**Basics of Mechanical Engineering-2**

**Prof. J. Ramkumar**

**Prof. Amandeep Singh Oberoi**

**Department of Mechanical Engineering**

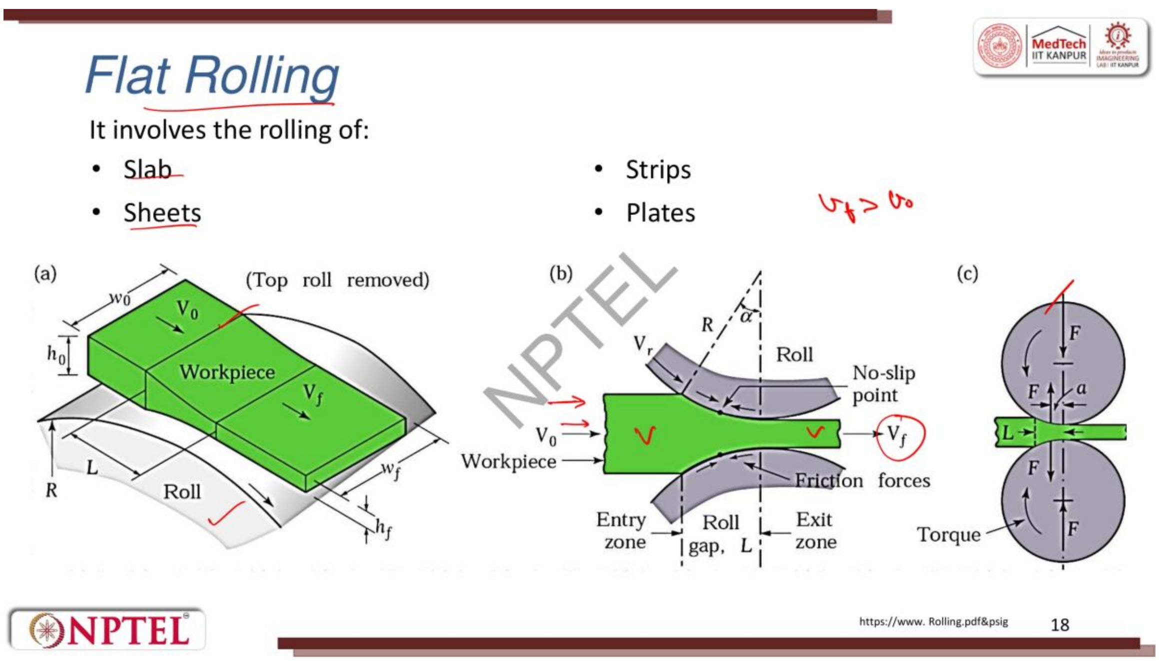
**Indian Institute of Technology, Kanpur**

