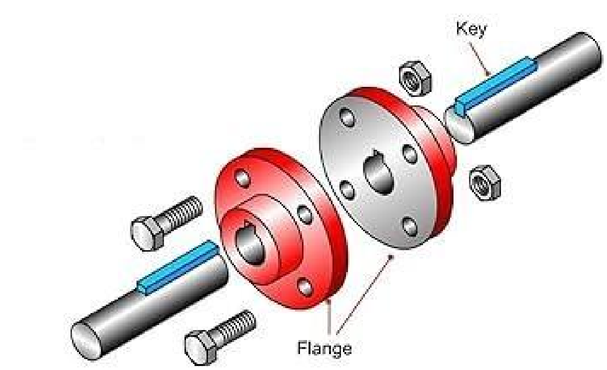
COUPLINGS

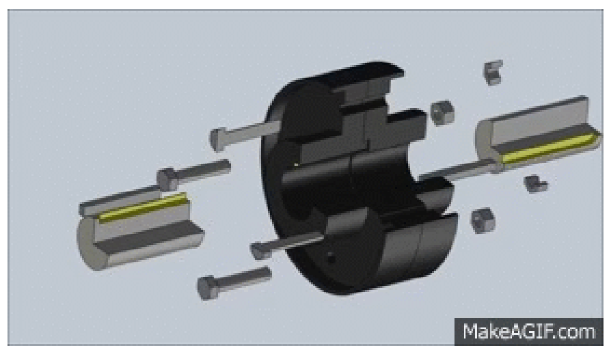
In mechanical power transmission systems, **couplings** serve the critical function of connecting rotating shafts. These mechanical devices allow for the efficient transfer of torque between shafts. Couplings may also be used to connect the driving shaft of a machine to a separately constructed driven unit.

RIGID COUPLINGS

Rigid couplings are primarily used in situations where precise alignment between the connected shafts can be maintained. The most common example is the flange coupling.This type of coupling is known for its simplicity and low manufacturing cost. However, its effectiveness depends on the accurate alignment of the connected shafts. Any misalignment can result in severe bending stresses and premature wear of the bearings.

Flanged-Face Coupling





The hub of a flange coupling must be long enough to accommodate the key that transmits torque between the shaft and the hub. As a general rule, the hub diameter is approximately twice the bore (shaft diameter), and the flange thickness is selected based on the permissible bearing pressure on the coupling bolts.

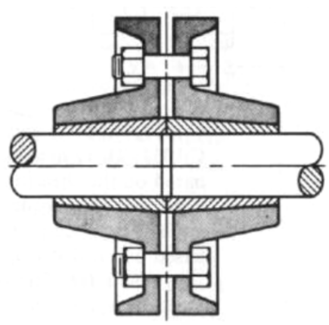
Types of Rigid Couplings

1. **Flanged-Face Coupling (Flange Coupling)**

   Each half of a flanged-face coupling is keyed to its respective shaft. The mating faces are finished perpendicular to the shaft axis to ensure precise alignment. Bolts and holes are accurately machined to produce a tight and secure fit. These couplings are available for shaft sizes up to an 8-inch bore.

2. **Flanged-Compression Coupling**

   This coupling type transmits power using frictional forces. The connection is achieved by pulling the flanges toward each other over slotted, tapered sleeves. This method eliminates the need to cut keyways, simplifying shaft preparation. Standard sizes for this coupling go up to a 3-inch bore.

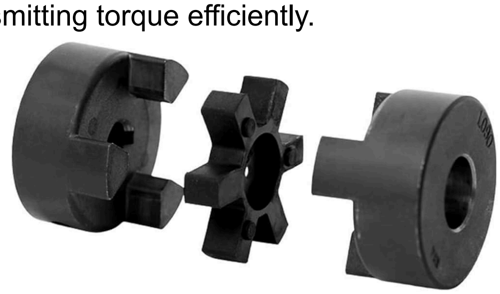


3. **Ribbed Compression Coupling**

   A heavy-duty variant, the ribbed compression coupling, uses a long key that spans both shafts. The parts are clamped along this key, ensuring a strong connection. One of the advantages is that it allows for installation and removal without disturbing the shaft alignment. Standard sizes go up to a 7-inch bore.

FLEXIBLE COUPLINGS

In many practical situations, perfect shaft alignment is difficult to achieve. Slight misalignments due to manufacturing tolerances, thermal expansion, or foundation shifts may exist. For these cases, flexible couplings are employed. These couplings allow for minor angular, axial, or radial displacement while still transmitting torque efficiently.



Flexible couplings are often constructed using elastic or semi-elastic materials. One common example is the rubber bushed coupling, which incorporates rubber bushings between the bolt flanges to absorb shock and provide flexibility. These flexible connections are particularly valuable in reducing vibration, accommodating misalignments, and protecting more delicate machine components from torque spikes.

Types of Flexible Couplings

1. **Roller Chain Coupling**

   This type of coupling consists of two sprockets connected by a roller chain. The sprockets are fitted to the shafts, and the chain transmits torque. Flexibility comes from the lateral play between the chain and sprocket teeth. It allows for torsional flexibility and slight angular misalignment. It's relatively inexpensive and often comes with a protective casing to contain lubricant.

2. **Flexpin Coupling**

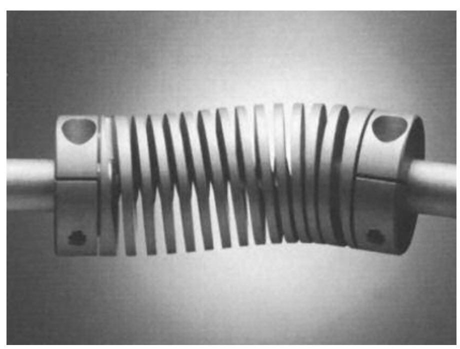
   Flexpin couplings use laminated steel pins between flanges to provide flexibility. These pins can bend slightly to accommodate angular and axial misalignment. In one half of the coupling, the pins are held in place with a spring-retaining ring, while the other half allows sliding motion. This design enables torsional flexibility and ease of maintenance.

3. **Flexible Disk Coupling**

An all-metal coupling that uses thin steel disks as the flexible element. These disks are bolted to the hub and center member in an alternating pattern. The flexibility comes from the disks bending slightly during angular or axial misalignment. This coupling offers zero backlash, no need for lubrication, and is excellent for high-precision applications.

4. **Flexure Spring Coupling**

This coupling transmits torque via a spring-like member that fits into grooves in the hub. When torque is applied, the spring bends slightly, accommodating angular and axial motion. The design ensures that spring stresses remain within safe limits even under load. It's compact and allows precise motion transfer.

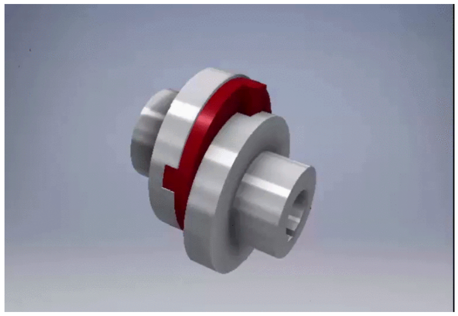


5. **Gear Type Coupling**

This type uses external gear teeth on the hub, which mesh with internal teeth in a sleeve. Flexibility is achieved by the play between the teeth, enabling angular and axial displacement. Gear couplings provide high torque capacity, but require regular lubrication and maintenance to prevent wear.

