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Notes On Clutches

A **clutch** is a mechanism for transmitting rotation, which can be engaged and disengaged. In everyday use, the term clutch refers to a subcomponent of motor vehicle engine's transmission designed to allow engagement or disengagement of the engine to the gearbox or whatever apparatus is being driven. Invention of the clutch is attributed to **Karl Benz**.

There are many different vehicle clutch designs, but most are based on one or more friction discs, pressed tightly together or against a flywheel using springs. The friction material is very similar to the material used in brake shoes and pads and used to contain asbestos. Also, clutches found in heavy duty applications such as trucks and competition cars use ceramic clutches that have a greatly increased friction coefficient, however these have a “grabby” action and are unsuitable for road cars. The spring pressure is released when the clutch pedal is depressed thus either pushing or pulling the diaphragm of the pressure plate, depending on type, and the friction plate is released and allowed to rotate freely. A wet clutch is immersed in a cooling lubricating fluid, which also keeps the surfaces clean and gives smoother performance and longer life. A dry clutch, as the name implies, is not bathed in fluid that robs it of some energy. Since the surfaces of a wet clutch can be slippery (as with a motorcycle clutch bathed in engine oil), stacking multiple clutch disks can compensate for slippage. Most Moto Guzzi and BMW motorcycles use a single plate clutch like a car.



Single, dry, clutch friction disc. The splined hub is attached to the disc with springs to damp chatter

In a car it is operated by the left-most pedal using hydraulics or a cable connection from the pedal to the clutch mechanism. Even though the clutch may physically be located very close to the pedal, such remote means of actuation are necessary to eliminate the effect of slight engine movement, engine mountings being flexible by design. With a rigid mechanical linkage, smooth engagement would be near-impossible, because engine movement inevitably occurs as the drive is “taken up”. No pressure on the pedal means that the clutch plates are engaged (driving), while depressing the pedal will disengage the clutch plates, allowing the driver to shift gears.

There are other clutches found in a car. For example, the radiator fan may have a clutch that is heat-activated. This is an electrorheological clutch, drive and driven members are selectively engaged by the application of a voltage to an electroheological fluid (ER). When the temperature is low, the fluid is thin and so the clutch slips. When the temperature is high, the fluid thickens, causing the fan to spin.

A manual transmission contains cogs for selecting gears. These cogs have matching teeth, called dog teeth, which means that the rotation speeds of the two parts have to match for engagement. This speed matching is achieved by a secondary clutch called a synchromesh, a device that uses frictional contact to bring the two parts to the same speed, and a locking mechanism called a blocker ring to prevent engagement of the teeth (full movement of the shift lever into gear) until the speeds are synchronized.

On most motorcycles, the clutch is operated by the clutch lever, located on the left handlebar. No pressure on the lever means that the clutch plates are engaged (driving), while pulling the lever back towards the rider will disengage the clutch plates, allowing the rider to shift gears. Some cars and mopeds have a centrifugal clutch, using centrifugal forces to engage the clutch above certain rpm, see Saxomat.

While engaging the clutch, the engine speed may need to be increased from idle, using the manual throttle, so that the engine does not stall. However, raising the engine speed too high will cause excessive clutch plate wear and cause a harsh, jerky start. This kind of start is desired in drag racing and other competitions, however.

A clutch may also be a device on a shaft that will “slip” when higher than normal resistance is encountered on a machine. An example of a clutch such as this may be mounted on the driving shaft of a large grass mower. The clutch will “slip” or “give” if the blades were to hit a rock, stump, or other immobile object.

Plate clutch

Axial or Plate Clutch

The Disk Clutch is used to transmit torque from an input to an output shaft via circular plates (disks). One of each pair of plates is coated with a friction lining material. The force applied to the friction element may be manual, electrical, pneumatic, hydraulic or inertial via a mechanical linkage. As the input and output shafts are fixed the clutch should include a method of allowing the driving plates to move axially against the driven plates which are fixed to the driven shaft (or vice versa).

A selection of disk clutch plate materials with their important properties

Desirable Properties for friction materials/linings for clutches

- The two materials in contact must have a high coefficient of friction.
- The materials in contact must resist wear effects, such as scoring, galling, and ablation.
- The friction value should be constant over a range of temperatures and pressures
- The materials should be resistant to the environment (moisture, dust, pressure)
- The materials should possess good thermal properties, high heat capacity, good thermal conductivity, withstands high temperatures
- Able to withstand high contact pressures
- Good shear strength to transfer friction forces to structure
- Should be safe to use and acceptable for the environment

Note: Brake materials from asbestos are not safe and are no longer acceptable for use in brakes and clutches

Important properties of materials used for brakes and clutches

Note: These properties are very general in nature and should not be used for detail design.

