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2.72 Elements of Mechanical Design
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2.72
Elements of Mechanical Design

Lecture 18: Friction-based elements

Reading and plans

Reading:

- 14.1 – 14.7
- 16.2, 16.6, 16.9

Today:

- Friction-based elements

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Friction-based machine elements

Purpose:

- Bring two bodies to same relative speed
- Friction forces do the work
- Force/Torque and Mass/Inertia are in play

Used in many types of ubiquitous machines

- Drum brakes
- Disk brakes
- Clutches
- etc…

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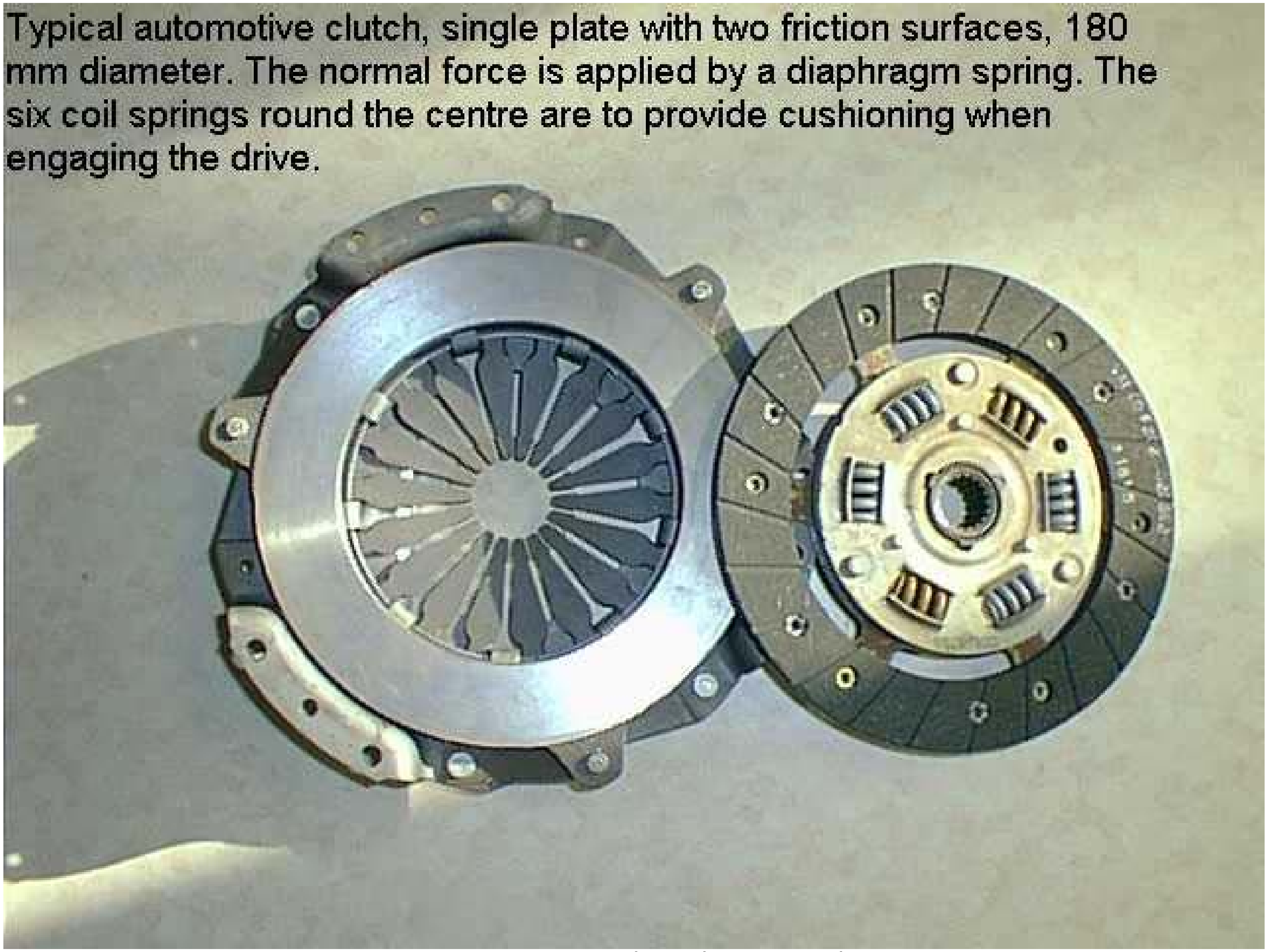
Clutches



www.tech.plymouth.ac.uk/sme/desnotes/clutlabe.jpg

Courtesy of David Grieve. Used with permission.

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Drum brakes

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http://www.carbibles.com/images/drum-double.jpg

http://peugeot.mainspot.net/glossary/14_drum_brake_assembly.jpg

Can you imagine how much fun it is to put this together…

What would be problematic?

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Disk brakes

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What are the holes for?

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Perspective on heat, back of the envelope

Assume you need to stop a 2 ton truck: 65 to 0 mph; how much energy must be dissipated as heat/sound?

Assuming that this happens so fast that the steel components of the brake absorb the heat (assume little energy goes into sound/vibration) before it is taken away by convection or conduction… what max magnitude of ΔT are we looking at? (e.g. worst case)

Really need modeling software to do this properly but rough analysis is enlightening…

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Types of actuation

Pneumatic/hydraulic (e.g. pistons)

- High force (hydraulic)
- Inexpensive (pneumatic)
- Maintenance (hardware/leaks & fluid)

Magnetic (e.g. solenoids)

- Low maintenance
- Fast reaction time
- Ease of control

Mechanical (e.g. lever)

- Moderate force
- Moderate maintenance

The best thing to do is to make a matrix of FRs and DPs and then select from that. Vendors are usually very helpful in filling out the matrix.

