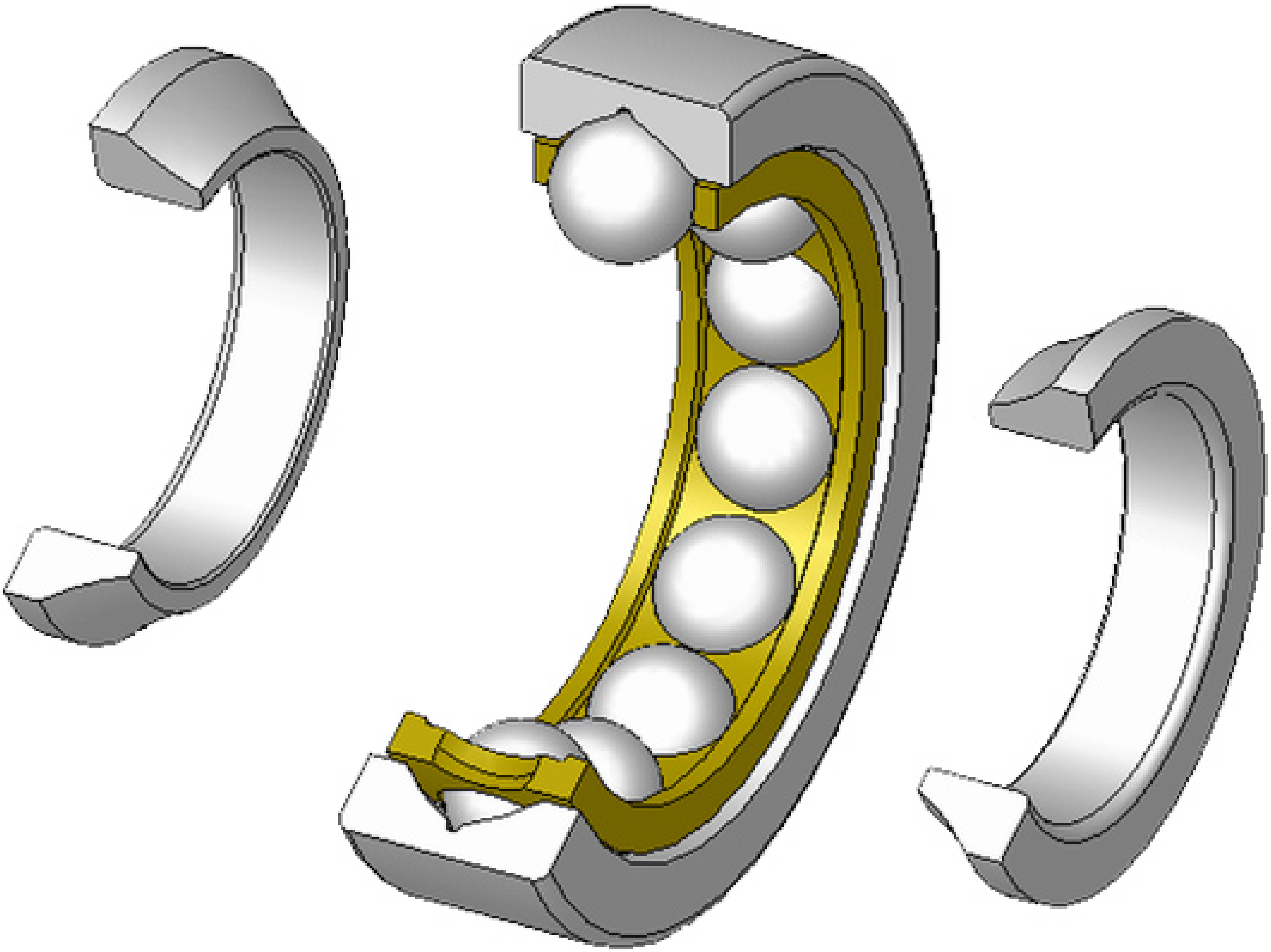
Machine Element Devices



Temika Stein

First Edition, 2012

ISBN 978-81-323-2874-2

Published by:
Orange Apple
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1 - Drive Shaft

Chapter 2 - Key (engineering)

Chapter 3 - Nut (hardware)

Chapter 4 - Retaining Ring

Chapter 5 - Rivet

Chapter 6 - Clutch

Chapter 7 - Brake

Chapter 8 - O-ring

Chapter 9 - Belt (mechanical)

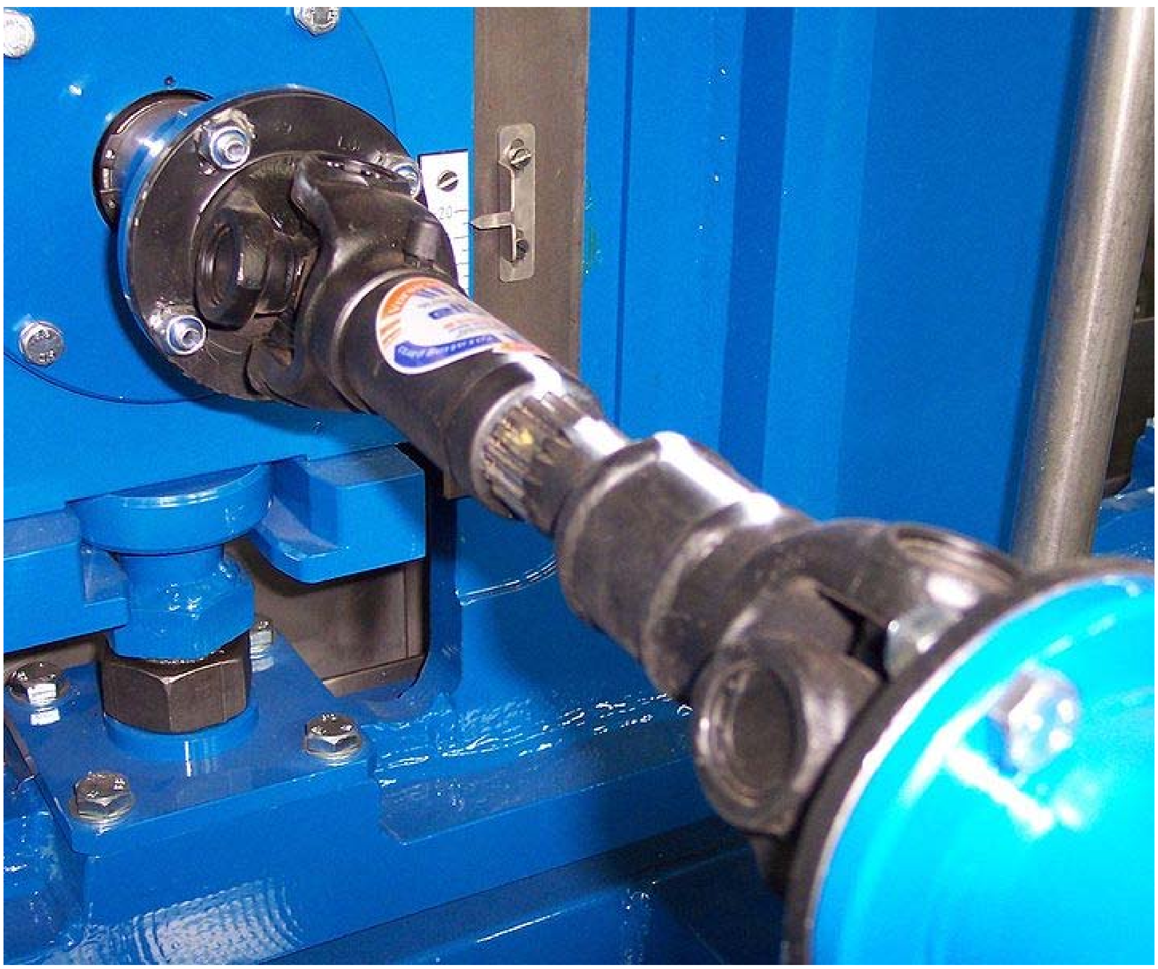
Chapter 10 - Bearing (mechanical)

Chapter 11 - Rolling-element Bearing

Chapter 12 - Screw

Chapter- 1

Drive Shaft



Drive shaft with universal joints at each end and a spline in the center

A **drive shaft**, **driveshaft**, **driving shaft**, **propeller shaft**, or **Cardan shaft** is a mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them.

Drive shafts are carriers of torque: they are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, whilst avoiding too much additional weight as that would in turn increase their inertia.

Drive shafts frequently incorporate one or more universal joints or jaw couplings, and sometimes a splined joint or prismatic joint to allow for variations in the alignment and distance between the driving and driven components.

History

The term **drive shaft** first appeared during the mid 19th century. In Storer's 1861 patent reissue for a planing and matching machine, the term is used to refer to the belt-driven shaft by which the machine is driven. The term is not used in his original patent. Another early use of the term occurs in the 1861 patent reissue for the Watkins and Bryson horse-drawn mowing machine. Here, the term refers to the shaft transmitting power from the machine's wheels to the gear train that works the cutting mechanism.

In the 1890s, the term began to be used in a manner closer to the modern sense. In 1891, for example, Battles referred to the shaft between the transmission and driving trucks of his Climax locomotive as the drive shaft, and Stillman referred to the shaft linking the crankshaft to the rear axle of his shaft-driven bicycle as a drive shaft. In 1899, Bukey used the term to describe the shaft transmitting power from the wheel to the driven machinery by a universal joint in his Horse-Power. In the same year, Clark described his Marine Velocipede using the term to refer to the gear-driven shaft transmitting power through a universal joint to the propeller shaft. Crompton used the term to refer to the shaft between the transmission of his steam-powered Motor Vehicle of 1903 and the driven axle.

Automotive drive shafts

Vehicles

An automobile may use a longitudinal shaft to deliver power from an engine/transmission to the other end of the vehicle before it goes to the wheels. A pair of short drive shafts is commonly used to send power from a central differential, transmission, or transaxle to the wheels.

A truck double propeller shaft

Front-engine, rear-wheel drive

In front-engined, rear-drive vehicles, a longer drive shaft is also required to send power the length of the vehicle. Two forms dominate: The torque tube with a single universal joint and the more common Hotchkiss drive with two or more joints. This system became known as *Système Panhard* after the automobile company Panhard et Levassor patented it.

Most of these vehicles have a clutch and gearbox (or transmission) mounted directly on the engine with a drive shaft leading to a final drive in the rear axle. When the vehicle is stationary, the drive shaft does not rotate. A few, mostly sports, cars seeking improved weight balance between front and rear, and most commonly Alfa Romeos or Porsche 924s, have instead used a rear-mounted transaxle. This places the clutch and transmission at the *rear* of the car and the drive shaft between them and the engine. In this case the drive shaft rotates continuously as long as the engine does, even when the car is stationary and out of gear.

Early automobiles often used chain drive or belt drive mechanisms rather than a drive shaft. Some used electrical generators and motors to transmit power to the wheels.

Front-wheel drive

In British English, the term "drive shaft" is restricted to a transverse shaft that transmits power to the wheels, especially the front wheels. A drive shaft connecting the gearbox to a rear differential is called a **propeller shaft**, or **prop-shaft**. A prop-shaft assembly consists of a propeller shaft, a slip joint and one or more universal joints. Where the engine and axles are separated from each other, as on four-wheel drive and rear-wheel drive vehicles, it is the propeller shaft that serves to transmit the drive force generated by the engine to the axles.

A drive shaft connecting a rear differential to a rear wheel may be called a **half shaft**. The name derives from the fact that two such shafts are required to form one rear axle.

Several different types of drive shaft are used in the automotive industry:

- One-piece drive shaft
- Two-piece drive shaft
- Slip-in-tube drive shaft

The slip-in-tube drive shaft is a new type that also helps in crash energy management. It can be compressed in the event of a crash, so is also known as a collapsible drive shaft.

Four wheel and all-wheel drive

These evolved from the front-engine rear-wheel drive layout. A new form of transmission called the transfer case was placed between transmission and final drives in both axles. This split the drive to the two axles and may also have included reduction gears, a dog clutch or differential. At least two drive shafts were used, one from the transfer case to each axle. In some larger vehicles, the transfer box was centrally mounted and was itself driven by a short drive shaft. In vehicles the size of a Land Rover, the drive shaft to the front axle is noticeably shorter and more steeply articulated than the rear shaft, making it a more difficult engineering problem to build a reliable drive shaft, and which may involve a more sophisticated form of universal joint.

Modern light cars with all-wheel drive (notably Audi or the Fiat Panda) may use a system that more closely resembles a front-wheel drive layout. The transmission and final drive for the front axle are combined into one housing alongside the engine, and a *single* drive shaft runs the length of the car to the rear axle. This is a favoured design where the torque is biased to the front wheels to give car-like handling, or where the maker wishes to produce both four-wheel drive and front-wheel drive cars with many shared components.

Drive shaft for Research and Development (R&D)

The automotive industry also uses drive shafts at testing plants. At an engine test stand a drive shaft is used to transfer a certain speed / torque from the Internal combustion engine to a dynamometer. A "shaft guard" is used at a shaft connection to protect against contact with the drive shaft and for detection of a shaft failure. At a transmission test stand a drive shaft connects the prime mover with the transmission.

Motorcycle drive shafts

A 1913 FN (Fabrique Nationale), Belgium, 4cylinders and shaft drive

A 1923 BMW R32, with a shaft-drive, boxer twin engine

Drive shafts have been used on motorcycles almost as long as there have been motorcycles. As an alternative to chain and belt drives, drive shafts offer relatively maintenance-free operation and long life. A disadvantage of shaft drive on a motorcycle is that gearing or a Hobson's joint or similar is needed to turn the power 90° from the shaft to the rear wheel, losing some power in the process. On the other hand, it is easier to protect the shaft linkages and drive gears from dust, sand and mud.

The best known motorcycle manufacturer to use shaft drive for a long time—since 1923—is BMW. Among contemporary manufacturers, Moto Guzzi is also well-known for its shaft drive motorcycles. The British company, Triumph and all four Japanese brands, Honda, Suzuki, Kawasaki and Yamaha, have produced shaft drive motorcycles. All geared models of the Vespa scooter produced to date have been shaft-driven. The automatic models, however, use a belt.