Suppliers information should be used for important work. Asbestos should not be used for new or replacement equipment.

Material Combination	Coefficient of Friction		Temp.(max)	Pressure (Max)
	Wet	Dry	Deg.C	MPa
Cast Iron/Cast Iron	0,05	0,15-0,20	300	0,8
Cast Iron/Steel	0,06	0,15-0,20	300	0,8-1,3
Hard Steel/Hard Steel	0,05	0,15-0,20	300	0,7
Wood/Cast Iron-steel	0,16	0,2-0,35	150	0,6
Leather/Cast Iron-steel	0,12-0,15	0,3-0,5	100	0,25
Cork/Cast Iron-Steel	0,15-0,25	0,3-0,5	100	0,1
<u>Felt/Cast Iron- Steel</u>	<u>0,18</u>	<u>0,22</u>	<u>140</u>	<u>0,06</u>
<u>Woven Asbestos/Cast Iron-Steel</u>	<u>0,1-0,2</u>	<u>0,3-0,6</u>	<u>250</u>	<u>0,7</u>
<u>Moulded Asbestos/Cast Iron-Steel</u>	<u>0,08-0,12</u>	<u>0,2-0,5</u>	<u>250</u>	<u>1,0</u>
<u>Impregnated Asbestos/Cast Iron-Steel</u>	<u>0,12</u>	<u>0,32</u>	<u>350</u>	<u>1.0</u>
<u>Carbon-graphite/Cast Iron-Steel</u>	<u>0,05-0,1</u>	<u>0,25</u>	<u>500</u>	<u>2.1</u>
<u>Kelvar/Cast Iron-Steel</u>	<u>0,05-0,1</u>	<u>0,35</u>	<u>325</u>	<u>3,0</u>

Nomenclature

F = Applied Force (N)

P = Clutch transmitted Power kW

M = Torque (Nm)

F = Actuating Force (N)

μ = Coefficient of Friction.

r = Radius of clutch ring thickness dr (m)

r_i, r_o = Inner, Outer radius of clutch plate. (m)

n = Rotational Speed (RPM)

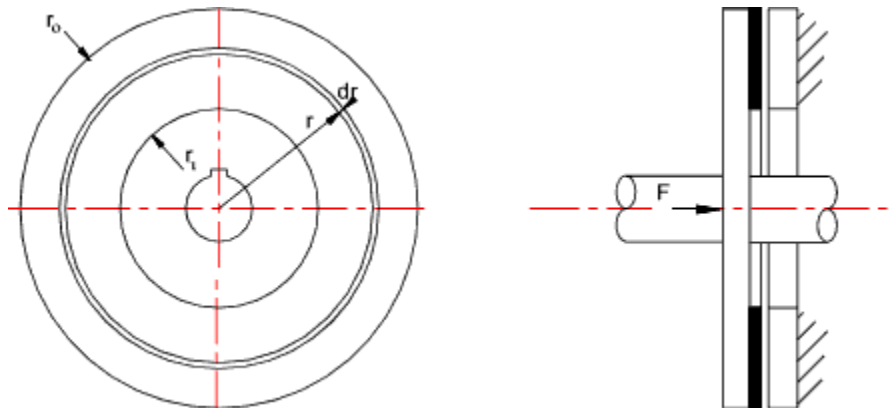
p = Pressure for friction surface(N/m²)

p_{max} = Maximum pressure for friction surface(N/m²)

Theory

There are two operating conditions applicable to clutch plates

- Uniform wear.. Applicable for practical clutch assemblies after period of operation
- Uniform pressure.. Applicable for new clutch plates.



The plate clutch is used in automotive and industrial service to connect and disconnect the transmission of rotation / torque / power.

To determine the torque transmitted it is necessary to make an assumption about the pressure distribution over the friction surfaces. For perfectly aligned new surfaces, it could be assumed that the pressure is uniformly distributed over the entire surface. However once the system has had some use, a better assumption is that the rate of wear is uniform over the friction surfaces. As a first approximation it can be assumed that the wear rate is proportional to the product of the velocity of sliding and the pressure. Since the sliding velocity is proportional to the radius r to the annular element dr , the following can be written:

wear = k p r, since the wear is constant for the entire face, the maximum pressure will occur at the inner radius, r_i hence wear = k $p_{\max} r_i$

Eliminating wear and the constant, k, gives the pressure at any radius, p

$$p = p_{\max} r_i / r$$

The total force F_n which must be exerted by the actuating spring, is found by multiplying the element area $2 \times 3.142 \times r \times dr$, by the pressure and integrating over the surface. This gives

$$F_n = 2 \times 3.142 \times p_{\max} r_i (r_o - r_i)$$

The torque is found by multiplying the force on the element by the coefficient of friction, f, and the radius, and integrating over the area. This gives:

$$T = 3.142 \times f \times p_{\max} \times r_i (r_o^2 - r_i^2) = 0.5 f (r_o + r_i) F_n$$

Single plate clutches have lining on both sides of the plate. Multiple plate disc clutches have friction linings on both sides of alternate plates. The above gives the torque for a single face, thus this quantity must be multiplied by the number of friction faces to find the torque for the entire clutch.