**Week 06**

**Lecture 22**

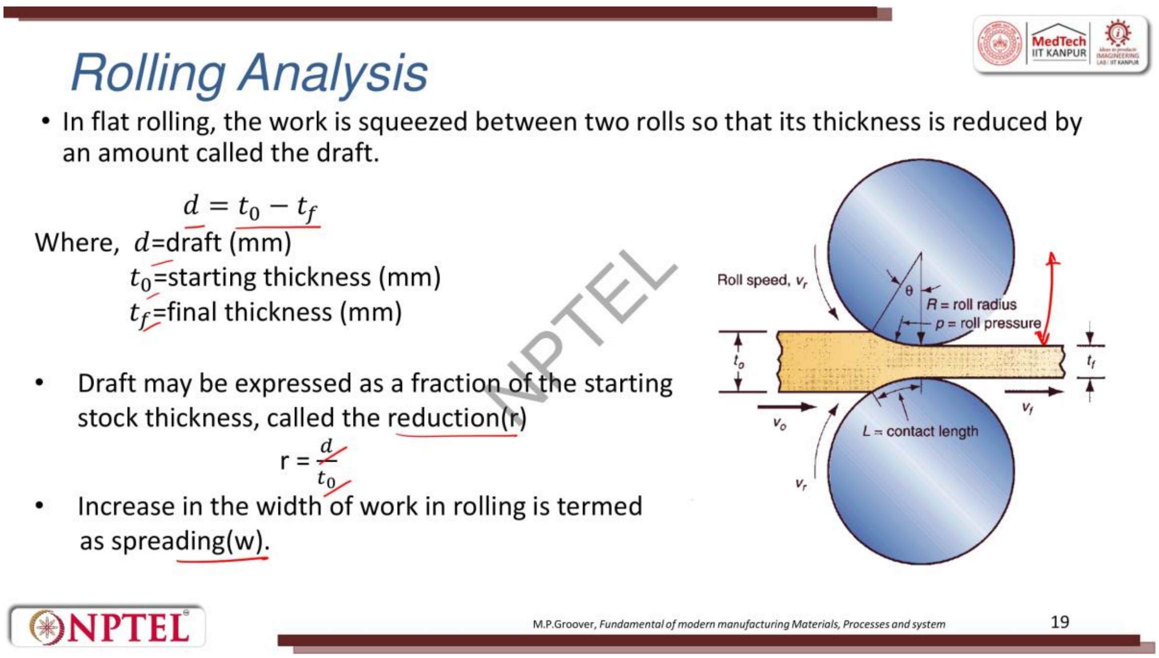
**Tutorial-3 Forming (Part 2 of 2)**

Welcome all to the second part of the tutorial session on metal forming. We are in the course Basics of Mechanical Engineering II, and I am Dr. Amadeep Singh Oberoi, tutorial session on metal forming. We have discussed forming mechanisms, extrusion, and drawing in the previous part of the tutorial. I will discuss in this tutorial the rolling and forging processes, majorly. So, what is rolling?




Let us try to recall the concept. Flat rolling involves rolling of slabs and sheets. Here, you can see the workpiece is given in green color. And the roll is given in gray color. This is the rolling process where the initial velocity or the entrance velocity is V0, and the exit velocity is Vf, which is higher.

So, Vf is always greater than V0 because the volume would stay the same, as per the continuity equilibrium equation that we have been discussing. This is a simple flat rolling. These are known as roll mills.




In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the draft. Draft is $d = t_0 - t_f$ all measured in millimeters.

Draft may be expressed as a fraction of the starting stock thickness. So, there is a term known as reduction r, which is draft per unit of the initial thickness. This is reduction r. The increase in the width of the work in rolling is termed as spreading. That is, the roll is spreading across. That also is w.

## Rolling Analysis

- In rolling, conservation of matter is preserved, so the volume of metal exiting the rolls equals the volume entering:

$$t_0 w_0 L_0 = t_f w_f L_f$$

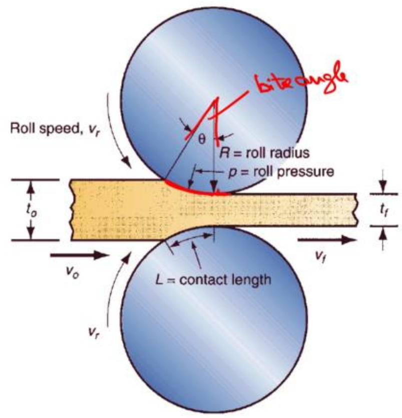
Where,

$w_0$, $L_0$ are starting width and length,

$w_f$, $L_f$ final width and length respectively.

- Also in rolling process before and after volume rates of material flow must be the same, if $v_0$ and $v_f$ are the entering and exiting velocities of the work (m/s), then:

$$t_0 w_0 v_0 = t_f w_f \; v_f$$








So, let me further explain: the volume is always preserved. That is the conservation of matter, as discussed.

That means $t_0 w_0 L_0 = t_f w_f L_f$ meaning the volume stays the same. Where $w_0$ and $L_0$ are the starting width and length, and wf and Lf are the final width and length, respectively. So here, as I mentioned, $V_0$ and Vf are the initial and final velocities.

## Rolling Analysis

- If , θ = arc angle made by roller with work
  R= radius of roller

Also known as the **neutral point, velocity of work** $v_r$ = surface velocity (roll speed in m/s) and,

