Brake

A **brake** is a mechanical device that inhibits motion by absorbing energy from a moving system.[1] It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction.

Functions

Most brakes commonly use friction between two surfaces pressed together to convert the kinetic energy of the moving object into heat, though other methods of energy conversion may be employed. For example, regenerative braking converts much of the energy to electrical energy, which may be stored for later use. Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Eddy current brakes use magnetic fields to convert kinetic energy into electric current in the brake disc, fin, or rail, which is converted into heat. Still other braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel.

Brakes are generally applied to rotating axles or wheels, but may also take other forms such as the surface of a moving fluid (flaps deployed into water or air). Some vehicles use a combination of braking mechanisms, such as drag racing cars with both wheel brakes and a parachute, or airplanes with both wheel brakes and drag flaps raised into the air during landing.

Since kinetic energy increases quadratically with velocity ( ), an object moving at 10 m/s has 100 times as much energy as one of the same mass moving at 1 m/s, and consequently the theoretical braking distance, when braking at the traction limit, is 100 times as long. In practice, fast vehicles usually have significant air drag, and energy lost to air drag rises quickly with speed.

Almost all wheeled vehicles have a brake of some sort. Even baggage carts and shopping carts may have them for use on a moving ramp. Most fixed-wing aircraft are fitted with wheel brakes on the undercarriage. Some aircraft also feature air brakes designed to reduce their speed in flight. Notable examples include gliders and some World War II-era aircraft, primarily some fighter aircraft and many dive bombers of the era. These allow the aircraft to maintain a safe speed in a steep descent. The Saab B 17 dive bomber and Vought F4U Corsair fighter used the deployed undercarriage as an air brake.

Friction brakes on automobiles store braking heat in the drum brake or disc brake while braking then conduct it to the air gradually. When traveling downhill some vehicles can use their engines to brake.

When the brake pedal of a modern vehicle with hydraulic brakes is pushed against the master cylinder, ultimately a piston pushes the brake pad against the brake disc which slows the wheel down. On the brake drum it is similar as the cylinder pushes the brake shoes against the drum which also slows the wheel down.

Types

Brakes may be broadly described as using friction, pumping, or electromagnetics. One brake may use several principles: for example, a pump may pass fluid through an orifice to create friction:

1. **Frictional**

Frictional brakes are most common and can be divided broadly into "shoe" or "pad" brakes, using an explicit wear surface, and hydrodynamic brakes, such as parachutes, which use friction in a working fluid and do not explicitly wear. Typically the term "friction brake" is used to mean pad/shoe brakes and excludes hydrodynamic brakes, even though hydrodynamic brakes use friction. Friction (pad/shoe) brakes are often rotating devices with a stationary pad and a rotating wear surface. Common configurations include shoes that contract to rub on the outside of a rotating drum, such as a band brake; a rotating drum with shoes that expand to rub the inside of a drum, commonly called a "drum brake", although other drum configurations are possible; and pads that pinch a rotating disc, commonly called a "disc brake". Other brake configurations are used, but less often. For example, PCC trolley brakes include a flat shoe which is clamped to the rail with an electromagnet; the Murphy brake pinches a rotating drum, and the Ausco Lambert disc brake uses a hollow disc (two parallel discs with a structural bridge) with shoes that sit between the disc surfaces and expand laterally.

A drum brake is a vehicle brake in which the friction is caused by a set of brake shoes that press against the inner surface of a rotating drum. The drum is connected to the rotating roadwheel hub.

Drum brakes generally can be found on older car and truck models. However, because of their low production cost, drum brake setups are also installed on the rear of some low-cost newer vehicles. Compared to modern disc brakes, drum brakes wear out faster due to their tendency to overheat.

The disc brake is a device for slowing or stopping the rotation of a road wheel. A brake disc (or rotor in U.S. English), usually made of cast iron or ceramic, is connected to the wheel or the axle. To stop the wheel, friction material in the form of brake pads (mounted in a device called a brake caliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop.

