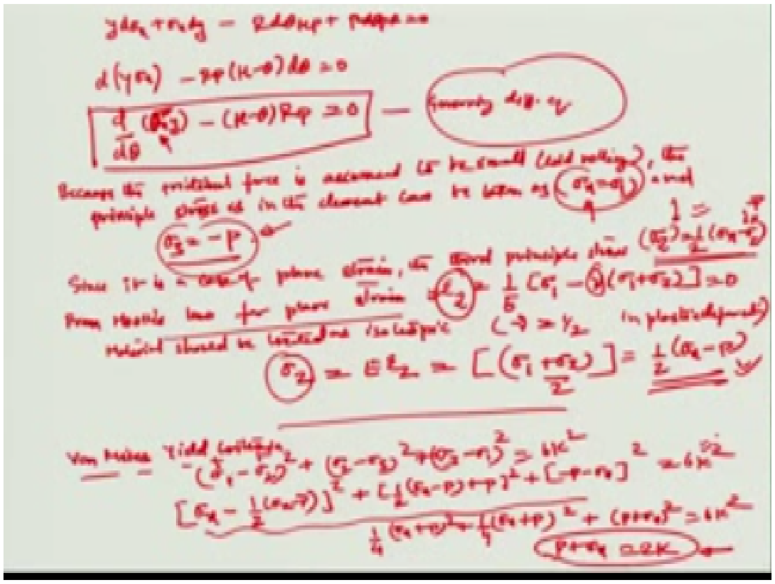

Where we actually to look up you know into what is going to be the plane strain condition for this particular rolling so that we could substitute for the value of σx as we had obtained earlier this is σx I am sorry for in the earlier governing equation case so let us now apply the one misses yield criteria here so let us say if we apply the one misses yield criteria to look at what is going to be the condition for which plastic flow can be initiated we have here σx – you know.

So basically the criteria says $\sigma 1 - \sigma 3$ sorry $(\sigma 1 - \sigma 2)^2 + \sigma 2 - \sigma 3)^2 3 - \sigma 1)^2$ should be greater than or equal to in this particular case it should be equal to 6 k^2 I think I had evaluated this condition earlier looking at the you know strain energy module of the deformation module and here in this particular example if we just substitute the values of the various σ, so $\sigma 1$ is basically σx in this case $\sigma 2$ as just being found out to be ½ σx – pressure p.

So square of this + you can say again ½ of $\sigma x - p + e^2 + - p - \sigma x^2$ should be = to $6k^2$ or in other words we have a you know actually if we just looked at or if you just biblically solve this little basically lead us to ¼ $\sigma x + p^2$ + ¼ (6x + p) again whole square + $e\sigma x^2$ should be equal to 6 k^2 or in other words p+ σx can be recorder as twice k okay so that is going to be the condition for 1 misses yield criteria to hold were there can be a relationship between the ultimate yield stress k and the you know the roll pressure as well as the principle stress σf .

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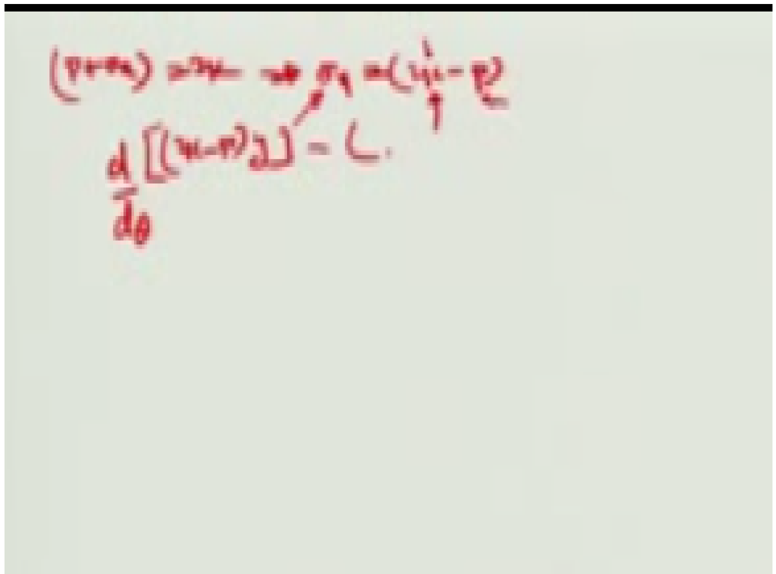