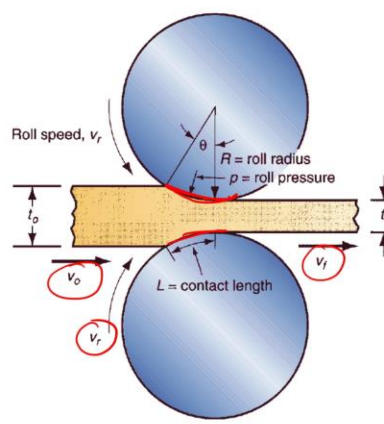
$v_0 < v_r < v_f$

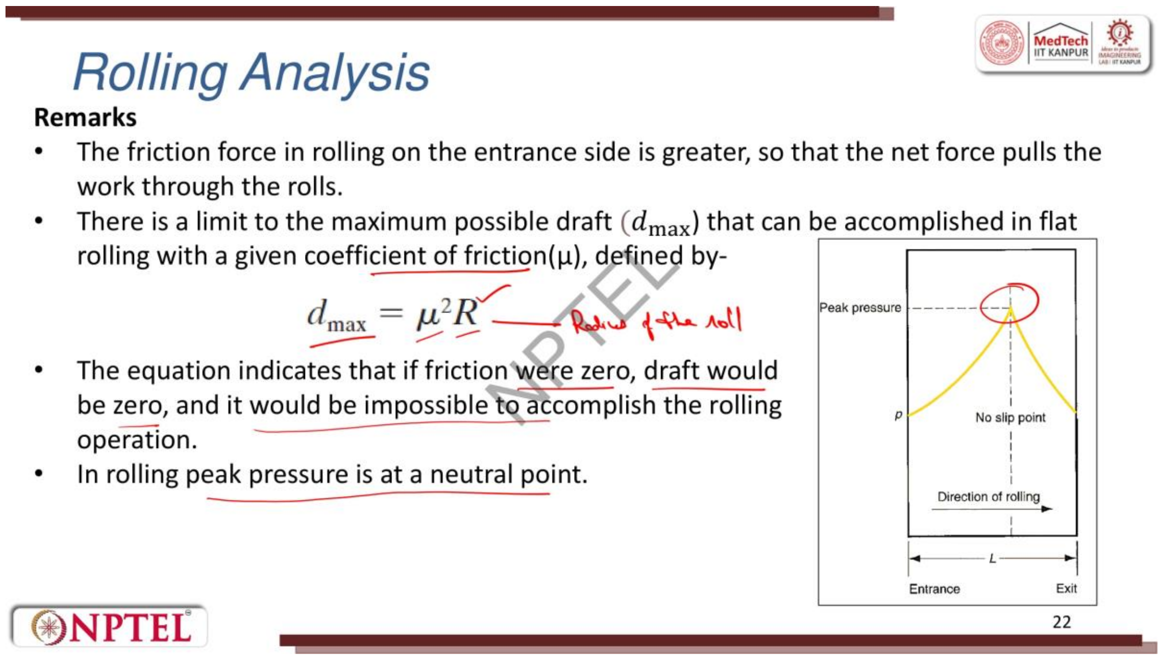
- At the **no-slip point and roller is equal and o**n either side of this point, slipping and friction occur between roll and work.
- The amount of slip between the rolls and the work known as the forward slip(s) is equal to