Ceramic brakes,[3] also called "carbon ceramic", are high-end type of frictional brakes with brake pads and rotors made from porcelain compound blends, that feature better stopping capability and greater resistance to overheat. Due to their high production cost, ceramic brakes aren't widely used as factory equipment, and their availability on the automotive aftermarket is low compared to traditional metallic brakes. However, being performance-oriented equipment, ceramic brakes are popular among racers.

2. Pumping

Pumping brakes are often used where a pump is already part of the machinery. For example, an internal-combustion piston motor can have the fuel supply stopped, and then internal pumping losses of the engine create some braking. Some engines use a valve override called a Jake brake to greatly increase pumping losses. Pumping brakes can dump energy as heat, or can be regenerative brakes that recharge a pressure reservoir called a hydraulic accumulator.

3. Electromagnetic

Electromagnetic brakes are likewise often used where an electric motor is already part of the machinery. For example, many hybrid gasoline/electric vehicles use the electric motor as a generator to charge electric batteries and also as a regenerative brake. Some diesel/electric railroad locomotives use the electric motors to generate electricity which is then sent to a resistor bank and dumped as heat. Some vehicles, such as some transit buses, do not already have an electric motor but use a secondary "retarder" brake that is effectively a generator with an internal short-circuit. Related types of such a brake are eddy current brakes, and electro-mechanical brakes (which actually are magnetically driven friction brakes, but nowadays are often just called "electromagnetic brakes" as well).

Electromagnetic brakes slow an object through electromagnetic induction, which creates resistance and in turn either heat or electricity. Friction brakes apply pressure on two separate objects to slow the vehicle in a controlled manner.

Characteristics

Brakes are often described according to several characteristics including:

- **Peak force** – The peak force is the maximum decelerating effect that can be obtained. The peak force is often greater than the traction limit of the tires, in which case the brake can cause a wheel skid.
- **Continuous power dissipation** – Brakes typically get hot in use, and fail when the temperature gets too high. The greatest amount of power (energy per unit time) that can be dissipated through the brake without failure is the continuous power dissipation. Continuous power dissipation often depends on e.g., the temperature and speed of ambient cooling air.
- **Fade** – As a brake heats, it may become less effective, called brake fade. Some designs are inherently prone to fade, while other designs are relatively immune. Further, use considerations, such as cooling, often have a big effect on fade.
- **Smoothness** – A brake that is grabby, pulses, has chatter, or otherwise exerts varying brake force may lead to skids. For example, railroad wheels have little traction, and friction brakes without an anti-skid mechanism often lead to skids, which increases maintenance costs and leads to a "thump thump" feeling for riders inside.
- **Power** – Brakes are often described as "powerful" when a small human application force leads to a braking force that is higher than typical for other brakes in the same class. This notion of "powerful" does not relate to continuous power dissipation, and may be confusing in that a brake may be "powerful" and brake strongly with a gentle brake application, yet have lower (worse) peak force than a less "powerful" brake.
- **Pedal feel** – Brake pedal feel encompasses subjective perception of brake power output as a function of pedal travel. Pedal travel is influenced by the fluid displacement of the brake and other factors.
- **Drag** – Brakes have varied amount of drag in the off-brake condition depending on design of the system to accommodate total system compliance and deformation that exists under braking with ability to retract friction material from the rubbing surface in the off-brake condition.
- **Durability** – Friction brakes have wear surfaces that must be renewed periodically. Wear surfaces include the brake shoes or pads, and also the brake disc or drum. There may be tradeoffs, for example a wear surface that generates high peak force may also wear quickly.
- **Weight** – Brakes are often "added weight" in that they serve no other function. Further, brakes are often mounted on wheels, and unsprung weight can significantly hurt traction in some circumstances. "Weight" may mean the brake itself, or may include additional support structure.
- **Noise** – Brakes usually create some minor noise when applied, but often create squeal or grinding noises that are quite loud.

