Design of Machines and Mechanical Systems (PC-BTM711)

Session 21
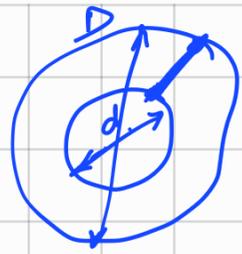
Module 4: Design of Clutches – Further Topics

Session Outcomes

- Obtain torque carrying capacity of single plate clutch

- Design of multi-disk clutches

- Discuss Friction Materials

- Develop energy equation for clutch

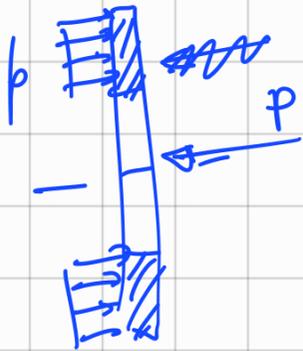- Perform thermal calculations for clutch

$$P = 2\pi \int_{d/2}^{D/2} \boxed{p\, r}\, dr \qquad const = p_a \cdot \frac{d}{2}$$

$$m_t = 2\pi\mu \int_{d/2}^{D/2} p\, r^2\, dr$$

(i) Uniform pressure theory

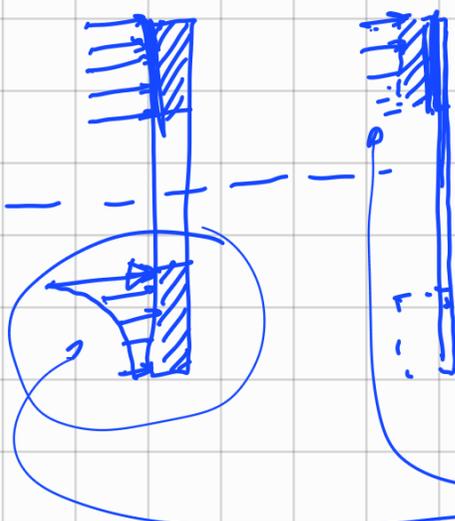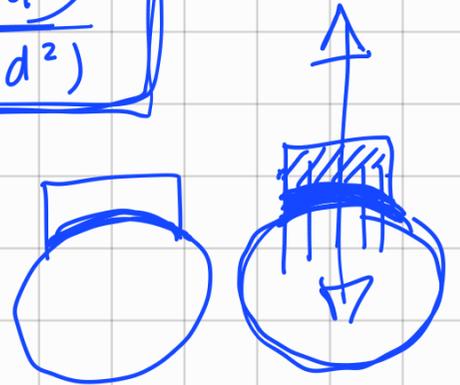New clutches, const. pr. across radius is maintained

$$\boxed{P} = 2\pi p \int_{d/2}^{D/2} r\cdot dr = \boxed{\frac{\pi\, p}{4}\,(D^2 - d^2)}$$

$$\boxed{m_t} = 2\pi\mu p \int_{d/2}^{D/2} r^2\cdot dr = \boxed{\frac{\pi\mu p}{12}\,(D^3 - d^3)}$$

$$\boxed{m_t = \frac{\mu P}{3}\cdot\frac{(D^3 - d^3)}{(D^2 - d^2)}}$$

(ii) Uniform wear theory

wear $\propto$ Heat generated $\rightarrow$ rate of heat gen

wear $\propto p\, v$

wear $\propto p \cdot \left(\frac{2\pi n}{60}\right)\cdot r$

$\boxed{wear} \propto p \cdot r$

$$\boxed{p \cdot r = \boxed{constant}}$$

$$p_{max} = \boxed{p_a}$$

$$p_a \cdot \frac{d}{2} = \boxed{\text{constant}}$$

$$\therefore \boxed{p \cdot r = p_a \cdot \frac{d}{2}}$$

$$\boxed{P} = 2\pi \int_{d/2}^{D/2} p_a \cdot \frac{d}{2} \cdot dr = \boxed{\frac{\pi \, p_a \, d}{2} (D - d)}$$