So basically now if I put p σ $x = 2k$ from the last relationship I have value for σ x principle stress and terms of the maximum shear yield stress of the material twice $k - p$ so you now indicating a variable σ x of the rolling process in terms of a material property k and also the roll pressure p and that is going to be our goal here to ultimately solve the governing equation so the governing equation can now be changed to $d/d\theta$ of you know just substituting the value of a σx here makes it twice $k - p$ times of y okay.

Minus of and please understand also one more issue is that you know the change in the direction of the friction force should happen before and after the neutral point.

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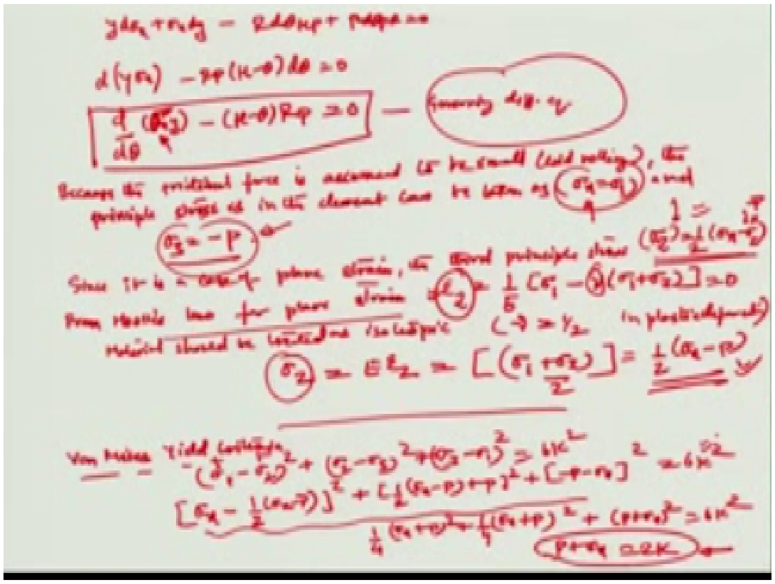

So in one case the whole frictional term as been suggested here in this equation you know this is the frictional term related to this equation, so this is a sort of a enabler and in the other case the after the neutral point as been crossed over this should be disabler so we should consider the + sign here you remember the way we had in some of our pervious side.

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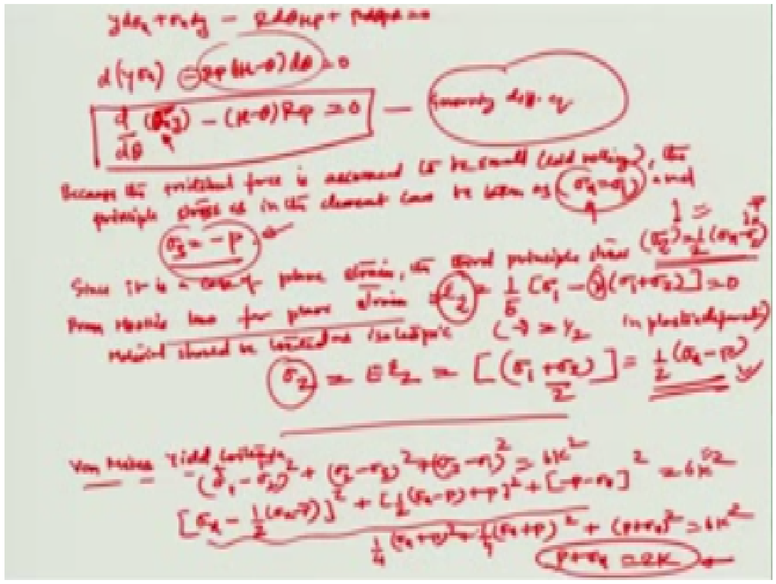