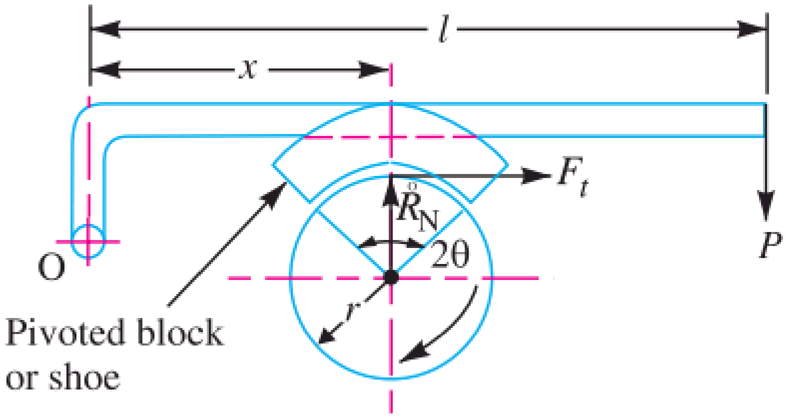
Inefficiency

A significant amount of energy is always lost while braking, even with regenerative braking which is not perfectly efficient. Therefore, a good metric of efficient energy use while driving is to note how much one is braking. If the majority of deceleration is from unavoidable friction instead of braking, one is squeezing out most of the service from the vehicle. Minimizing brake use is one of the fuel economy-maximizing behaviors.

While energy is always lost during a brake event, a secondary factor that influences efficiency is "off-brake drag", or drag that occurs when the brake is not intentionally actuated. After a braking event, hydraulic pressure drops in the system, allowing the brake caliper pistons to retract. However, this retraction must accommodate all compliance in the system (under pressure) as well as thermal distortion of components like the brake disc or the brake system will drag until the contact with the disc, for example, knocks the pads and pistons back from the rubbing surface.

During this time, there can be significant brake drag. This brake drag can lead to significant parasitic power loss, thus impact fuel economy and overall vehicle performance.

Pivoted Block or Shoe Brake



The angle of contact is less than 60°, then it may be assumed that the normal pressure between the block and the wheel is uniform. But when the angle of contact is greater than 60°, then the unit pressure normal to the surface of contact is less at the ends than at thecenter. In such cases, the block or shoe is pivoted to the lever, instead of being rigidly attached to the lever. This gives uniform wear of the brake lining in the direction of the applied force. The braking torque for a pivoted block or shoe brake (i.e. when 2θ > 60°) is given by

$$T_B = \mathring{F}_t \times r = \mu'.R_N.\ r$$

$$\mu' = \text{Equivalent coefficient of friction} = \frac{4\mu \sin\theta}{2\theta + \sin 2\theta}, \text{ and}$$

$$\mu = \text{Actual coefficient of friction.}$$

Band brakes:

The operating principle of this type of brake is the following. A flexible band of leather or rope or steel with friction lining is wound round a drum. Frictional torque is generated when tension is applied to the band. It is known (see any text book on engineering mechanics) that the tensions in the two ends of the band are unequal because of friction and bear the following relationship: 1 2 , T e T μ β = where = tension in the taut side, T1 = tension in the slack side, T2 μ = coefficient of kinetic friction and β = angle of wrap. If the band is wound around a drum of radius R, then the braking torque is T T TR T e br (12 1) (1) −μ β =− = − R Depending upon the connection of the band to the lever arm, the member responsible for application of the tensions, the band brakes are of two types, (a) Simple band brake: In simple band brake one end of the band is attached to the fulcrum of the lever arm (see figures 12.2.1(a) and 1(b)). The required force to be applied to the lever is 1 b P T l = for clockwise rotation of the brake drum and P T l = for anticlockwise rotation of the brake drum, where l = length of the lever arm and

b = perpendicular distance from the fulcrum to the point of attachment of other end of the band.

Differential band brake:

In this type of band brake, two ends of the band are attached to two points on the lever arm other than fulcrum (see figures 12.2.2(a) and 12.2.2(b)). Drawing the free body diagram of the lever arm and taking moment about the fulcrum it is found that 2 1 a PT T l l = − b , for clockwise rotation of the brake drum and 1 2 a PT T l l = − b , for anticlockwise rotation of the brake drum. Hence, P is negative if

e T b μ β = > for clockwise rotation of the brake drum and 1 2 T a e T b μ β = < for counterclockwise rotation of the brake drum. In these cases the force is to be applied on the lever arm in opposite direction to maintain equilibrium. The brakes are then self locking. The important design variables of a band brake are the thickness and width of the band. Since the band is likely to fail in tension, the following relationship is to be satisfied for safe operation. T wts 1 = T where w = width of the band, t = thickness of the band and = allowable tensile stress of the band material.