Motorcycle engines positioned such that the crankshaft is longitudinal and parallel to the frame are often used for shaft driven motorcycles. This requires only one 90° turn in power transmission, rather than two. Bikes from Moto Guzzi and BMW, plus the Triumph Rocket III and Honda ST series all use this engine layout.

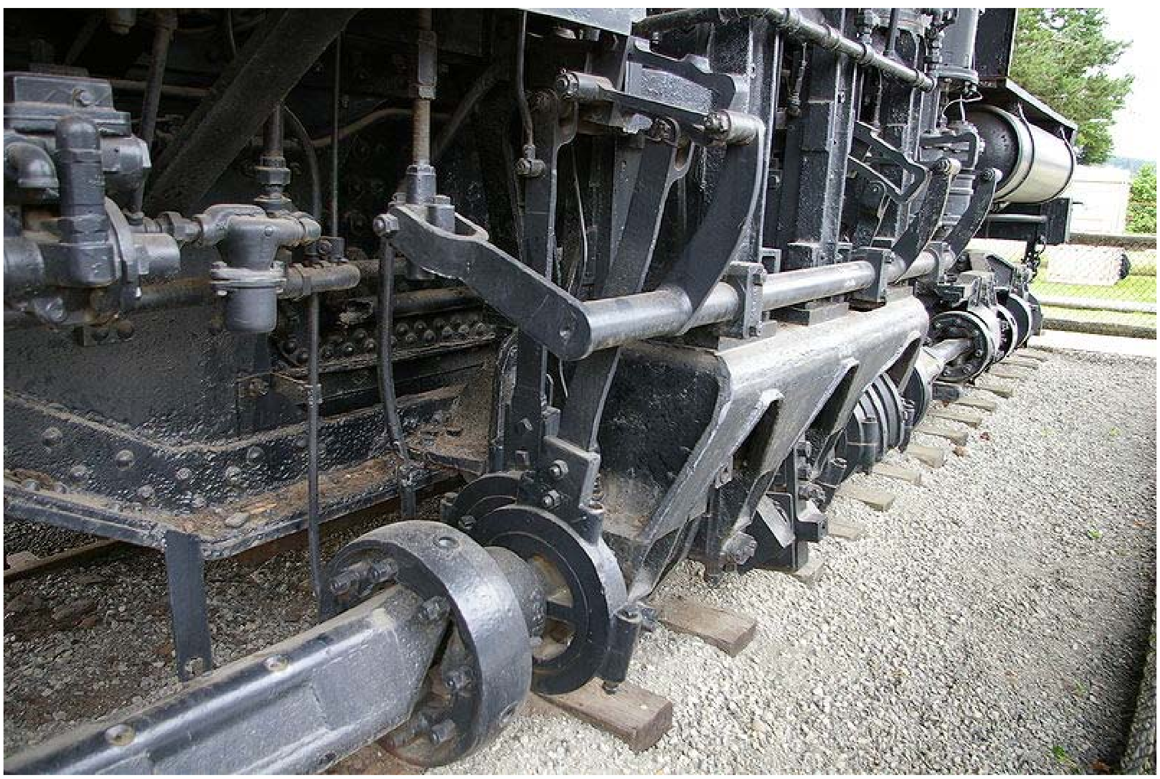
Motorcycles with shaft drive are subject to shaft effect where the chassis climbs when power is applied. This is counteracted with systems such as BMW's Paralever, Moto Guzzi's CARC and Kawasaki's Tetra Lever.

Marine drive shafts

On a power-driven ship, the drive shaft, or propeller shaft, usually connects the transmission inside the vessel directly to the propeller, passing through a stuffing box or other seal at the point it exits the hull. There is also a thrust block, a bearing to resist the axial force of the propeller. As the rotating propeller pushes the vessel forward, any length of drive shaft between propeller and thrust block is subject to compression, and when going astern to tension. Except for the very smallest of boats, this force isn't taken on the gearbox or engine directly.

Cardan shafts are also often used in marine applications between the transmission and either a propeller gearbox or waterjet.

Locomotive drive shafts



The rear drive shaft, crankshaft and front drive shaft of a Shay locomotive.

The Shay, Climax and Heisler locomotives, all introduced in the late 19th century, used quill drives to couple power from a centrally mounted multi-cylinder engine to each of the trucks supporting the engine. On each of these geared steam locomotives, one end of each drive shaft was coupled to the driven truck through a universal joint while the other end was powered by the crankshaft, transmission or another truck through a second universal joint. A quill drive also has the ability to slide lengthways, effectively varying its length. This is required to allow the bogies to rotate when passing a curve.

Cardan shafts are used in some diesel locomotives (mainly diesel-hydraulics, such as British Rail Class 52) and some electric locomotives (e.g. British Rail Class 91). They are also widely used in diesel multiple units.

Drive shafts in bicycles

A shaft-driven bicycle.

The drive shaft has served as an alternative to a chain-drive in bicycles for the past century, although never becoming very popular. A shaft-driven bicycle is described as an "Acatane", from one of their early makers. When used on a bicycle, a drive shaft has several advantages and disadvantages:

Advantages

- Drive system is less likely to become jammed, a common problem with chain-driven bicycles

- The rider cannot become dirtied from chain grease or injured by the chain from "Chain bite", which occurs when clothing or even a body part catches between the chain and a sprocket
- Lower maintenance than a chain system when the drive shaft is enclosed in a tube
- More consistent performance. Dynamic Bicycles claims that a drive shaft bicycle can deliver 94% efficiency, whereas a chain-driven bike can deliver anywhere from 75-97% efficiency based on condition
- Greater clearance: with the absence of a derailleur or other low-hanging machinery, the bicycle has nearly twice the ground clearance

Disadvantages

- A drive shaft system weighs more than a chain system, usually 1-2 pounds heavier
- At optimum upkeep, a chain delivers greater efficiency
- Many of the advantages claimed by drive shaft's proponents can be achieved on a chain-driven bicycle, such as covering the chain and gears with a metal or plastic cover
- Use of lightweight derailleur gears with a high number of ratios is impossible, although hub gears can be used
- Wheel removal can be complicated in some designs (as it is for some chain-driven bicycles with hub gears).

Chapter- 2

Key (engineering)

In mechanical engineering, a **key** is a machine element used to connect a rotating machine element to a shaft. Through this connection the key prevents relative rotation between the two parts and allows torque to be transmitted through. For a key to function the shaft and rotating machine element must have a **keyway**, also known as a **keyseat**, which is a slot or pocket for the key to fit in. The whole system is called a **keyed joint**. A keyed joint still allows relative axial movement between the parts.

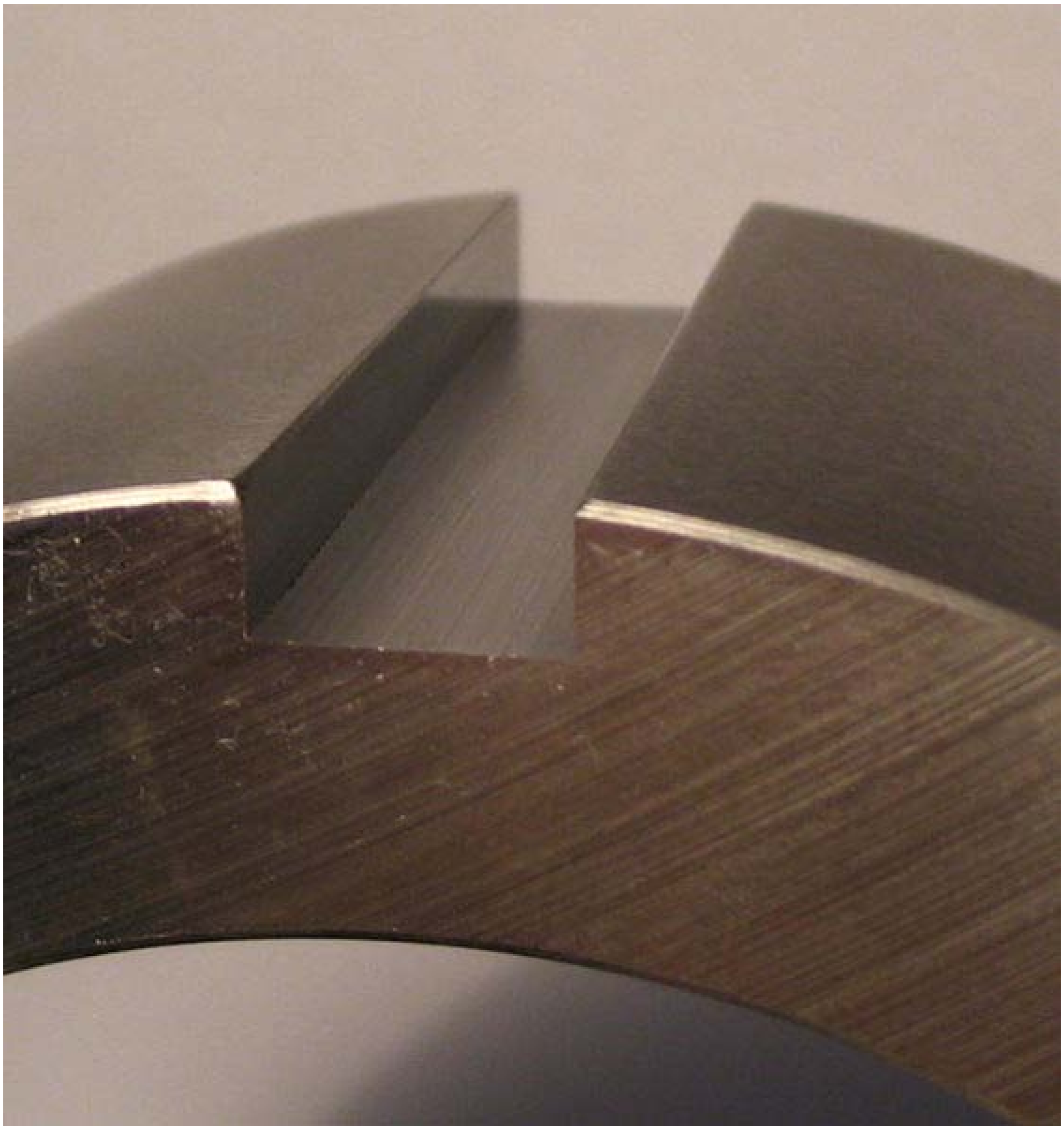
Commonly keyed components include gears, pulleys, and couplings.

Types

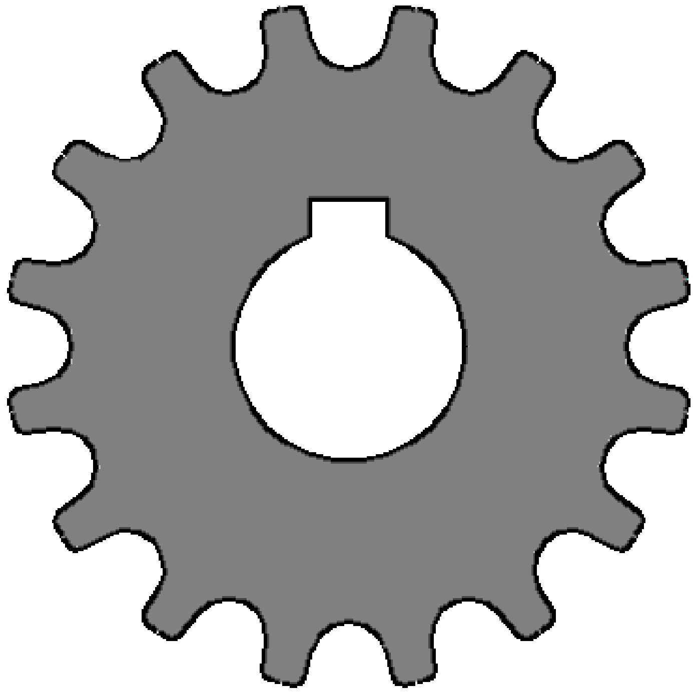
There are three main types of keys: *parallel*, *Woodruff*, and *tapered* keys.

Parallel keys

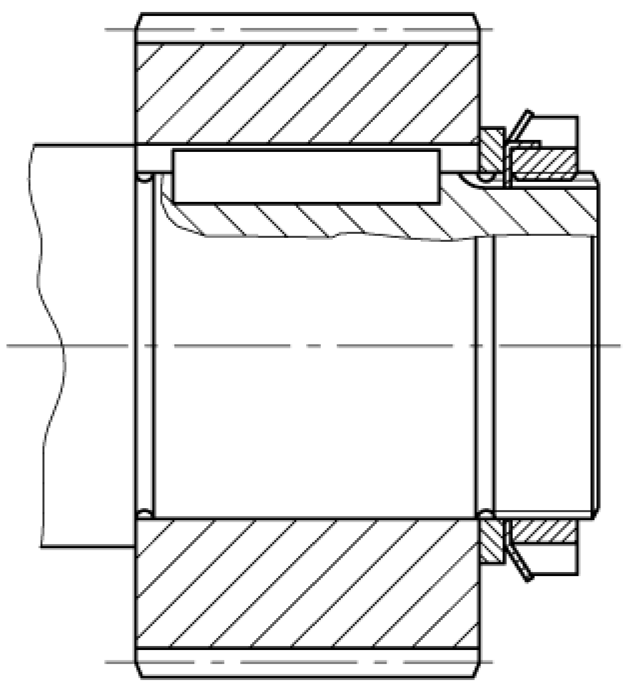
Parallel keys are the most widely used. They have a square or rectangular cross-section. Square keys are used for smaller shafts and rectangular faced keys are used for shaft diameters over 6.5 in (170 mm). Set screws often accompany parallel keys to lock the mating parts into place so they do not move. The keyway is a longitudinal slot in both the shaft and mating part.