$$s = \frac{v_f - v_r}{v_r}$$

- The true strain experienced by the work in rolling is

$$\epsilon = \ln \frac{t_o}{t_f}$$

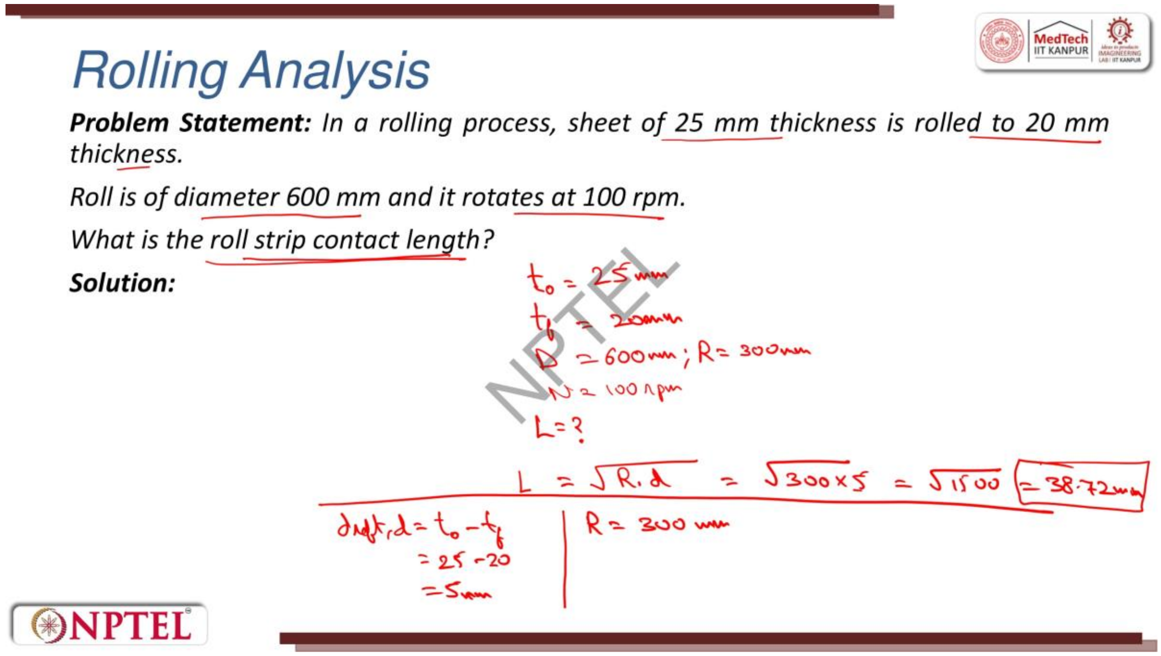





Now, if θ and r are the arc angle made by the roller with the work and the radius of the roller. This is the neutral point where the velocity of work vr (the surface velocity, roll speed in meters per second) is such that $v_0$ is less than vr, which is less than vf. So, we have vr here. This is vr, this is $v_0$, this is vf. The final velocity is higher, as I mentioned.

It is also mentioned that this is the intermediate velocity data surface velocity when the rolling is actually happening here. At the no-slip point, the roller is equal, and on either side of this point, slipping and friction occur between the roll and the work. The amount of slip between the rolls and the work is known as forward slip. That is also given: slip is equal to the difference between the final and the neutral velocity per unit of the neutral velocity. We have true strain, which is given by the log of the ratio of the thicknesses, which are the initial and the final thickness.

Also, there is a maximum possible draft equation, which is equal to nu squared R. Here, nu is the coefficient of friction, and capital R is the radius of the roll. The equation indicates that if friction were 0, draft would be zero, and it would be impossible to accomplish a rolling operation. The rolling peak pressure is at the neutral point. This has already been discussed here.




Let me come to the problem statement. In a rolling process, a sheet of 25-millimeter thickness is rolled to 20-millimeter thickness. We have been given the roll diameter as 600 millimeters. I will put it as n is equal to 100 rotations per minute. What is the roll-strip contact length?

Contact length is a question mark. L contact length is equal to the square root of r multiplied by draft.

t0 = 25 mm

tf = 20 mm

D = 600 mm ; R = 300 mm

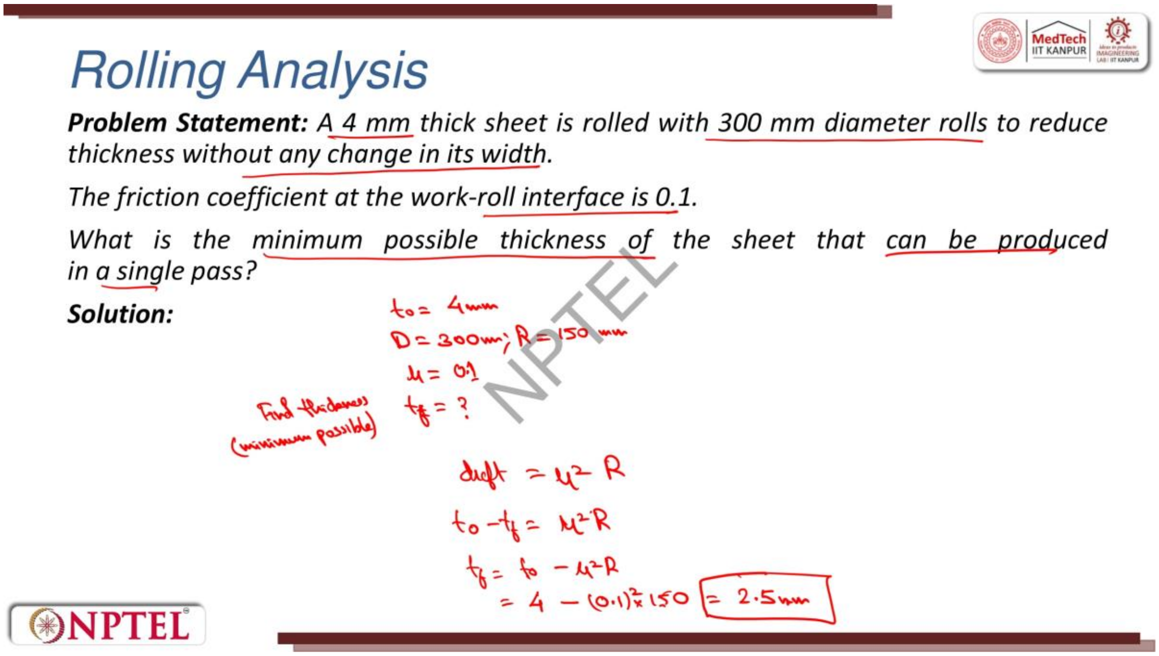
N = 100rpm

L = ?