Try to enable or disable this frictional force so bit elemental the value this element reaches the neutral point where the velocity of the material is equal to the roll velocity we assume the fraction to be assisting in the rolling process and beyond that obviously the roll velocity falls down and the informational deformational velocity + the infinity velocity that is Vf is more than the roll velocity so this going to be a disabler so it is going to pull the material back you know because of the relative lower relative velocity or there because of the positive relative velocity between the direction of the motion of the element and the wheel element okay.

So because of all this the you have to go up to the neutral point for the friction to be enabler and beyond the neutral point for a friction to be disabler for the rolling to happen so in this event also here we are just change this expression to + - to you know really get to.

So in one case the I am sorry this as to be here so in one case you know the rolling can be positive rolling before the neutral point and in another case the extent of friction should be a desirable so we have a + - μ term incorporated here and so therefore we can say this as - + - μ – θ or be equal to 0 okay, so if it is aiding the process before the neutral point the Sin of the friction coefficient is positive and we have assuming that the friction coefficient is descending the rolling process or it is going to be in the direction which will prevent the rolling from happening that is what – μ okay, we understand this very carefully so therefore we can write down this whole you know expression as.

If I make an assumption here that as a material is being rolled and it undergoes strain hardly so let say as the material, is rolled in that stream harden and also increased k values on the other hand you know you can say that because of the rolling process the y decreases and in other hand because only rolling process the y decreases so I can you know just assume in the problem here conditioning where the although it is only in the approximation that this is strain hard is not very huge.

In that event it kind of remains valid numerically when the ky that is though increase in this strain hardly in the reduction the sectional area or you can say the sectional thickness of the material may remain a constant or may be a constant and independent of θ so this is only a assumption however in actual rolling process may not be typically true but you know in coal rolling process where the friction does not get varied very much and also we can assume the strain hard mean.

You know may not be so drastic okay this assumption is thinking valid okay, so if we have this simplification without resulting in much error, we can pull out the ky term from here because it is now independent of θ and we can write twice ky d/dθ of 1 – P / 2k so the expression here plus obviously then we would like to write this term in a different way it is now domain Sin here writing θ - + μ just opposite so just Sin from this + - okay times of Rp R times of the pressure P R times of the pressure P R is the roll radius P is the pressure equal to 0 and have you said that I further try to find out for small θ how y can be expressed so as θ is small okay, we can easily say y to be.

Represented as $y = Tf / 2 + R\theta^2/2$ so you know we can save the assume the Rθ to be the element length and obviously because θ is a small and it is Rθ is at angle θ with respect to the horizontal direction or at mangle 90 – θ the vertical direction, and if I look at such a.

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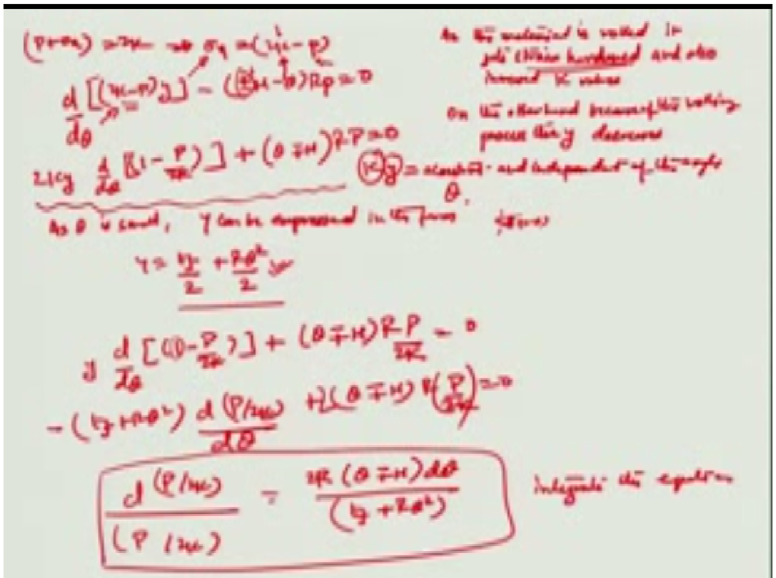

