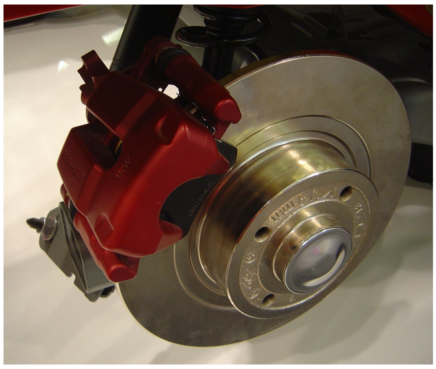
Disc brake

A **disc brake** is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc (or *rotor* in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads, mounted on 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. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade.



Close-up of a disc brake on a car

The development and use of disc-type brakes began in England in the 1890s. The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham, UK factory in 1902 and used successfully on Lanchester cars. Compared to drum brakes, disc brakes offer better stopping performance, because the disc is more readily cooled. As a consequence, disc brakes are less prone to brake fade, and disc brakes recover more quickly from immersion (wet brakes are less effective). Most drum brake designs have at least one leading shoe, which gives a servo-effect. By contrast, a disc brake has no self-servo effect and its braking force is always proportional to the pressure placed on the brake pad by the braking system via any brake servo, braking pedal or lever. This tends to give the driver better "feel" to avoid impending lockup. Drums are also prone to "bell mouthing", and trap worn lining material within the assembly, both causes of various braking problems.

On automobiles, disc brakes are often located within the wheel

motorbike disc brake of Kawasaki W800

History

Disc-style brakes development and use began in England in the 1890s. The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham factory in 1902 and used successfully on Lanchester cars. However, the limited choice of metals in this period meant that he had to use copper as the braking medium acting on the disc. The poor state of the roads at this time, no more than dusty, rough tracks, meant that the copper wore quickly, making the disc brake system non-viable (as recorded in *The Lanchester Legacy*). It took another half century for his innovation to be widely adopted.

The 1950 Crosley Hot Shot is often given credit for the first U.S. production disc brakes but the Chrysler Crown Imperial actually had them first as standard equipment at the beginning of the 1949 model year. The Crosley disc was a Goodyear development, a caliper type with ventilated rotor, originally designed for aircraft applications. Only the Hot Shot featured it. Lack of sufficient research caused enormous reliability problems, especially in regions requiring the use of salt on winter roads, such as sticking and corrosion. Drum brake conversions for Hot Shots were quite popular.

The Chrysler four-wheel disc brake system was more complex and expensive than Crosley's, but far more efficient and reliable. It was built by Auto Specialties Manufacturing Company (Ausco) of St. Joseph, Michigan, under patents of inventor H.L. Lambert, and was first tested on a 1939 Plymouth. Unlike the caliper disc, the Ausco-Lambert used twin expanding discs that rubbed against the inner surface of a cast-iron brake drum, which doubled as the brake housing. The discs spread apart to create friction against the inner drum surface through the action of standard wheel cylinders.

Chrysler discs were "self energizing," in that some of the braking energy itself contributed to the braking effort. This was accomplished by small balls set into oval holes leading to the brake surface. When the disc made initial contact with the friction surface, the balls would be forced up the holes forcing the discs further apart and augmenting the braking energy. This made for lighter braking pressure than with calipers, avoided brake fade, promoted cooler running, and provided one-third more friction surface than standard Chrysler twelve-inch drums. But because of the expense, the brakes were only standard on the Chrysler Crown Imperial through 1954 and the Town and Country Newport in 1950. They were optional, however, on other Chryslers, priced around $400, at a time when an entire Crosley Hot Shot retailed for $935. Today's owners consider the Ausco-Lambert very reliable and powerful, but admit its grabbiness and sensitivity.

Reliable caliper-type disc brakes were developed in the UK by Dunlop and first appeared in 1953 on the Jaguar C-Type racing car. The 1955 Citroën DS featuring powered inboard front disc brakes was the first French application of this technology, while the 1956 Triumph TR3 was the first English production car to feature modern disc brakes. The first production car to have disc brakes at all 4 wheels was the Austin-Healey 100S in 1954. The first British company to market a production saloon (sedan) fitted with disc brakes to all four wheels was Jensen Motors with the introduction of a Deluxe version of the Jensen 541 with Dunlop disc brakes. The first German production car with disc brakes was the 1961 Mercedes-Benz 220SE coupe featuring British-built Girling units on the front. The next American production automobile equipped with caliper-type disc brakes was the 1963 Studebaker Avanti (the Bendix system was optional on some of the other Studebaker models). Front disc brakes became standard equipment in 1965 on the Rambler Marlin (the Bendix units were optional on all American Motors' Rambler Classic and Ambassador models), as well as on the Ford Thunderbird, and the Lincoln Continental. A four-wheel disc brake system was also introduced in 1965 on the Chevrolet Corvette Stingray.