The keyway in a shaft for a parallel key



A sprocket with an internal parallel keyway



Cross-section of a parallel keyed joint

Woodruff keys

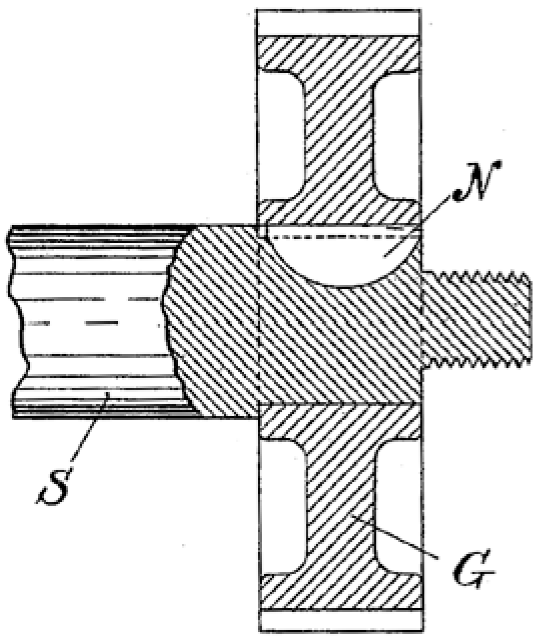
Woodruff keys, also known as *half-moon keys*, are semicircular shaped keys that, when installed, leave a protruding tab. The keyway in the shaft is a semi-circular pocket and the mating part has a longitudinal slot. They are used to improve the concentricity of the shaft and the mating part, which is critical for high speed operations. The main advantage of the Woodruff key is that avoids the milling of a keyway near shaft shoulders, which already have stress concentrations.

Common applications include machine tools, automotive applications, snowblowers and marine propellers.

This type of key was developed by W.N. Woodruff of Connecticut, who was presented in 1888 with the John Scott Medal by the Franklin Institute for the invention.

A Woodruff key installed

A Woodruff key and keyway



Gear G is held on shaft S by Woodruff key N

Tapered keys

The final type of key is the tapered key, which is tapered on one side, the side that engages the hub. The keyway in the hub is broached with a taper matching that of the tapered key. Some taper keys have a *gib*, or tab, for easier removal during disassembly. The purpose of the taper is to secure the key itself as well as to firmly engage the shaft to the hub without the use of a set screw. The problem with taper keys is that they can change the center of rotation of the shaft to be slightly off of the mating part.

Others

A "Scotch key" also provides a keyway not by milling but by drilling axially into the part and the shaft, so that a round key can be used.

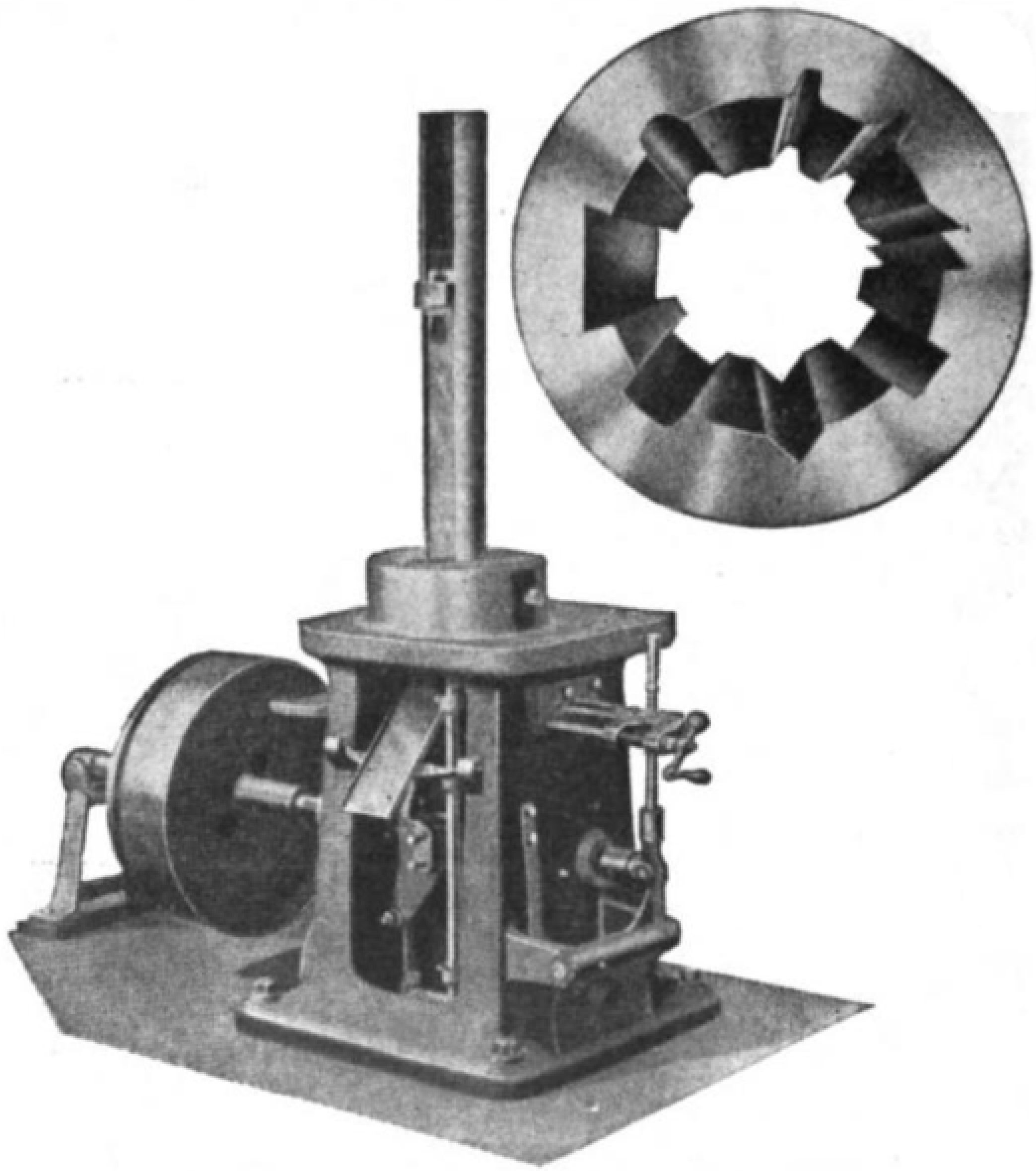
Keyseating

Keyseating is the creation of the slots in the mating items. Keyseating can be done on a variety of different machines including a keyseater, a broacher, either a vertical or horizontal mill, or with a chisel and file.

Broaching

Broaching primarily used to cut square cornered internal keyways. The specific broach, bushing and guide are used for each given keyway cross-section, which makes this process more expensive than most of the alternatives. However, it can produce the most accurate keyway out of all the processes. There are three main steps in broaching a keyway: First, the workpiece is set on the arbor press and the bushing is placed in the opening of the workpiece. Next, the broach is inserted and pushed through, cutting the keyway. Finally, shims are placed between the bushing and the broach to achieve the correct depth necessary for the key.

Keyseater



A keyseater and a sample of various shapes that can be cut

Keyseaters, also known as *keyseating machines* and *keyway cutters*, are specialized machines designed to cut keyways. They are very similar to vertical shapers; the difference is that the cutting tool on a keyseater enters the workpiece from the bottom and cuts on the down-stroke, while the tool on a shaper enters the workpiece from the top and cuts downward. Another difference is a keyseater has a guiding system above the workpiece to minimize deflection, which results in a closer tolerance cut. The process starts by clamping the workpiece to the table with a fixture or vise. The workpiece is properly located and then the reciprocating arm is started. Some models have a stationary table so the cutter is fed horizontally into the workpiece, while others have a movable table that feeds the workpiece into a fixed cutter. These machines can cut other straight sided features other than keyways. They can also produce blind slots, which are slots that do not extend through the whole workpiece.

Milling

Parallel, tapered, and Woodruff keyways can be produced on a milling machine. End mills or slotting cutters are used for parallel and tapered keyways, while a Woodruff cutter is used for Woodruff keyways.

For internal keyways that are not too long, the keyways can be milled if a radius is acceptable.

Chiseling

One of the earliest forms of keyseating was done by chiseling. The keyway is roughed out using a chisel and then filed to size; the key is tried frequently to avoid over filing. This technique is long, tedious, and rarely used anymore.

Keyed joints

Two parallel keys can be used either 90° or 180° apart from each other if the shaft connection needs to be more robust.

Improperly machined keyways that had cutter deflection or drifting occur, may not be strong enough for the required application.

Chapter- 3

Nut (hardware)

A nut threaded onto a bolt

A **nut** is a type of hardware fastener with a threaded hole. Nuts are almost always used opposite a mating bolt to fasten a stack of parts together. The two partners are kept together by a combination of their threads' friction, a slight stretch of the bolt, and compression of the parts. In applications where vibration or rotation may work a nut loose, various locking mechanisms may be employed: Adhesives, safety pins or lockwire, nylon inserts, or slightly oval-shaped threads. The most common shape is hexagonal, for similar reasons as the bolt head - 6 sides give a good granularity of angles for a tool to approach from (good in tight spots), but more (and smaller) corners would be vulnerable to being rounded off. Other specialized shapes exist for certain needs, such as wing nuts for finger adjustment and captive nuts for inaccessible areas.

Nuts are graded with strength ratings compatible with their respective bolts; for example, an ISO property class 10 nut will be able to support the bolt proof strength load of an ISO property class 10.9 bolt without stripping. Likewise, an SAE class 5 nut can support the proof load of an SAE class 5 bolt, and so on.

Nuts come in many sizes. This one is part of the Sydney Harbour Bridge

Types

L to R: Wing, hex, hex flange, and slab weld nuts.

L to R: Slotted, square, T, cap (or acorn), nylon locking, and castellated nuts.

Hexagon nuts.

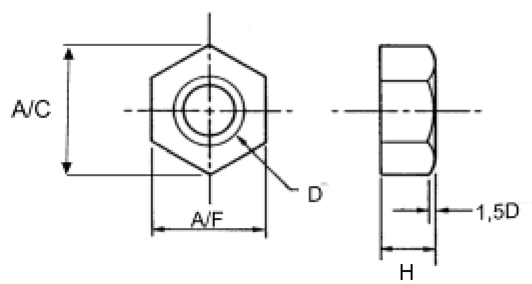
- Acorn nut (cap nut)
- Barrel nut
- Cage nut
- Clip-on nut (J-nut or U-nut)
- Coupling nut
- Cross dowel
- Flange nut (collar nut)
- Insert nut
- Internal wrenching nut (Allen nut)
- Knurled nut (thumb nut)
- Lug nut
- Nut-type MJT
- Panel nut
- PEM nut (for metal)
- Plate nut (nut plate)
- Rivet nut or blind nut
- Self-aligning nut
- Sex bolt
- Slotted nut
- Split nut
- Square nut
- Staked/welded nut (for plastic)

- Swage nut
- T-nut
- T-slot nut (T-groove) nut
- Weld nut
- Well nut
- Wing nut

Locknuts

- Castellated nut
- Distorted thread locknut
    - Centerlock nut
    - Elliptical offset locknut
    - Toplock nut
- Interfering thread nut
    - Tapered thread nut
- Jam nut
- Jet nut (K-nut)
- Keps nut (K-nut or washer nut) with a star-type lock washer
- Nyloc plate nut
- Polymer insert nut (Nyloc)
- Serrated face nut
- Serrated flange nut
- Speed nut (Sheet metal nut or Tinnerman nut)
- Split beam nut

Standard metric hex nuts sizes



nut quotation

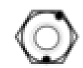
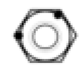
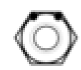
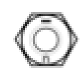
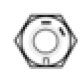
Note that flat (wrench) sizes differ from industry standards. For example, wrench sizes of fastener used in Japanese built cars comply with JIS automotive standard.

Nominal diameter hole *D* (mm)		**Pitch *P* (mm)**		**Flat size *A/F* (mm)**			**External diameter *A/C* (mm)**	**Height *H* (mm)**		
1st choice	**2nd choice**	**coarse**	**fine**	**ISO**	**DIN**	**JIS**		**Hex Nut**	**Jam Nut**	**Nylon Nut**
1		0.25		2.5						
1.2		0.25								
	1.4	0.3								
1.6		0.35		3.2						
	1.8	0.35								
2		0.4		4				1.6	1.2	-
2.5		0.45		5				2	1.6	-
3		0.5		5.5			6.4	2.4	1.8	4
	3.5	0.6		6						
4		0.7		7	7	7	8.1	3.2	2.2	5
5		0.8		8	8	8	9.2	4	2.7	5
6		1	0.75	10	10	10	11.5	5	3.2	6
	7	1			11			5.5	3.5	-
8		1.25	1	13	13	12	15	6.5	4	8
10		1.5	1.25 or 1	16	17	14	19.6	8	5	10
12		1.75	1.5 or 1.25	18	19	17	22.1	10	6	12
	14	2	1.5	21	22	19		11	7	14
16		2	1.5	24	24	22	27.7	13	8	16
	18	2.5	2 or 1.5		27			15	9	18.5
20		2.5	2 or 1.5	30	30		34.6	16	10	20
	22	2.5	2 or 1.5	32						
24		3	2	36			41.6	19		
	27	3	2	41						
30		3.5	2	46			53.1	24		
	33	3.5	2							
36		4	3	55			63.5	29		
	39	4	3							
42		4.5	3							
	45	4.5	3							