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Many variations…

Purpose is to cover general fundamentals so you can extend to specific cases

Issues in play

Materials

Physics

Friction-based machines

Issues of concern in engineering of these devices:

- Force Torque Energy loss ΔTemperature

Practical design/performance criteria:

- Torque Friction Wear/longevity

Failure criteria:

- Maximum temperature Maximum pressure

There is no cook book formula, you must KNOW the application and then prioritize what is important.

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Assumptions

Pressure:

- Distribution, typically assume simple shapes for first order
- Relationship to deformation is linear
- Contact area vs. actuation area -> rigidity

Relative rigidity of:

- Friction material　　Backing material　　Opposed surface

Independence of:

- Material properties as function of temperature
- Pressure and deformation of friction material
- Coefficient of friction & pressure
- Coefficient of friction & deformation of friction material

Sometimes the vendor or OEM will have the info you need, usually geek engineers have it.

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Materials

Desire:

- High friction
- Constant friction
- Inert
- Wear resistance
- Flexibility

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http://www.aa1car.com/library/brake_pads.jpg

http://www.aa1car.com/library/brake_dust.jpg

http://www.mooseutilities.com/showImage.jsp?class_id=499&image_type=fullsize&rank=100

Sintered metal

- f ~ 0.30 (dry)
- Pmax ~ 500 psi
- Tmax ~ 930 F

Asbestos composites

- f ~ 0.35 (dry)
- Pmax ~ 700 psi
- Tmax ~ 800ish F

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Servicing brakes

If you are interested, you can walk through a brake repair at:

http://www.diy-brake-repair.com/how-to-change-brake-pads.html

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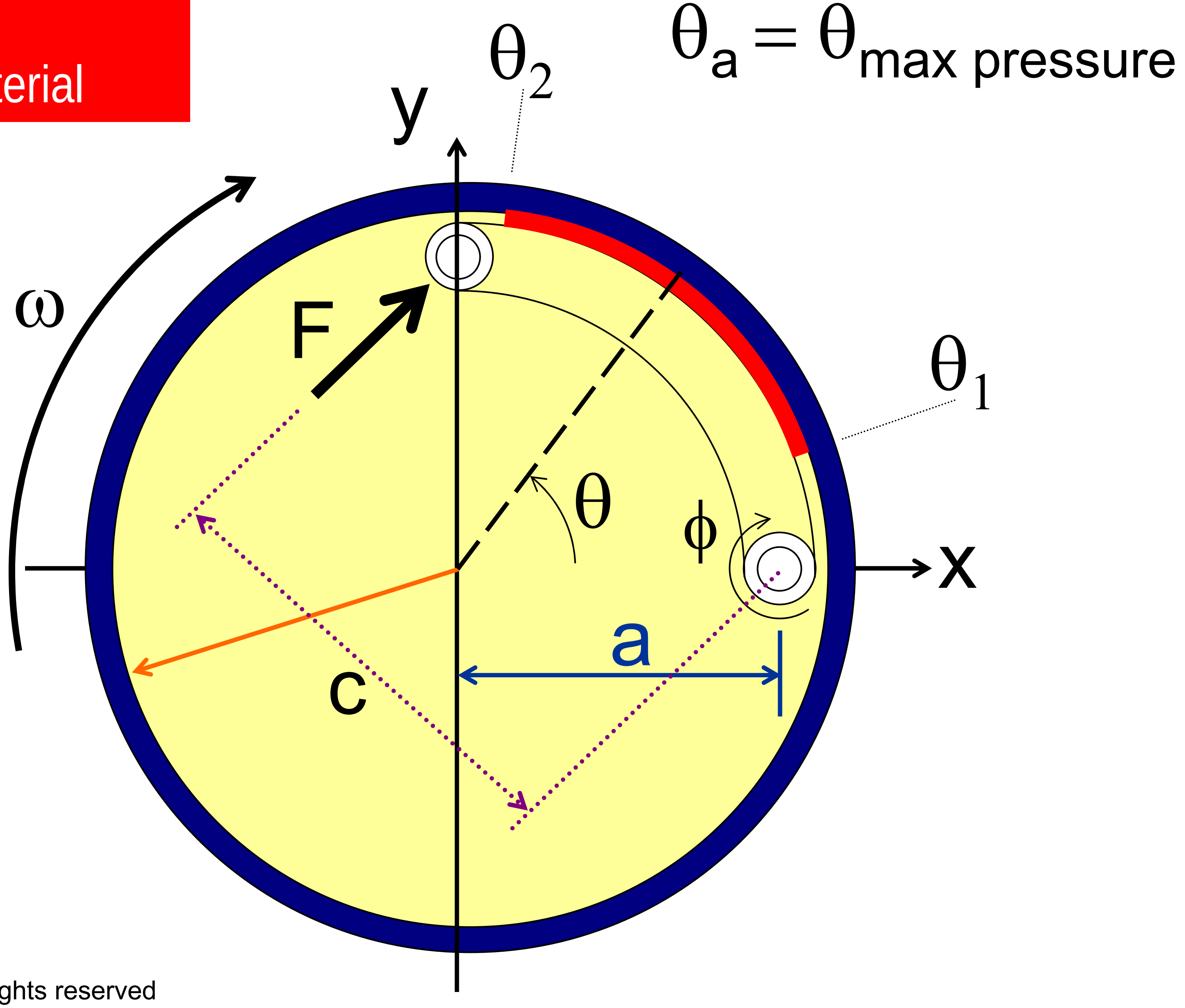
Drum-based Friction Elements