$$M_t = 2\pi \mu \int_{d/2}^{D/2} \left(p_a \cdot \frac{d}{2} \right) \cdot r \cdot dr$$

$$\boxed{M_t = \frac{\pi \mu \, p_a \, d}{8} (D^2 - d^2)}$$

$$\boxed{M_t = \frac{\mu P}{4} (D + d)} \quad \text{---. Uniform wear theory}$$

Torque Transmitting Capacity

- Uniform Pressure Theory

$$M_t = \frac{\mu P}{3} \frac{(D^3 - d^3)}{(D^2 - d^2)}$$

QUIZ # Uniform Pressure Theory

Uniform pressure theory is applied under which of the following conditions ?

1) New condition

2) After some time in service

Torque Transmitting Capacity
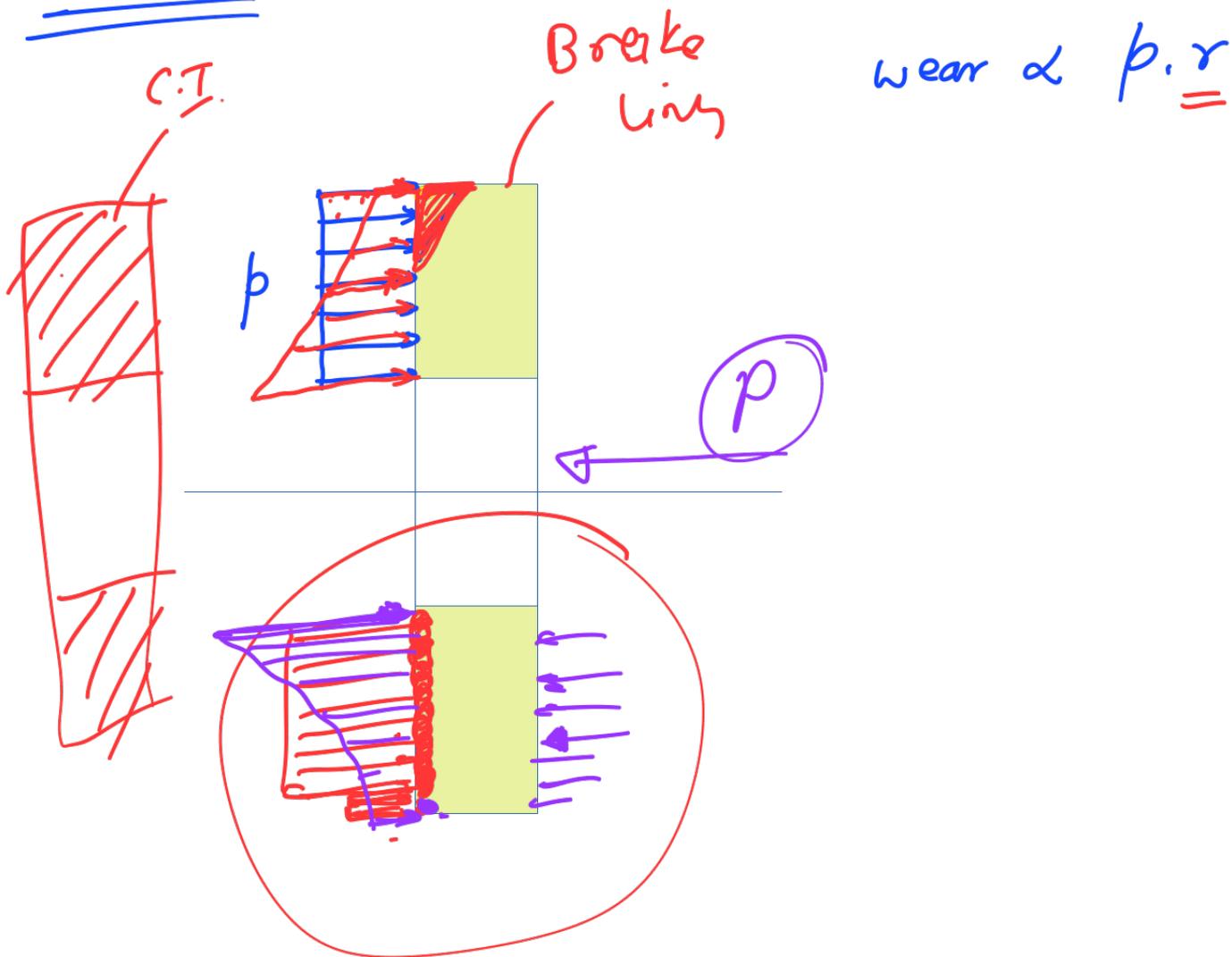
- Uniform Wear Theory

