16. Clutches and Brakes

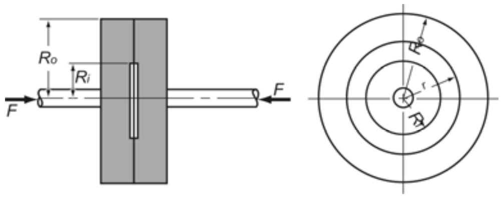
Objectives

- Recognize the basic geometries of clutch and brake systems.
- Calculate the frictional forces and torque capabilities in brake systems.
- Understand the principles of heat generation and heat removal from brake systems.
- Calculate frictional brake horsepower and recognize how to use it.

Introduction

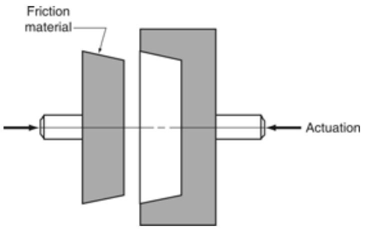
- Clutch is a device that connects and disconnects two collinear shafts.
  - Similar to couplings
  - Friction and hence heat dissipation
- Purpose of a brake is to stop the rotation of a shaft.
- Braking action is produced by friction as a stationary part bears on a moving part.
  - Heat dissipation is a problem
  - Brake fade during continuous application of braking due to heat generated

Plate clutch



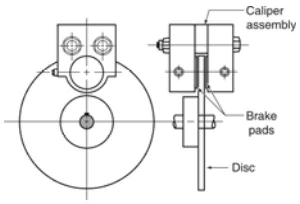
- Uses Spring loaded flat surfaces
- Transmit power in either direction

Cone clutch

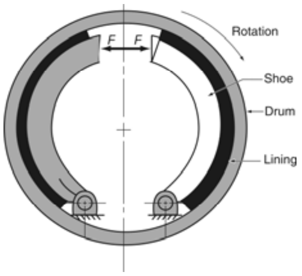


- Uses tapered friction surfaces
- Easy to engage

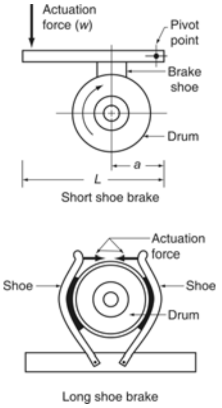
Caliper disc brake



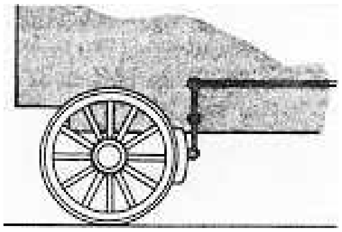
Drum brake



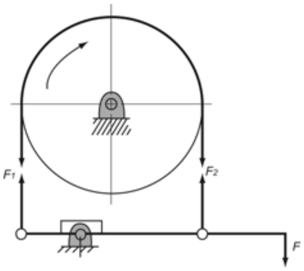
Drum brake



Block brake – Wagon brake

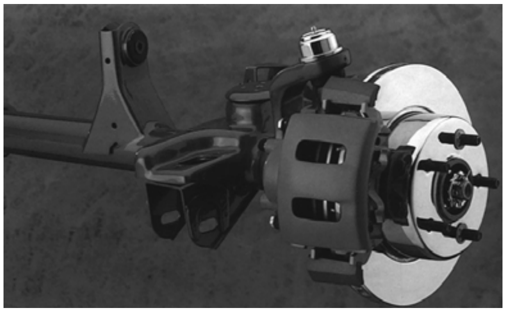


Band brake



- Belt wrapped around the wheel

Fig. 16-7 Disc brake



Friction Materials

- Asbestos fibers embedded in an epoxy-type material
  - Good thermal properties
  - High friction coefficient (0.35 to 0.50)
  - Environmental concerns
- Polymer compounds with impregnated material
  - Metal shavings
  - Graphite
  - Sintered iron