Illustration here write herein this method where we are talking about this to be $R\theta$ and this component of $R\theta$ to be $R\theta$ Sin θ okay and Sin θ can be approximated as θ so therefore $R\theta$ times of Sin θ is $R\theta$ times of θ and that is going to be the additional which is going to here and therefore we can say that you know y can be estimated as Tf + $R\theta^2$ whole / 2 so having estimated the value of y here if I substituted this y from the relationship we would like to try to obtained.

Again you know for the y we can actually/ this whole expression by 2k therefore the expression comes out the y times of d / dθ of 1 – P/2k okay + θ - +μ times of R times of P/again 2k imam dividing the whole expression by 2k = 0 or if I put the value of y so here as you know Ts + $R\theta^2$ and obviously d/d θ of one is zero so I can have this as –(d P/2k)/d θ and this divided by 2 + θ ± μ R P/2k = 0, okay. So we can actually arrive at some logarithmic form as a solution for these equation based on all this criteria's and further I can multiply this whole expression by 2.

So both sides so I have a twice coefficient x du^2 = 0 or then I can actually rearrange this expression and write this d P/2k/P/2k okay, P/2K basically is equal to now twice R times of θ ± μ times of dθ/ Tf+ R θ^2 so if we where to integrate this final form for the solution so we integrate this equation in the next step we are left with.

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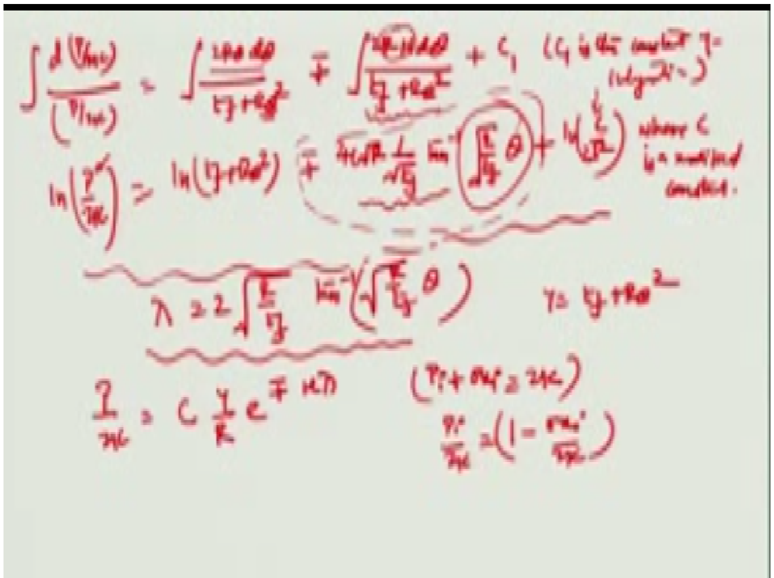

Integral of d P/2k/ P /2k okay = integral of 2 R θ d θ/ Tf + Rθ^2 one component ± integral of twice R μ d θ we are just algebraically simplifying this expression enabling it to contribute and plus C1 where C1 is the constant of integration, okay. So we have c1 is the constant of integration so having said that now if we looked at this solution this obviously would be okay, so this becomes equal to LN P/2k.