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Many early implementations for automobiles located the brakes on the inboard side of the driveshaft, near the differential, but most brakes today are located inside the road wheels. (An inboard location reduces the unsprung weight and eliminates a source of heat transfer to the tires.)

Disc brakes were most popular on sports cars when they were first introduced, since these vehicles are more demanding about brake performance. Discs have now become the more common form in most passenger vehicles, although many (particularly light weight vehicles) use drum brakes on the rear wheels to keep costs and weight down as well as to simplify the provisions for a parking brake. As the front brakes perform most of the braking effort, this can be a reasonable compromise.

The first motorcycles to use disc brakes were racing vehicles. The first mass-produced road-going motorcycle to sport a disc-brake was the 1969 Honda CB750. Disc brakes are now common on motorcycles, mopeds and even mountain bikes.

Historically, brake discs were manufactured throughout the world with a strong concentration in Europe and America. Between 1989 and 2005, manufacturing of brake discs migrated predominantly to China.

Brake disc

The **brake disc** is the disc component of a disc brake against which the brake pads are applied. The material is typically grey iron, a form of cast iron. The design of the disc varies somewhat. Some are simply solid, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces (usually included as part of a casting process). The weight and power of the vehicle determines the need for ventilated discs. The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily-loaded front discs.

Many higher-performance brakes have holes drilled through them. This is known as cross-drilling and was originally done in the 1960s on racing cars. For heat dissipation purposes, cross drilling is still used on some braking components, but is not favored for racing or other hard use as the holes are a source of stress cracks under severe conditions.

Discs may also be slotted, where shallow channels are machined into the disc to aid in removing dust and gas. Slotting is the preferred method in most racing environments to remove gas and water and to deglaze brake pads. Some discs are both drilled and slotted. Slotted discs are generally not used on standard vehicles because they quickly wear down brake pads; however, this removal of material is beneficial to race vehicles since it keeps the pads soft and avoids vitrification of their surfaces.

As a way of avoiding thermal stress, cracking and warping, the disc is sometimes mounted in a half loose way to the hub with coarse splines. This allows the disc to expand in a controlled symmetrical way and with less unwanted heat transfer to the hub.

On the road, drilled or slotted discs still have a positive effect in wet conditions because the holes or slots prevent a film of water building up between the disc and the pads. Cross-drilled discs may eventually crack at the holes due to metal fatigue. Cross-drilled brakes that are manufactured poorly or subjected to high stresses will crack much sooner and more severely.

Motorcycles and scooters

A drilled motorcycle brake disc

In the 1920s Douglas built the first disc brakes.Wikipedia:Citation needed Motorcycle discs are usually stainless steel, drilled and occasionally slotted, to help remove rain water. Many motorcycle discs are of a floating design where the disc rides on small dowels and is allowed to slightly move laterally. This allows for better disc centering when used with a fixed caliper. It can also prevent heat transfer to the wheel hub under hard braking. This allows the disc to expand while heating up without increasing tension in such a way that the disc would become warped. Calipers have evolved from simple "single-piston" units to two-, four- and even six-piston items. Since (compared to cars) motorcycles have a higher centre of gravity:wheelbase ratio, they experience more weight transference when braking. The front brake(s) provide most of the required deceleration, while the rear brake serves mainly to "balance" the motorcycle during braking. A modern sports bike will typically have twin front discs of large diameter,

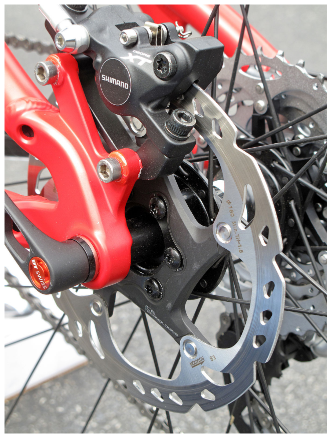
but only a very much smaller single rear disc. This is because the rear wheel can only transfer a fraction of the stopping power due to the weight transfer to the front that occurs when braking. The same effect lets the front wheel transfer a lot more stopping power before locking up.