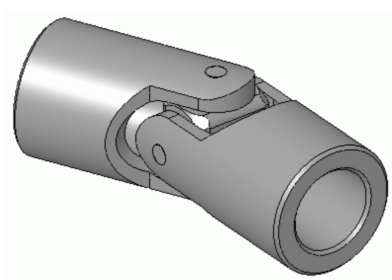
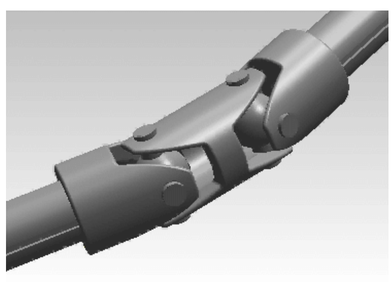
Special Coupling Designs

Some mechanical systems require couplings that can accommodate more than just minor misalignment or axial movement. One such design is the **Oldham coupling**,



It consists of three parts: two hubs with slots and a central disk with tongues at right angles. This disk transmits torque while allowing for lateral (parallel) misalignment between shafts. As the shafts rotate, the central disk slides back and forth to maintain connection, making the Oldham coupling ideal for low to moderate speed applications where offset between shafts is expected.

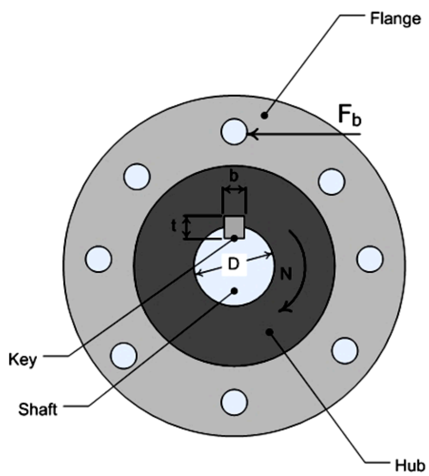
Another important design is the universal joint, which is used to connect shafts that intersect at an angle. a **single universal joint** introduces non-uniform angular velocity in the driven shaft. This variation can lead to performance issues, especially in high-speed machinery.

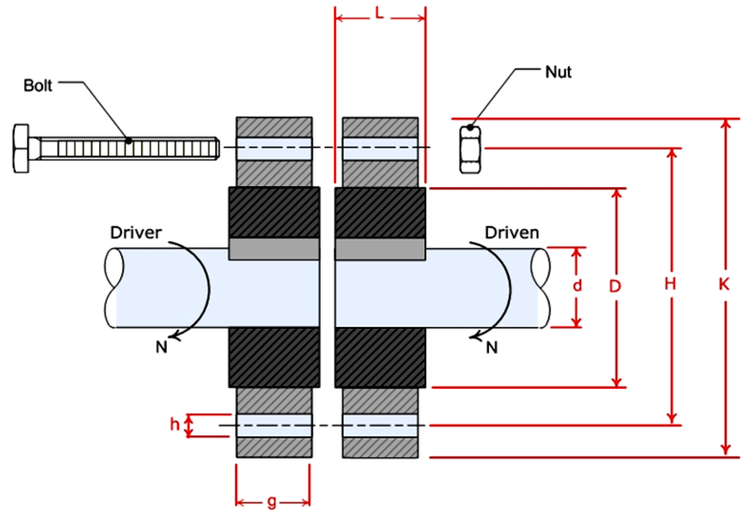
 Single universal joint	 Two universal joints

To solve this, **two universal joints** should be used in sequence and correctly phased. This arrangement ensures that the angular velocity remains uniform, despite the angular misalignment between shafts.

FLANGE COUPLING

Flange coupling is a mechanical device that is used to connect two shafts at their ends to transmit power. Two flanges are coupled together by means of bolts and nuts.





Where: h = bolt diameter
d = shaft diameter
D = hub diameter
H = bolt circle diameter
k = Flange diameter
L = width of the hub
g = width of the flange
The dimension of the key is: b x t

Power Transmitted by the flange coupling:

$$P = \frac{2\pi TN}{60}$$

Where: P = power transmitted, kW
T = torque or torsional moment
N = speed (rpm)

Design of flange coupling:

1. Based on torsional stress in the shaft

$$S_s = \frac{16\,T}{\pi\, d^3}$$; Solid shaft

$$\frac{0.60\,S_y}{FS} = \frac{16T}{\pi d^3}$$

S_y = yield stress based on shaft material

2. Based on the compressive stress between the key/hub or key/shaft

$$S_c = \frac{4T}{dtL}$$

$$\frac{S_y}{FS} = \frac{4T}{dtL}$$

S_y = yield stress based on the weakest material, either from the key, hub, or shaft.

3. Based on shearing of the key

$$S_S = \frac{2T}{dbL}$$

$$\frac{0.60\,S_y}{FS} = \frac{2T}{dbL}$$

S_y = yield stress based on the material of the key

4. Based on the shearing of bolts and flange faces

$$S_S = \frac{F_b}{A_S}$$

Where: Torque capacity per bolt $T_b = F_b\left(\frac{H}{2}\right)$

$$T_b = \frac{Total\ torque\ transmitted}{number\ of\ bolts} = \frac{T}{N_b}$$

Force which can cause shearing $F_b = \frac{2T_b}{H}$

Area under shear $A_S = \frac{\pi}{4}h^2$

Substituting;

$$S_S = \frac{2T_b}{H\left[\frac{\pi}{4}h^2\right]} = \frac{2T}{H\left[\frac{\pi}{4}h^2\right]N_b}$$

$$\frac{0.60\,S_y}{FS} = \frac{2T}{H\left[\frac{\pi}{4}h^2\right]N_b}$$

S_y = yield stress based on the material of the bolt

5. Based on compression between the bolts and flange

$$S_C = \frac{F_b}{A_C}$$

Where: Torque capacity per bolt: $T_b = F_b\left(\frac{H}{2}\right) = \frac{T}{N_b}$

Force which can cause compression: $F_b = \frac{2T_b}{H}$

Area under compression: $A_C = hg$

Substituting;

$$S_C = \frac{2T_b}{H\,h\,g} = \frac{2T}{H\,h\,g\,N_B}$$

$$\frac{0.60\,S_y}{FS} = \frac{2T}{H\,h\,g\,N_b}$$

S_y = yield stress based on the weaker material either bolt or flange

6. Based on shearing between the hub and flange

$$S_S = \frac{F_{HF}}{A_S}$$

Where: Torque capacity per bolt $T = F_{HF}\left(\frac{D}{2}\right)$

Force which can cause compression $F_{HF} = \frac{2T}{D}$

Area under shear $A_S = \pi\,Dg$

Substituting;

$$S_C = \frac{2T}{\pi\,D^2 g}$$

$$\frac{0.60\, S_y}{FS} = \frac{2T}{\pi\, D^2 g}$$

S_y = yield stress based on the material of hub or flange.

In mechanical design, particularly in flange coupling assemblies, the **key** is intentionally designed to be the first component to fail under excessive load. The key serves as a sacrificial element, transmitting torque between the shaft and hub through shear. Compared to other components like the shaft, bolts, flange, or hub, the key is inexpensive, easy to replace, and its shear strength can be precisely controlled during design. If a failure occurs, having the key fail first protects more vital and costly components from damage, prevents catastrophic breakdowns, and allows for quicker repairs. In contrast, failure of the shaft, bolts, or flange would be more dangerous, expensive, and difficult to repair. Therefore, from both a theoretical and practical engineering perspective, it is ideal for the key to be the first point of failure in a flange coupling system.

Design Considerations

When designing couplings for mechanical systems, several important factors must be considered. First, the torque to be transmitted and the alignment of the shafts determine the type of coupling to be used—rigid or flexible. For shafts that experience axial movement, such as those connected by splines or feather keys, provisions must be made to allow this motion without compromising torque transmission.

Shearing stress at joints and connections, bearing pressure on bolts, and material fatigue limits must also be evaluated. In high-speed systems or systems requiring uniform angular motion, it is essential to use designs like correctly phased universal joints to ensure consistent rotational speed and minimize vibration and wear.

In designing keys for mechanical couplings, it is important to ensure that the shear stress in the key remains below the allowable shear strength of the key material, as shear is the most common mode of failure. At the same time, crushing stress on the key's contact surfaces should also be checked and kept below the allowable compressive strength, particularly in cases involving short or heavily loaded keys. While shear failure is the primary concern in key design, crushing stress is treated as a secondary condition that must still be considered to ensure overall reliability and safety of the connection.