Band and block brakes:

Sometimes instead of applying continuous friction lining along the band, blocks of wood or other frictional materials are inserted between the band and the drum. In this case the tensions within the band at both sides of a block bear the relation 1 1 1 tan 1 tan T T μ θ μ θ + = ′ − , where = tension at the taut side of any block T1 = tension at the slack side of the same block T1 ′ 2θ = angle subtended by each block at center. If n number of blocks are used then the ratio between the tensions at taut side to slack side becomes 1 2 1 tan 1 tan n T T μ θ μ θ + = − . The braking torque is T TT br = − ( ) 1 2 R

Disc Brake

In this type of brake two friction pads are pressed axially against a rotating disc to dissipate kinetic energy. The working principle is very similar to friction clutch. When the pads are new the pressure distribution at pad-disc interface is uniform, i.e. p = constant . If F is the total axial force applied then F p A = , where A is the area of the pad. The frictional torque is given by braking A F T r A dA μ= v∫ where μ = coefficient of kinetic friction and r is the radial distance of an infinitesimal element of pad. After some time the pad gradually wears away. The wear becomes uniforms after sufficiently long time, when pr = constant = (say) c where dA F p dA c r = = v v ∫ ∫ . The braking torque is ' braking AF T pr dA Ac dA r μ = == μ μ ∫ ∫ v v It is clear that the total braking torque depends on the geometry of the pad. If the annular pad is used then 3 3 1 2 2 2 1 2 2 3 br R R T F R R μ − = − 1 2 2 br R R T Fμ + ′ = where 1 and R R2 are the inner and outer radius of the pad.

Friction materials and their properties.

The most important member in a mechanical brake is the friction material. A good friction material is required to possess the following properties: • High and reproducible coefficient of friction. • Imperviousness to environmental conditions. • Ability to withstand high temperature (thermal stability) • High wear resistance. • Flexibility and conformability to any surface. Some common friction materials are woven cotton lining, woven asbestos lining, molded asbestos lining, molded asbestos pad, Sintered metal pads etc.

Energy Consideration

It has been noted that the most common brakes employ friction to transform the braked system's mechanical energy, irreversibly into heat which is then transferred to the surrounding environment - • Kinetic energy is absorbed during slippage of either a clutch or brake, and this energy appears as heat. • If the heat generated is faster than it is dissipated, then the temperature rises. Thorough design of a brake therefore requires a detailed transient thermal analysis of the interplay between heat generated by friction, heat transferred through the lining and the surrounding metalwork to the environment, and the instantaneous temperature of the surface of the drum as well as the lining. For a given size of brake there is a limit to the mechanical power that can be transformed into heat and dissipated without lthe temperatures reaching damaging levels. Temperature of the lining is more critical and the brake size is characterized by lining contact area, A. The capacity of a clutch or brake is therefore limited by two factors: 1. The characteristics of the material and, 2. The ability of the brake to dissipate heat.

Heat Generated In Braking

During deceleration, the system is subjected to an essentially constant torque T exerted by the brake, and in the usual situation this constancy implies constant deceleration too. Application of the work or energy principle to the system enables the torque exerted by the brake and the work done by the brake, U, to be calculated from:-

$U = \Delta E = T\ \Delta\theta$ (2) Where ΔE is the loss of system total energy which is absorbed by the brake during deceleration, transformed into heat, and eventually dissipated. The elementary equations of constant rotational deceleration apply, thus when the brake drum is brought to rest from an initial speed ωo :- Deceleration = ωo 2 / 2 (1) $\Delta\theta = \omega m.\Delta t$; $\omega m = \omega o/2 = \Delta\theta/\Delta t$ where ωm is the mean drum speed over the deceleration period. The mean rate of power transformation by the brake over the braking period is :- $Pm = U / \Delta t = T\ \omega m$ (3) which forms a basis for the selection or the design of the necessary brake dimensions. The rise in temperature in the lining material is also important as rate of wear is also a function of the temperature. Further for any lining material, the maximum allowable temperature is also another performance criteria.