Bicycles

See also: Bicycle brake § Disc brakes

Mountain bike disc brakes may range from simple, mechanical (cable) systems, to expensive and powerful, quad-piston hydraulic disc systems, commonly used on downhill racing bikes. Improved technology has seen the creation of the first vented discs for use on mountain bikes, similar to those on cars, introduced to help avoid heat fade on fast alpine descents. Although less common, discs are also used on road bicycles for all-weather cycling with predictable braking, although drums are sometimes preferred as harder to damage in crowded parking, where discs are sometimes bent. Most bicycle brake discs are made of steel. Stainless steel is preferred due to its anti-rust properties. Some lightweight discs are made of titanium or aluminium. Discs are thin, often about 2 mm. Some use a two-piece floating disc style, others use a floating caliper, others use pads that float in the caliper, and some use one moving pad that makes the caliper slide on its mounts, pulling the other pad into contact with the disc. Because the "motor" is small, an uncommon feature of bicycle brakes is that the pads retract to eliminate residual drag when the brake is released. In contrast, most other brakes drag the pads lightly when released so as to minimise initial operational travel.

Mountain bike front disc brake



Rear disc brake caliper and rotor on a mountain bike

Other vehicles

See also Railway disc brakes

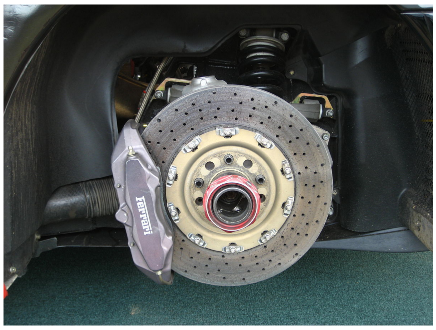
Disc brakes are increasingly used on very large and heavy road vehicles, where previously large drum brakes were nearly universal. One reason is that the disc's lack of self-assist makes brake force much more predictable, so peak brake force can be raised without more risk of braking-induced steering or jackknife on articulated vehicles. Another is disc brakes fade less when hot, and in a heavy vehicle air and rolling drag and engine braking are small parts of total braking force, so brakes are used harder than on lighter vehicles, and drum brake fade can occur in a single stop. For these reasons, a heavy truck with disc brakes can stop in about 120% the distance of a passenger car, but with drums stopping takes about 150% the distance. In Europe, stopping distance regulations essentially require disc brakes for heavy vehicles. In the U.S., drums are allowed and are typically preferred for their lower purchase price, despite higher total lifetime cost and more frequent service intervals.

Still-larger discs are used for railroad cars and some airplanes. Passenger rail cars and light rail vehicles often use disc brakes outboard of the wheels, which helps ensure a free flow of cooling air. In contrast, some airplanes have the brake mounted with very little cooling and the brake gets quite hot in a stop, but this is acceptable as there is then time for cooling, and where the maximum braking energy is very predictable.

A railroad bogie and disc brakes

For automotive use, disc brake discs are commonly manufactured out of a material called grey iron. The SAE maintains a specification for the manufacture of grey iron for various applications. For normal car and light-truck applications, SAE specification J431 G3000 (superseded to G10) dictates the correct range of hardness, chemical composition, tensile strength, and other properties necessary for the intended use. Some racing cars and airplanes use brakes with carbon fiber discs and carbon fiber pads to reduce weight. Wear rates tend to be high, and braking may be poor or grabby until the brake is hot.

Racing



Reinforced carbon brake disc on a Ferrari F430 Challenge race car

In racing and very-high-performance road cars, other disc materials have been employed. Reinforced carbon discs and pads inspired by aircraft braking systems such as those used on Concorde were introduced in Formula One by Brabham in conjunction with Dunlop in 1976. Carbon–carbon braking is now used in most top-level motorsport worldwide, reducing unsprung weight, giving better frictional performance and improved structural properties at high temperatures, compared to cast iron. Carbon brakes have occasionally been applied to road cars, by the French Venturi sports car manufacturer in the mid 1990s for example, but need to reach a very high operating temperature before becoming truly effective and so are not well suited to road use. The extreme heat generated in these systems is easily visible during night racing, especially at shorter tracks. It is not uncommon to be able to look at the cars, either live in person or on television and see the brake discs glowing red during application.