CLUTCH

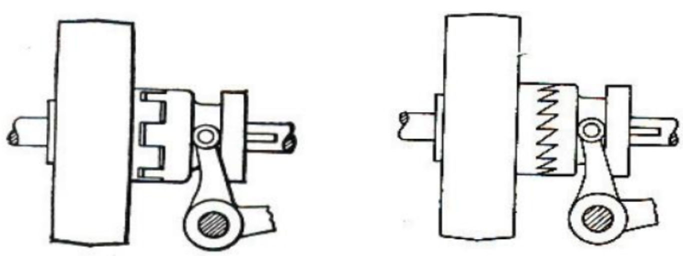
Clutches are mechanical devices that are used to connect and disconnect the shaft of the driver and driven machine. One common type of clutch is the pressure disc clutch, which is based on one or more friction discs pressed by springs against a flywheel.

When the driving machine (such as an internal-combustion engine) operates continuously and the driven member needs to be selectively connected, a clutch becomes necessary. This is particularly important in cases where the driver must reach operational speed before transmitting power to the load.

Clutches can be categorized into two main types: **positive clutches** and **friction clutches**. Positive clutches provide a direct mechanical interlock between driving and driven parts, while friction clutches transmit torque through frictional contact.

1. **Positive Clutches (Jaw Clutch)**

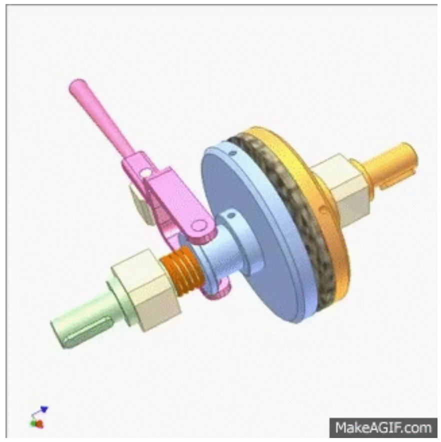
   The simplest form of a positive clutch is the **jaw clutch**. This type of clutch uses interlocking jaws to transmit torque. For unidirectional power transmission, the jaws may be cut at an angle to form a saw-tooth profile. This design enhances engagement strength and ease.

   However, a major limitation of the jaw clutch is that it requires both parts to be at the same velocity before engagement. Otherwise, the impact can produce high stresses and potential damage to the components. In automotive applications, jaw clutches with gear-tooth-shaped jaws are used to connect the engine to the transmission shaft in high-speed gears. Modern transmissions employ **synchronizing units** with friction surfaces to match speeds and reduce shock during engagement.

2. **Friction Clutches (Plate Clutches)**

   A widely used type of friction clutch is the plate friction clutch, which typically consists of two flanges. One flange is rigidly attached to the driving shaft, while the other is connected to the driven shaft through a feather key or spline, allowing axial movement.



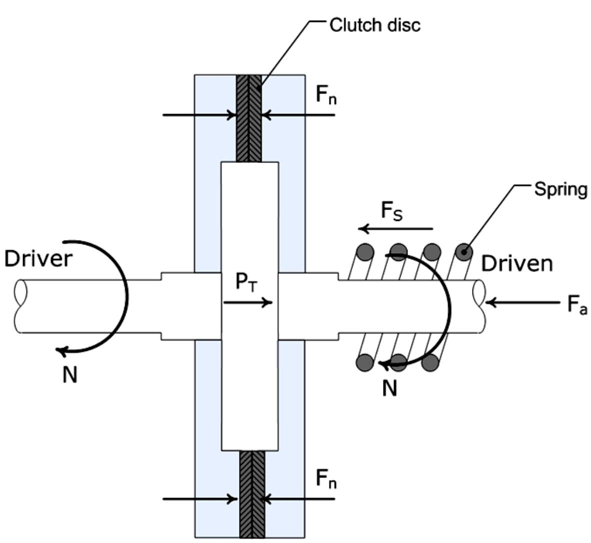
When a suitable mechanism presses the movable flange against the fixed one, torque is transmitted through the resulting friction. The amount of torque transmitted depends on:

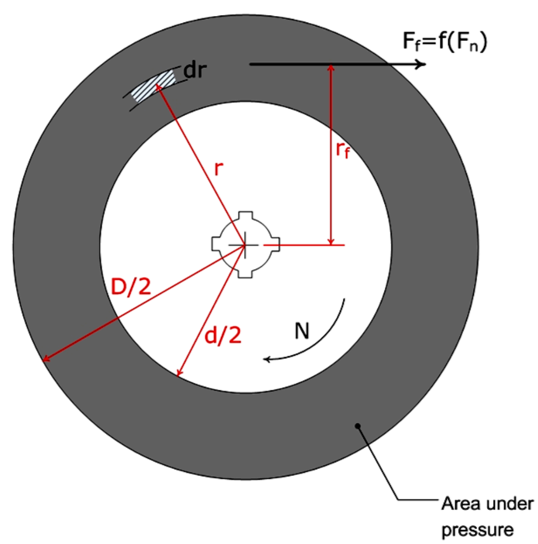
a. The axial force applied,
b. The mean radius of the friction surfaces
c. The coefficient of friction between the materials.

FOR NEW PRESSURE DISC CLUTCH
(UNIFORM PRESSURE CLUTCH)

In this model, it is assumed that the pressure is evenly distributed across the contact area of the friction surfaces — typically the contact between clutch plates. This assumption is particularly valid when:

a. The surfaces are new and not yet worn.
b. The contact is over a relatively rigid plate.





Where: F_a = axial load

F_s = force exerted by the spring

F_n = normal force acting at the clutch disc

$$F_a = F_s = F_n$$

F_f = frictional force

f = coefficient of friction

$$F_f = fF_n$$

r_f = frictional radius

P_T = power transmitted = $\frac{2\pi TN}{60}$

N_C = pair of mating or contacting surfaces

N_C = 1 for single disc clutch

Axial Load, F_a

The total clamping force that pushes the pressure plate(s) and the friction disc(s) together along the shaft axis.

$$P = \frac{F_a}{A}$$

$$F_a = P(A) = P\,dA$$

Where: A = area under pressure

$dA = 2\pi r\,dr$

$$F_a = P\,2\pi r\,dr = 2\pi P \int_{d/2}^{D/2} r\,dr$$

$$F_a = 2\pi r P\left[\frac{(D/2)^2 - (d/2)^2}{8}\right]$$

$$F_a = \pi P\left[\frac{D^2 - d^2}{4}\right]$$

Pressure produced by the mating surfaces because of the axial load, F_a

$$P = \frac{F_a}{\pi\left[\frac{D^2 - d^2}{4}\right]}$$

Torque Transmitted, T

$T = F_f r_f$ but: $F_f = fF_n$; $F_n = F_a$ and $r_f \approx r$

$T = fF_a r$

Then;

$$T = f\,P\,(2\pi r\,dr)\,r = 2\pi f\,P\left(r^2\,dr\right)$$

$$T = f\,P\,(2\pi r\,dr)\,r = 2\pi fP\int_{d/2}^{D/2} r^2\,dr$$

$$T = 2\pi fP\left[\frac{(D/2)^3 - (d/2)^3}{3}\right]$$

$$T = 2\pi fP\left[\frac{D^3 - d^3}{24}\right] \qquad \text{but} \qquad P = \frac{F_a}{\pi\left[\frac{D^2 - d^2}{4}\right]}$$

Substituting;

$$T = 2\pi f\,\frac{F_a}{\pi\left[\frac{D^2 - d^2}{4}\right]}\left[\frac{D^3 - d^3}{24}\right]$$

Simplifying simultaneously:

Torque transmitted for pair of contact surface

$$T = fF_a\left[\frac{D^3 - d^3}{3\left(D^2 - d^2\right)}\right]$$

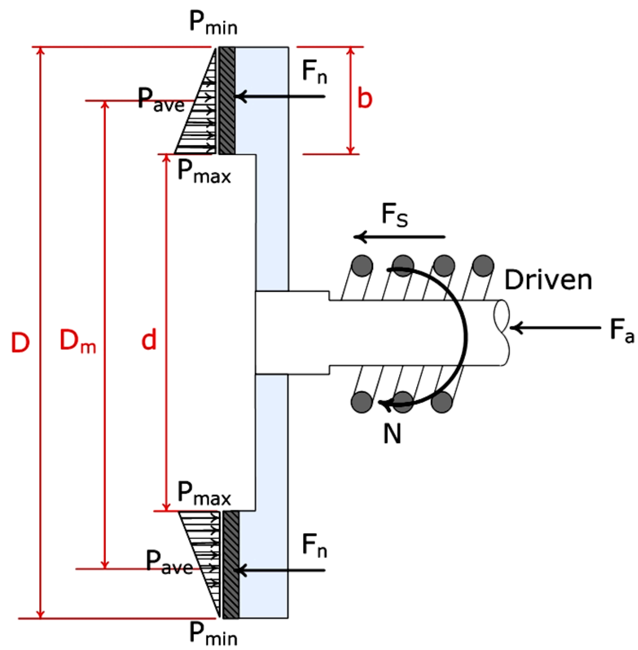
Where: $r_f = \frac{1}{3}\left[\frac{D^3 - d^3}{\left(D^2 - d^2\right)}\right] = \frac{2}{3}\left[\frac{R^3 - r^3}{\left(R^2 - r^2\right)}\right]$

Hence, the torque transmitted for any number of contact surfaces

$$T = fF_a\left[\frac{D^3 - d^3}{3\left(D^2 - d^2\right)}\right]N_C$$

FOR OLD PRESSURE DISC CLUTCH
(UNIFORM WEAR CLUTCH)

The uniform pressure assumption is ideal when clutch surfaces are new. But over time, wear occurs due to friction during engagement—especially if lubrication is absent. This wear leads to a different distribution of pressure across the surface.
To ensure that the clutch plates continue to maintain contact evenly, the rate of wear must be uniform across the radius of the friction surface.



Axial Load, F_a

$$P = \frac{F_a}{A}$$

$$F_a = P(A) = P\, dA$$

Where: A = area under pressure
$dA = 2\pi r\, dr$

$$F_a = P\, 2\pi r\, dr = 2\pi\, (Pr\, dr)$$

Where: Wear constant, W

After some use, the outer radius experiences slightly less wear because the linear velocity (sliding speed) is higher there. The inner radius, however, has a smaller area and therefore sustains **higher pressure per unit area**, which results in **more wear on the inner face** of the clutch.

The wear constant (W) represents the product of pressure P and radius r at the contact surface where wear is assumed to be uniform. It comes from the **uniform wear theory**, which assumes that: 1. The wear rate is proportional to the work done by friction (i.e., proportional to pressure × sliding velocity). 2. Since the sliding velocity varies with radius (v = ωr), wear will be distributed in such a way that Pr = constant = W.

$$W = Pr = P_{max}(d/2) = P_{min}(D/2) = P_{ave}(D_m/2)$$

$$F_a = 2\pi Pr \int_{d/2}^{D/2} dr$$

$$F_a = 2\pi Pr\left[\frac{D}{2} - \frac{d}{2}\right] = 2\pi Pr\left[\frac{D-d}{2}\right]$$

Hence;

$$F_a = \pi Pr(D - d)$$

$$F_a = \pi P_{max}\left(\frac{d}{2}\right)(D - d)$$

$$F_a = \pi P_{min}\left(\frac{D}{2}\right)(D - d)$$

$$F_a = \pi P_{ave}\left(\frac{D_m}{2}\right)(D - d)$$

Pressure produced by the mating surfaces because of the axial load, F_a

$$P = \frac{F_a}{\pi\, r\, (D - d)}$$

Torque Transmitted, T

$T = F_f r_f$ but: $F_f = fF_n$; $F_n = F_a$ and $r_f \approx r$

$T = fF_a r$

Then;

$$T = f\,P\,(2\pi r\,dr)\,r = 2\pi f P r \int_{d/2}^{D/2} dr$$

$$T = 2\pi f P r\left[\frac{(D/2)^3 - (d/2)^3}{2}\right]$$

$$T = 2\pi f P r\left[\frac{D^2 - d^2}{8}\right]$$ but $$P = \frac{F_a}{\pi\,r(D-d)}$$

Substituting;

$$T = 2\pi f\left[\frac{F_a}{2\pi\,(D - d)}\right] r\left[\frac{D^2 - d^2}{8}\right]$$

Simplifying simultaneously:

Torque transmitted for pair of contact surface

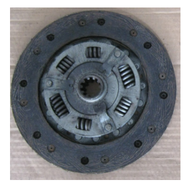
$$T = fF_a\left[\frac{D+d}{4}\right]$$

Where: $r_f = \frac{D+d}{4}$

Hence, the torque transmitted for any number of contact surfaces

$$T = fF_a\left[\frac{D+d}{4}\right]N_C$$

Summary:

	FOR NEW PRESSURE DISC CLUTCH (UNIFORM PRESSURE CLUTCH)	FOR OLD PRESSURE DISC CLUTCH (UNIFORM WEAR CLUTCH)
Pressure produced by the mating surfaces because of the axial load, F_a	$P = \frac{F_a}{\pi\left[\frac{D^2 - d^2}{4}\right]}$	$P = \frac{F_a}{\pi\, r\,(D - d)}$
Torque Transmitted, T for any number of contact surfaces, N_C	$T = fF_a r_f N_C$	
Frictional radius, r_f	$r_f = \frac{D^3 - d^3}{3\left(D^2 - d^2\right)}$	$r_f = \frac{D + d}{4}$
		

The distinction between uniform pressure and uniform wear is critical in clutch design and analysis. When a clutch is new, engineers assume uniform pressure over the surface, giving higher torque efficiency due to better contact. As the clutch wears down, contact shifts toward the outer edge, and uniform wear assumptions are used to accurately predict performance. Understanding both models ensures safer, longer-lasting clutch systems in real-world mechanical designs.

As Engineers, we need to calculate for both new and old clutches not because the clutch won't eventually be replaced, but because engineers need to guarantee performance and safety across the entire service life of the clutch. New clutch analysis ensures maximum capacity, while old clutch analysis ensures minimum capacity before failure or replacement.

Proper Maintenance and Care of Clutch:

1. Preserve the Friction Coefficient (f):
   The torque capacity is directly proportional to the friction coefficient between mating surfaces. If oil or grease contaminates the clutch, f drops drastically.
   - *Keep the clutch free from oil leaks (e.g., from rear main seal).*

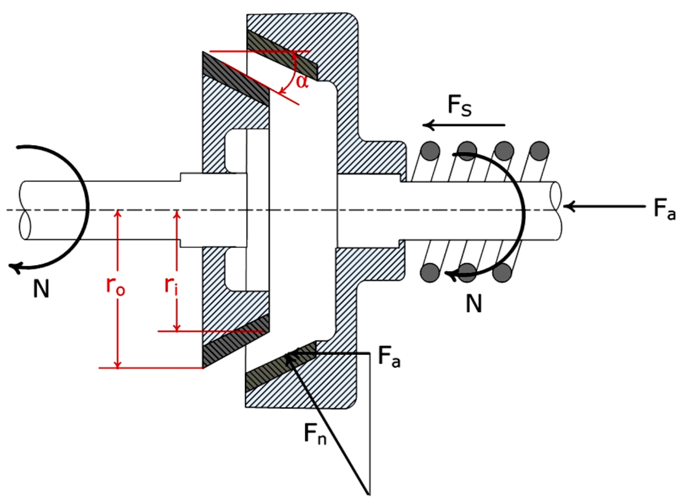
2. Maintain Sufficient Axial Force (F_a):