48		5	3
	52	5	4
56		5.5	4
	60	5.5	4
64		6	4

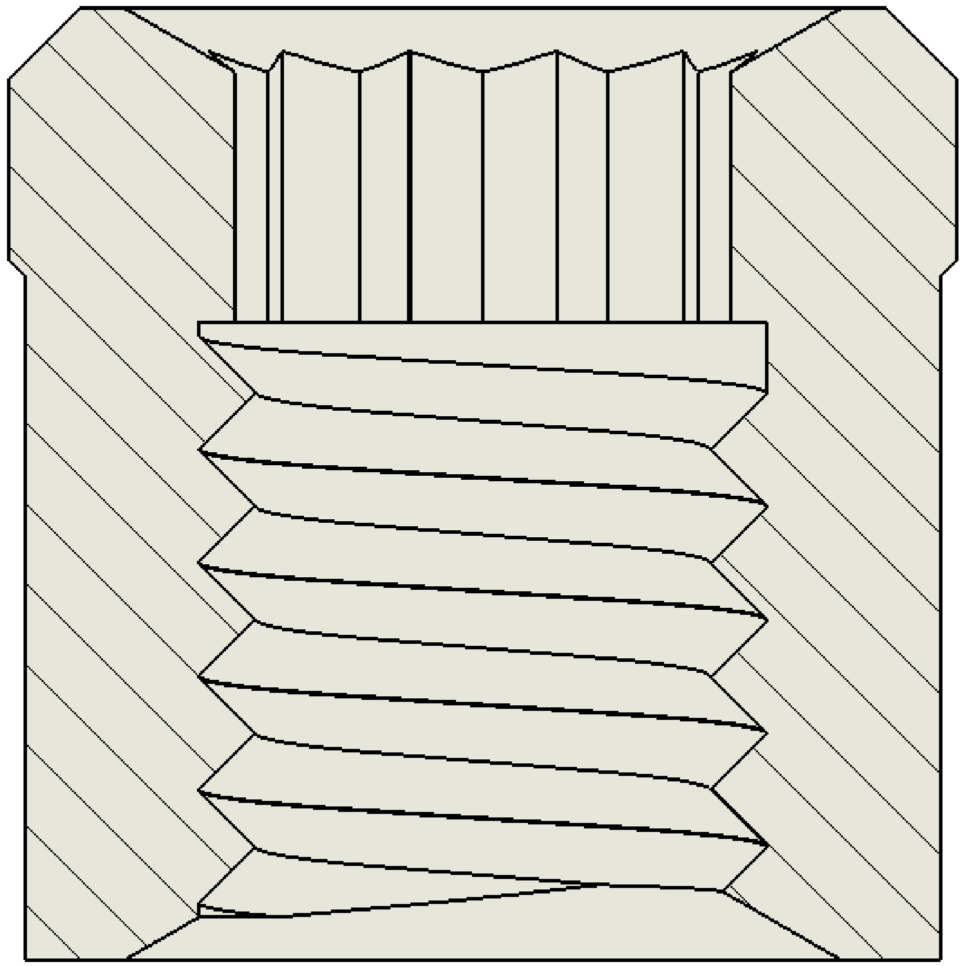
Classifications

Mechanical specifications of Metric/English sized nuts

Material	Proof strength	Tensile yield strength (min.)	Tensile ultimate strength (min.)	Nut marking	Nut class
		ISO 898 (Metric)			
Low or medium carbon steel	380 MPa (55 ksi)	420 MPa (61 ksi)	520 MPa (75 ksi)		5
Medium carbon steel Q&T	580 MPa (84 ksi)	640 MPa (93 ksi)	800 MPa (116 ksi)		8
Alloy steel Q&T	830 MPa (120 ksi)	940 MPa (136 ksi)	1040 MPa (151 ksi)		10
		SAE J995 (English)			
Low or medium carbon steel	55 ksi (379 MPa)	57 ksi (393 MPa)	74 ksi (510 MPa)		2
Medium carbon steel Q&T	85 ksi (586 MPa)	92 ksi (634 MPa)	120 ksi (827 MPa)		5
Alloy steel Q&T	120 ksi (827 MPa)	130 ksi (896 MPa)	150 ksi (1034 MPa)		8

Internal wrenching nut

Internal wrenching nut



Cut-away view of an internal wrenching nut

An **internal wrenching nut**, also known as an **Allenut** or **Allen nut**, is a cylindrical nut that is internally threaded on one side and has an Allen socket on the other side; the outside of the nut is smooth or has knurling on it. The Allen socket may be 6 point or 12 point (also known as a double hex socket). They are used where hex or square nuts won't fit.

Lug nut

Lug-nuts on an Acura.

A **lug nut** is a fastener, specifically a nut, used to secure a wheel on a vehicle. Typically, lug nuts are found on automobiles, trucks (lorries), and other large vehicles utilizing rubber tires.

Design

A lug nut is a nut with one rounded or conical (tapered) end, used on steel and most aluminum wheels. A set of lug nuts are typically used to secure a wheel to threaded wheel studs and thereby to a vehicle's axles.

Wheel bolt and washer, for aluminium wheel

Some designs use lug bolts instead of nuts, which screw into a tapped (threaded) hole in the wheel's hub or brake drum or disc. This configuration is commonly known as a bolted joint.

The lug's taper is normally 60 degrees (although 45 is common for wheels designed for racing applications), and is designed to center the wheel accurately on the axle, and to reduce the tendency for the nut to loosen, due to fretting induced precession, as the car is driven. Honda uses a spherical rather than a tapered seat, but the nut performs the same function. Older style alloy wheels have a 1/2 to 1 inch shank slipping into the wheel to center it and a washer that applies pressure to clamp the wheel to the axle.

Removal and installation

Disc brake with 5 wheel studs sticking out

Lug nuts may be removed using a lug, socket or impact wrench. If the wheel is to be removed then an automotive jack to raise the vehicle and some wheel chocks would be used as well. Wheels that have hubcaps or hub covers need these removed beforehand, typically with a screwdriver, flatbar, or prybar. Lug nuts can be difficult to remove, as they may become frozen to the wheel stud. In such cases a breaker bar or repeated blows from an impact wrench can be used to free them. Alternating between tightening and loosening can free especially stubborn lug nuts.

Lug nuts must be installed in an alternating pattern, commonly referred to as a star pattern. This ensures a uniform distribution of load across the wheel mounting surface. When installing lug nuts, it is recommended to tighten them with a calibrated torque wrench. While a lug, socket or impact wrench may be used to tighten lug nuts the final tightening should be performed by a torque wrench, ensuring an accurate and adequate load is applied. Torque specifications vary by vehicle and wheel type. Both vehicle and wheel manufacturers provide recommended torque values and should be consulted when an installation is done. Failure to abide by the recommended torque value can result in damage to the wheel and brake rotor/drum. Additionally, under tightened lug nuts may come loose with time.

History

Some cars made up to about 1960 used left-hand and right-hand threaded lug nuts for different sides of the vehicle to prevent loosening, until it was realized that the taper seat performed the same function. In order to allow the easy detection of loose lug nuts, some large vehicles are fitted with loose wheel nut indicators, which spin with the nut and highlight misaligned nuts.

Weld nut

A **weld nut** is a special type of nut specifically designed to be welded to another object. There are various types for different applications.

Types

Round base nuts

These nuts have a long threaded cylinder with a large circular base to make welding easy. They also sometimes have projections (known as weld nibs or bosses) to keep the nut from warping while welding with a high current.

Slab base nuts

Slab base weld nut

These are very similar to the round base nuts, but with an obround, or slab shaped, base. These are used in channels, tubes, or other tight quarters.

Tab base nuts

Tab base nuts are designed for spot welding on flat workpieces. They have a locating boss around the threads to locate it in a pilot hole.

Hex & square nuts

These nuts are very similar to standard square or hex nuts, but have a locating boss and welding projections. The bosses also keep weld splatter out of the threads.

Retainer weld nuts

Retainer weld nuts, also known as bridge weld nuts, have a floating nut retained inside a retainer to compensate for inconsistencies. The retainer is welded to the workpiece while the nut is allowed to float.

Tube end nuts

Tube end nuts are sized to fit into the end of standard sized tubing, thus creating a threaded tube from standard stock.

Locknut

Nylon lock nuts

A **locknut**, also known as a **lock nut**, **locking nut**, **prevailing torque nut**, **stiff nut** or **elastic stop nut**, is a nut that resists loosening under vibrations and torque. Elastic stop nuts and prevailing torque nuts are of the particular type where some portion of the nut deforms elastically to provide a locking action. The first type used a fiber instead of nylon and was invented in 1931.

Types

There are various kinds of specialised lock nuts, including:

- Castellated nut
- Distorted thread locknut
    - Centerlock nut
    - Elliptical offset locknut
    - Toplock nut
- Interfering thread nut
    - Tapered thread nut
- Jam nut
- Jet nut (K-nut)
- Keps nut (K-nut or washer nut) with a star-type lock washer
- Nyloc plate nut
- Polymer insert nut (Nyloc)
- Serrated face nut
- Serrated flange nut
- Speed nut (Sheet metal nut or Tinnerman nut)
- Split beam nut

Chapter- 4

Retaining Ring

A **retaining ring** is a fastener that holds components or assemblies onto a shaft or in a housing/bore when installed in a groove. Once installed, the exposed portion acts as a shoulder which retains the specific component or assembly.

Self-locking retaining rings may be installed in applications where no groove exists.

Retaining rings are typically made from carbon steel, stainless steel or beryllium copper and may feature a variety of finishes for corrosion protection depending on the type of environment in which they are used.

Types

There are three main types of retaining rings available, each of which may then be broken down into sub-types depending on unique application needs:

- **Tapered section**
    - Axially assembled
        - Inverted
        - Beveled
        - Bowed
    - Radially assembled
    - Self-locking
- **Constant section**
- **Spiral**

Tapered section retaining rings

Axially installed retaining rings

Tapered section retaining rings decrease symmetrically from the center to the free ends, remaining circular when contracted or expanded within the limits of normal use. This assures contact with the groove along the entire periphery of the ring. These rings may be installed axially (horizontally along the center point of an axis) or radially (externally along the radius of a circle). Depending on the size of the ring in question, it may be manufactured in one of two ways:

- For smaller rings: using a die and stamping on a press from a coil of steel or copper
- For larger rings: wire forming, in which rectangular wire is coiled into the shape of the ring.

Axially assembled

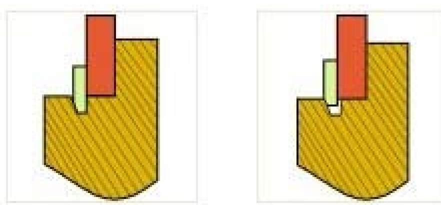
Axially assembled retaining rings are installed into machined grooves in housings/bores (internal) or on shafts (external). These rings are manufactured with lug holes--small holes in the lugs of both axial internal and external retaining rings--that are used to install/remove them, using pliers designed for this purpose.

Inverted retaining rings

Inverted retaining rings are a variation of axially assembled rings in which the lug holes are inverted to fit in the bottom of the groove. Inverting the lugs allows greater clearance on a shaft or in a housing and forms a higher uniform shoulder good for retaining bearings and other components with large corner radii or chamfers.

Beveled retaining rings

Beveled retaining rings feature a 15° beveled or angled edge. This angle allows the ring to wedge itself between the groove and the retained part until it can go no farther, effectively "locking" everything in place. Think of placing a cork in a bottle. The cork is forced into the opening until it is wedged as far into the opening as possible. The same thing happens when a beveled retaining ring is installed into an application. The ring is wedging itself into place between the groove wall and the retained part, resulting in what is referred to as rigid end-play take-up.



Beveled ring minimum and maximum insertion

Bowed retaining rings

Bowed retaining rings are curved versions of standard flat internal and external retaining rings and exert a pre-load on an assembly when installed in the groove. This takes up the end-play and acts like a spring, which keeps the assembly in compression.

In manufacturing, parts can not be produced to an exact dimension; as a result, if they are made on the low side of the tolerance, they will be loose or have play on the shaft when a standard ring is installed. If they are made on the high side of the tolerance, they will extend further into the groove and prevent a standard ring from being fully installed. Compensating for accumulated tolerances is what bowed retaining rings are designed to do, by acting as a spring once installed into the groove.

Radially assembled

Radially installed retaining rings

Radially assembled retaining rings are installed externally into machined grooves on a shaft. These rings have no lug holes and must be installed using applicators.

Self-locking

Self-locking retaining rings can be installed in a housing/bore or on a shaft that has not had a groove machined into it. Self-locking rings with no lug holes are impossible to remove without either destroying the ring or warping it out of specified tolerances.

Constant section retaining rings

Constant section retaining rings feature a uniform, constant section. In other words, the material used to make the ring is the same width at any point along the circumference of the ring. When they are contracted or expanded, they take on an elliptical deformation. As a result, they contact the groove at three or more isolated points but never continuously around the periphery. These rings are made from either flat or round wire.

Spiral retaining rings

Spiral Rings

Spiral retaining rings are axially installed into housings/bores (internal) or onto shafts (external), making 360° contact with the groove. These rings are manufactured by coiling flat wire into the shape of the finished retaining ring. These rings lack lugs and holes, making them difficult to remove once installed.