Uniform wear

The wear (W) at any location on a clutch is assumed to be proportional to the pressure intensity (p) and the associated relative velocity (v) of the local ring of contact.

Wear is proportional to pv which is proportional to pr

Therefore $W = kpr$ where k is a proportionality constant

$W/k = pr = K$... K = constant because both W and k are constants

Because pr is a constant then the maximum pressure occurs at the minimum radius.

Therefore $K = pr = p_{\max} r_i$ or $p = p_{\max} r_i / r$

The maximum permissible pressure ($p_{\max}$) depends on the friction material used.

The actuating force F is normal to the friction surface and equates to the integral of the pressure x area over the friction surface.

$$F = \int_{r_i}^{r_o} p \cdot 2 \cdot \pi \cdot r \cdot dr = \int_{r_i}^{r_o} p_{\max} \cdot 2 \cdot \pi \cdot \frac{r_i}{r} dr = p_{\max} \cdot 2 \cdot \pi \cdot r_i (r_o - r_i)$$

The torque capacity of a clutch plate is the integral of the friction force (μF) x Radius (r)

$$T = \int_{r_i}^{r_o} r \cdot \mu \cdot p \cdot 2 \cdot \pi \cdot r \cdot dr = \int_{r_i}^{r_o} 2 \cdot \pi \cdot \mu \cdot r^2 \cdot p_{\max} \frac{r_i}{r} dr = \pi \cdot \mu \cdot r_i \cdot p_{\max} \cdot (r_o^2 - r_i^2)$$

$$= \pi \cdot \mu \cdot r_i \cdot p_{\max} \cdot (r_o - r_i) \cdot (r_o + r_i) = \frac{F \cdot \mu \cdot (r_o + r_i)}{2}$$

Uniform pressure

When considering the capacity of a disk clutch plate subject uniform pressure, every point on the clutch plate face is subject to the the maximum design pressure for the friction material. This condition applies mainly to new clutch plates

The actuating force F is normal to the friction surface and equates to the integral of the pressure x area over the friction surface.

$$F = \int_{r_i}^{r_o} p_{\max} \cdot 2 \cdot \pi \cdot r \cdot dr = p_{\max} \cdot \pi \cdot (r_o^2 - r_i^2)$$

The torque capacity of a clutch plate is the integral of the friction force (μF) x Radius (r)

$$T = \int_{r_i}^{r_o} r \cdot \mu \cdot p_{\max} \cdot 2 \cdot \pi \cdot r \cdot dr = \frac{2}{3} \pi \cdot \mu \cdot p_{\max} \cdot (r_o^3 - r_i^3) = \frac{2}{3} F \cdot \mu \cdot \frac{(r_o^3 - r_i^3)}{(r_o^2 - r_i^2)}$$

Multiple Plate

The above theory relates to single plate clutches. For multiple plates in contact the torque values should be multiplied by the number of contacting plates

Cone clutch

A **cone clutch** serves the same purpose as a disk or plate clutch. However, instead of mating two spinning disks, the cone clutch uses two conical surfaces to transmit friction and torque. The cone clutch transfers a higher torque than plate or disk clutches of the same size due to the wedging action and increased surface area. Cone clutches are generally now only used in low peripheral speed applications although they were once common in automobiles and other combustion engine transmissions. They are usually now confined to very specialist transmissions in racing, rallying, or in extreme off-road vehicles, although they are common in power boats.

The clutch drives between internal and external cones instead of plates. The clutch is engaged when the inner cone (external) is forced into the outer (internal) cone. The cone clutch utilizes the wedging action of the parts to increase the normal force on the lining. Thus an increase in the tangential friction and the torque results. The clutch has improved thermal properties over a plate clutch .

The cone clutch is an axially actuated clutch which is able to transmit a relatively high torque for its size compared to a single disk plate clutch of the same dimensions. This results from the wedging action and increased friction area. Cone clutches are not used widely now and are generally used for low peripheral speed applications.