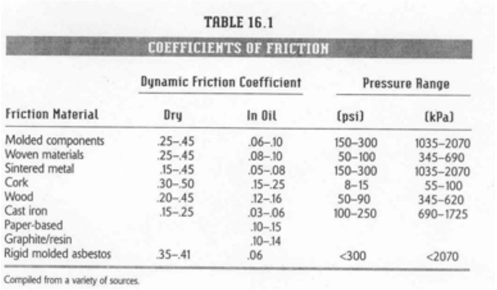


TABLE 16.1

COEFFICIENTS OF FRICTION

	Dynamic Friction Coefficient		Pressure Range	
Friction Material	Dry	In Oil	(psi)	(kPa)
Molded components	.25–.45	.06–.10	150–300	1035–2070
Woven materials	.25–.45	.08–.10	50–100	345–690
Sintered metal	.15–.45	.05–.08	150–300	1035–2070
Cork	.30–.50	.15–.25	8–15	55–100
Wood	.20–.45	.12–.16	50–90	345–620
Cast iron	.15–.25	.03–.06	100–250	690–1725
Paper-based		.10–.15		
Graphite/resin		.10–.14		
Rigid molded asbestos	.35–.41	.06	<300	<2070

Compiled from a variety of sources.

Torque and Forces

- Sliding friction
- Friction force, $F_f = f\,N$
- f = coefficient of friction
- N = normal force

Plate type clutch

- Rotating torque, T_f = $\boxed{f\ N\left(\frac{R_o + R_i}{2}\right)}$
- R_o = outside radius
- R_i = inside radius

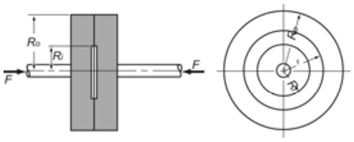
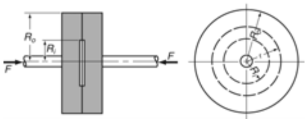


Plate type clutch

- Friction power can be calculated as,
- P_f = $\boxed{\frac{T_f\ n}{63{,}000}}$

Example Problem 16-1: Torques and Forces on Clutches and Brakes

- A plate-type clutch has the following properties:
  - –R_o = 12 in
  - – R_i = 9 in
  - – engagement force of 120 lb (normal force)
  - – turns at 2000 rpm
- Friction disc has coefficient of friction of .3.
- Determine torque and power that can be transmitted by this system.



Example Problem 16-1: Torques and Forces on Clutches and Brakes (cont'd.)

- Torque capacity:

$$T_f = f\,N\,\frac{(r_o + r_i)}{2} \qquad (16\text{-}2)$$

$$T_f = .3\,(120\ lb)\left(\frac{12\ in + 9\ in}{2}\right)$$

$$T_f = 378\ in\text{-}lb$$

- Power:

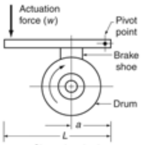
$$P_f = \frac{T_f\ n}{63{,}000} \qquad (16\text{-}3)$$

$$P_f = \frac{378\ (2000)}{63{,}000}$$

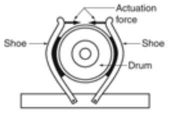
$$P_f = 12\ hp$$

Example Problem 16-2: Torques and Forces on Clutches and Brakes

- For the short-shoe drum brake shown, determine the braking torque for the following dimensions:
  - – a = 4 in
  - – L = 20 in
  - – D = 12 in
  - – f = .4
  - – W = 100 lb:



Short shoe brake



Long shoe brake

Example Problem 16-2: Torques and Forces on Clutches and Brakes (cont'd.)

- Find moments to determine normal force:

$$\Sigma M_p = WL - a\,N$$

$$\Sigma M_p = 100\,lb \;\; 20\,in - 4\,in\,N$$

$$N = 500\,lb$$

- Torque friction:

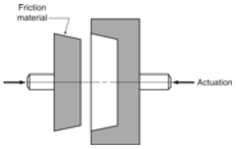
$$T_f = f\,N\,\frac{D}{2}$$

$$T_f = .4\,(500\,lb)\,\frac{12\,in}{2}$$

$$T_f = 1200\,in\text{-}lb$$

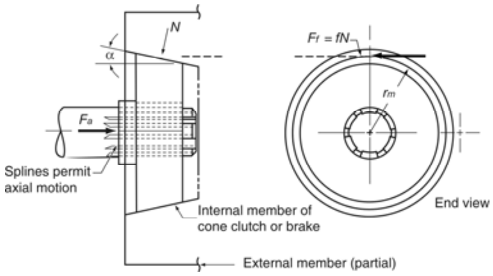
- This analysis assumes the lever arms stay approximately horizontal.