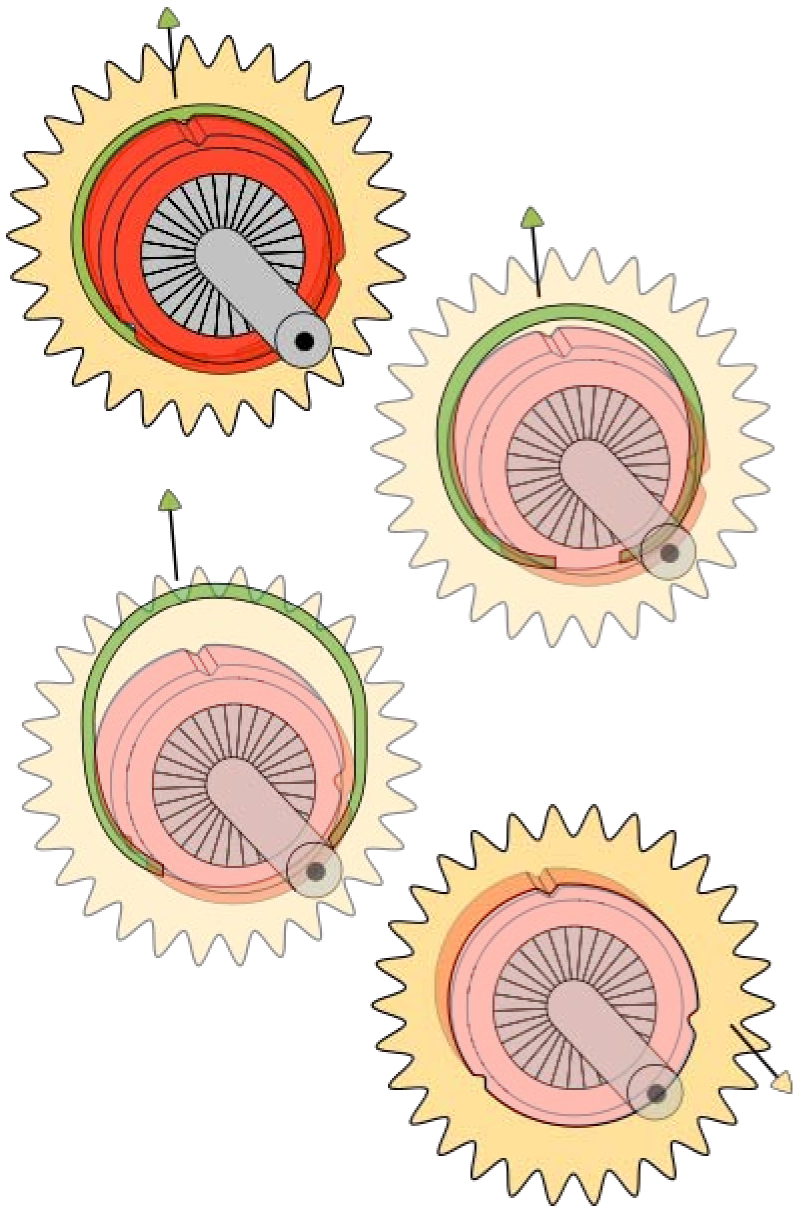
Protective finishes

The following are various surface finished used on retaining rings:

- Passivation
- Phosphate
- Zinc plating (Trivalent and Hexavalent)
- Oil
- Cadmium plating

Circlip

Internal circlip



This diagram illustrates the removal of a snap ring from the rear hub of a bicycle, on which it is used to retain a single rear sprocket

A **circlip** (a combination of 'circle' and 'clip', and pronounced thus), also known as a **C-Clip**, **snap ring** or **Jesus clip**, is a type of fastener consisting of a semi-flexible metal ring with open ends which can be snapped into place, into a machined groove on a dowel pin or other part to permit rotation but to prevent lateral movement. There are two basic types: internal and external, referring to whether they are fitted into a tube or over a shaft. Circlips are often used to secure pinned connections.

Details

The clips are known as *wrist pin clips* or *wrist pin retainers* when used to keep retain piston wrist pins.

Common examples include "E-clips" (e-ring) and the (both internal and external) snap ring or circlip. This general type of fasteners are sized to provide an interference fit onto (or into, in the case of an internal fastener) a groove or land when in use, such that they must be elastically deformed in order to install or remove them.

Installation and lubrication

As they are stamped out of sheetmetals there is a smooth side and a rough side. Install the circlip with the smooth side facing the part and the rough side facing out. (The rough edge could dig into the part enough to be pushed off the position by the part's motion.) This is particularly important when the circlip is installed directly against rotating(moving) part. Wet or dry lubrication is required for the circlip to maintain its function.

Circlips which are fitted may be removed with a pair of needle-nosed pliers or a special snap ring tool if the circlip is designed to include entry points for the pliers or tool. Alternatively, cautious leverage with a flat-headed screwdriver may be necessary in lieu of the correct tools or design of snap-ring.

Chapter- 5

Rivet

Solid rivets

A **rivet** is a permanent mechanical fastener. Before being installed a rivet consists of a smooth cylindrical shaft with a head on one end. The end opposite the head is called the *buck-tail*. On installation the rivet is placed in a punched or pre-drilled hole, and the tail is *upset*, or *bucked* (i.e. deformed), so that it expands to about 1.5 times the original shaft diameter, holding the rivet in place. To distinguish between the two ends of the rivet, the original head is called the *factory head* and the deformed end is called the *shop head* or buck-tail.

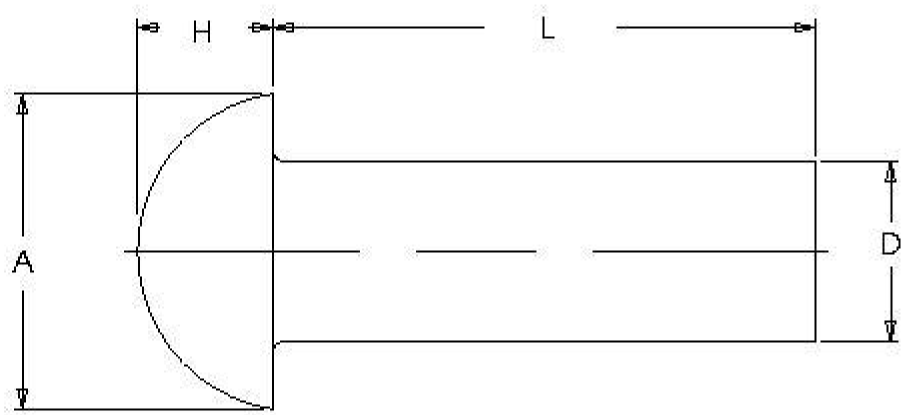
Because there is effectively a head on each end of an installed rivet, it can support tension loads (loads parallel to the axis of the shaft); however, it is much more capable of supporting shear loads (loads perpendicular to the axis of the shaft). Bolts and screws are better suited for tension applications.

Fastenings used in traditional wooden boat building, like copper nails and clinch bolts, work on the same principle as the rivet but were in use long before the term *rivet* came about and, where they are remembered, are usually classified among the nails and bolts respectively.

Types

There are a number of types of rivets, designed to meet different cost, accessibility, and strength requirements:

Solid rivets



A typical technical drawing of a universal head solid rivet

Solid rivets are one of the oldest and most reliable types of fasteners, having been found in archaeological findings dating back to the Bronze Age. Solid rivets consist simply of a shaft and head which are deformed with a hammer or rivet gun. The use of a rivet compression or crimping tool can also be used to deform this type of rivet; this tool is mainly used on rivets close to the edge of the fastened material, since the tool is limited by the depth of its frame. A rivet compression tool does not require two people and is generally the most foolproof way to install solid rivets.

Riveting team working on the cockpit shell of a C-47 transport at the plant of North American Aviation. The woman on the left operates an air hammer, while the man on the right holds a bucking bar

Solid rivets are used in applications where reliability and safety count. A typical application for solid rivets can be found within the structural parts of aircraft. Hundreds of thousands of solid rivets are used to assemble the frame of a modern aircraft. Such rivets come with rounded (universal) or 100° countersunk heads. Typical materials for aircraft rivets are aluminium alloys (2017, 2024, 2117, 7050, 5056, 55000, V-65), titanium, and nickel-based alloys (e.g. Monel). Some aluminum alloy rivets are too hard to buck and must be softened by annealing prior to being bucked. "Ice box" aluminum alloy rivets harden with age, and must likewise be annealed and then kept at sub-freezing temperatures (hence the name "ice box") to slow the age-hardening process. Steel rivets can be found in static structures such as bridges, cranes, and building frames.

The setting of these fasteners requires access to both sides of a structure. Solid rivets are driven using a hydraulically, pneumatically, or electromagnetically driven squeezing tool or even a handheld hammer. Applications in which only one side is accessible require the use of blind rivets.

High strength structural steel rivets

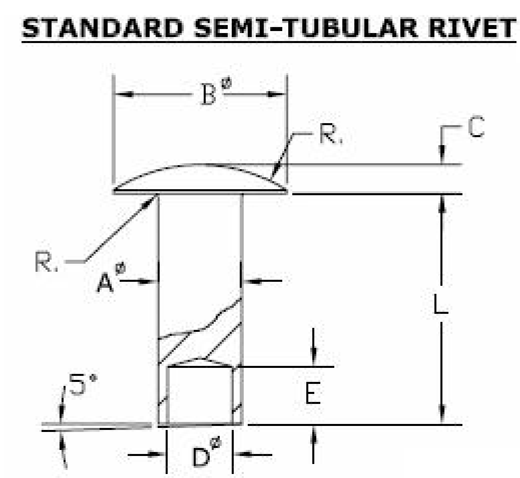
Until relatively recently, structural steel connections were either welded or riveted. High-strength bolts have completely replaced structural steel rivets. Indeed, the latest steel construction specifications published by AISC (the 13th Edition) no longer covers their installation. The reason for the change is primarily due to the expense of skilled workers required to install high strength structural steel rivets. Whereas two relatively unskilled workers can install and tighten high strength bolts, it took a minimum of four highly skilled riveters to install rivets in one joint at a time.

At a central location near the areas being riveted, a furnace was set up. Rivets were placed in the furnace and heated to a glowing hot temperature, at which time the furnace operator would use tongs to individually remove and throw them to catchers stationed near the joints to be riveted. The catcher would place the glowing hot rivet into the hole to be riveted, and quickly turn around to await the next rivet. One worker would then hold a heavy rivet set against the round head of the rivet, while the hammerer would apply a pneumatic rivet hammer to the unformed head, causing it to mushroom tightly against the joint in its final domed shape. Upon cooling, the rivet would contract and exert further force tightening the joint. This process was repeated for each rivet.

The last commonly used high strength structural steel rivets were designated ASTM A502 Grade 1 rivets.

Such riveted structures may be insufficient to resist seismic loading from earthquakes if the structure was not engineered for such forces, a common problem of older steel bridges. This is due to the fact that a hot rivet cannot be properly heat treated to add strength and hardness. In the seismic retrofit of such structures it is common practice to remove critical rivets with an oxygen torch, precision ream the hole, and then insert a machined and heat treated bolt.

Semi-tubular rivets



A typical technical drawing of a oval head semi-tubular rivet

Semi-tubular rivets (also known as tubular rivets) are similar to solid rivets, except they have a partial hole (opposite the head) at the tip. The purpose of this hole is to reduce the amount of force needed for application by rolling the tubular portion outward. The force needed to apply a semitubular rivet is about 1/4 of the amount needed to apply a solid rivet. Tubular rivets can also be used as pivot points (a joint where movement is preferred) since the swelling of the rivet is only at the tail. Solid rivets expand radially and generally fill the hole limiting movement. The type of equipment used to apply semi-tubular rivets range from prototyping tools (less than $50) to fully automated systems. Typical installation tools (from lowest to highest price) are hand set, manual squeezer, pneumatic squeezer, kick press, impact riveter, and finally PLC-controlled robotics. The most common machine is the impact riveter and the most common use of semitubular rivets is in lighting, brakes, ladders, binders, HVAC duct work, mechanical products, and electronics. They are offered from 1/16-inch (1.6 mm) to 3/8-inch (9.5 mm) in diameter (other sizes are considered highly special) and can be up to 8 inches (203 mm) long. A wide variety of materials and platings are available, most common base metals are steel, brass, copper, stainless, aluminum and most common platings are zinc, nickel, brass, tin. All tubular rivets are waxed to facilitate proper assembly. The finished look of a tubular rivet will have a head on one side, with a rolled over and exposed shallow blind hole on the other. Semi-tubular rivets are the fastest way to rivet in mass production but require a capital investment.

Blind rivets

Three aluminium blind rivets: 1/8", 3/32", and 1/16"

Blind rivets are tubular and are supplied with a mandrel through the center. The rivet assembly is inserted into a hole drilled through the parts to be joined and a specially designed tool is used to draw the mandrel into the rivet. This expands the blind end of the rivet and then the mandrel snaps off. (A **POP rivet** is a brand name for blind rivets sold by Emhart Teknologies.) These types of blind rivets have non-locking mandrels and are avoided for critical structural joints because the mandrels may fall out, due to vibration or other reasons, leaving a hollow rivet that will have a significantly lower load carrying capability than solid rivets. Furthermore, because of the mandrel they are more prone to failure from corrosion and vibration. Unlike solid rivets, blind rivets can be inserted and fully installed in a joint from only one side of a part or structure, "blind" to the opposite side.

Prior to the adoption of blind rivets, installation of a solid rivet typically required two assemblers: one person with a rivet hammer on one side and a second person with a bucking bar on the other side. Seeking an alternative, inventors such as Carl Cherry and Lou Huck experimented with other techniques for expanding solid rivets. The blind rivet was developed by the United Shoe Machinery Corporation.

Due to this feature, blind rivets are mainly used when access to the joint is only available from one side. The rivet is placed in a pre-drilled hole and is set by pulling the mandrel head into the rivet body, expanding the rivet body and causing it to flare against the reverse side. As the head of the mandrel reaches the face of the blind side material, the pulling force is resisted, and at a predetermined force, the mandrel will snap at its break point, also called "Blind Setting". A tight joint formed by the rivet body remains, the head of the mandrel remains encapsulated at the blind side, although variations of this are available, and the mandrel stem is ejected.

Most blind rivets have limited use on aircraft and are never used for structural repairs. However, they are useful for temporarily lining up holes. In addition, some "home built" aircraft use blind rivets. They are available in flat head, countersunk head, and modified flush head with standard diameters of 1/8, 5/32 and 3/16 inch. Blind rivets are made from soft aluminum alloy, steel (including stainless steel), copper, and Monel.

The rivet body is normally manufactured using one of three methods:

Name	Description
Wire	the most common method
Tube	common in longer lengths, not normally as strong as wire
Sheet	least popular and generally the weakest option

There is a vast array of specialty blind rivets that are suited for high strength or plastic applications. Typical types include:

Name	Description
TriFold	a rivet that splits into three equal legs like a molly bolt. Typically used in soft plastics where a wide footprint is needed at the rear surface. Used in automotive interiors and vinyl fences.
Structural rivet(a)	an "external" mechanically locked structural blind rivet that is used where a watertight, vibration resistant connection is of importance. Typically used in manufacture or repair of truck bodies. A special nose piece is required to apply this rivet.
Structural rivet(b)	an "internal" mechanically locked structural blind rivet that is used where a watertight, vibration resistant connection is of importance. Typically used in manufacture or repair of truck bodies.

Internally and externally locked structural blind rivets can be used in aircraft applications because, unlike other types of blind rivets, the locked mandrels cannot fall out and are water tight. Since the mandrel is locked into place they have the same or greater load carrying capacity as solid rivets and may be used to replace solid rivets on all but the most critical stressed aircraft structures.

The typical assembly process requires the operator to install the rivet in the nose of the tool by hand then actuate the tool. However, in recent years automated riveting systems have become popular in an effort to reduce assembly costs and repetitive disorders. The cost of such tools range from US$1,500 for autofeed pneumatics to US$50,000 for fully robotic systems.