$$M_t = \frac{\mu P}{4}(D + d)$$

Under **uniform wear theory** maximum pressure occurs at which location ?
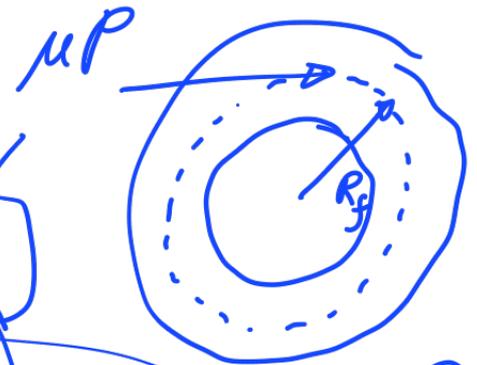
1) Inner radius ✓

2) Outer radius

New & Worn-out States

Friction Radius

Generalized Torque Capacity Equation : $M_t = \mu P R_f$
where R_f is the friction radius

For uniform pressure theory : $R_f = \dfrac{1}{3}\dfrac{(D^3 - d^3)}{(D^2 - d^2)}$

For uniform wear theory : $R_f = \dfrac{1}{4}(D + d) = r_m$

$M_t = \mu P R_f$

$M_t = \dfrac{\mu P}{3}\left(\dfrac{D^3 - d^3}{D^2 - d^3}\right)$

$M_t = \mu P \cdot R_f$

$(R_f)_{UP} > (R_f)_{UW}$

D	d	$\dfrac{1}{3}\dfrac{(D^3 - d^3)}{(D^2 - d^2)}$	$\dfrac{1}{4}(D + d)$
140	80	56.36	55
200	100	77.78	75
200	180	95.088	95

Uniform Pressure or Wear theory?
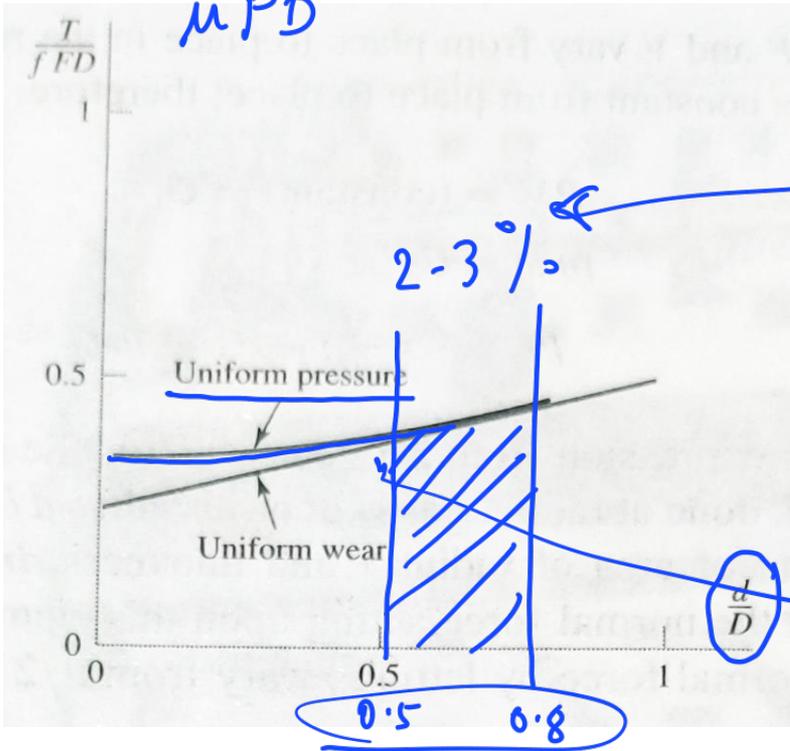
Torque capacity comparison
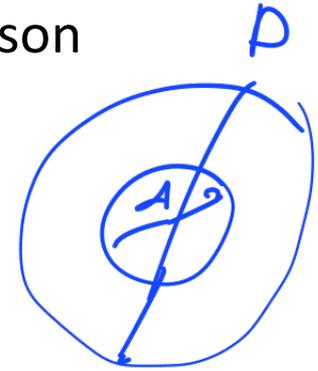
Which theory is conservative?