Ceramic composites

Mercedes Benz AMG carbon ceramic brake

Ceramic discs are used in some high-performance cars and heavy vehicles.

The first development of the modern ceramic brake was made by British engineers working in the railway industry for TGV applications in 1988. The objective was to reduce weight, the number of brakes per axle, as well as provide stable friction from very high speeds and all temperatures. The result was a carbon-fibre-reinforced ceramic process which is now used in various forms for automotive, railway, and aircraft brake applications.

Due to the high heat tolerance and mechanical strength of ceramic composite discs, they are often used on exotic vehicles where the cost is not prohibitive to the application. They are also found in industrial applications where the ceramic disc's light weight and low-maintenance properties justify the cost relative to alternatives. Composite brakes can withstand temperatures that would make steel discs bendable.

Porsche Carrera S composite ceramic brake

Porsche's Composite Ceramic Brakes (PCCB) are siliconized carbon fiber, with very high temperature capability, a 50% weight reduction over iron discs (therefore reducing the unsprung weight of the vehicle), a significant reduction in dust generation, substantially increased maintenance intervals, and enhanced durability in corrosive environments over conventional iron discs. Found on some of their more expensive models, it is also an optional brake for all street Porsches at added expense. It is generally recognized by the bright yellow paintwork on the aluminum six-piston calipers that are matched with the discs. The discs are internally vented much like cast-iron ones, and cross-drilled.

Adjustment mechanism

In automotive applications, the piston seal has a square cross section, also known as a square-cut seal.

As the piston moves in and out, the seal drags and stretches on the piston, causing the seal to twist. The seal distorts approximately 1/10 of a millimeter. The piston is allowed to move out freely, but the slight amount of drag caused by the seal stops the piston from fully retracting to its previous position when the brakes are released, and so takes up the slack caused by the wear of the brake pads, eliminating the need for return springs.

As the seal returns to its original shape when the brakes are released, it also helps to hold the brake pads slightly away from the rotors. As the seal wears out or loses elasticity with age, the action the seal provides will diminish, and the brake pads will drag more on the rotors in the neutral position. This is why calipers must be pushed in with a brake caliper retraction tool when installing new brake pads.

In some rear disc calipers, the parking brake activates a mechanism inside the caliper that performs some of the same function.

Disc damage modes

Discs are usually damaged in one of four ways: scarring, cracking, warping or excessive rusting. Service shops will sometimes respond to any disc problem by changing out the discs entirely, This is done mainly where the cost of a new disc may actually be lower than the cost of labour to resurface the old disc. Mechanically this is unnecessary unless the discs have reached manufacturer's minimum recommended thickness, which would make it unsafe to use them, or vane rusting is severe (ventilated discs only). Most leading vehicle manufacturers recommend brake disc skimming (US: turning) as a solution for lateral run-out, vibration issues and brake noises. The machining process is performed in a brake lathe, which removes a very thin layer off the disc surface to clean off minor damage and restore uniform thickness. Machining the disc as necessary will maximise the mileage out of the current discs on the vehicle.

Run-out

Run-out is measured using a dial indicator on a fixed rigid base, with the tip perpendicular to the brake disc's face. It is typically measured about $^1⁄_2$ in (12.7 mm) from the outside diameter of the disc. The disc is spun. The difference between minimum and maximum value on the dial is called lateral run-out. Typical hub/disc assembly run-out specifications for passenger vehicles are around 0.0020 in (50.8 μm). Runout can be caused either by deformation of the disc itself or by runout in the underlying wheel hub face or by contamination between the disc surface and the underlying hub mounting surface. Determining the root cause of the indicator displacement (lateral runout) requires disassembly of the disc from the hub. Disc face runout due to hub face runout or contamination will typically have a period of 1 minimum and 1 maximum per revolution of the brake disc.

Discs can be machined to eliminate thickness variation and lateral run-out. Machining can be done in situ (on-car) or off-car (bench lathe). Both methods will eliminate thickness variation. Machining on-car with proper equipment can also eliminate lateral run-out due to hub-face non-perpendicularity.