Cone clutch



- This becomes a bit complicated because of the cone angle
- In this case the frictional force is given by
- $T_f = F_f\,r_m = f\,N\,r_m$
- Normal force, N = $\dfrac{F_a}{\sin\alpha + f\cos\alpha}$
- F_a = axial force
- A = cone angle

Fig. 16.8 Cone clutch geometry



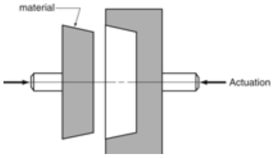
Cone clutch

- Combining the above two equations we get

$$T_f = \frac{f\,r_m\,F_a}{\sin\alpha + f\cos\alpha}$$

Example Problem 16-3: Torques and Forces on Clutches and Brakes

- For the cone clutch shown, determine the torque-transmitting capacity based on the following parameters:
  - D_{mean} = 12 inches
  - F_a = 75 lb
  - f = .35
  - α = 20°
- Also solve if α = 10° and compare the results.



Example Problem 16-3: Torques and Forces on Clutches and Brakes (cont'd.)

$$T_f = \frac{f\,r_m\,F_a}{\sin\alpha + f\cos\alpha} \tag{16-5}$$

$$T_f = \frac{.35\left(\frac{12\,in}{2}\right)75\,lb}{\sin 20° + .35\,\cos 20°}$$

$$T_f = 235\,in\text{-}lb$$

For α = 10°:

$$T_f = \frac{.35\left(\frac{12\,in}{2}\right)75\,lb}{\sin 10° + .35\,\cos 10°}$$

$$T_f = 304\,in\text{-}lb$$

- The smaller angle creates a greater wedging force and, correspondingly, larger torque capacity.

Example Problem 16-4: Torques and Forces on Clutches and Brakes

- A truck has total weight of 40,000 lb and is traveling 60 mph.
- The brake design calls for it to be able to stop in 400 feet.
- Determine stopping force required.
- Determine stopping torque required if wheels are 36 inches in diameter.
- Determine torque per brake, assuming there are 10 sets of brakes.
- Assuming each brake is a disc brake with mean radius of 10 inches, determine normal brake force if *f* = .4.

Example Problem 16-4: Torques and Forces on Clutches and Brakes

- First, find the rate of deceleration. Converting 60 mph to ft/sec:

$$60\ mph\ \frac{5280\ ft}{mile}\ \frac{hr}{3600\ sec} = 88\ ft/sec$$

Example Problem 16-4: Torques and Forces on Clutches and Brakes (cont'd.)

- Find the stopping rate:

$$D = V_a\ t$$

$$t = \frac{D}{V_a}$$

$$t = \frac{400\ ft}{\frac{88}{2}\ ft/sec}$$

$$t = 9\ sec$$

$$V = a\ t$$

$$a = \frac{V}{t}$$

$$a = \frac{88\ ft/sec}{9\ sec}$$

$$a = 9.8\ ft/sec^2$$

- Find the stopping force:

$$F = \frac{W}{g}\ a$$

$$F = \frac{40{,}000\ lb}{32.2\ ft/sec^2}\ 9.8\ ft/sec^2$$

$$F = 12{,}100\ lb$$

Example Problem 16-4: Torques and Forces on Clutches and Brakes (cont'd.)

- Find the torque, if the wheels are 36 inches in diameter:

$$T = F\ r$$

$$T = 12{,}100\ lb\ \frac{36\ in}{2}$$

$$T = 217{,}800\ in\text{-}lb$$

  - For each wheel:

$$T = 21{,}780\ in\text{-}lb$$

  - Braking normal force:

$$T_f = f\ N\ r_m \qquad (16\text{-}2)$$

$$N = \frac{T_f}{f\ r_m}$$

$$N = \frac{21{,}780\ in\text{-}lb}{.4\ \ 10\ in}$$

$$N = 5{,}450\ lb$$

- This is a significant normal force, especially for a disc brake system.