Drive rivet

A drive rivet is a form of blind rivet that has a short mandrel protruding from the head that is driven in with a hammer to flare out the end inserted in the hole. This is commonly used to rivet wood panels into place since the hole does not need to be drilled all the way through the panel, producing an aesthetically pleasing appearance. They can also be used with plastic, metal, and other materials and require no special setting tool other than a hammer and possibly a backing block (steel or some other dense material) placed behind the location of the rivet while hammering it into place. Drive rivets have less clamping force than most other rivets.

Flush rivet

A flush rivet is used primarily on external metal surfaces where good appearance and the elimination of unnecessary aerodynamic drag are important. A flush rivet takes advantage of a countersink hole, they are also commonly referred to as countersunk rivets. Countersunk or flush rivets are used extensively on the exterior of aircraft for aerodynamic reasons. Additional post-installation machining may be performed to perfect the airflow.

Friction-lock rivet

One early form of blind rivet that was the first to be widely used for aircraft construction and repair was the Cherry friction-lock rivet. Originally, Cherry friction-locks were available in two styles, hollow shank pull-through and self-plugging types. The pull-through type is no longer common, however, the self -plugging Cherry friction-lock rivet is still used for repairing light aircraft.

Cherry friction-lock rivets are available in two head styles, universal and 100 degree countersunk. Furthermore, they are usually supplied in three standard diameters, 1/8, 5/32 and 3/16 inch.

A friction-lock rivet cannot replace a solid shank rivet, size for size. When a friction-lock is used to replace a solid shank rivet, it must be at least one size larger in diameter.the reason behind this is that friction-lock rivet loses considerable strength if its center stem falls out due to vibrations or damage.

Rivet alloys, their shear strengths and condition in which they are driven.

Alloy type	Alphabetical letter	Driven condition	Marking on head
1100	A	1100-F	PLAIN
2117	AD	2117T3	DIMPLE
5056	B	5056H32	RAISED CROSS
2017	D	2017T31	RAISED DOT
2024	DD	2024T31	TWO RAISED DASHES
7050	E	7050T73	RAISED RING

Self-pierce rivets

Self-pierce riveting (SPR) is a process of joining two or more materials using an engineered rivet. Unlike solid, blind and semi-tubular rivets, self-pierce rivets do not require a drilled or punched hole.

SPRs are cold forged to a semi-tubular shape and contain a partial hole to the opposite end of the head. The end geometry of the rivet has a chamfered poke which aids the piercing of the materials being joined, a hydraulic or electric servo rivet setter drives the rivet into the material and an upsetting die provides a cavity for the displaced bottom sheet material to flow.

The self-pierce rivet fully pierces the top sheet material(s) but only partially pierces the bottom sheet. As the tail end of the rivet does not break through the bottom sheet it provides a water or gas tight joint. With the influence of the upsetting die, the tail end of the rivet flares and interlocks into the bottom sheet forming a low profile button.

Rivets need to be harder than the materials being joined, they are heat treated to various levels of hardness depending on the materials ductility and hardness. Rivets come in a range of diameters and lengths depending on the materials being joined, head styles are either flush countersunk or pan heads.

Depending on the rivet setter configuration, i.e. hydraulic, servo, stroke, nose-to-die gap, feed system etc., cycle times can be as quick as one second. Rivets are typically fed to the rivet setter nose from tape and come in cassette or spool form for continuous production.

Riveting systems can be manual or automated depending on the application requirements, all systems are very flexible in terms of product design and ease of integration into a manufacturing process.

SPR joins a range of dissimilar materials such as steel, aluminum, plastics, composites and pre-coated or pre-painted materials. Benefits include low energy demands, no heat, fumes, sparks or waste and very repeatable quality.

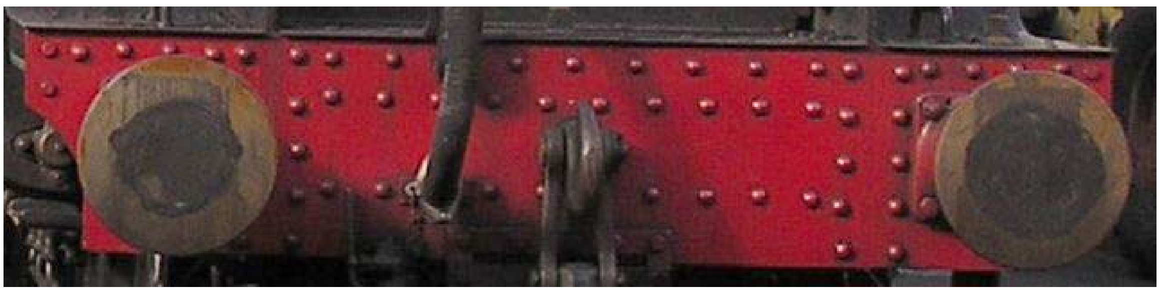
Sizes

Installing rivets on M3 tank hull

Rivet diameters are commonly measured in $^1\!/_{32}$-inch increments and their lengths in $^1\!/_{16}$-inch increments, expressed as "dash numbers" at the end of the rivet identification number. A "dash 3 dash 4" (XXXXXX-3-4) designation indicates a $^3\!/_{32}$-inch diameter and $^4\!/_{16}$-inch (or $^1\!/_4$-inch) length. Some rivets lengths are also available in "half sizes" and will have a dash number such as –3.5 ($^7\!/_{32}$ inch) to indicate that it is a half-size rivet. The letters and digits in a rivet's identification number that precede its dash numbers indicate the specification under which the rivet was manufactured and the head style. On many rivets, a size in 32nds may be stamped on the rivet head. Other makings on the rivet head, such as small raised or depressed dimples or small raised bars indicate the rivet's alloy.

To become a proper fastener, a rivet should be placed in hole ideally 4–6 thousandths of an inch larger in diameter. This allows the rivet to be easily and fully inserted, then setting allows the rivet to expand, tightly filling the gap and maximizing strength.

Applications



A riveted buffer beam on a steam locomotive

A riveted truss bridge over the Orange River

Detail of a 1941 riveted ship hull, with the rivets clearly visible

Before welding techniques and bolted joints were developed, metal framed buildings and structures such as the Eiffel Tower, Shukhov Tower and the Sydney Harbour Bridge were generally held together by riveting. Also automobile chassis were riveted. Riveting is still widely used in applications where light weight and high strength are critical, such as in an aircraft. Many sheet-metal alloys are preferably not welded as deformation and modification of material properties can occur.

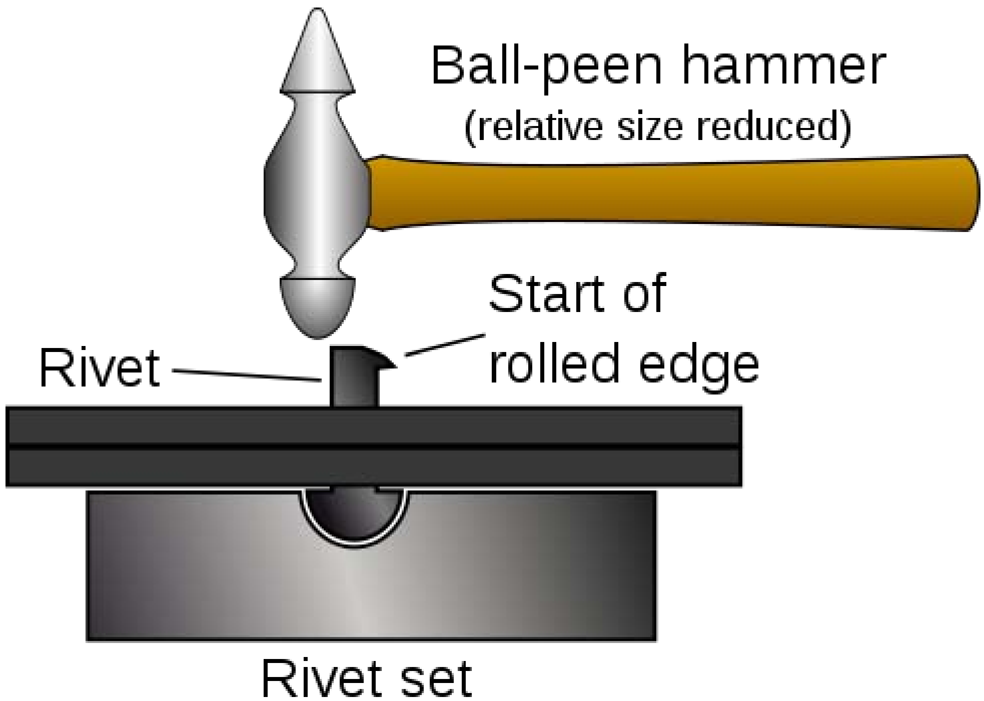
Blind rivets are used almost universally in the construction of plywood road cases.

Common but more exotic uses of rivets are to reinforce jeans and to produce the distinctive sound of a sizzle cymbal.

Joint analysis

The stress and shear in a rivet is analyzed like a bolted joint. However, it is not wise to combine rivets with bolts and screws in the same joint. Rivets fill the hole where they are installed to establish a very tight fit (often called interference fit). It is difficult or impossible to obtain such a tight fit with other fasteners. The result is that rivets in the same joint with loose fasteners will carry more of the load—they are effectively more stiff. The rivet can then fail before it can redistribute load to the other loose fit fasteners like bolts and screws. This often results in catastrophic failure of the joint when the fasteners "unzip". In general, a joint composed of similar fasteners is the most efficient because all fasteners will reach capacity simultaneously.

Installation



Manual installation of a solid rivet

Impact Method for Solid Rivet and Semitubular rivets

Solid & semi tubular rivets

There are several methods for installing solid rivets.

- Manual with hammer and handset or bucking bar
- Pneumatic Hammers
- Handheld Squeezers
- Riveting machines
- Pin Hammer, Rivet Set

Rivets that are small enough and soft enough are often "bucked". In this process the installer places a rivet gun against the factory head and holds a bucking bar against the tail or a hard working surface. The bucking bar is a specially shaped solid block of metal. The rivet gun provides a series of high-impulse forces that upset the rivet in place. Rivets that are large or hard may be more easily installed by squeezing instead. In this process a tool in contact with each end of the rivet clinches to deform the rivet.

Rivets may also be upset by hand, using a ball-peen hammer. The head is placed in a special hole made to accommodate it, known as a rivet-set. The hammer is applied to the buck-tail of the rivet, rolling an edge so that it is flush against the fastened material.

Testing

Solid rivets for construction

A hammer is also used to "ring" an installed rivet, as a non-destructive test for tightness and imperfections. The inspector taps the head (usually the factory head) of the rivet with the hammer while touching the rivet and base plate lightly with the other hand and judges the quality of the audibly returned sound and the feel of the sound traveling through the metal to the operator's fingers. A rivet tightly set in its hole will return a clean and clear ring, while a loose rivet will return a recognizably different sound.

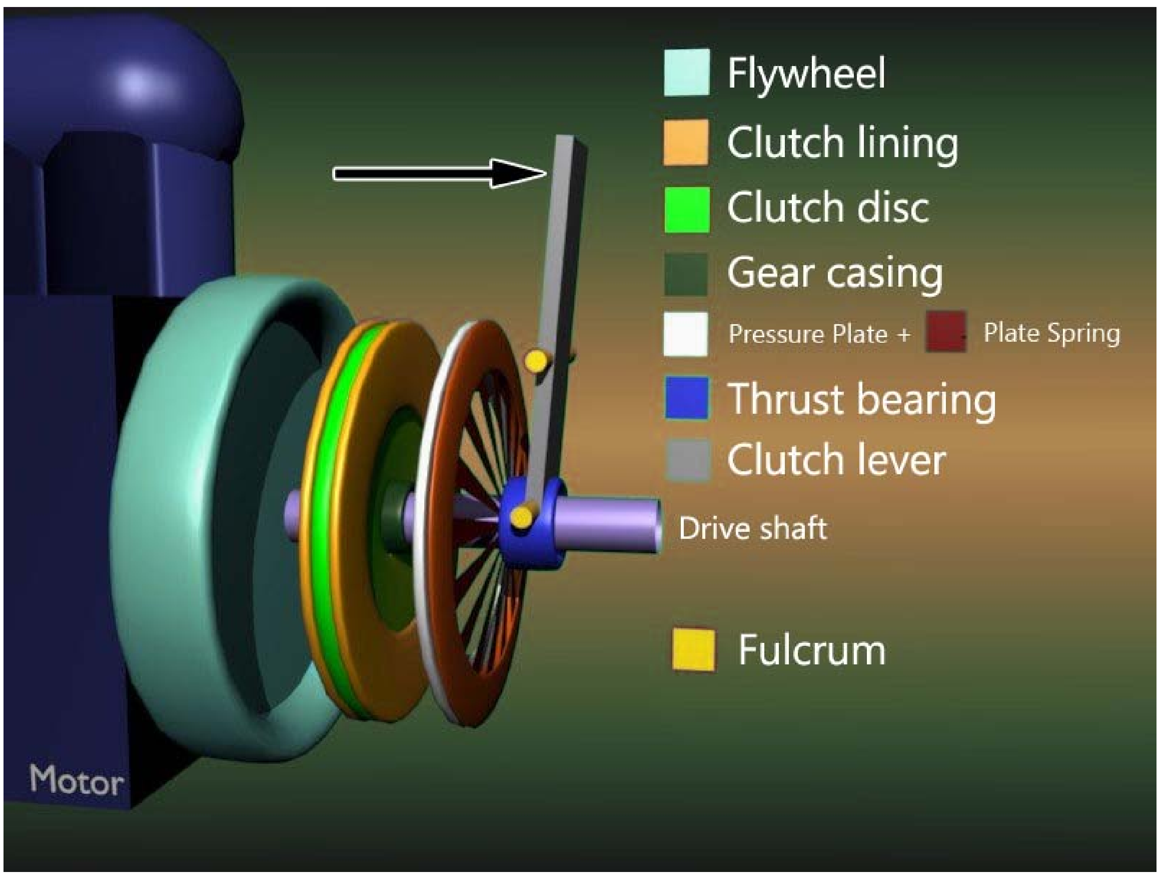
Testing of blind rivets

A blind rivet has strength properties that can be measured in terms of shear and tensile strength. Occasionally rivets also undergo performance testing for other critical features, such as pushout force, break load and salt spray resistance. A standardized destructive test according to the Inch Fastener Standards is widely accepted

The shear test involves installing a rivet into two plates at specified hardness and thickness and measuring the force necessary to shear the plates. The tensile test is basically the same, except that it measures the pullout strength. Per the IFI-135 standard, all blind rivets produced must meet this standard. These tests determine the strength of the rivet, and not the strength of the assembly. To determine the strength of the assembly a user must consult an engineering guide or the Machinery's Handbook

Chapter- 6

Clutch



Clutch for a drive shaft: The clutch **disc** (center) spins with the flywheel (left). To disengage, the lever is pulled (black arrow), causing a white pressure plate (right) to disengage the green clutch disc from turning the drive shaft, which turns within the thrust-bearing ring of the lever. Never will all 3 rings connect, with no gaps.