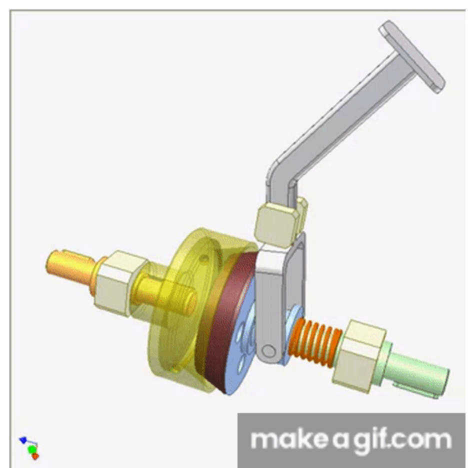
   If the pressure plate loses spring force due to wear or fatigue, the clutch will slip even under moderate load.
   - *Replace worn pressure plates and check clutch spring tension during maintenance.*
3. Minimize Sudden Overloads (Torque Surges):
   Frequent abrupt torque spikes can exceed clutch capacity and damage surfaces.
   - *Engage and disengage smoothly. Avoid aggressive launches.*
4. Respect the Rated Load Cycles of N_C Contact Surfaces:

   Repeated heat cycles reduce the effectiveness of clutch materials.
   - *Allow cooldown during heavy usage. Avoid slipping under load.*

Cone Clutch

A cone clutch uses the conical surfaces of two mating components to transmit torque via friction. It functions similarly to a disk clutch but uses a cone instead of flat plates.





Torque Transmitted, T

$$T = fF_n r_m$$

Where: F_n = normal force

r_m = mean radius

Axial force, F_a

1. Axial force required to produce normal force Fn, for steady operation and after the clutch is engaged.

$$F_a = F_n \sin\alpha$$

$$T = \frac{fF_a r_m}{\sin\alpha}$$

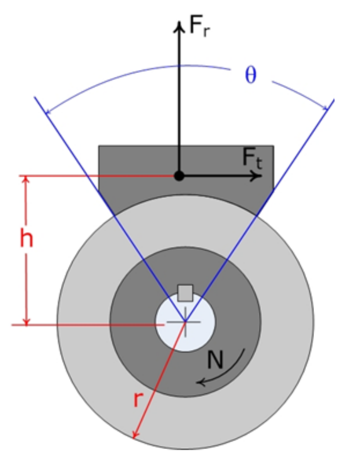
Where: Angle α typically varies from 7.5 to 30 degrees

2. Axial force required to engage when one member is rotating and the other is stationary.

$$F_a = F_n[\sin\alpha + f\cos\alpha]$$

Block Clutch

A block clutch, also known as a shoe clutch or drum clutch, is a type of friction clutch that transmits power by pressing one or more friction blocks (or shoes) against a rotating drum. It is commonly used in low to moderate torque applications such as belt-driven machinery or older industrial setups.



Torque Transmitted, T

$$T = \frac{4f F_r r \sin\frac{\theta}{2}}{\theta + \sin\theta}$$

In terms of the maximum pressure, P_{max} between the drum and block
Derivation: Page 189 Design of Machine Members 2nd Edition by Venton Levy Doughtie

$$T = 2f P_{max} w r^2 \sin\frac{\theta}{2}$$

Where: F_r = radial force
r = radius of the drum
θ = angle of contact between the drum against the block, radians
f = coefficient of friction
w = width of block parallel to the axis of rotation of the drum

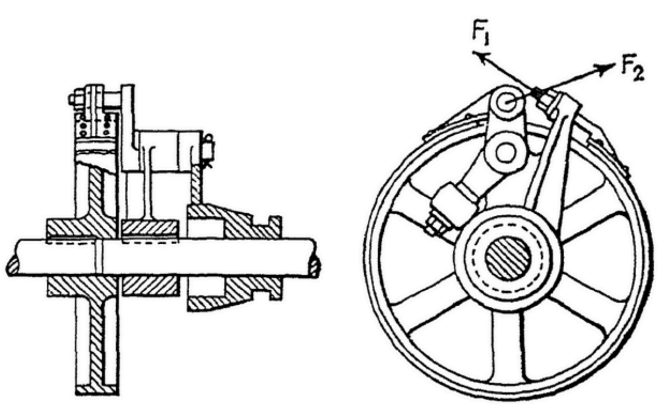
Internal Expanding Rim Clutch

The internal expanding rim clutch, or internal-shoe clutch, transmits torque by pressing friction shoes outward against the inner surface of a drum. It consists of three main parts: the friction surfaces, the torque transmission path, and the actuating mechanism. These clutches are classified by their actuation method—expanding-ring, centrifugal, magnetic, hydraulic, or pneumatic.

Expanding-ring clutches are used in machinery like textile equipment and work well at low speeds. Centrifugal clutches engage automatically as speed increases, making them ideal for electric motors.

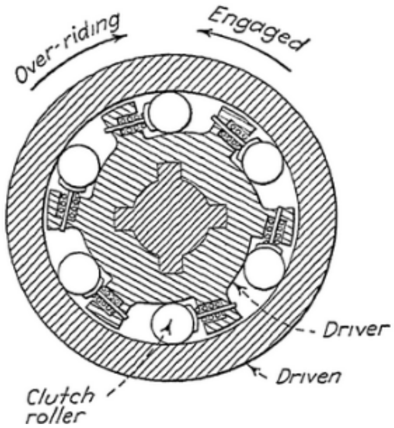
Band Clutch

A band clutch uses a flexible steel band, typically lined with a friction material like wood, composite blocks, or asbestos fabric, to grip the outside surface of a rotating drum.



Unidirectional clutches

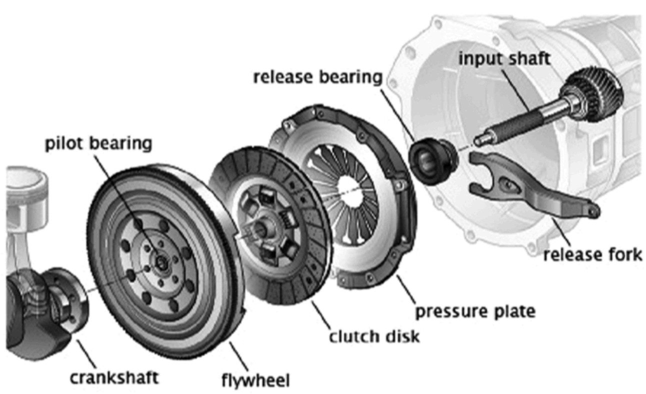
Unidirectional clutches, also known as one-way or overrunning clutches, are designed to transmit power in only one direction. These clutches engage when the driving shaft rotates in a specified direction but automatically disengage when the direction is reversed or when the driven shaft rotates faster than the driver. This feature is especially useful in systems that require torque transmission during motion in one direction only, such as in starter motors or conveyor belts.



Rollers are placed inside tapered pockets on the inner member. When the inner member rotates in the clockwise direction, the rollers move toward the wide ends of the pockets, allowing the inner part to rotate freely without engaging the outer sleeve. However, when the rotation is counterclockwise, friction forces the rollers to wedge tightly between the inner and outer members, locking them together and allowing torque to be transmitted. This automatic engagement and disengagement mechanism is commonly used in the freewheeling units of modern automobiles and in other applications where reverse torque transmission is undesirable.

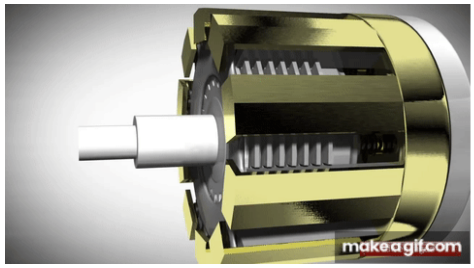
Automobile clutches

Automobile clutches have evolved from early cone-type designs with leather or asbestos facings, which required large surfaces due to low pressure capacity. As engines became more powerful, multiple-disk clutches were introduced to handle higher torque without increasing size or axial pressure. Metal-to-metal clutches with oil baths became common to reduce wear and friction. Later, improved friction materials led to the development of dry multiple-disk clutches, which are now widely used in machine tools. Today's compact, efficient clutches, such as single- or double-plate types, can transmit full engine power with smaller diameters.