Rotational Inertia and Brake Power

- Inertia and frictional horsepower
- Energy from rotating torque
- $U_f = F\ \pi\ D\ N_t = T_f\ 2\ \pi\ N_t$
- U_f = Frictional work
- D = effective diameter
- N_t = number of turns

Rotational Inertia and Brake Power

- Power associated with stopping

$$P_f = \frac{T_f\ n}{63{,}000} = \frac{U_f}{550\ t}$$

- T_f in-lb
- n rpm
- t seconds

- Energy absorbed can be the potential energy or the kinetic energy
- Potential energy, $\Delta PE = W\,(h_1 - h_2)$
- Potential energy, $\Delta KE = \boxed{\dfrac{W}{2\,g}\,(V_1^2 - V_2^2)}$

Heat generated

- Temperature rise is $\boxed{\Delta T = \dfrac{U_f}{W_m\,c}}$
- c = specific heat
  - = 101 ft-lb/lb/°F for cast iron
  - = 93 ft-lb/lb/°F for steel
  - = 15 ft-lb/lb/°F for aluminum
- W_m = weight of brake system that can absorb the heat

Example Problem 16-5: Rotational Inertia and Brake Power

- 3500-pound automobile is traveling 50 mph and decelerates on flat ground at a rate of 20 ft/sec^2.
- Each of the four steel brake drums weighs 10 pounds.
- Assuming all heat is absorbed by the drums during this period, find energy absorbed, average frictional power, and temperature rise of drums.

Example Problem 16-5: Rotational Inertia and Brake Power

– Converting 50 mph to ft/sec:

$$50\ mph\ \frac{hr}{3600\ sec}\ \frac{5280\ ft}{mile} = 73\ ft/sec$$

– Kinetic energy to be absorbed:

$$KE = \frac{W\,V^2}{2g} \tag{16-9}$$

$$KE = \frac{3500\ lb\ (73\ ft)^2}{2(32.2\ ft/sec^2)\ sec^2}$$

$$KE = 289{,}620\ ft\text{-}lb$$

(Energy gain *U* = *KE* lost.)

Example Problem 16-5: Rotational Inertia and Brake Power (cont'd.)

$$U_f = W\,c\,\Delta T \tag{16-12}$$

$$\Delta T = \frac{U_f}{W\,c}$$

$$\Delta T = \frac{289{,}620\ ft\text{-}lb}{40\ lb\ \ 93\ \frac{ft\text{-}lb}{lb°F}}$$

$$\Delta T = 78°$$

– Finding the stopping time:

$$\Delta V = a\,t$$

$$t = \frac{\Delta V}{a}$$

$$t = \frac{73\ ft/sec}{20\ ft/sec^2}$$

$$t = 3.7\ sec$$

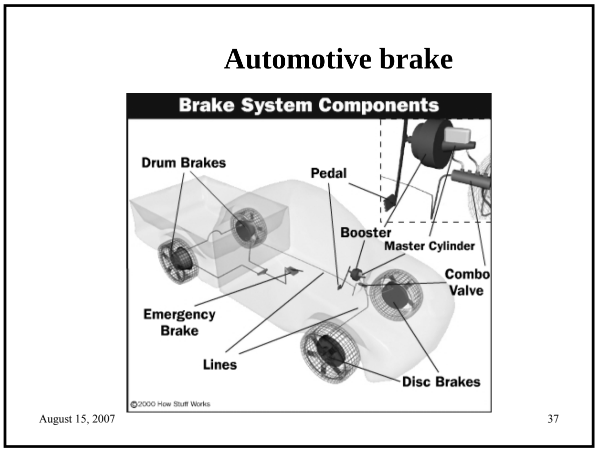
Example Problem 16-5: Rotational Inertia and Brake Power (cont'd.)

– Frictional power could then be found:

$$f_{hp} = \frac{U_f}{550\,t} = \frac{KE}{550\,t} \tag{16-7}$$

$$f_{hp} = \frac{289{,}620}{550\,(3.7)}$$

$$f_{hp} = 142$$



Automotive brake