Disc brake

The disc brake or disk brake is a device for slowing or stopping the rotation of a wheel while it is in motion. A brake disc (or rotor in U.S. 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 (both disc and drum) convert motion to heat, but if the brakes get too hot, they will become less effective because they cannot dissipate enough heat. This condition of failure is known as brake fade.

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, UK 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.

Modern-style disc brakes first appeared on the low-volume Crosley Hotshot in 1949, although they had to be discontinued in 1950 due to design problems.[1] Chrysler's Imperial also offered a type of disc brake from 1949 through 1953, though in this instance they were enclosed with dual internal-expanding, full-circle pressure plates. Reliable modern disc brakes were developed in the UK by Dunlop and first appeared in 1953 on the Jaguar C-Type racing car. The Citroën DS of 1955, with powered inboard front disc brakes, and the 1956 Triumph TR3 were the first European production cars to feature modern disc brakes.[2] The first production car to feature disc brakes at all 4 corners was the Austin-Healey 100S in 1954.[3] The first British company to market a production saloon fitted with disc brakes to all four wheels was Jensen Motors Ltd with the introduction of a Deluxe version of the Jensen 541 with Dunlop disc brakes.[4] The next American production cars to be fitted with disc brakes were the 1963 Studebaker Avanti[5] (optional on other Studebaker models), standard equipment on the 1965 Rambler Marlin (optional on other AMC models), and the 1965 Chevrolet Corvette Stingray (C2). The 1965 Ford Thunderbird came with front disc brakes as standard equipment.

Disc brakes offer better stopping performance than comparable drum brakes, including resistance to "brake fade" caused by the overheating of brake components, and are able to recover quickly from immersion (wet brakes are less effective). Unlike a drum brake, the disc brake has no self-servo effect and the 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.
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.

**Discs**

The design of the disc varies somewhat. Some are simply solid cast iron, 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). This "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily-loaded front discs. The front brakes provide most of the stopping power.

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, water, and de-glaze 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.

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. Crossdrilled 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.

Smaller brake systems are fitted to motorcycles, mopeds and even bicycles. The market for mountain bike disc brakes is large and ranges from simple, mechanical (cable) systems, to expensive and powerful, 6-pot (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 rotors are made of stainless steel, although some lightweight rotors are made of titanium or aluminum. Rotors are thin, often about 2mm. Some use a two-piece floating rotor 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 rotor. Because the "motor" is small, an uncommon feature of bicycle brakes is pads that retract to eliminate residual drag when the brake is released. In contrast, most other brakes
Disc brake

drag the pads lightly when released.

Disc brakes are increasingly used on very large and heavy road vehicles, where previously large drum brakes were nearly universal. One reason is 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 disk 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.

Yet larger discs are used for railroads and some airplanes. Passenger rail cars and light rail 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 the maximum braking energy is very predictable.

For auto 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, the SAE specification is J431 G3000 (superseded to G10). This specification 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 rotors 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.

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

Racing

In racing and very high performance road cars, other disc materials have been employed. Reinforced carbon discs and pads inspired by aircraft braking systems 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.

Ceramic composites

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.

The requirement for a large section of ceramic composite material having very high heat tolerance and mechanical strength often relegates ceramic discs to exotic vehicles where the cost is not prohibitive to the application, and industrial use 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.

**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 original 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: rotor 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.

**Warping**

Measuring this is accomplished using a dial indicator on a fixed rigid base, with the tip perpendicular to the brake rotor's face. It is typically measured about 1/2" (12 mm) from the outside diameter of the rotor. The rotor is spun. The difference between minimum and maximum value on the dial is called lateral runout. Typical hub/rotor assembly runout specifications for passenger vehicles are around 0.0020" or 50 micrometers. 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 rotor surface and the underlying hub mounting surface. Determining the root cause of the indicator displacement (lateral runout) requires disassembly of the rotor from the hub. Rotor 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 rotor.

Incorrect fitting can 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.

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 or greater (on automobile rotors). Rotors can be machined to eliminate thickness variation and lateral runout. 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 runout due to hub-face non-perpendicularity.
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 rotor's wear surface, reducing braking power and making scratches on the disc. Generally a moderately scarred / scored rotor, 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 rotor during manufacturing on the hub of the rotor or on 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", or 0.03125 inches (0.794 mm), lining thickness above the rivets on riveted pads and 2/32", or .00625 inches (0.159 mm), lining thickness on bonded pads.

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, so removing mass increases the heat stress it will have to contend with. 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 rotor must be replaced.
Rusting

The discs are commonly made from cast iron and a certain amount of what is known as "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 rotors may develop severe rust corrosion inside the ventilation slots, compromising the strength of the structure and needing replacement.

Calipers

The brake caliper is the assembly which houses the brake pads and pistons. The pistons are usually made of aluminum or chrome-plated steel. There are two types of calipers: floating or fixed. A fixed caliper does not move relative to the disc and is, thus, less tolerant of rotor imperfections. It uses one or more 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, which can occur due to dirt or corrosion entering at least one mounting mechanism and stopping its normal movement. This can cause the pad attached to the caliper to rub on the disc when the brake is not engaged, or cause it to engage at an angle. Sticking can occur due to 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 and excessive wear on the affected pad.

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 occur due to failure of the piston to retract - this is usually a consequence of not operating the vehicle during a time that it is stored 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

The brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Although it is commonly thought that the pad material contacts the metal of the disc to stop the car, the pads work with a very thin layer of their own material and generate a semi-liquid friction boundary that creates the actual braking force. Of course, 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. Some have a thin piece of soft metal that rubs against the disc when the pads are too thin, causing the brakes to squeal, while others have 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. More expensive cars may use 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. When working on an older car's brakes, care must be taken not to inhale any dust present on the caliper (or drum). Although newer pads can be made of exotic materials like ceramics, kevlar and other plastics, inhalation of brake dust should still be avoided regardless of material.

### Brake squeal

Sometimes a loud noise or high pitch 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 makes brake-squeal worse, 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 semimetallic 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.  

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. 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.\textsuperscript{[18]} \textsuperscript{[19]} \textsuperscript{[20]} \textsuperscript{[21]}

Cold judder, on the other hand, is the result of uneven disc wear patterns or DTV (disc thickness variation). These variations in the disc surface are usually the result of extensive vehicle road usage. DTV is usually attributed to the following causes: waviness of rotor surface, misalignment of axis (runout), elastic deflection, wear and friction material transfers.\textsuperscript{[10]} \textsuperscript{[21]} \textsuperscript{[22]}

**Brake dust**

When braking force is applied, small amounts of material are gradually ground off the brake pads. This material is known as "brake dust" and a fair amount of it usually deposits itself on the braking system and the surrounding wheel. Brake dust can badly damage the finish of most wheels if not washed off. Airborne brake dust is known to be a health hazard, so most repair manuals recommend the use of a chemical 'brake cleaner' instead of compressed air to remove the dust. Different brake pad formulations create different amounts of dust, and some formulations, particularly metallic brake pads, are much more damaging than others. Ceramic brake pads contain significantly fewer metal particles, and therefore produce less corrosion of surrounding metal parts.

**Patents**

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See also

- Balancing machine
- Brake lining
- Brake bleeding
- Brake fluid

External links

- Using Ceramics, Brakes Are Light but Cost Is Heavy
- Disc brake pads
  - Free video content from CDX eTextbook

References