Basic model of inner drum brake

Red = friction material



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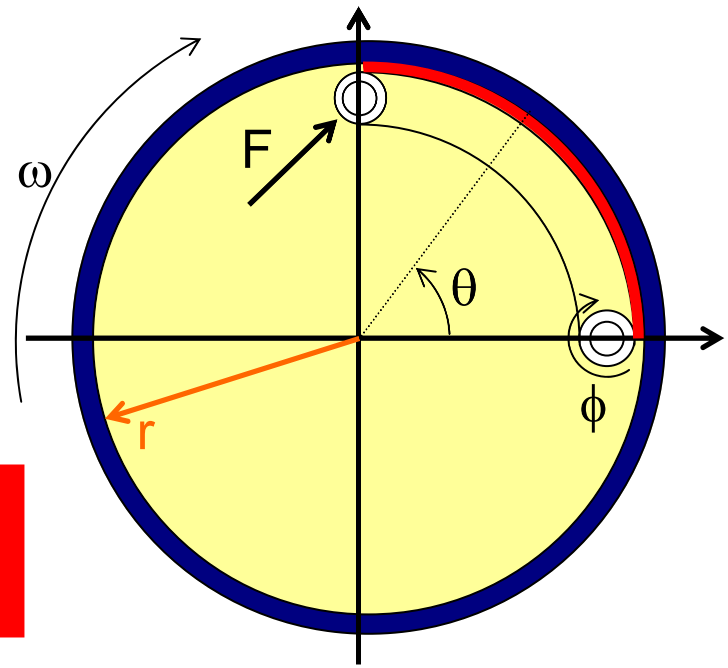
Pressure distribution

If we assume:

- Shoe and drum rigid relative to material
- p ~ Compression
- *f* ≠ Temperature or compression

Red = friction material



Then when pad rotates by Δϕ, pad:

$$Compression(\theta) = r\,(\Delta\phi)\sin(\theta)$$

Can prove this via math (Shigley) but observation works

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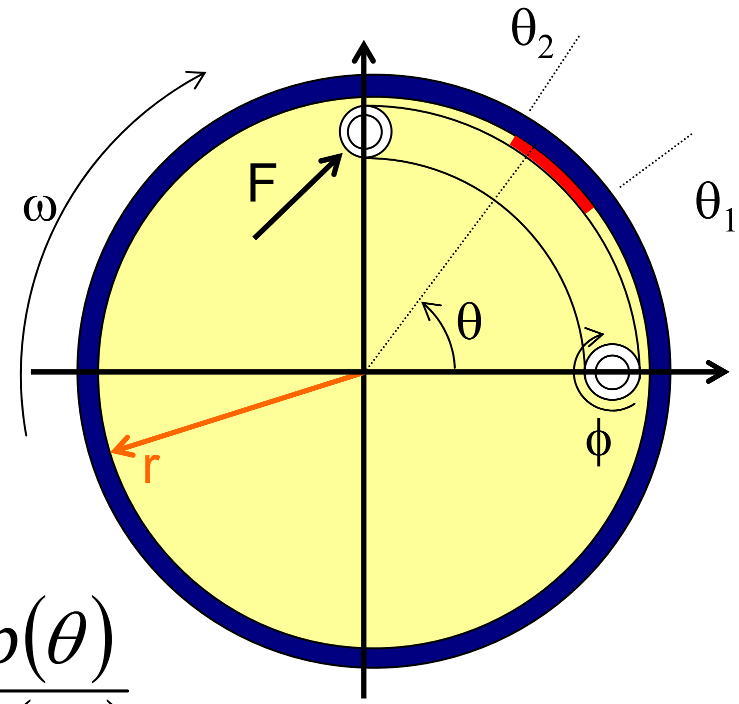
Pressure distribution

So if…

$$Compression(\theta) = r\,(\Delta\phi)\sin(\theta)$$



Then…

$$\frac{Compression(\theta)}{Compression(\theta_a)} = \frac{r\,(\Delta\phi)\sin(\theta)}{r\,(\Delta\phi)\sin(\theta_a)} = \frac{p(\theta)}{p(\theta_a)}$$

And….

$$\frac{p(\theta)}{\sin(\theta)} = \frac{p_a}{\sin(\theta_a)}$$

This is ultra-useful as we need to know the pressure profile in order to integrate and find moment/torque