The cone angle α is always above 8° and is normally between 12° and 15° . If the angle is less than this value then the clutch is liable to jam in engagement.

Nomenclature

F_a = Axial Applied Force (N)

F_n = Axial Normal Force (N)

P = Clutch Power kW

M = Clutch Torque (Nm)

μ = Coefficient of Friction.

r = Radius of clutch ring thickness dr (m)

r_i, r_o = Inner, Outer radius of clutch. (m)

n = Rotational Speed (RPM)

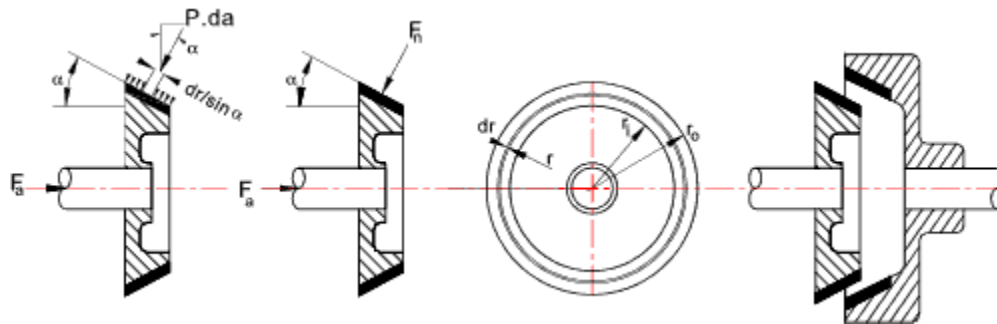
p = Pressure for friction surface (N/m^2)

p_{max} = Maximum pressure for friction surface (N/m^2)

Theory

There are two operating conditions applicable to clutch plates

- Uniform wear. Applicable for practical clutch assemblies after period of operation
- Uniform pressure. Applicable for new clutch plate friction linings.



Cone Clutch

Wear is proportional to p_v which is proportional to p_r

Therefore $W = kpr$ where k is a proportionality constant

$W/k = pr = K$... $K = \text{constant}$ because both W and k are constants

Because pr is a constant then the maximum pressure occurs at the minimum radius.

Therefore $K = pr = p_{\max} r_i$ or $p = p_{\max} r_i / r$

The maximum permissible pressure ($p_{\max}$) depends on the friction material used.

Referring to figure above consider an element of area dA of radius r and width $dr / \sin \alpha$ therefore $dA = (2 \cdot \pi \cdot r \cdot dr) / \sin \alpha$.

Uniform Wear

$$F_a = \int p \cdot dA \sin \alpha = \int_{r_i}^{r_o} \left(p_{\max} \cdot \frac{r_i}{r} \right) \left(\frac{2 \cdot \pi \cdot r \cdot dr}{\sin \alpha} \right) \sin \alpha = 2 \cdot \pi \cdot p_{\max} r_i \int_{r_i}^{r_o} dr = 2 \cdot \pi \cdot p_{\max} r_i (r_o - r_i)$$

The torque capacity of the clutch is the integral of the product of friction force of the area element and the associated radius.

$$T = \int \mu \cdot p \cdot dA \cdot r = \int_{r_i}^{r_o} \left(p_{\max} \cdot \frac{r_i}{r} \right) \left(\frac{2 \cdot \pi \cdot r \cdot dr}{\sin \alpha} \right) \mu \cdot r = \frac{2 \cdot \pi \cdot p_{\max} r_i}{\sin \alpha} \int_{r_i}^{r_o} r \cdot dr = \frac{\mu \cdot \pi \cdot p_{\max} r_i}{\sin \alpha} \cdot (r_o^2 - r_i^2)$$

From the above formulae for Force and torque it is clear that:

$$T = F \cdot \mu \cdot (r_o + r_i) / (2 \cdot \sin \alpha)$$

For uniform pressure $p = r p_{\max}$ therefore

$$F_a = \int p \cdot dA \sin \alpha = \int_{r_i}^{r_o} p_{\max} \cdot \left(\frac{2 \cdot \pi \cdot r \cdot dr}{\sin \alpha} \right) \sin \alpha = \pi \cdot p_{\max} r_i (r_o^2 - r_i^2)$$

$$T = \int \mu \cdot p \cdot dA \cdot r = \int_{r_i}^{r_o} p_{\max} \cdot \mu \cdot r \left(\frac{2 \cdot \pi \cdot r \cdot dr}{\sin \alpha} \right) = \frac{2 \cdot \mu \cdot \pi p_{\max} r_i}{3 \cdot \sin \alpha} (r_o^3 - r_i^3)$$