Incorrect fitting can distort (warp) discs; the disc's retaining bolts (or the wheel/lug nuts, if the disc is simply sandwiched in place by the wheel, as on many cars) must be tightened progressively and evenly. The use of air tools to fasten lug nuts is extremely bad practice, unless a torque tube is also used. The vehicle manual will indicate the proper pattern for tightening as well as a torque rating for the bolts. Lug nuts should never be tightened in a circle. Some vehicles are sensitive to the force the bolts apply and tightening should be done with a torque wrench.

Often uneven pad transfer is confused for disc warping. In reality, the majority of brake discs which are diagnosed as "warped" are actually simply the product of uneven transfer of pad material. Uneven pad transfer will often lead to a thickness variation of the disc. When the thicker section of the disc passes between the pads, the pads will move apart and the brake pedal will raise slightly; this is pedal pulsation. The thickness variation can be felt by the driver when it is approximately 0.17 mm (0.0067 in) or greater (on automobile discs).

This type of thickness variation has many causes, but there are three primary mechanisms which contribute the most to the propagation of disc thickness variations connected to uneven pad transfer. The first is improper selection of brake pads for a given application. Pads which are effective at low temperatures, such as when braking for the first time in cold weather, often are made of materials which decompose unevenly at higher temperatures. This uneven decomposition results in uneven deposition of material onto the brake disc. Another cause of uneven material transfer is improper break in of a pad/disc combination. For proper break in, the disc surface should be refreshed (either by machining the contact surface or by replacing the disc as a whole) every time the pads are changed on a vehicle. Once this is done, the brakes are heavily applied multiple times in succession. This creates a smooth, even interface between the pad and the disc. When this is not done properly the brake pads will see an uneven distribution of stress and heat, resulting in an uneven, seemingly random, deposition of pad material. The third primary mechanism of uneven pad material transfer is known as "pad imprinting." This occurs when the brake pads are heated to the point that the material begins to break-down and transfer to the disc. In a properly broken in brake system (with properly selected pads), this transfer is natural and actually is a major contributor to the braking force generated by the brake pads. However, if the vehicle comes to a stop and the driver continues to apply the brakes, the pads will deposit a layer of material in the shape of the brake pad. This small thickness variation can begin the cycle of uneven pad transfer.

Once the disc has some level of variation in thickness, uneven pad deposition can accelerate, sometimes resulting in changes to the crystal structure of the metal that composes the disc in extreme situations. As the brakes are applied, the pads slide over the varying disc surface. As the pads pass by the thicker section of the disc, they are forced outwards. The foot of the driver applied to the brake pedal naturally resists this change, and thus more force is applied to the pads. The result is that the thicker sections see higher levels of stress. This causes an uneven heating of the surface of the disc, which causes two major issues. As the brake disc heats unevenly it also expands unevenly. The thicker sections of the disc expand more than the thinner sections due to seeing more heat, and thus the difference in thickness is magnified. Also, the uneven distribution of heat results in further uneven transfer of pad material. The result is that the thicker-hotter sections receive even more pad material than the thinner-cooler sections, contributing to a further increase in the variation in the disc's thickness. In extreme situations, this uneven heating can actually cause the crystal structure of the disc material to change. When the hotter sections of the discs reach extremely high temperatures (1,200–1,300 °F or 649–704 °C), the carbon within the cast iron of the disc will react with the iron molecules to form a carbide known as cementite. This iron carbide is very different from the cast iron the rest of the disc is composed of. It is extremely hard, very brittle, and does not absorb heat well. After cementite is formed, the integrity of the disc is compromised. Even if the disc surface is machined, the cementite within the disc will not wear or absorb heat at the same rate as the cast iron surrounding it, causing the uneven thickness and uneven heating characteristics of the disc to return.

Scarring

Scarring (US: Scoring) can occur if brake pads are not changed promptly when they reach the end of their service life and are considered worn out. Once enough of the friction material has worn away, the pad's steel backing plate (for glued pads) or the pad retainer rivets (for riveted pads) will bear directly upon the disc's wear surface, reducing braking power and making scratches on the disc. Generally a moderately scarred / scored disc, which operated satisfactorily with existing brake pads, will be equally usable with new pads. If the scarring is deeper but not excessive, it can be repaired by machining off a layer of the disc's surface. This can only be done a limited number of times as the disc has a minimum rated safe thickness. The minimum thickness value is typically cast into the disc during manufacturing on the hub or the edge of the disc. In Pennsylvania, which has one of the most rigorous auto safety inspection programs in North America, an automotive disc cannot pass safety inspection if any scoring is deeper than .015 inches (0.38 mm), and must be replaced if machining will reduce the disc below its minimum safe thickness.