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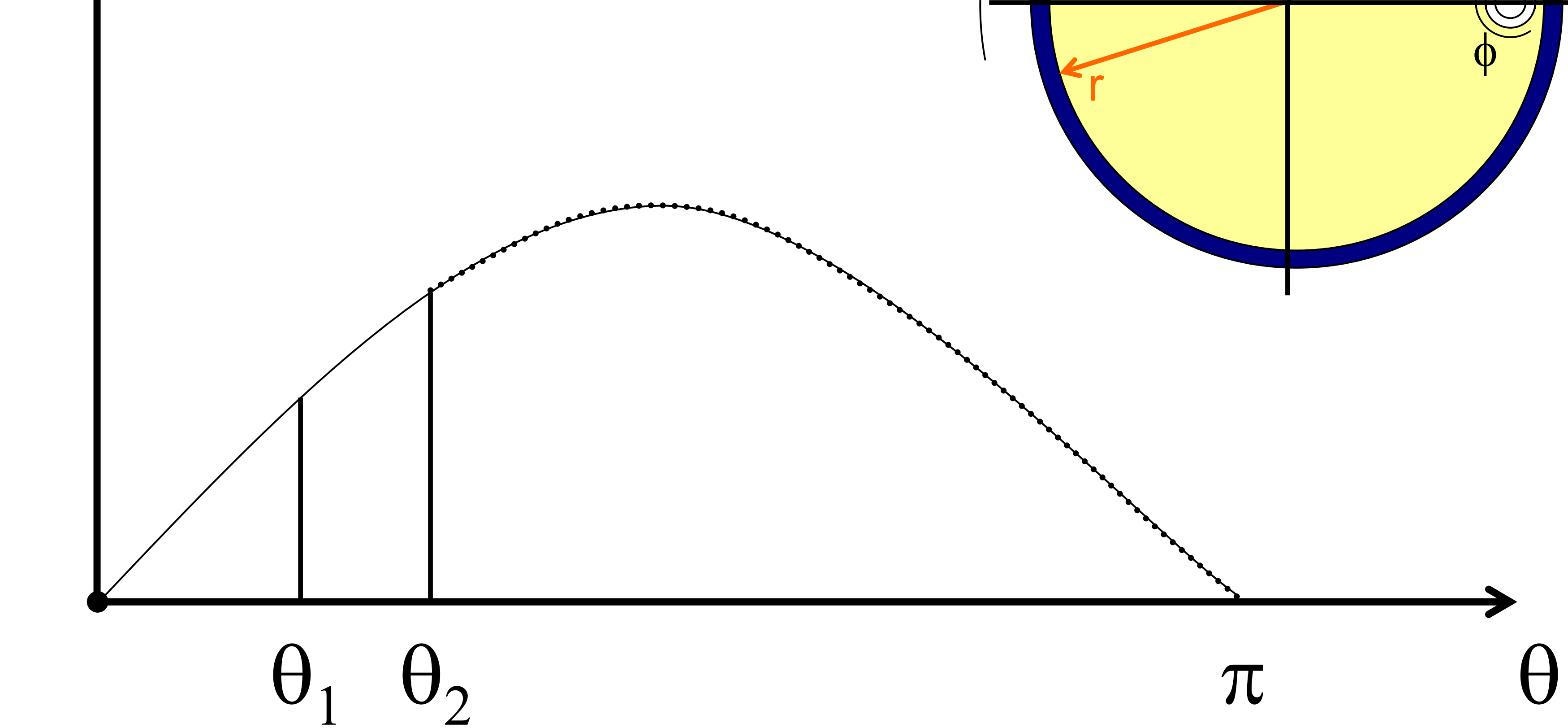
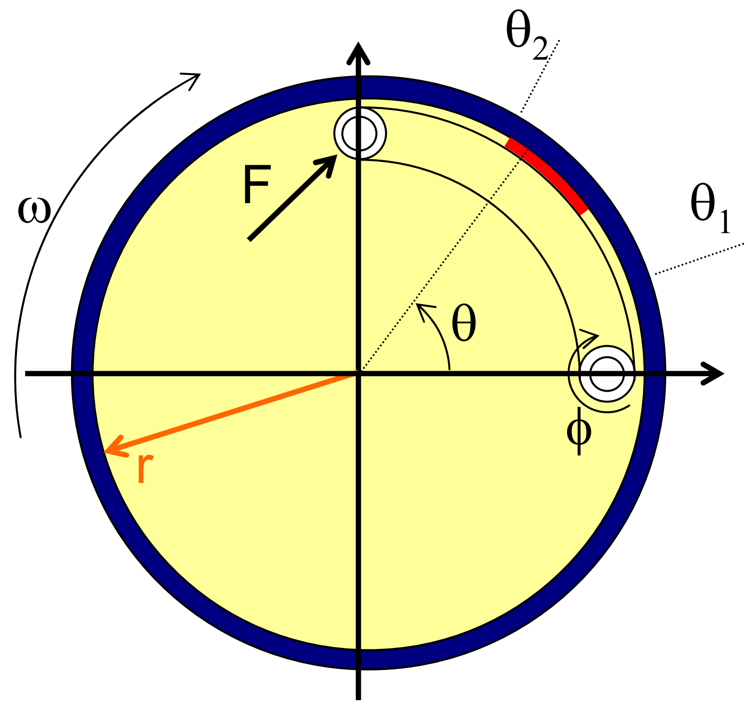
For small included angle