Temperature Rise

The temperature rise of the brake assembly can be approximated by the classic expression,, E T C.m Δ = Where is temperature ΔT is rise in temperature in o C,'C' is the specific heat of the brake drum material – (500J/Kg for steel or Cast Iron) and m is the mass (kg) of the brake parts dissipating the heat into the surroundings. Though the equation appears to be simple, there are so many variables involved that it would be most unlikely that such an analysis would even approximate experimental results. On the other hand the temperature-rise equations can be used to explain what happens when a clutch or brake is operated frequently. For this reason such analysis are most useful, for repetitive cycling, in pin pointing those design parameters that have the greatest effect on performance. An object heated to a temperature T1 cools to an ambient temperature Ta according to the exponential relation.

Time-temperature relation

(AU / WC)t T T (T T)e i a 1 a − − = − Where T1 = instantaneous temperature at time t, ˚C A= heat transfer area, m2 U= Heat Transfer coefficient, W/(m2 .s. ˚C) T1 = Initial temperature, ˚C Ta = Ambient temperature, ˚C C - Specific heat t - time of operation, s

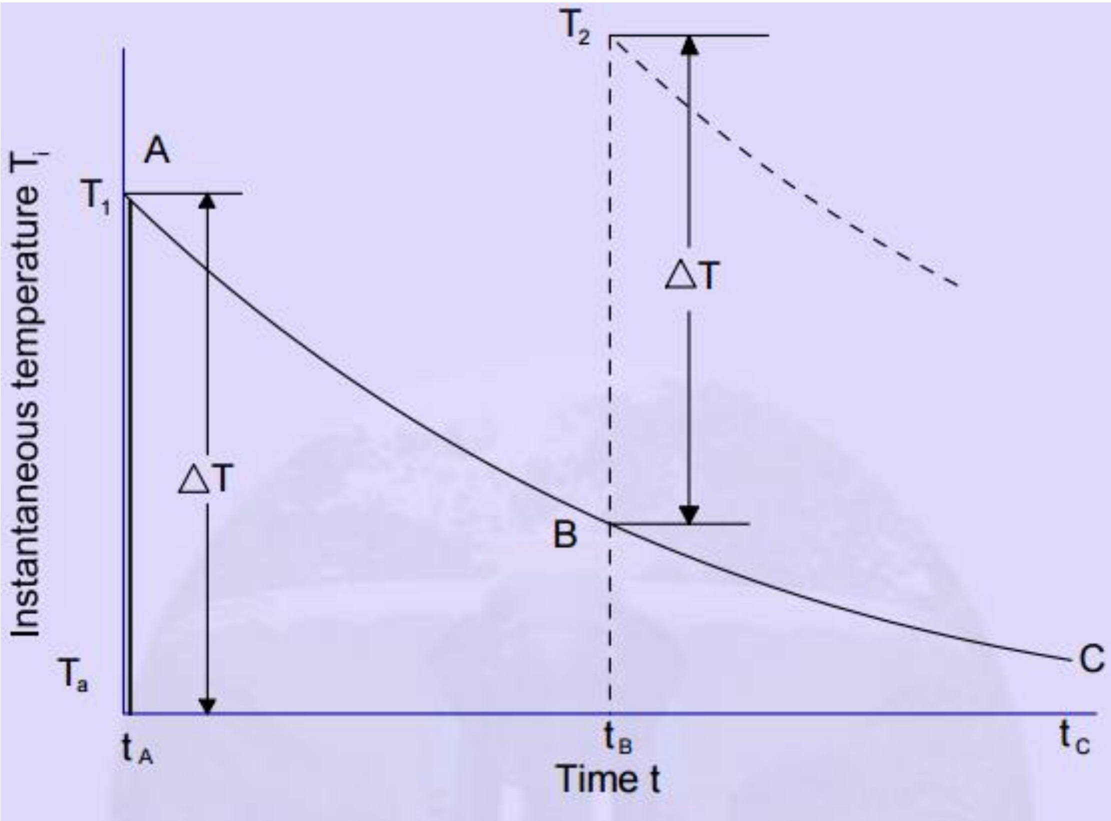


Figure shows an application of Eq. (a). At time tA a clutching or braking operation causes the temperature to rise to T1 at A. Though the rise occurs in a finite time interval, it is assumed to occur instantaneously. The temperature then drops along the decay line ABC unless interrupted by another braking operation. If a second operation occurs at time tB, the temperature will rise along the dashed line to T2 and then begin an exponential drop as before. About 5 -10 % of the heat generated at the sliding interface of a friction brake must be transferred through the lining to the surrounding environment without allowing the lining to reach excessive temperatures, since high temperatures lead to hot spots and distortion, to fade (the fall-off in friction coefficient) or, worse, to degradation and charring of the lining which often incorporates organic constituentsIn order to determine the brake dimensions the energy need to be absorbed during critical braking conditions is to be estimated.

Energy to be Absorbed

If t is the time of brake application and ωm the mean or average angular velocity then the energy to be absorbed in braking E E = T. ωm .t = Ek+ Ep+ Ei where Ek is the kinetic energy of the rotating system Ep is the potential energy of the moving system Ei is the inertial energy of the system Energy to be absorbed ( ) k 2 2 2 2 1 1 E 2 g 1 mv 2 1 v v 2 g ω = = ω = − ( ) p 2 i 2 2 2 1 E mgh h 1 E I 2 1 I 2 = = ω = ω = ω −ω

Frictional Material

A brake or clutch friction material should have the following characteristics to a degree, which is dependent upon the severity of the service. • A high and uniform coefficient of friction. • Imperviousness to environmental conditions, such as moisture. • The ability to withstand high temperatures together with good thermal conductivity. • Good resiliency. • High resistance to wear, scoring, and galling.