Rear side of a Ford V6 engine, looking at the clutch housing on the flywheel

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

A **clutch** is a mechanical device which provides for the transmission of power (and therefore usually motion) from one component (the driving member) to another (the driven member). The opposite component of the clutch is the brake.

Clutches are used whenever the ability to limit the transmission of power or motion needs to be controlled either in amount or over time (e.g. electric screwdrivers limit how much torque is transmitted through use of a clutch; clutches control whether automobiles transmit engine power to the wheels).

In the simplest application clutches are employed in devices which have two rotating shafts. In these devices one shaft is typically attached to a motor or other power unit (the driving member) while the other shaft (the driven member) provides output power for work to be done. In a drill for instance, one shaft is driven by a motor and the other drives a drill chuck. The clutch connects the two shafts so that they may be locked together and spin at the same speed (engaged), locked together but spinning at different speeds (slipping), or unlocked and spinning at different speeds (disengaged).

Friction Clutches

Friction clutches are by far the most well-known type of clutches.

Materials

Various materials have been used for the disc friction facings, including asbestos in the past. Modern clutches typically use a compound organic resin with copper wire facing or a ceramic material. A typical coefficient of friction used on a friction disc surface is 0.35ų for organic and 0.25ų for ceramic. Ceramic materials are typically used in heavy applications such as trucks carrying large loads or racing, though the harder ceramic materials increase flywheel and pressure plate wear.

Push/Pull

Friction disk clutches generally are classified as "Push Type" or "Pull Type" depending on the location of the pressure plate fulcrum points. In a pull type clutch, the action of pressing the pedal pulls the release bearing, pulling on the diaphragm spring and disengaging the vehicle drive. The opposite is true with a push type, the release bearing is pushed into the clutch disengaging the vehicle drive. In this instance, the release bearing can be known as a thrust bearing (as per the image above).

Pads

Clutch pads are attached to the frictional pads, part of the clutch. They are most commonly made of rubber but have been known to be made of asbestos. They are usually around $120 dollars (£77 pounds) but different car manufactures vary. Clutch pads usually last about 100,000 miles, depending on how vigorously the car is driven.

Dampers

In addition to the damped disc centres which reduce driveline vibration, pre-dampers may be used to reduce gear rattle at idle by changing the natural frequency of the disc. These weaker springs are compressed solely by the radial vibrations from an idling engine. They are fully compressed and no longer in use once drive is taken up by the main damper springs.

Load

Mercedes truck examples: A clamp load of 33KN (33,000N) is normal for a single plate 430. The 400 Twin application offers a clamp load of a mere 23KN (23,000N). Bursts speeds are typically around 5,000rpm with the weakest point being the facing rivet.

Manufacturing

Modern clutch development focuses its attention on the simplification of the overall assembly and/or manufacturing method. For example drive straps are now commonly employed to transfer torque as well as lift the pressure plate upon disengagement of vehicle drive. With regards to the manufacture of diaphragm springs, heat treatment is crucial. Laser welding is becoming more common as a method of attaching the drive plate to the disc ring with the laser typically being between 2-3KW and a feed rate 1m/minute.

Multiple plate clutch

This type of clutch has several driving members interleaved or "stacked" with several driven members. It is used in race cars including F1, IndyCar, World Rally and even most club racing, motorcycles, automatic transmissions and in some diesel locomotives with mechanical transmissions. It is also used in some electronically controlled all-wheel drive systems.

Wet vs. dry

A "wet clutch" is immersed in a cooling lubricating fluid which also keeps the surfaces clean and gives smoother performance and longer life. Wet clutches, however, tend to lose some energy to the liquid. 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 the lower coefficient of friction and so eliminate slippage under power when fully engaged.

The Hele-Shaw clutch was a wet clutch that relied entirely on viscous effects, rather than on friction.

A "dry clutch", as the name implies, is not bathed in fluid and should be, literally, dry.

Centrifugal

Some vehicles such as mopeds use a centrifugal clutch. This clutch system employs centrifugal force to automatically engage the clutch when the engine rpm rises above a threshold and to automatically disengage the clutch when the engine rpm falls low enough. The system involves a clutch shoe or shoes attached to the driven shaft, rotating inside a clutch bell attached to the output shaft. The shoe(s) are held inwards by springs until centrifugal force overcomes the spring tension and the shoe(s) make contact with the bell, driving the output.

Cone clutch

Distinguished by conical friction surfaces. The cone's taper means that a given amount of movement of the actuator makes the surfaces approach (or recede) much more slowly than in a disc clutch. As well, a given amount of actuating force created more pressure on the mating surfaces.

Torque limiter

AKA slip clutch, or *Safety clutch:*

This device allows a rotating shaft to "slip" when higher than normal resistance is encountered on a machine. An example of a safety clutch is the one mounted on the driving shaft of a large grass mower. The clutch will "slip" or "give" if the blades hit a rock, stump, or other immobile object. Motor-driven mechanical calculators had these, between the drive motor and gear train, to limit damage when the mechanism jammed. (Motors had high stall torque.)

> Carefully-designed types disengage (but continue to transmit torque) in such tools as controlled-torque screwdrivers.
> Many safety clutches are NOT friction clutches, but belong to the "interference clutch" family of which the dog clutch (discussed briefly later) is the most well-known.

Major Types of Clutches by Application

Vehicular (General)

There are different designs of vehicle clutch but most are based on one or more friction discs pressed tightly together or against a flywheel using springs. The friction material varies in composition depending on many considerations such as whether the clutch is "dry" or "wet". Friction discs once contained asbestos but this has been largely eliminated. 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 generally considered unsuitable for passenger 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. However, raising the engine speed too high while engaging the clutch will cause excessive clutch plate wear. Engaging the clutch abruptly when the engine is turning at high speed causes a harsh, jerky start. This kind of start is necessary and desirable in drag racing and other competitions, where speed is more important than comfort.

Automobile Powertrain

This plastic pilot shaft guide tool is used to align the clutch disk as the spring-loaded pressure plate is installed. The transmission's drive splines and pilot shaft have a complementary shape. A number of such devices fit various makes and models of drivetrains

In a modern car with a manual transmission the clutch is operated by the left-most pedal using a hydraulic or cable connection from the pedal to the clutch mechanism. On older cars the clutch might be operated by a mechanical linkage. 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 vibrations and 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 pressing the pedal disengages the clutch plates, allowing the driver to shift gears or coast.

Motorcycles

Motorcycles typically employ a wet clutch with the clutch riding in the same oil as the transmission. These clutches are usually made up of a stack of alternating plain steel and friction plates. Some of the plates have lugs on their inner diameters locking them to the engine crankshaft, while the other plates have lugs on their outer diameters that lock them to a basket which turns the transmission input shaft. The plates are forced together by a set of coil springs or a diaphragm spring plate when the clutch is engaged.

> 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 through cable or hydraulic actuation, allowing the rider to shift gears or coast.

Racing motorcycles often use slipper clutches to eliminate the effects of engine braking which, being applied only to the rear wheel, can lead to instability.

Automobile Non-powertrain

There are other clutches found in a car. For example, a belt-driven engine cooling fan may have a clutch that is heat-activated. The driving and driven members are separated by a silicone-based fluid and a valve controlled by a bimetallic spring. When the temperature is low, the spring winds and closes the valve, which allows the fan to spin at about 20% to 30% of the shaft speed. As the temperature of the spring rises, it unwinds and opens the valve, allowing fluid past the valve which allows the fan to spin at about 60% to 90% of shaft speed.

Other clutches such as for an air conditioning compressor electronically engaged clutches using magnetic force to couple the driving member to the driven member.

Other General Clutches and Example Applications

- Dog clutches: Utilization in automobile manual transmissions mentioned above. Positive engagement, non-slip. Typically used where slipping is not acceptable. Partial engagement under any significant load tends to be destructive.

- Hydraulic clutch: The driving and driven members are not in physical contact; coupling is hydrodynamic.

- Electromagnetic clutch: Typically a clutch that is engaged by an electromagnet that is an integral part of the clutch assembly.

  However, magnetic particle clutches have magnetically influenced particles contained in a chamber between driving and driven members which upon application of direct current causes the particles to clump together and adhere to the operating surfaces. Engagement and slippage are notably smooth.

- Overrunning clutch or freewheel: If some external force makes the driven member rotate faster than the driver, the clutch effectively disengages.

  Examples include:
  This was essential for the operation of Borg-Warner Overdrive transmissions in cars;
  Typical bicycles have these so that the rider can stop pedaling and coast;
  Another application includes an oscillating member where this clutch can then convert the oscillations into intermittent linear or rotational motion of the complimentary member;
  Still others use ratchets with the pawl mounted on a moving member;
  The winding knob of a camera employs a (silent) wrap-spring type as a clutch in winding and as a brake in preventing it from being turned backwards.

- Wrap-spring clutches: These have a helical spring wound with square-cross-section wire. In simple form the spring is fastened at one end to the driven member; its other end is unattached. The spring fits closely around a cylindrical driving member. If the driving member rotates in the direction that would unwind the spring the spring expands minutely and slips although with some drag. Rotating the driving member the other way makes the spring wrap itself tightly around the driving surface and the clutch locks up.

Specialty Clutches/Applications

- Single-revolution clutch: When inactive it is disengaged and the driven member is stationary. When "tripped", it locks up solidly (typically in milliseconds or tens of ms) and rotates the driven member just one full turn. If the trip mechanism is operated when the clutch would otherwise disengage the clutch remains engaged. Variants include half-revolution (and other fractional-revolution) types. These were an essential part of printing telegraphs such as the Teletype page printers, as well as electric typewriters, notably the IBM Selectric. They were also found in motor-driven mechanical calculators; the Marchant had several of them. They are also used in farm machinery and industry. Typically, these were a variety of dog clutch.

  Single-revolution clutches in teleprinters were of this type. Basically the spring was kept expanded (details below) and mostly out of contact with the driving sleeve, but nevertheless close to it. One end of the spring was attached to a sleeve surrounding the spring. The other end of the spring was attached to the driven member inside which the drive shaft could rotate freely. The sleeve had a projecting tooth, like a ratchet tooth. A spring-loaded pawl pressed against the sleeve and kept it from rotating. The wrap spring's torque kept the sleeve's tooth pressing against the pawl.
  To engage the clutch, an electromagnet attracted the pawl away from the sleeve. The wrap spring's torque rotated the sleeve which permitted the spring to contract and wrap tightly around the driving sleeve. Load torque tightened the wrap so it did not slip once engaged. If the pawl were held away from the sleeve the clutch would continue to drive the load without slipping.
  When the clutch was to disengage power was disconnected from the electromagnet and the pawl moved close to the sleeve. When the sleeve's tooth contacted the pawl the sleeve and the load's inertia unwrapped the spring to disengage the clutch.
  Considering that the drive motors in some of these (such as teleprinters for news wire services) ran 24 hours a day for years the spring could not be allowed to stay in close contact with the driving cylinder; wear would be excessive. The other end of the spring was fastened to a thick disc attached to the driven member. When the clutch locked up the driven mechanism coasted and its inertia rotated the disc until a tooth on it engaged a pawl that kept it from reversing. Together with the restraint at the other end of the spring created by the trip pawl and sleeve tooth, this kept the spring expanded to minimize contact with the driving cylinder.

These clutches were lubricated with conventional oil but the wrap was so effective that the lubricant did not defeat the grip.
These clutches had long operating lives cycling for tens, maybe hundreds of millions of cycles without need of maintenance other than occasional lubrication with recommended oil.

- "Cascaded-Pawl" single-revolution clutches: These superseded wrap-spring single-revolution clutches in page printers (such as teleprinters) including the Model 28 Teletype (and its successors using the same design principles). As well, the IBM Selectric typewriter had several of them.

  These were typically disc-shaped assemblies mounted on the drive shaft. Inside the hollow disc-shaped housing were two or three freely-floating pawls arranged so that when the clutch was tripped, the load torque on the first pawl to engage created force to keep the second pawl engaged, which in turn kept the third one engaged. The clutch did not slip once locked up. This sequence happened quite fast, on the order of milliseconds.
  The first pawl had a projection that engaged a trip lever. If the lever engaged the pawl the clutch was disengaged. When the trip lever moved out of the way the first pawl engaged, creating the cascaded lockup just described. As the clutch rotated it would stay locked up if the trip lever were out of the way, but if the trip lever engaged the clutch would quickly unlock.

- "Kickback" clutch-brakes:

  These mechanisms were found in some types of synchronous-motor-driven electric clocks. Many different types of synchronous clock motors were used, including the pre-World War II Hammond manual-start clocks. Some types of self-starting synchronous motors always started when power was applied, but in detail, their behavior was chaotic and they were equally likely to start rotating in the wrong direction.
  Coupled to the rotor by one (or possibly two) stages of reduction gearing was a wrap-spring clutch-brake. The spring did not rotate. One end was fixed; the other was free. It rode freely but closely on the rotating member, part of the clock's gear train. The clutch-brake locked up when rotated backwards, but also had some spring action. The inertia of the rotor going backwards engaged the clutch and "wound" the spring. As it "unwound", it re-started the motor in the correct direction. Some designs had no explicit spring as such; it was simply a compliant mechanism. The mechanism was lubricated; wear did not seem to be a problem.