$$\frac{p(\theta)}{\sin(\theta)} = \frac{p_a}{\sin(\theta_a)}$$





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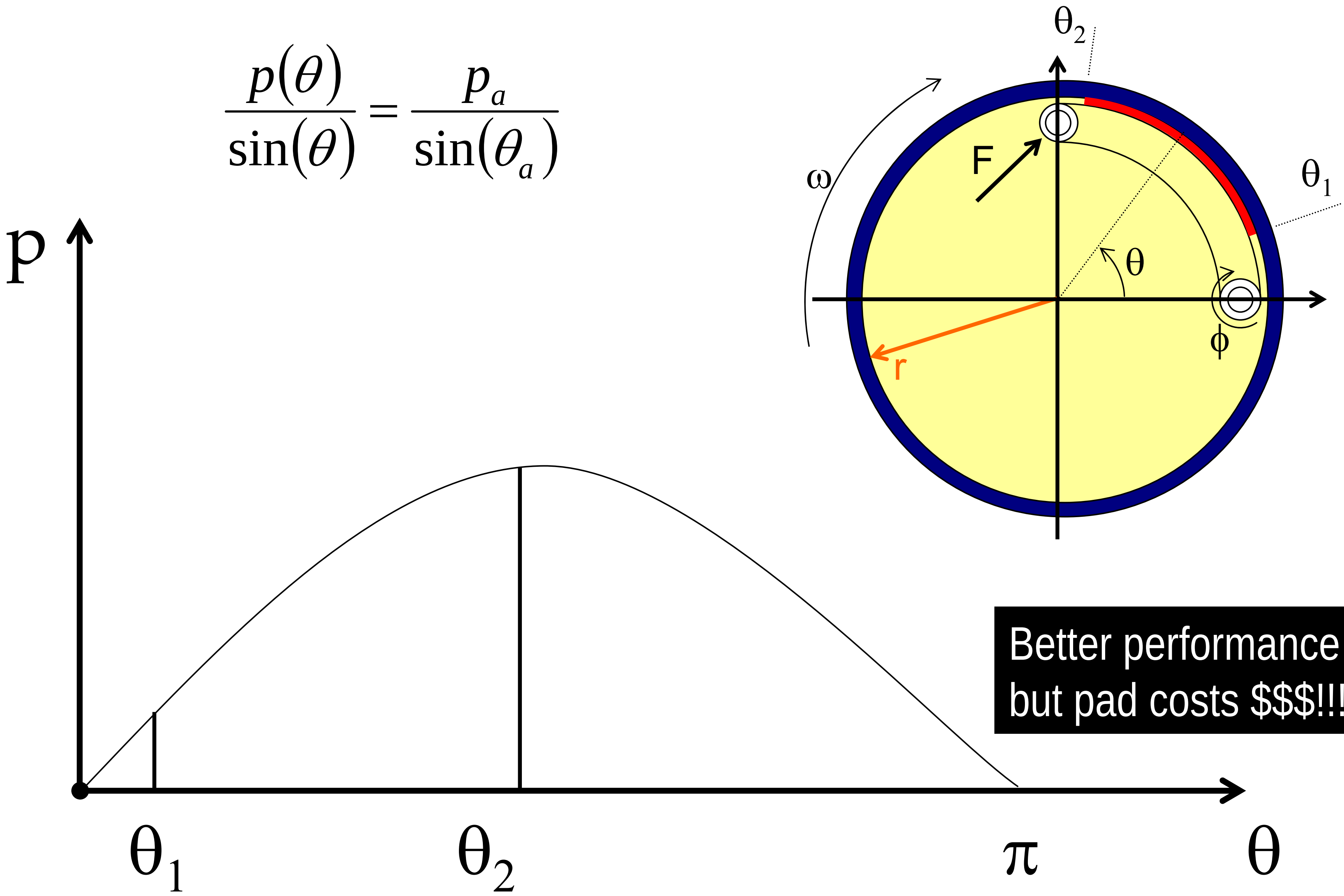
For large included angle

$$\frac{p(\theta)}{\sin(\theta)} = \frac{p_a}{\sin(\theta_a)}$$



Better performance
but pad costs $$$!!!

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Where to put brake material?

Best bang for the buck!

Where to put the brake material

Cost metric?