Uni. Wear

Ref: Shigley, Engineering Machine Design

Service Factor

Table 11.1 *Service factors for clutches (K_s)*

Type of Prime mover	Type of Driven equipment			
	Light steady loads (Starting torque is equal to or slightly greater than running torque)- centrifugal pumps, light-duty fans and blowers, liquid mixers and agitators, centrifugal compressors, gear pumps, textile and wood working machinery	Moderate loads (High starting torque or above average running torque)- machine tools, heavy-duty centrifugal pumps, cooling towers, slurry agitators, boiler feed pumps, hoists and conveyors	Medium load (Starting torque is approximately double running torque) - dredge pumps, light-duty hammermills, lineshafts, paper converting machinery, rotary kilns, rotary or screw-type pumps for high viscosity fluids	Heavy duty loads (High starting torque, shock loading, light torque reversals during drive)- mine ventilating fans, reciprocating pumps or compressors, Paper making machinery, heavy-duty hammermills, ore crushers, pulverising mills
Steam and gas turbines	1.00	1.25	1.50	1.75
AC electric motors	1.25	1.50	1.50	1.75
DC electric motors, hydraulic motors	1.25	1.50	1.75	2.00
Spark ignition engines (Petrol, natural gas or propane)	1.75	1.75	2.00	(*)
Compression ignition engines (Diesel)	2.00	2.50	2.75	(*)

(*) To be consulted with manufacturers

Note: $(M_t)_{des} = K_s (M_t)$
where K_s = service factor
        $(M_t)_{des}$ = torque capacity of clutch for design purpose
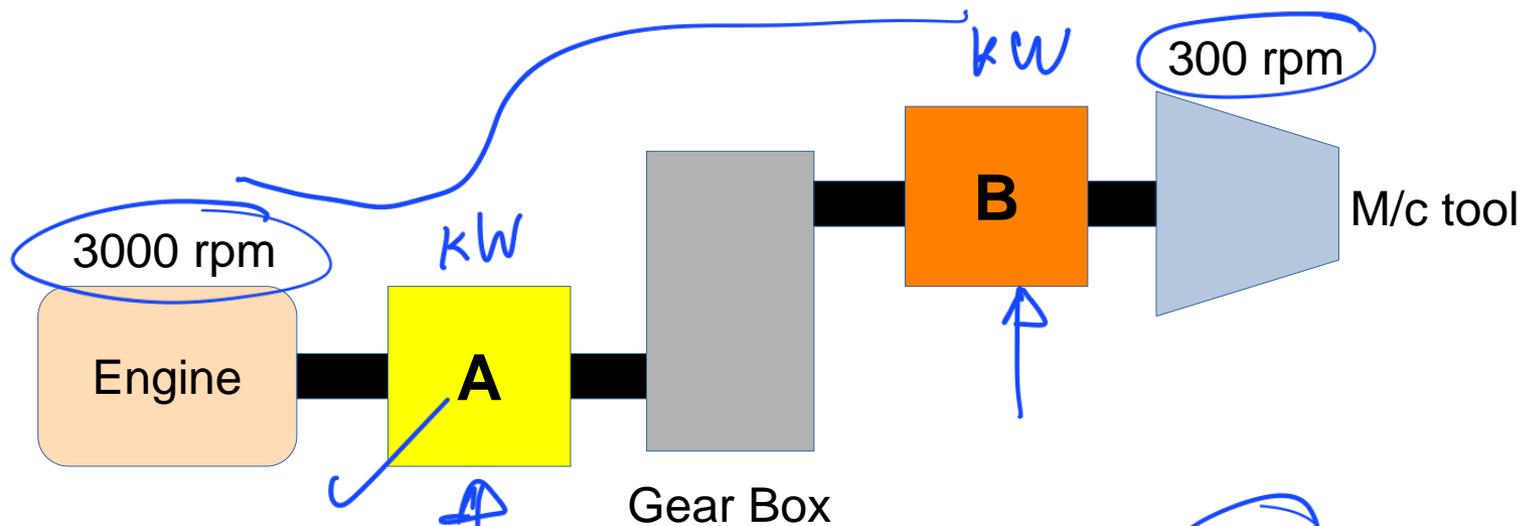 (M_t) = rated torque