d = t0 – tf = 25 – 20 = 5 mm

Solution:

L = $\sqrt{R.d}$ = $\sqrt{300 \times 5}$ = $\sqrt{1500}$ = 38.72 mm




Another problem statement says a 4 mm thick sheet is rolled with 300 mm diameter rolls to reduce thickness without any change in its width. The friction coefficient at the work roll interface is 0.1, but the minimum possible thickness of the sheet. That can be produced in a single pass is the minimum possible thickness.

t0 = 4 mm

D = 300 mm ; R = 150 mm

μ = 0.1

tf = ?

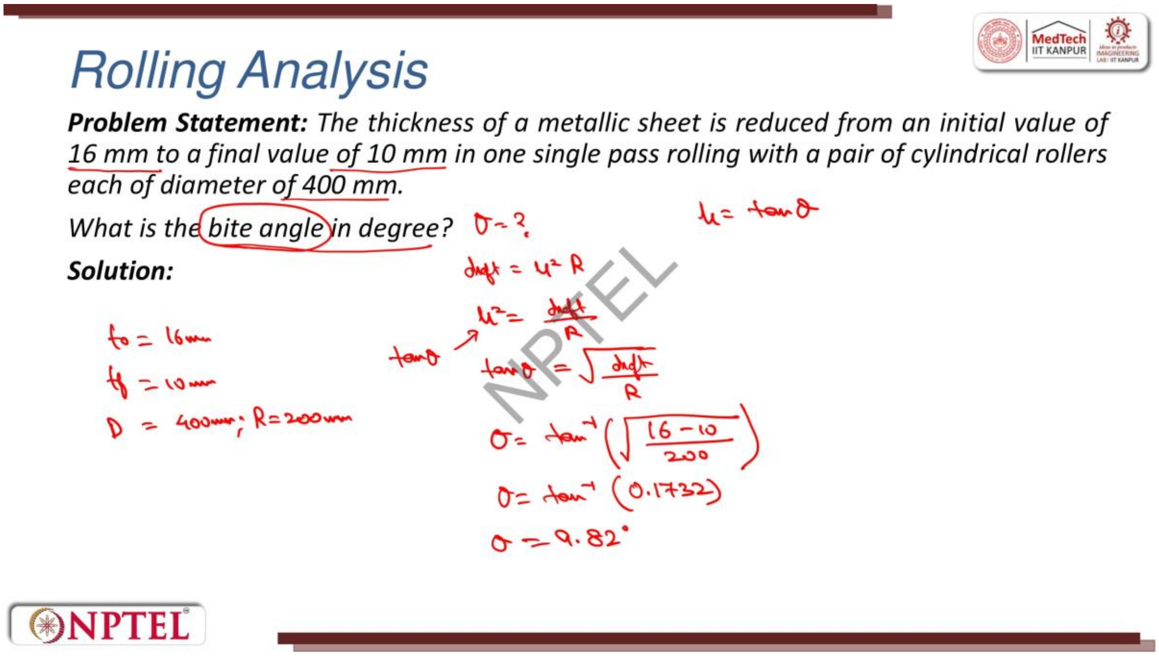
Solution:

draft = $\mu^2 R$

t0 – tf = $\mu^2 R$

tf = t0 - $\mu^2 R$

= 4 – $(0.1)^2$ x 150 = 2.5 mm




Another very quick and small problem that we can try to solve. Here, the thickness of a metallic sheet is reduced from an initial value of 16 millimeters to a final value of 10 millimeters in one single-pass rolling with a pair of cylindrical rollers. Each of diameter 400 millimeters, what is the bite angle in degrees?