And this particular integral here because obviously this is y you have dy so dy/Tf + y becomes LN Tf + R θ^2 and then this particular integral would have solution so basically you can this is actually a $\tan^{-1}$ integral so this is going to be 2 μ √R/ 1 times of 1/√Tf times of $\tan^{-1}$ R/Tf θ + the LN (C/2R) where C is a modified constant, okay. So it would come up from just dividing this R μ, okay.

So you have Tf and then also dividing by Tf further so that you can have a 1 + x^2 so dx/ 1 + x^2 formulation of which tan-1 is the integral, so the argument there would come out to be √R/Tf times of θ okay and that is how you arrive at this formulation so therefore if this is going to be the final solution for the definite integral the goal that we must have is to be able to estimate what is going to be this C value.

For you to be enabling or for you to be able to tell about exactly what is the roll pressure which is needed to set forth yield criteria of rolling which is as per one vises as we have developed earlier as p + σx = 2 k where k is the sort of you can say the ultimate here the yield stress of the material, so you know the if we write this sort of clear manner let us say we make λ which is equal to 2/√ R/ Ef times of tan-1√R/Tf θ.

So we assume this as the λ so we can leave with here you know a case where P/2k can be estimated as some values C times of Y/R okay. Because you already know y to be equal to Tf + R θ^2 okay, so y/R times of $e^{\pm \mu \lambda}$ okay. So which is this particular term here, so basically we are talking about you know CY/2R and also this would necessitate so we already know that our initial pressure PI of the roll + the σ xi which is the initial.

The initial reaction force the inlet side of the roll should be equal to 2k by the warmness's criterion so therefore the pi/2k could be easily written as 1- σ xi / 2k, and initial you know point or at initial point obviously the λ I which is going to be there okay it can be defined in terms of the θ I which is going to be the initial contact length okay of the roll so θ = θi I think I had illustrated this earlier how θi is that at snap shot at t equal to exactly 0 supposing the rolling process was already continuing and you have at t = 0 you are taking a snap shot that is basically the contact at the length that the roll would have at the beginning of the process with respect tot the work piece which is actually the angle θi.

So λi here can be recorded as 2√ r/tf tan inverse √r/tf times of the variable θ at initial condition is θi, so having set that now if we assume the initial pressure roll pressure to be pi and the initial principle stress to be σxi, here of course the material property which is not getting change too much in this particular case so we are left with p/2k = c times of, so let us just substitute this corresponding to the initial condition we have pi/2k let us assume the constants value c to be c – okay it is constant of integration mind you which is also quite dependent in general with θ here. So θ will change really this particular you know final formulation of c. So let us assume this value to be c – constant of course will be something before the neutral point and after the neutral point the constant would be c+ okay. You already know that in one case friction design nab lour in other case the friction is disabler.

So obviously this c value will be c – before the neutral point has reached and will be c + after neutral point, so from calculation say call so you just changing the coefficients to +- 2 µ√r so assume c – here and why That the initial point is equal to the initial thickness ti and r e because the friction in this particular case is playing a Saar because it is playing is a enabler we have -µΛi okay. And so from this expression we can easily get the value of so you know I am sorry there is a ½ term here you have to remember y is actually the half the thickness.

So actually y is ti/2 whether it is a initial of final that is how you represented y before. So we have the c- value here calculated as from this expression write here as if I substitute at again the value of pi which is 1- σxi / 2k from this expression c- comes to be equal to 2r/ ti times of 1- σxi /2k times $e+\mu\lambda i$ so that is how you calculate one of the constants before the neutral point has been arrived at obviously because of the change of the value here this constant would also significant will change value wise.

And therefore as I told you before the neutral point and after the neutral point because switch in components are completely separate the constant of integrations would be c- c + in both the cases. So let us now apply this equation at the end the rolling process to find out what is going to be the you know the region beyond the neutral point.