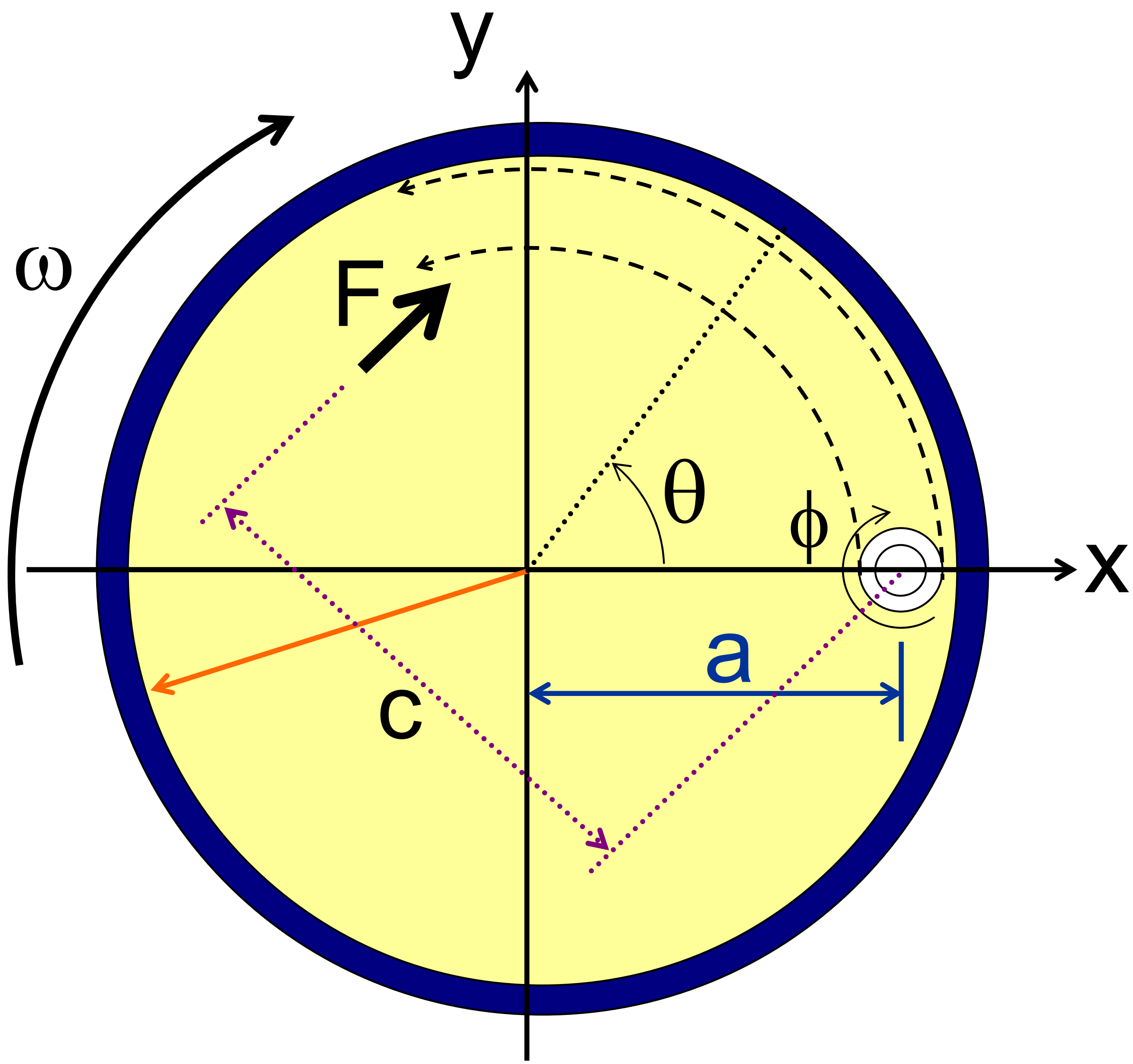
- Torque/$

Envelope metric

- Torque/V

Max T metric

- $Torque_{max}$



Why not just get a “KA” actuator?

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Modeling Behavior

Drum-type example

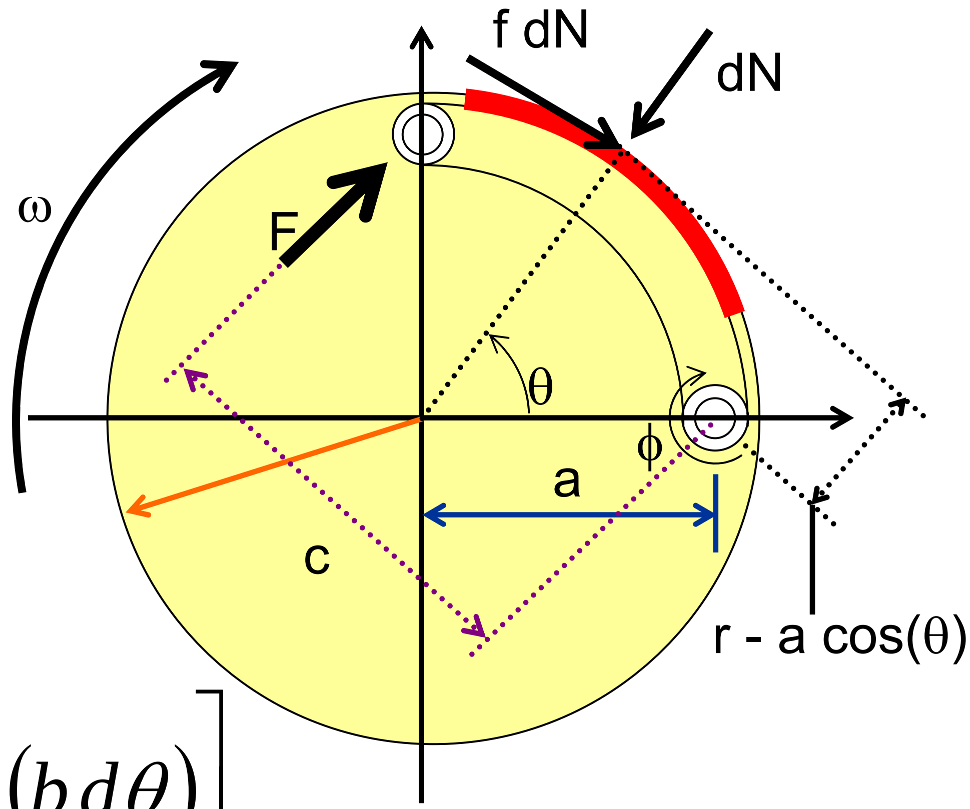
Total torque applied to DRUM

$$T = \int f\ r\ dN$$

$$T = \int f\ r\ [p\ (b\ r\ d\theta)]$$

$$T = \int_{\theta 1}^{\theta 2} f\ r^2 \left[\frac{p_a}{\sin(\theta_a)} \sin(\theta)\,(b\, d\theta) \right]$$

$$T = f\ b\ r^2 p_a \frac{\cos(\theta_1) - \cos(\theta_2)}{\sin(\theta_a)}$$



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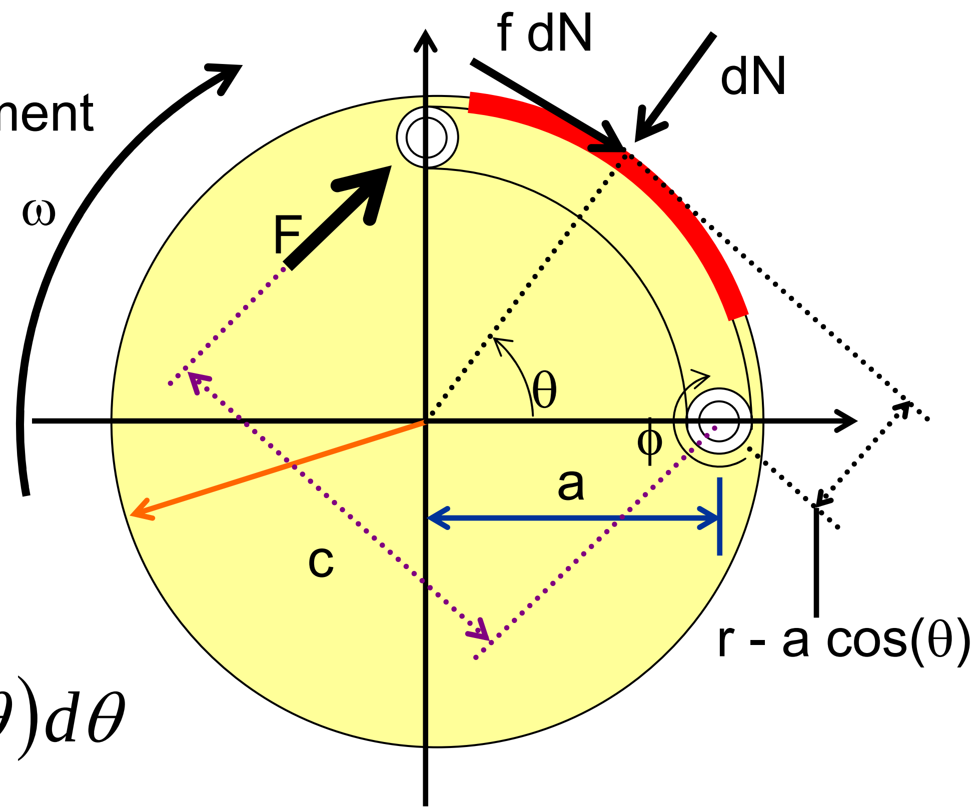
Might it be self energizing? Look at the SHOE