$t0 = 16$ mm

$tf = 10$ mm

$D = 400$ mm ; $R = 200$ mm

$\theta = ?$

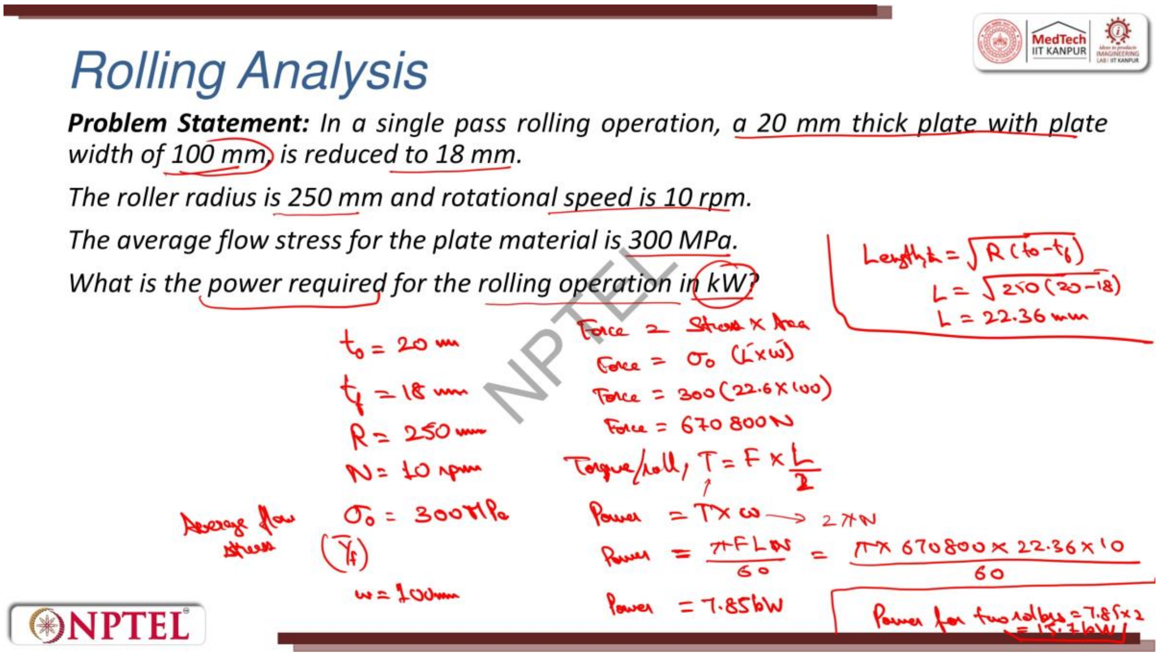
Solution:

$\text{draft} = \mu^2 R$

$\mu^2 = \text{draft}/R$

$\tan\theta = \sqrt{\frac{draft}{R}}$

$\theta = \tan^{-1}\left(\sqrt{\frac{16-10}{200}}\right) = \tan^{-1}(0.1732) = 9.82$ degree




Let me now also take a problem in rolling. Where we will try to determine the power or force that is there in rolling. In this problem, a single-pass rolling operation of a 20 mm thick plate with a plate width of 100 mm is reduced to 18 mm. The roller radius is 250 mm, and the rotational speed is 10 rpm. The average flow stress of the plate material is 300 mega Pascal. What is the power required for the rolling operation in kilowatts?

t0 = 20 mm

tf = 18 mm

R = 250 mm

N = 10 rpm

σo = 300 MPa

W = 100 mm

Solution:

Force = Stress x Area

Force = σo (L x w)