To prevent scarring, it is prudent to periodically inspect the brake pads for wear. A tire rotation is a logical time for inspection, since rotation must be performed regularly based on vehicle operation time and all wheels must be removed, allowing ready visual access to the brake pads. Some types of alloy wheels and brake arrangements will provide enough open space to view the pads without removing the wheel. When practical, pads that are near the wear-out point should be replaced immediately, as complete wear out leads to scarring damage and unsafe braking. Many disc brake pads will include some sort of soft steel spring or drag tab as part of the pad assembly, which is designed to start dragging on the disc when the pad is nearly worn out. The result is a moderately loud metallic squealing noise, alerting the vehicle user that service is required, and this will not normally scar the disc if the brakes are serviced promptly. A set of pads can be considered for replacement if the thickness of the pad material is the same or less than the thickness of the backing steel. In Pennsylvania, the standard is 1/32".

Cracking

Cracking is limited mostly to drilled discs, which may develop small cracks around edges of holes drilled near the edge of the disc due to the disc's uneven rate of expansion in severe duty environments. Manufacturers that use drilled discs as OEM typically do so for two reasons: appearance, if they determine that the average owner of the vehicle model will prefer the look while not overly stressing the hardware; or as a function of reducing the unsprung weight of the brake assembly, with the engineering assumption that enough brake disc mass remains to absorb racing temperatures and stresses. A brake disc is a heat sink, but the loss of heat sink mass may be balanced by increased surface area to radiate away heat. Small hairline cracks may appear in any cross drilled metal disc as a normal wear mechanism, but in the severe case the disc will fail catastrophically. No repair is possible for the cracks, and if cracking becomes severe, the disc must be replaced. These cracks occur due to the phenomenon of low cycle fatigue as a result of repeated hard braking.[1]

Rusting

The discs are commonly made from cast iron and a certain amount of surface rust is normal. The disc contact area for the brake pads will be kept clean by regular use, but a vehicle that is stored for an extended period can develop significant rust in the contact area that may reduce braking power for a time until the rusted layer is worn off again. Over time, vented brake discs may develop severe rust corrosion inside the ventilation slots, compromising the strength of the structure and needing replacement.

Calipers

Disc brake caliper (twin-piston, floating) removed from brake pad for changing pads

The **brake caliper** is the assembly which houses the brake pads and pistons. The pistons are usually made of plastic, aluminium or chrome-plated steel.

Calipers are of two types, floating or fixed. A fixed caliper does not move relative to the disc and is thus less tolerant of disc imperfections. It uses one or more single or pairs of opposing pistons to clamp from each side of the disc, and is more complex and expensive than a floating caliper.

A floating caliper (also called a "sliding caliper") moves with respect to the disc, along a line parallel to the axis of rotation of the disc; a piston on one side of the disc pushes the inner brake pad until it makes contact with the braking surface, then pulls the caliper body with the outer brake pad so pressure is applied to both sides of the disc. Floating caliper (single piston) designs are subject to sticking failure, caused by dirt or corrosion entering at least one mounting mechanism and stopping its normal movement. This can lead to the caliper's pad's rubbing on the disc when the brake is not engaged or engaging it at an angle. Sticking can result from infrequent vehicle use, failure of a seal or rubber protection boot allowing debris entry, dry-out of the grease in the mounting mechanism and subsequent moisture incursion leading to corrosion, or some combination of these factors. Consequences may include reduced fuel efficiency, extreme heating of the disc or excessive wear on the affected pad. A sticking front caliper may also cause steering vibration.

Various types of brake calipers are also used on bicycle rim brakes.

Pistons and cylinders

The most common caliper design uses a single hydraulically actuated piston within a cylinder, although high performance brakes use as many as twelve. Modern cars use different hydraulic circuits to actuate the brakes on each set of wheels as a safety measure. The hydraulic design also helps multiply braking force. The number of pistons in a caliper is often referred to as the number of 'pots', so if a vehicle has 'six pot' calipers it means that each caliper houses six pistons.