Two moment components

- Shigley switches: Torque to Moment



From normal load

$$M_N = b\ r\ a \frac{p_a}{\sin(\theta_a)} \int_{\theta_1}^{\theta_2} \sin^2(\theta) d\theta$$

When will the friction torque pull the show into the drum?

From friction load

$$M_f = f\ b\ r \frac{p_a}{\sin(\theta_a)} \int_{\theta_1}^{\theta_2} \sin(\theta)(r - a\cos(\theta)) d\theta$$

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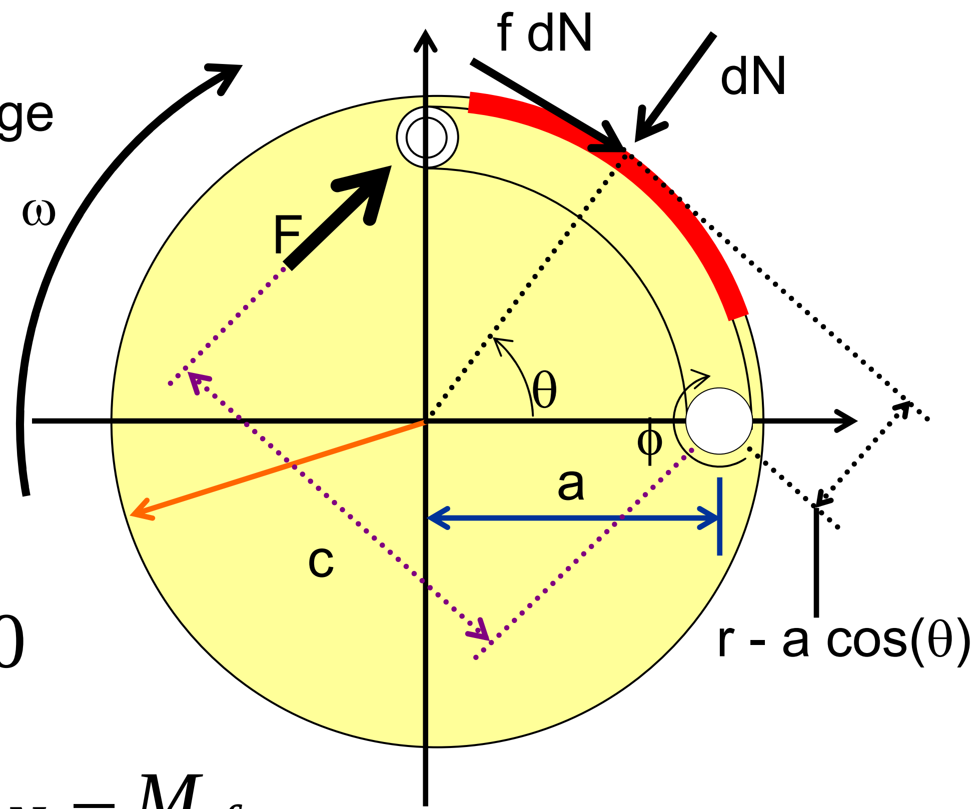
So it can be self energizing if…

What do we mean?

- Rotation + geometry = self-engage
- Trick = geometry condition
- How to go about this?



Moments on the shoe

$$\Sigma M = -F\ c - M_f + M_N = 0$$

$$F\ c = M_N - M_f \rightarrow F = \frac{M_N - M_f}{c}$$

You can change geometry to avoid or leverage this…

$$a = ? \qquad\qquad c = ?$$

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Wear

Modeling and estimating wear

Sliding force:

$$F_s = \; f \; p \; A$$

Work by sliding force over displacement "S"

$$W_s = \; (f \;\; p \;\; A) \; (S) = (f \;\; p \;\; A) \; (v \;\; t)$$

Material volume removed ~ work

- w = wear in linear units

$$w \;\; A = \; K \; p \;\; A \,(v \;\; t) \rightarrow w = \; K \; p (v \;\; t)$$