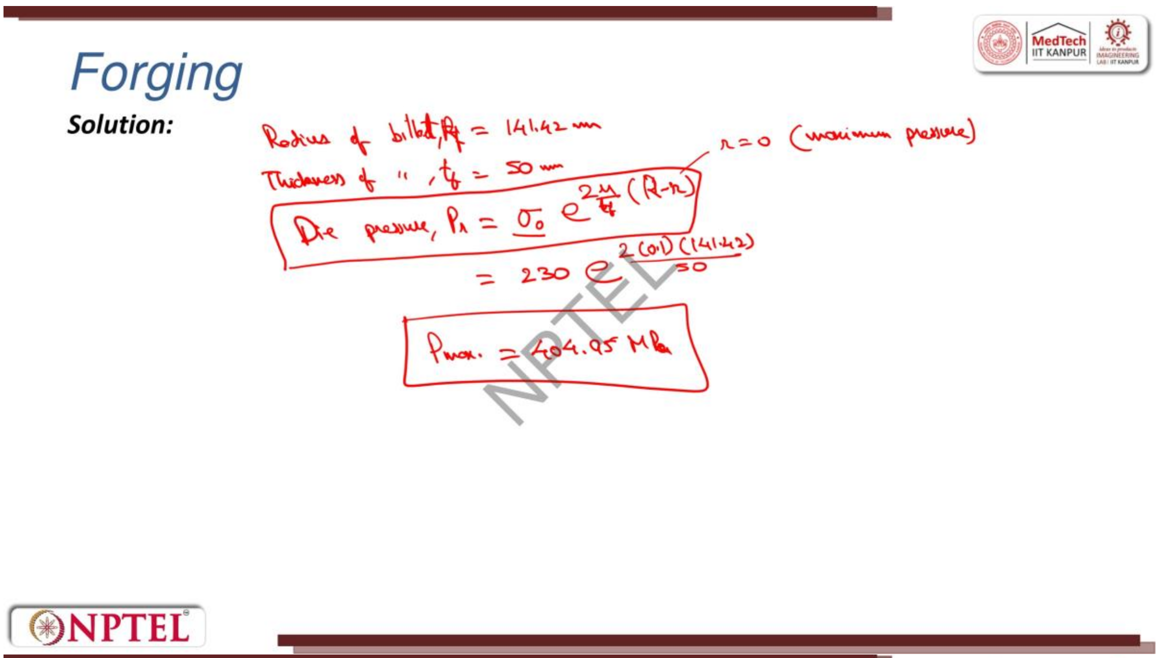
Force = 300 ( 22.6 x 100) = 6708.00 N

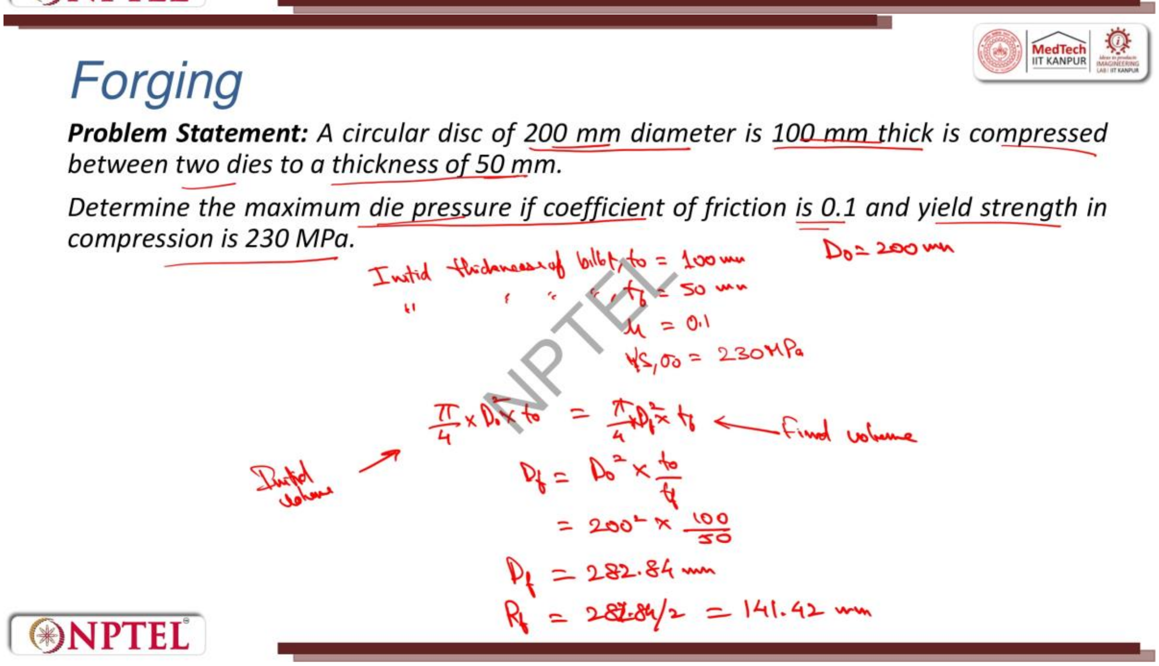
Torque/roll, T = F x L/2 (Length, L = $\sqrt{R(to - tf)} = \sqrt{250(20-18)}$ = 22.36 mm)

Power = T x w (w = 2πN)

Power = $\frac{\pi FLN}{60} = \frac{\pi \times 6708.00 \times 22.36 \times 10}{60} = 7.85\ kW$