Brake failure can result from failure of the piston to retract, which is usually a consequence of not operating the vehicle during prolonged storage outdoors in adverse conditions. On high-mileage vehicles, the piston seals may leak, which must be promptly corrected. The brake disc must have enough surface to perform well, and the **coefficient of friction** is the most important factor to be considered when designing a brake system.

Brake pads

Main article: Brake pad

Brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Friction can be divided into two parts. They are: Adhesive and abrasive.

Depending on the properties of the material of both the pad and the disc and the configuration and the usage, pad and disc wear rates will vary considerably. The properties that determine material wear involve trade-offs between performance and longevity.

The brake pads must usually be replaced regularly (depending on pad material), and some are equipped with a mechanism that alerts drivers that replacement is needed, such as a thin piece of soft metal that rubs against the disc when the pads are too thin causing the brakes to squeal, a soft metal tab embedded in the pad material that closes an electric circuit and lights a warning light when the brake pad gets thin, or an electronic sensor.

Generally road-going vehicles have two brake pads per caliper, while up to six are installed on each racing caliper, with varying frictional properties in a staggered pattern for optimum performance.

Early brake pads (and linings) contained asbestos, producing dust which should not be inhaled. Although newer pads can be made of ceramics, Kevlar, and other plastics, inhalation of brake dust should still be avoided regardless of material.

Brake squeal

Sometimes a loud noise or high pitched squeal occurs when the brakes are applied. Most **brake squeal** is produced by vibration (resonance instability) of the brake components, especially the pads and discs (known as *force-coupled excitation*). This type of squeal should not negatively affect brake stopping performance. Simple techniques like adding chamfers to linings, greasing or gluing the contact between caliper and the pads (finger to backplate, piston to backplate), bonding insulators (damping material) to pad backplate, inclusion of a brake shim between the brake pad and back plate, etc. may help to reduce squeal. Cold weather combined with high early-morning humidity (dew) often worsens brake squeal, although the squeal stops when the lining reaches regular operating temperatures. Dust on the brakes may also cause squeal; there are many commercial brake cleaning products that can be used to remove dust and contaminants. Finally, some lining wear indicators, located either as a semi-metallic layer within the brake pad material or with an external squealer "sensor", are also designed to squeal when the lining is due for replacement. The typical external sensor is fundamentally different because it occurs when the brakes are off, and goes away when the brakes are on.

Overall brake squeal can be annoying to the vehicle passengers, passers-by, pedestrians, etc. especially as vehicle designs become quieter. Noise, vibration, and harshness (NVH) are among the most important priorities for today's vehicle manufacturers.

Apart from noise generated from squeal, brakes may also develop a phenomenon called *brake judder* or *shudder*.

Brake judder

Brake judder is usually perceived by the driver as minor to severe vibrations transferred through the chassis during braking.[2][3][4][5][6][7][8][9][10]

The judder phenomenon can be classified into two distinct subgroups: *hot* (or *thermal*), or *cold* judder.

Hot judder is usually produced as a result of longer, more moderate braking from high speed where the vehicle does not come to a complete stop.[11] It commonly occurs when a motorist decelerates from speeds of around 120 km/h (74.6 mph) to about 60 km/h (37.3 mph), which results in severe vibrations being transmitted to the driver. These vibrations are the result of uneven thermal distributions, or *hot spots*. Hot spots are classified as concentrated thermal regions that alternate between both sides of a disc that distort it in such a way that produces a sinusoidal waviness around its edges. Once the brake pads (friction material/brake lining) comes in contact with the sinusoidal surface during braking, severe vibrations are induced, and can produce hazardous conditions for the person driving the vehicle.[12][13][14][15]

Cold judder, on the other hand, is the result of uneven disc wear patterns or disc thickness variation (DTV). These variations in the disc surface are usually the result of extensive vehicle road usage. DTV is usually attributed to the following causes: waviness and roughness of disc surface,[16] misalignment of axis (runout), elastic deflection, wear and friction material transfers.[17]

Brake dust

When braking force is applied, the act of abrasive friction between the brake pad and the rotor wears both the rotor and pad away. The "**brake dust**" that is seen deposited on wheels, calipers and other braking system components consists mostly of rotor material. Brake dust can damage the finish of most wheels if not washed off.Wikipedia:Citation needed Generally a brake pad that aggressively abrades more rotor material away, such as metallic pads, will create more brake dust.

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External links

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