Multiple-Disk Clutch-Brake Systems

In industrial and high-performance environments—such as CNC machinery, automotive racing, marine propulsion systems, and automated manufacturing—multiple-disk clutch-brake systems are preferred for applications that require rapid and frequent engagement and disengagement, commonly referred to as rapid cycling. These systems are engineered for durability, efficiency, and smooth operation under intense operating conditions.



A multiple-disk clutch-brake system consists of alternating friction plates (typically made of a high-friction material) and steel drive plates, which are stacked within a confined space between the driving and driven components. The friction plates are usually splined to the shaft, while the steel plates are keyed to the housing. This design allows for the transfer of torque when axial force compresses the plates together.

One of the key advantages of this configuration is that it multiplies the total frictional surface area, enabling higher torque transmission without increasing the clutch's overall diameter. This makes it ideal for compact, high-power applications.

Clutch Design Requirements

A well-designed clutch must effectively withstand and dissipate heat, offer adequate torque capacity, and ensure long service life. In high-speed applications such as automobiles, the driven parts should have low inertia, and the clutch system should be well-balanced. It must allow for positive release, smooth engagement, low operating force, and easy maintenance.

To minimize wear and enhance engagement, flexible facings are used on driven disks, ensuring maximum contact area. In automotive applications, slits in spring steel disks and segmented facings are used to reduce warping and promote uniform contact. The driving disks, often made of cast iron, should be thick enough to dissipate heat effectively. However, high-carbon steel disks may warp into a conical shape under heat.

Material Considerations and Friction

- Facing materials significantly affect clutch performance. Materials like asbestos fabric, molded asbestos, wood, leather, and cork are commonly used.
- Friction coefficients vary based on whether the surfaces are dry or lubricated
- New materials typically have higher friction, but for safety, design uses values from older facings.

Friction materials play a vital role in the performance and reliability of brakes and clutches. These materials are designed to provide a high and consistent coefficient of friction under varying conditions of load, speed, and temperature. They must resist wear, maintain their integrity under extreme temperatures, and function effectively even in harsh environments, such as those with moisture or contaminants. Other important characteristics include resiliency, environmental compatibility, and flexibility to accommodate different operational stresses and thermal expansions.

According to the reference material, several types of friction materials are commonly used depending on the application:

1. **Woven-Cotton Lining** – This material consists of fabric belts impregnated with resins and polymerized for strength. It is commonly used in heavy machinery due to its flexibility and availability in long rolls, with thicknesses from 1/8 inch to 1 inch. It provides good friction performance for large equipment under continuous operation.
2. **Woven-Asbestos Lining** – Though no longer widely used due to health concerns, woven-asbestos linings were historically important. Similar in construction to cotton linings, they contain asbestos and some metal particles, making them stiffer and suitable for high-load applications.
3. **Molded-Asbestos Linings and Pads** – These contain asbestos fibers and friction modifiers bound by a thermosetting polymer, typically used in drum brakes. Molded-asbestos pads were used in both brakes and clutches and are more rigid compared to linings.
4. **Sintered-Metal Pads** – Made from copper or iron particles mixed with friction modifiers, these are subjected to high heat and pressure to form a dense, wear-resistant pad. They are suitable for high-performance braking and clutch systems, especially in industrial or heavy-duty automotive applications.
5. **Cermet Pads** – These pads are similar to sintered-metal pads but contain a significant ceramic content. They offer improved temperature resistance and are highly durable, making them ideal for harsh operating environments.

Key performance metrics for selecting friction materials include:

- Wear resistance
- Thermal conductivity
- Specific heat capacity
- Coefficient of friction under dry and lubricated conditions

Materials may also be operated in oil-lubricated environments, especially in wet clutches and brakes. While lubrication can reduce the coefficient of friction, it significantly improves heat dissipation and extends the service life of the friction components.

In practice, engineers select friction materials based on operating temperature, required friction level, wear life, and compatibility with system lubricants. Specialized catalogs and manufacturer specifications should be consulted for final selection due to the diversity and specificity of available materials.

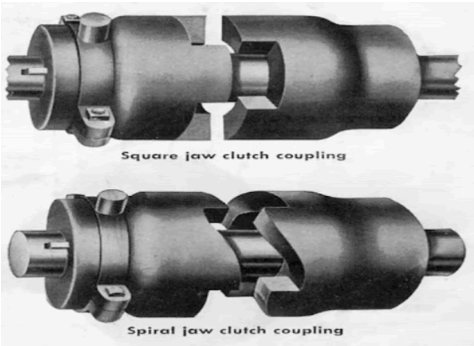
Design Tips

- Use lower unit pressures for frequently slipping or shock-loaded clutches to reduce wear.
- High-density facings (e.g., woven materials) last longer and reduce scoring.
- Wood blocks perform well in industrial applications.
- Ensure sufficient starting torque by designing for 75–100% overload capacity.
- Adjust service factors if the clutch is exposed to varying loads or shock.

Miscellaneous Clutches

a) Square-Jaw Clutch

The square-jaw clutch is a type of *positive-contact clutch*. It transmits torque by the direct engagement of interlocking jaws or teeth. The figure shows a shift lever that slides the clutch axially to engage the square teeth of the clutch halves. This form of clutch is ideal when zero-slip is required, making it suitable for *synchronous or indexing applications* where accurate torque transfer is essential. The engagement must occur when both shafts are either at rest or rotating at identical speeds, since engaging at high speed could cause mechanical damage due to the shock and lack of cushioning.

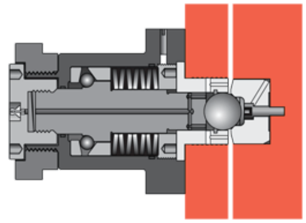


Key characteristics of square-jaw clutches:

- No slip: Torque is transmitted purely through mechanical interlock.
- No heat generation: There’s no frictional slipping.
- Cannot engage at high speed: Must engage while stopped or synchronized.
- Shock during engagement: Engagement is abrupt and may cause noise or stress.
- Useful for precise motion control or timing applications like machine tools, printing presses, and power presses.

b) Overload Release Clutch

The overload release clutch is a torque-limiting safety device. It includes a detent mechanism — a ball held in a groove by a spring. Under normal torque, the ball remains seated and transmits motion. When the transmitted torque exceeds a preset limit (set by spring force), the ball is forced out of the groove, instantly disconnecting the drive and protecting the system from overload damage.



Features:

- Prevents system damage: Protects against overload by disengaging.
- Resettable: Once the overload is removed, it can often be re-engaged.
- Audible “click” upon disengagement can act as an alert.
- Used in linear actuators, motor-driven screwdrivers, and automated tools where motion must stop at a defined limit.

BRAKES

Brakes are mechanical devices designed to control or stop the motion of bodies through the use of friction. They differ from clutches in purpose: while clutches transmit motion by connecting rotating bodies, brakes are meant to retard or halt motion by creating frictional resistance. Brakes are widely used in machinery and vehicles to ensure safe operation by regulating motion, slowing speed, or maintaining rest.

The functioning of brakes relies on the frictional force that arises when a moving surface is brought into contact with a stationary one. This frictional interaction converts the kinetic energy of the moving part into heat, which must then be dissipated effectively to avoid overheating.