Analogous to material removal rate in metal cutting

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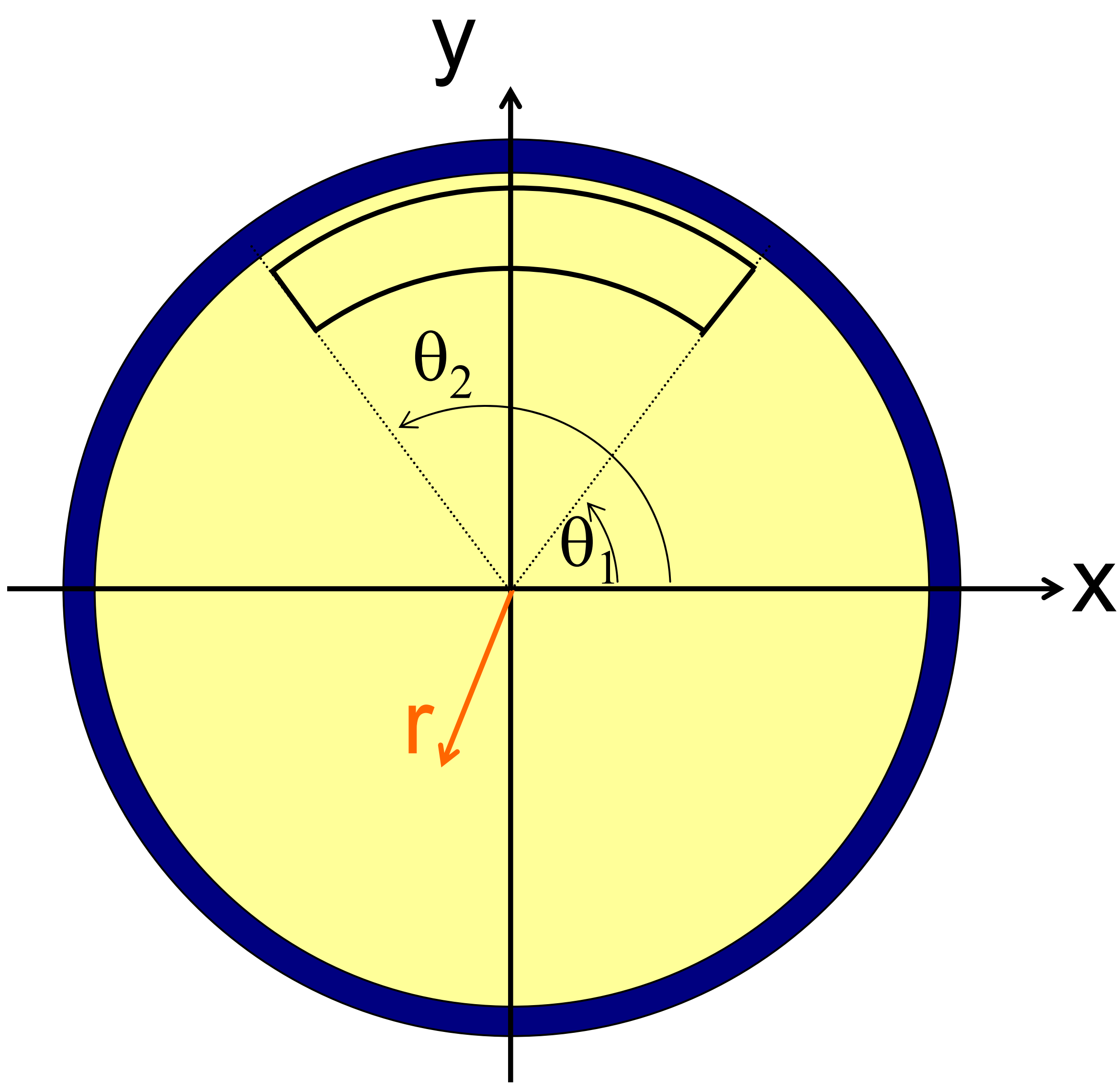
Exercise

disc-type

brakes and clutches

Basic model of disc clutch/break



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Uniform wear vs. uniform pressure

Why

- Uniform wear → p v = constant? → Longevity

$$p(\omega\, r) = p_a(\omega_a r_a)$$

- Uniform pressure? → Performance

$$p = p_a$$

Calculating torque/moment, general form:

$$T = \int_{\theta 1}^{\theta 2} \int_{ri}^{ro} f \;\; r \;\, dN$$

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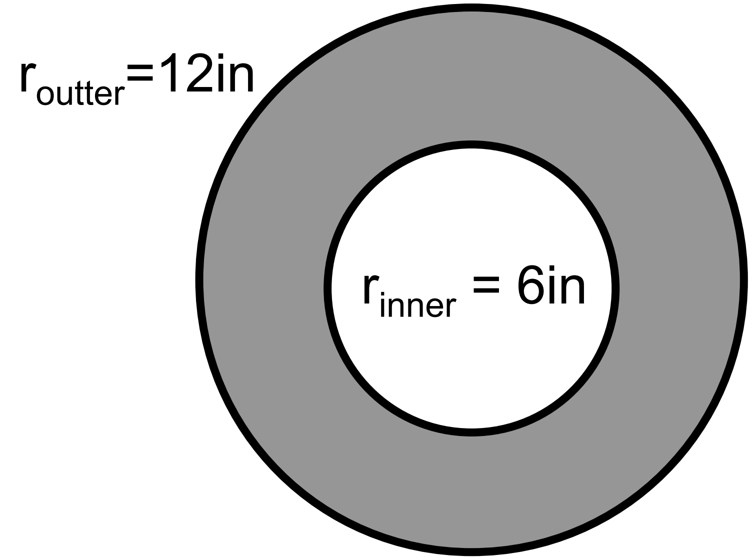
Activity: Disc clutch

Bossman hears about "new" constant wear brake technology and asks you for a "back of the envelope" engineering assessment of clutch performance for:

- (a) constant pressure and;
- (b) constant wear.



You must explain the pros/cons and relay the implications of making this design change via qualitative & quantitative means. What do you tell him? Ratios and analogy might be helpful here…

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