Electromagnetic Braking/ Fail-Safe Brake

Electromagnetic brakes (also called **electro-mechanical brakes** or **EM brakes**) slow or stop motion using electromagnetic force to apply mechanical resistance (friction). The original name was "electro-mechanical brakes" but over the years the name changed to "electromagnetic brakes", referring to their actuation method. Since becoming popular in the mid-20th century especially in trains and trams, the variety of applications and brake designs has increased dramatically, but the basic operation remains the same.

Both electromagnetic brakes and eddy current brakes use electromagnetic force but electromagnetic brakes ultimately depend on friction and eddy current brakes use magnetic force directly.

Thermal Considerations

During braking the kinetic energy of the car is converted into thermal energy through friction in the brakes. The heat from the rotors can have detrimental effect on the performance of the brake and other components of the car.

Once the rotor and the pad temperature get high (over 400ºC) brake fades sets in. Brake fade reduces the brake torque for a given actuation.

If the temperate of the rotor exceeds the operational temperature range of the pad, the coefficient of friction for the pad will start decreasing. This will reduce the brake torque for a given actuating force. Furthermore, there is the possibility of vaporization in the bonding material. The vapour forms a layer of high pressure gas between the pad and the disc which acts as a lubricant and reduces the coefficient of friction. This can be eliminated by providing an escape path for these gases, by slotting or cross-drilling the rotor [1]. Thus, a cross-drilled design will be used by Crambo.

The heat generated from braking raises the temperature of surrounding components, such as the callipers, hub, upright, wheel rim, etc. The heating of the callipers will also cause the temperature of the brake fluid to rise. If the brake fluid starts to boil, air bubbles will form creating a spongy effect to the brake pedal and reduce the brake torque. The heating of the wheel rim can causes the tire pressure to increase which may result in unstable driving conditions for race applications. Furthermore the heating of the hub can lead to bearing failures due to the grease in the bearings vaporising. Thus keeping the temperature of the rotor cool is crucial.

The temperature rise of rotor is dependent on the material and the mass of the rotor. The mass depends on the diameter and the thickness of the rotor. Generally the larger the mass the more heat can be absorbed and the cooler the rotor.

Actuating Force and Brake Pedal

The actuating force calculations for the front and rear master cylinders are found in Appendix E. The mechanical advantage for the brake pedal can be approximated to be 4 to 1 using these calculations. Moreover it is important to note that the brake boost advantage is 5 to 1.