0

Location of Clutch

## What should be the location of clutch in following power transmission system ?

300 rpm

kW

3000 rpm

kW

Engine

A

Gear Box

B

M/c tool

1) A

2) B

$m_t \downarrow$

High rpm

$kW = M_t \cdot \omega$

Example 1: Single Plate Clutch

A plate clutch consists of one pair of contacting surfaces and transmits 10 kW power at 1000 rpm. The ratio of outer diameter to inner diameter is 2.5. The coefficient of friction is 0.3 and the permissible intensity of pressure is 1.5 MPa. Calculate the inner and outer diameters using

- Uniform wear theory
- Uniform pressure theory
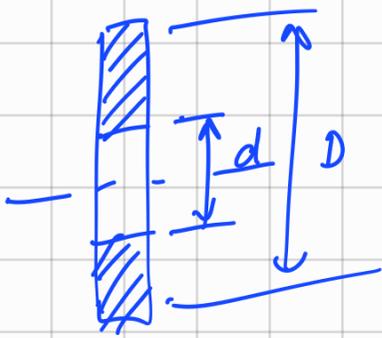
$$kW = 10$$
$$n = 1000 \ rpm$$
$$\mu = 0.3$$
$$P_a = 1.5 \ MPa$$

(i) **Uniform wear theory**

$$M_t = \frac{10 \times 10^6}{\left(\frac{2\pi \times 1000}{60}\right)} = \boxed{95,492.97 \ N \cdot mm}$$

$$M_t = \frac{\pi \mu \, P_a \cdot d}{8} (D^2 - d^2)$$

$$\therefore \ 95492.97 = \frac{\pi \times 0.3 \times 1.5 \times d}{8} \left[(2.5d)^2 - d^2\right]$$

$$= 0.9278 \ d^3$$

$$\boxed{\begin{array}{l} d = 46.9 \ mm \\ D = 117.25 \ mm \end{array}}$$ Uniform wear theory

(ii) **Uniform pressure theory**

$$M_t = \frac{\pi \mu P_a}{12} (D^3 - d^3)$$

$$95,492.97 = \frac{\pi \times 0.3 \times 1.5}{12} \left[(2.5d)^3 - d^3\right]$$

$$= 1.72297 \ d^3$$

$$\boxed{\begin{array}{l} d = 38.13 \ mm \\ D = 95.3 \ mm \end{array}}$$ U.P.

Friction Materials

- Desirable properties of friction lining
    - High coefficient of friction
    - Temperature stability of friction coefficient
    - Good thermal conductivity
    - Good resistance to abrasive wear and aggressive environment
- Types of friction lining
    - Fiber base (metal or semi-metallic, asbestos is banned being carcinogenic)
        - Woven
        - Moulded
    - Sintered
        - Bronze base
        - Iron base