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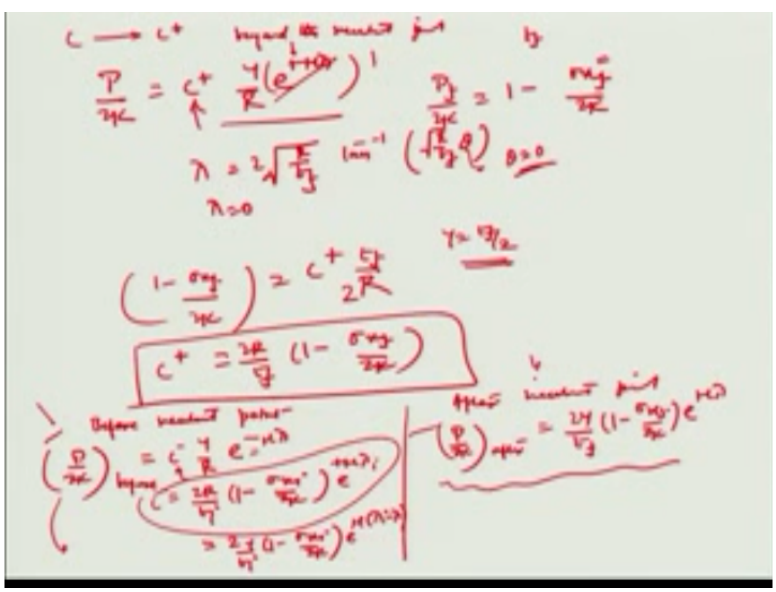

So let us look at so you know the beyond the neutral point the constant c is going to be c+ and if I word to write to expression for the pressure of p / 2k becomes equal to c+ y / r $e^{+\mu\lambda}$, that is how because this now an enabler so the friction is sorry a disabler so therefore the value has to be $+\mu\lambda$ and obviously the constant of integration is c+ I had earlier mentioned.

So in this particular case again at the final separation or at the end of the rolling process if thickness is pf you know which has been achieve the roll pressure pf /2 a = 1- again σxf / 2k where this is the final principle stress which is there or the from the sheet and at the exit point therefore I can easily have the θi the equal to you know again if I look at how we have formulated λ here so λ is basically equal to twice root of R/tf than inverse of root of /tf times of θ.

And I am saying that at the exit point of the roll the condition is corresponding to θ equal to 0 okay because the 5 we look at here again let us go back you know to the in the earliest module where you are talking about such a θ so the expression of θ equal to θi is really for the initial condition of the roll pressure but at the final extend you can see the value of θ is really from starting between o and o and o.

So the value here is 0 actually okay so in this particular value there is no angle when the formulation you know its leaves so corresponding to this θ equal to 0 with this you know the exit condition for the roll were equal to tf we can say that the θ is 0 turning with 0 so the λ becomes equal to 0 here and we are left through this 1.

And 1-σxf/2k becomes equal to c+y is tf in this particular case times of R because the tf you know as I told you why is actually tf/2 initial thickness that you get y as a design it is from the origin which is located at centrally across the neutral axis alternate the at end of the element so tf/2R and in other words we have the C+ here estimated after the element passes the neutral point estimated as twice R/tf times of 1-σxf/ twice k.

So these two are very important for us because we would like to apply these to what is going to be the pressure before the neutral point what is going to be the pressure after the neutral point so as I said of values which are because of all this calculations is that at you know I adjust but I took down as before neutral point and after neutral point.