Types and Configuration

Brakes can be classified based on the nature of their contact surfaces and their application methods. Common types include:

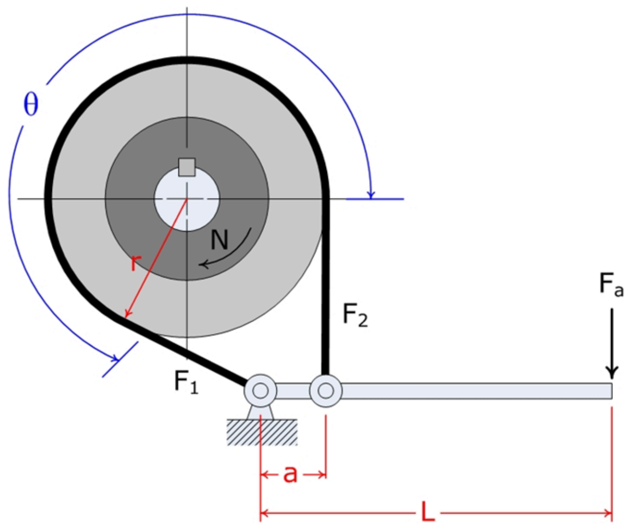
1. External shoe brakes (e.g., block brakes)
2. Internal shoe brakes
3. Disk brakes
4. Cone brakes
5. Expanding band and wrapping band brakes

Among these, external shoe brakes are most likely to be used in heavy-duty industrial applications due to their simplicity and effectiveness in large installations such as elevators and hoists.

SIMPLE BAND BRAKE

Band brakes are a type of friction brake system that uses a flexible element—typically a rope, belt, or steel band lined with friction material—wrapped around the outer surface of a rotating cylindrical drum. As the band tightens, frictional force is developed, slowing or stopping the rotation of the drum. This mechanism functions similarly to a belt drive system but in reverse,

A band brake operates by applying tension to a flexible band that partially or completely encircles a drum. The tension difference between the two ends of the band—denoted as the high-tension side (F_1) and the low-tension side (F_2)—creates a frictional force that opposes the motion of the rotating drum.



Tension in the band

(Derivation: page 844 of Shingley's Mechanical Engineering Design 9th Edition)

$$\frac{F_1}{F_2} = e^{f\theta}$$

Where:

F_1 = force in band on high-tension side, lb

F_2 = force in band low-tension side, lb

e = 2.7183

f = coefficient of friction

θ = angle of contact, rad

Torque developed by braking action

$$T = \left(F_1 - F_2\right)r$$

Where: r = radius of friction surface on the drum, in
T = brake torque, lb-in

Force applied at the lever

$$F_a = \frac{F_2 a}{L}$$

Note: If the direction of the drum is reversed, change F_2 to F_1.

Maximum pressure on the band

$$P_{max} = \frac{F_1}{wr}$$

Stress in the band

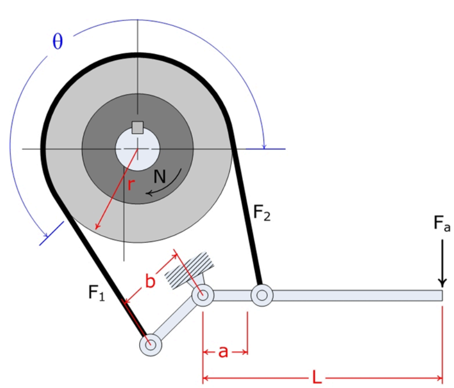
$$S_{band} = \frac{F_1}{wt}$$

Where: w = band width
t = band thickness

DIFFERENTIAL BAND BRAKE

Differential band brakes are a type of flexible friction brake that utilize a band wrapped around a rotating drum or wheel. The braking action is achieved by tightening the band, creating friction that slows or stops the motion of the drum. What distinguishes a differential band brake from other band brake types is the **asymmetrical attachment** of the band ends—both ends are fixed to a lever but at different distances from the fulcrum.

In this type of brake, both ends of the band are attached to the brake lever. It is assumed that distance b is greater than distance a.



In a differential band brake, one end of the band is attached **closer** to the fulcrum of the actuating lever, while the other is attached **farther** away. When force is applied to the lever, the tension difference between the two ends of the band tightens the band around the drum, thereby applying a braking force. The force difference across the band ($F = F_1 - F_2$) results in frictional torque that opposes the rotation of the drum.

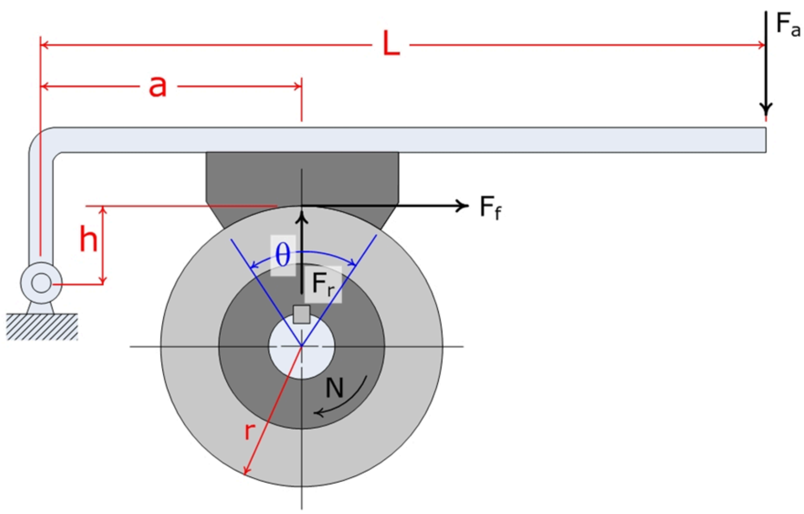
Force applied at the lever

$$F_a = \frac{F_2 a - F_1 b}{L}$$

Note: If the direction of the drum is reversed, F_2 to F_1 are interchangeable.

SELF-LOCKING DIFFERENTIAL BLOCK BRAKES

Self-locking band brakes are specially designed braking systems that are capable of automatically engaging when rotation is reversed. These brakes are particularly useful in hoisting mechanisms, cranes, and elevators, where it's critical to prevent a suspended load from descending unintentionally if the power supply is interrupted. The core principle behind this brake is directional locking, which allows free movement in one direction and automatic engagement in the other.



In a self-locking band brake, a flexible band wraps around a drum. The system is configured so that one end of the band is connected at a greater distance a from the pivot point than the other end, located at distance L. When rotation occurs in a certain direction, the tension in the band increases due to the geometric arrangement, leading to automatic tightening of the band on the drum. This tightness creates the braking force without requiring any additional input force.

Torque developed by braking action

$$T = \frac{4fF_r r \sin\left(\frac{\theta}{2}\right)}{\theta + \sin\theta}$$

$$T = \frac{P_{max} wr}{2}(\theta + \sin\theta)$$

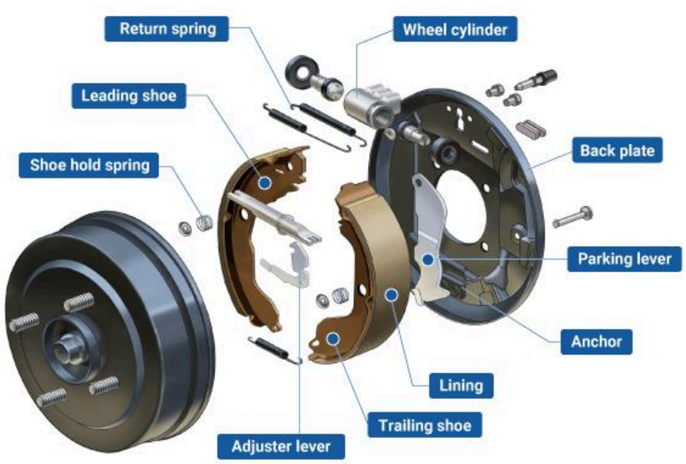
Where: F_r = radial force, lbs

Internal Shoe Brakes

Internal shoe brakes are among the most widely used types of drum brakes, particularly in automotive systems. They consist of a rotating drum and one or more brake shoes mounted internally. The brake shoes press outward against the inside surface of the drum to create friction, which decelerates or stops the drum's rotation.

This type of brake is especially common in vehicle rear wheels and parking brakes, valued for its compactness, self-energizing capability, and cost-efficiency.