Power for 2 rollers = 7.85 x 2 = 15.7 kW



There is a problem that mentions a circular disc of 200-millimeter diameter and 100-millimeter thickness. This is compressed between two dies to a thickness of 50 millimeters. Determine the maximum die pressure if the coefficient of friction is 0.1 and the yield strength in compression is 230 MPa.

t0 = 100 mm

tb = 50 mm

μ = 0.1

σo = 230 MPa

D0 = 200 mm

Solution:

$\pi/4 \times Do^2 \times to = \pi/4 \times Df^2 \times tf$

$Df = Do^2 \times to/tf = 200^2 \times 100/50$

Df = 282.84 mm

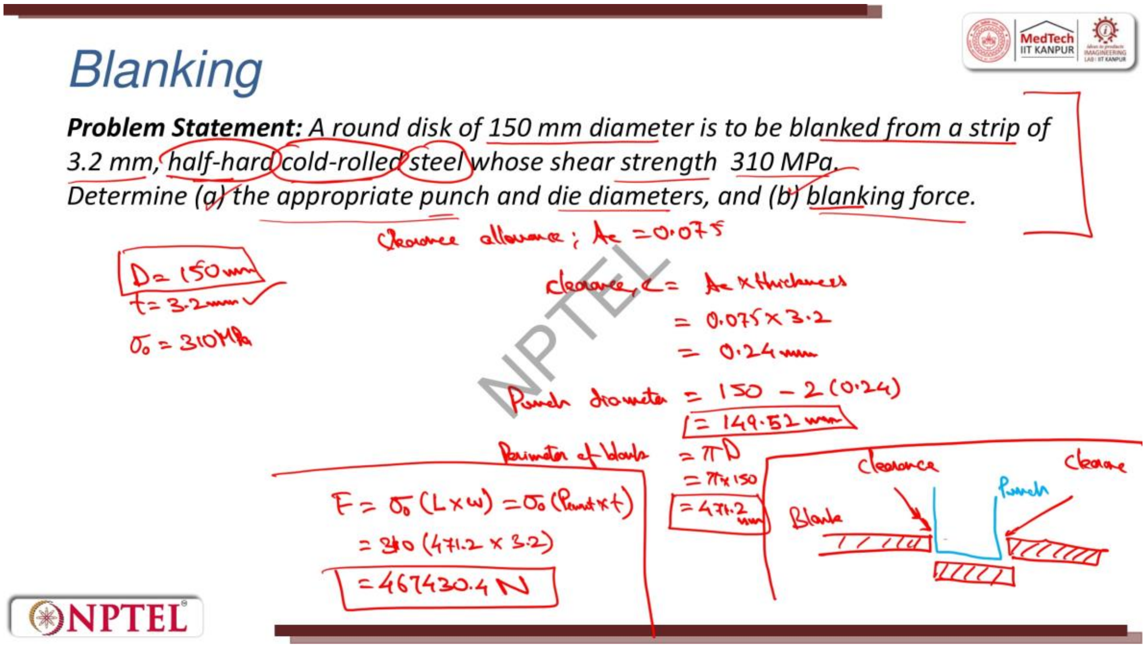
Rf = 282.84/2 = 141.42 mm

tf = 5 mm

Die pressure, Pr = $\sigma o\ e^{\frac{2u}{tf}(R-r)}$ (r = 0)

$= 230\ e^{\frac{2(0.1)(141.42)}{50}}$

Pmax = 404.95 MPa




Now let me see one problem in blanking. A round disc of 150 mm diameter is to blank from a strip of 3.2 mm. Half hard cold rolled steel whose shear strength is given as 310 MPa. We need to determine the appropriate punch and die diameters and blanking force.

D = 150 mm

T = 3.2 mm

$\sigma o$ = 310 MPa

Solution:

Clearance allowance; Ac = 0.075

Clearance, c = Ac x thickness

= 0.075 x 3.2 = 0.24 mm

Punch Diameter = 150 – 2 (0.24) = 149.52 mm

Perimeter of blank = $\pi$D = $\pi$ x 150 = 471.2 mm

F = $\sigma o$ (L x w) = $\sigma o$ (Perimeter x t)

= 310 (471.2 x 3.2)

= 467430.4 N

With this, I am concluding my tutorial session on metal forming. I will meet you in the next lecture, where we will demonstrate the virtual laboratory on metal forming. Thank you.