I have the P/2k value just write this before here as if you made a numbers it was C-y/R $^{e-+\lambda}$ and that corresponds to if I just substitute this value C-here from the expression then earlier that C- is equal to twice r/ti 1-σxi/2k times of $^{e-+\lambda i}$ okay so this is actually – and sorry this is – okay because as I told you before the neutral point so if I substitute this value for C- in this particular expression the final form which emerges here can be represented as twice y you know ti, where ti is initial thickness of the roll I am sorry it is take it off here okay

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And after this beyond equal point or after the neutral point the P/2k becomes equal to twice y/tf times of 1--σxi/2k times of $^{e-+\lambda}$ so that is how you can estimate the roll p[pressure before and roll pressure after and in fact you know if you really wanted to determine what is going to be the pressure at the neutral point. So you can nearly hither use the equation before or the equation after to actually look at what is going to be the pressure after and before the neutral point obviously physically what it would mean is that there is the continuity there is pressure continuity in the way limit is going towards the neutral point beyond the neutral point.

So at that particular point where θ=θn, the θ is the neutral point the pressure before and after should be exactly same. So there is one continuity of the pressure, otherwise there is a step and that is not what really happens what there is in a actually situation. So therefore I can say that I can probably neutral point analysis calculate what is going to be the value of that.

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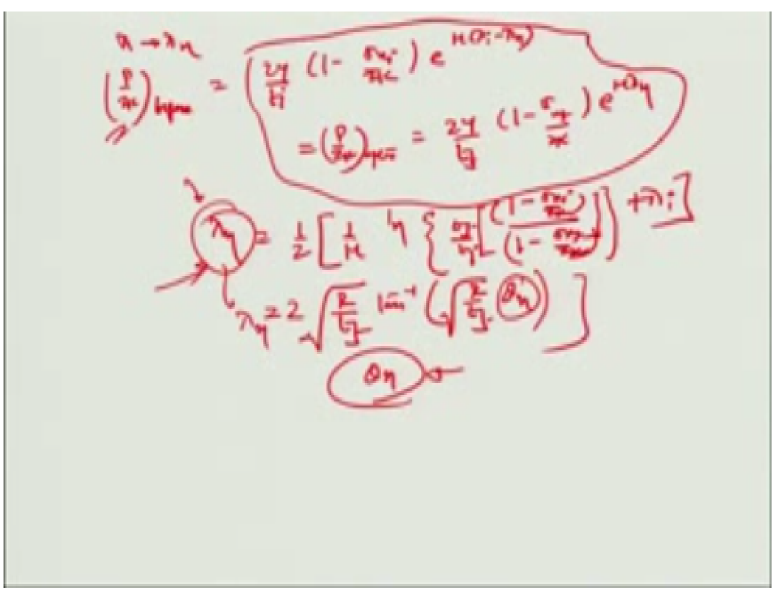

Γ corresponding to the neutral points, so from the equations, so I actually can predict the $\lambda = \lambda_n$ by equating equation before and after that is p/2k before which is actually 1y =2 y/ti 1-σ / 2k $e^{\mu\gamma i-\gamma}$ neutral let say, we are λ n and that is = p/2k which is actually twice after by tf - 1σ, f / p/2k μ λ. So if I equate these two expressions together, we can find out by taking natural sides γn value which comes out to 1/21/μ natural log of tf/ti times of 1-σxi x k/ 1-σxf/ k2 okay + the λ which was incorporated earlier from the 2/k before equation.

So that is how you find out the λ neutral corresponds to position which is corresponded to 2/r or tf times θ and so I will be able to sort of λn value what is going to neutral angel of a particular element in a rolling condition. So with this I would like to sort of end this particular module. I am also going to look at probably how to determine the rolls separating force, or what kind of talks that can be used or what kind of power loss in the bearing would happen but here you could actually have a very good estimate of rolling pressure.

To calculate you know all these different values related to power in equation while rolling, so with this i would like to sort of close this module in the next module we would like to look at again the roll separating force or the power transmitted bearing and then may be time permits to little bit some forming process and just schematically mention what the process like, in fact this kind of module need to transferred everywhere, forging extra I have shown for the rolling.

And then we would also like to have small introduction to manufacturing and beyond which I will show the video module 48 where we can actually use VMD title to which is very small. So with t is I would like to conclude thank you so much for being with me see you in next module bye.

Acknowledgement

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