Construction and Operation



An internal shoe brake typically includes:

- A rotating drum attached to the wheel
- Two brake shoes (front and rear)
- A pivot point for each shoe
- An actuating mechanism (such as a hydraulic brake cylinder) that pushes the shoes outward

When the brake pedal is pressed, hydraulic pressure from the brake cylinder forces the shoes to expand outward. Their curved surfaces contact the inner wall of the rotating drum, and friction is generated to slow or stop the wheel.

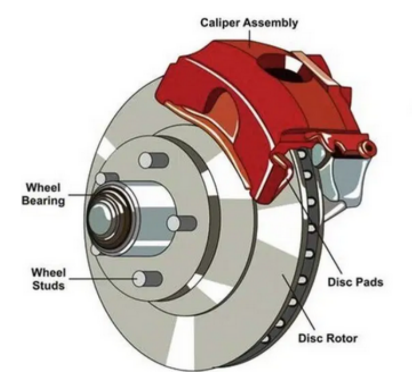
DISK BRAKES

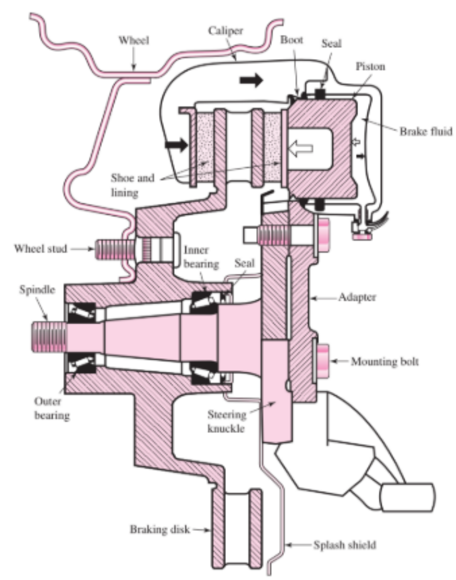
Disk brakes are a common type of friction brake used in automobiles, machinery, and industrial applications. They operate by pressing a frictional pad against the flat surface of a rotating disk (or rotor), converting kinetic energy into heat and thus slowing or stopping motion.

Disk brakes function similarly to disk clutches, and much of the same analysis applies to both systems. Unlike drum brakes, however, disk brakes do not rely on self-energization—meaning they do not use the frictional force to amplify the applied force. This characteristic makes them more consistent and less sensitive to environmental changes such as temperature and moisture.

Floating Caliper Brake

A widely used type of disk brake is the **floating caliper brake**. It uses a single hydraulic piston mounted in a caliper that can move laterally. When hydraulic pressure is applied, the piston pushes the friction pad against the disk. The reactive force moves the entire caliper to press the opposite pad against the other side of the disk. This floating action compensates for wear and maintains nearly uniform pressure distribution.This arrangement allows efficient conversion of hydraulic pressure into frictional force. This arrangement allows efficient conversion of hydraulic pressure into frictional force.





This configuration mimics the action of a screw clamp but with a piston replacing the screw. The floating caliper design ensures:

- Compensation for brake pad wear
- Nearly uniform pressure distribution
- Automatic centering of the caliper

When hydraulic pressure is released, a seal and boot mechanism pulls the piston slightly back to maintain clearance and avoid drag.

The concept of uniform wear is also important in brake design. It assumes that the product of pressure and velocity (PV) at any point on the contact surface remains constant. In practice, this means that even as the brake pad wears down, the pressure distribution adjusts to maintain balanced performance, ensuring predictable wear and longer service life.

Torque developed by braking action for 1 pair faces

$$T_f = fF_N \frac{(r_1 + r_2)}{2}$$

$$T_f = fF_N r_m$$

Where:

f = coefficient of friction

r_1 = inner radius of the pad

r_2 = outer radius of the pad

$r_1 = \frac{(r_1 + r_2)}{2} =$ mean radius of the annular surface

F_N = total axial force applied between pair of faces in contact

Design Considerations

Disk brakes are commonly made of cast iron or carbon composites (in high-performance applications). The friction pads are designed to withstand high temperatures and provide stable performance under varying loads.

Design must consider:

- Heat dissipation
- Pad wear compensation
- Pressure distribution
- Avoidance of rotor warping

Disk brakes are widely used for their simplicity, efficiency, and consistency under changing environmental and operating conditions. Their lack of self-energization is not a disadvantage but a design strength that enhances their reliability in safety-critical applications like vehicle braking systems.

HEAT DISSIPATION IN BRAKES

One of the most critical design considerations for brakes—especially those used continuously or repeatedly—is their ability to dissipate heat. When brakes are engaged, the kinetic or potential energy of the system is converted into thermal energy due to friction, which must be absorbed or radiated away to avoid excessive temperature rise.

$$Q = fF_r v$$

Where:
f = coefficient of friction
F_r = radial force
v = surface velocity
Q = Heat dissipated

Failure to adequately dissipate this heat can lead to overheating, brake fade, material degradation, or even brake failure. Therefore, thermal analysis is just as important as mechanical design in many braking applications.

Heat Dissipation

Although part of the heat is absorbed by the brake drum, a significant amount is:

- Radiated into the air
- Carried away by air currents
- Conducted into connected parts

The exact temperature of the brake drum after braking is not always predictable. However, designers ensure that heat dissipation equals or exceeds heat generation for safe, continuous operation.

The maximum safe temperature rise is usually limited to:

- 500°F for cast iron (350°F under severe duty)
- 150°F for wood or leather linings

Anti-lock Braking System (ABS)
The Anti-lock Braking System (ABS) is an advanced safety feature in vehicles designed to prevent wheel lock-up during sudden or hard braking. In traditional braking systems, applying excessive force to the brake pedal can cause the wheels to stop rotating while the vehicle is still in motion. This results in wheel skidding, reduced steering control, and longer stopping distances. ABS overcomes this by automatically modulating brake pressure to maintain optimal traction.

How ABS Works

1. Sensors: Speed sensors are installed on each wheel to continuously monitor wheel rotation.
2. Electronic Control Unit (ECU): The ECU receives signals from the wheel speed sensors and detects when a wheel is about to lock.
3. Hydraulic Valves: The ECU sends commands to hydraulic valves that increase, hold, or release brake pressure rapidly.
4. Pulsating Brake Action: Instead of continuous brake pressure, ABS applies and releases pressure in quick pulses (many times per second), ensuring that the wheels continue to rotate without locking up.

Benefits of ABS

- Maintains Steering Control: Drivers can steer the vehicle even under heavy braking, reducing the risk of collisions.
- Shorter Stopping Distance: On wet or slippery roads, ABS generally reduces the distance required to stop compared with locked-wheel braking.
- Improved Vehicle Stability: Prevents skidding and sideways slipping of the vehicle.
- Enhanced Safety: Especially useful during emergency braking or on uneven surfaces.

Hill Start Assist Control
Hill Start Assist Control (HAC) is a safety and convenience feature in modern vehicles that prevents rollback when starting on an incline. Without this system, a driver on a slope must quickly transition from the brake to the accelerator to avoid rolling backward. HAC automatically maintains brake pressure for a short duration (usually 2–3 seconds) after the driver releases the brake pedal, giving enough time to engage the accelerator smoothly. This function is especially helpful in manual transmission vehicles, where coordinating the clutch and accelerator on a hill can be challenging, but it is also increasingly included in automatic cars for driver comfort and safety.

How It Works
HAC integrates with the braking system, ABS (Anti-lock Braking System), and wheel-speed sensors to detect the slope and vehicle's movement. The sequence is:

1. Slope detection – Sensors (inclinometer or ABS wheel sensors) recognize when the vehicle is stopped on an upward incline.
2. Brake hold – When the driver releases the brake pedal, the system keeps hydraulic brake pressure applied for a few seconds.
3. Release – As the driver presses the accelerator and the system detects forward movement (torque applied to wheels), it gradually releases the brake pressure.

If the driver does not accelerate within the short holding period, the brakes automatically release to avoid overheating.