Chapter- 7

Brake

Disc brake on a motorcycle.

A **brake** is a device which inhibits motion. Its opposite component is a clutch.

Most commonly brakes use friction to convert kinetic energy 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. 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 mechansims, 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 ($K = mv^2 / 2$), an object traveling at 10 meters per second has 100 times as much energy as one traveling at 1 meter per second, 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 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 is pushed a piston pushes the pad towards the brake disc which slows the wheel down. On the brake drum it is similar as the cylinder pushes the brake shoes towards 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.

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.

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 resivoir called an hydraulic accumulator.

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.

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.

Brake boost

Most modern vehicles are equipped with a brake boost system that greatly increases the force applied to the vehicle's brakes by its operator. This additional force is supplied by the vacuum generated by the running engine, but this force is greatly reduced when the engine is running at full throttle and the available vacuum is diminished.

Because of this, reports of unintended acceleration are often accompanied by complaints of failed or weakened brakes, as the high-revving engine is unable to provide enough vacuum to power the brake booster. This problem is exacerbated in vehicles equipped with automatic transmissions as the vehicle will automatically downshift upon application of the brakes, thereby further elevating engine RPM and reducing available braking power while increasing the engine's effective torque.

Noise

Brake lever on a horse-drawn hearse.

Although ideally a brake would convert all the kinetic energy into heat, in practice a significant amount may be converted into acoustic energy instead, contributing to noise pollution.

For road vehicles, the noise produced varies significantly with tire construction, road surface, and the magnitude of the deceleration. Noise can be caused by different things. These are signs that there may be issues with brakes wearing out.

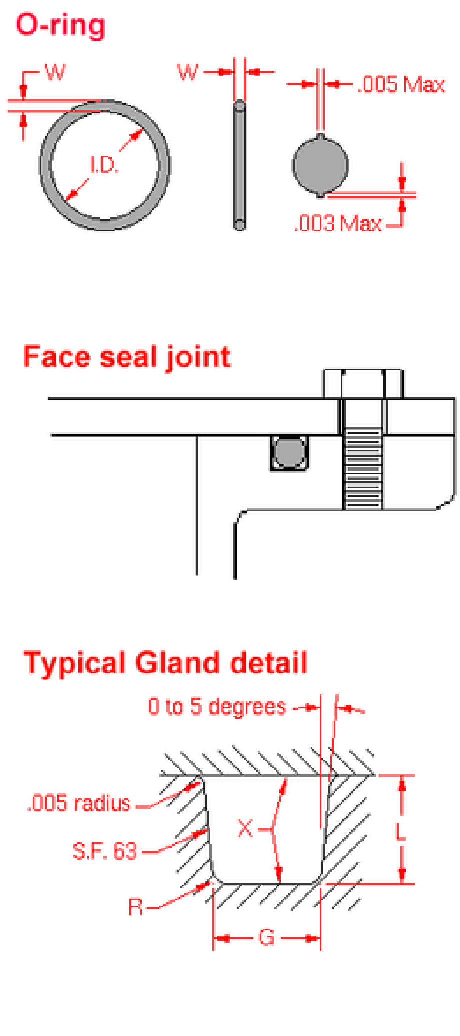
Inefficiency

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 vehicle performance.

Chapter- 8

O-ring



Typical O-ring and application

An **O-ring**, also known as a packing, or a **toric joint**, is a mechanical gasket in the shape of a torus; it is a loop of elastomer with a disc-shaped cross-section, designed to be seated in a groove and compressed during assembly between two or more parts, creating a seal at the interface.

The O-ring may be used in static applications or in dynamic applications where there is relative motion between the parts and the O-ring. Dynamic examples include rotating pump shafts and hydraulic cylinder pistons.

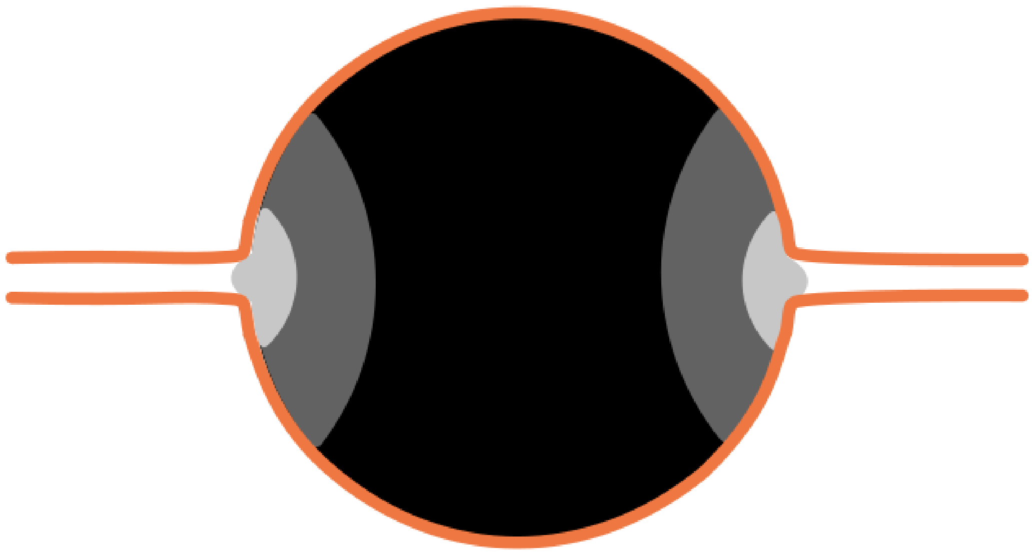
O-rings are one of the most common seals used in machine design because they are inexpensive, easy to make, reliable, and have simple mounting requirements. They can seal tens of megapascals (thousands of psi) pressure.

History

The US patent claim for the O-ring was filed in 1937 by a then 72-year-old Danish-born machinist, Niels Christensen. He came to the USA in 1891 and soon after that patented an air brake system for streetcars (trams). Despite his legal efforts, his intellectual property rights were passed from company to company until they ended up at Westinghouse. During World War II, the US government commandeered the O-ring patent as a critical war-related item and gave the right to manufacture to other organizations. Christensen got a lump sum payment of US$75,000 for his efforts. Litigation resulted in a $100,000 payment to his heirs in 1971, 19 years after his death.

There is also a Swedish patent for the O-ring, that is dated May 12, 1896. It was the inventor J. O. Lundberg who received patent for the invention.

Theory and design



O-ring mounting for an ultra-high vacuum application. Pressure distribution within the cross-section of the O-ring. The red lines are hard surfaces, which apply high pressure. The fluid in the seams has lower pressure. The soft O-ring bridges the pressure over the seams.

O-rings are one of the simplest, yet most engineered, precise, and useful seal designs ever developed. They are one of the most common and important elements of machine design. O-rings are available in various metric and inch standard sizes. Sizes are specified by the inside diameter and the cross section diameter (thickness). In the US the most common standard inch sizes are per SAE AS568B specification (i.e. AS568-214). ISO 3601-1:2008 contains the most commonly used standard sizes, both inch and metric, worldwide. The UK also has standards sizes known as BS sizes, typically ranging from BS001 to BS932. Several other size specifications also exist.

Typical applications

Successful O-ring joint design requires a rigid mechanical mounting that applies a predictable deformation to the O-ring. This introduces a calculated mechanical stress at the O-ring contacting surfaces. As long as the pressure of the fluid being contained does not exceed the contact stress of the O-ring, leaking cannot occur. Fortunately, the pressure of the contained fluid transfers through the essentially incompressible o-ring material, and the contact stress rises with increasing pressure. For this reason, an o-ring can easily seal high pressure as long as it does not fail mechanically. The most common failure is extrusion through the mating parts.

The seal is designed to have a point contact between the O-ring and sealing faces. This allows a high local stress, able to contain high pressure, without exceeding the yield stress of the O-ring body. The flexible nature of O-ring materials accommodates imperfections in the mounting parts. But it is still important to maintain good surface finish of those mating parts, especially at low temperatures where the seal rubber reaches its glass transition temperature and becomes increasingly crystalline. Surface finish is also especially important in dynamic applications. A surface finish that is too rough will abrade the surface of the o-ring, and a surface that is too smooth will not allow the seal to be adequately lubricated by a fluid film.

Vacuum applications

In vacuum applications, the permeability of the material makes point contacts quite useless. Instead, higher mounting forces are used and the ring fills the whole groove. Also, round back-up rings are used to save the ring from excessive deformation Because the ring feels the ambient pressure and the partial pressure of gases only at the seal, their gradients will be steep near the seal and shallow in the bulk (opposite to the gradient of the contact stress See: Vacuum_flange#KF.2FQF. High-vacuum systems below 10^{-9} Torr use copper or nickel O-rings. Also, vacuum systems that have to be immersed in liquid nitrogen use indium O-rings, because rubber becomes hard and brittle at low temperatures.

High temperature applications

In some high-temperature applications, O-rings may need to be mounted in a tangentially compressed state, to compensate for the Gow-Joule effect.

Material

Some small O-rings

O-ring selection is based on chemical compatibility, application temperature, sealing pressure, lubrication requirements, durometer, size and cost.

Synthetic rubbers - Thermosets:

- Butadiene rubber (BR)
- Butyl rubber (IIR)
- Chlorosulfonated polyethylene (CSM)
- Epichiorohydrin rubber(ECH, ECO)
- Ethylene propylene diene monomer (EPDM)
- Ethylene propylene rubber (EPR)
- Fluoroelastomer (FKM)
- Nitrile rubber (NBR)
- Perfluoroelastomer (FFKM)
- Polyacrylate rubber(ACM)
- Polychloroprene (neoprene) (CR)
- Polyisoprene (IR)
- Polysulfide rubber (PSR)
- Sanifluor
- Silicone rubber (SiR)
- Styrene butadiene rubber (SBR)

Thermoplastics:

- Thermoplastic elastomer (TPE) styrenics
- Thermoplastic polyolefin (TPO) LDPE, HDPE, LLDPE, ULDPE
- Thermoplastic polyurethane (TPU) polyether, polyester
- Thermoplastic etheresterelastomers (TEEEs) copolyesters
- Thermoplastic polyamide (PEBA) Polyamides
- Melt Processible Rubber (MPR)
- Thermoplastic Vulcanizate (TPV)

Other seals

There are variations in cross-section design other than circular. These include the O-ring with an x-shaped profile, commonly called the X-ring, Q-ring, or by the trademarked name Quad Ring. When squeezed upon installation, they seal with 4 contact surfaces—2 small contact surfaces on the top and bottom. This contrasts with the standard O-ring's comparatively larger single contact surfaces top and bottom. X-rings are most commonly used in reciprocating applications, where they provide reduced running and breakout friction and reduced risk of spiraling when compared to O-rings.

There are also rings with a square profile, commonly called square-cuts, lathe cuts, or Square rings. When O-rings were selling at a premium because of the novelty, lack of efficient manufacturing processes and high labor content, Square rings were introduced as an economical substitution for O-rings. The Square ring is typically manufactured by molding an elastomer sleeve which is then lathe-cut. This style of seal is sometimes less expensive to manufacture with certain materials and molding technologies (compression molding, transfer molding, injection molding), especially in low volumes. The physical sealing performance of Square rings in static applications is superior to that of O-rings, however in dynamic applications it is inferior to that of O-rings. Square rings are usually only used in dynamic applications as energizers in cap seal assemblies. Square rings can also be more difficult to install than O-rings.

Similar devices with a non-round cross-sections are called seals or packings.

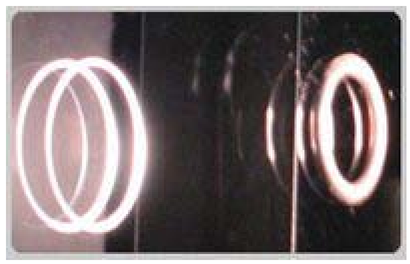
Failure modes

O-ring materials may be subjected to high or low temperatures, chemical attack, vibration, abrasion, and movement. Materials are selected according to the situation.

There are O-ring materials which can tolerate temperatures as low as -200 C or as high as 250+ C. At the low end, nearly all engineering materials become rigid and fail to seal; at the high end, the materials often burn or decompose. Chemical attacks can degrade the material, start brittle cracks or cause it to swell. For example, NBR seals can crack when exposed to ozone gas at very low concentrations, unless protected. Other failures can be caused by using the wrong size of ring for a specific recess, which may cause extrusion of the rubber.

Challenger disaster

The failure of an O-ring seal was determined to be the cause of the Space Shuttle *Challenger* disaster on January 28, 1986. A contributing factor was cold weather prior to the launch. This was famously demonstrated on television by Caltech physics professor Richard Feynman, when he placed a small O-ring into ice-cold water, and subsequently showed its loss of pliability before an investigative committee.



O-rings are now examined under high-power video microscopes for defects

The material of the failed O-ring was FKM which was specified by the shuttle motor contractor, Morton-Thiokol. FKM is not a good material for cold temperature applications. When an O-ring is cooled below its T_g (glass transition temperature), it loses its elasticity and becomes brittle. More importantly, when an O-ring is cooled near, but not beyond, its T_g, the cold O-ring, once compressed, will take longer than normal to return to its original shape. O-rings (and all other seals) work by creating positive pressure against a surface thereby preventing leaks. On the night before the launch, exceedingly low air temperatures were recorded. On account of this, NASA technicians performed an inspection. The ambient temperature was within launch parameters, and the launch sequence was allowed to proceed. However, the temperature of the rubber O-rings remained significantly lower than that of the surrounding air. During his investigation of the launch footage, Dr. Feynman observed a small out-gassing event from the Solid Rocket Booster (SRB) at the joint between two segments in the moments immediately preceding the disaster. This was blamed on a failed O-ring seal. The escaping high temperature gas impinged upon the external tank, and the entire vehicle was destroyed as a result.

The rubber industry has gone through its share of transformation after the accident. Many O-rings now come with batch and cure date coding, as in the medicine industry, to precisely track and control distribution. For aerospace and military/defense applications, O-rings are usually individually packaged and labeled with the material, cure date, and batch information. O-rings can, if needed, be recalled off the shelf. Furthermore, O-rings and other seals are routinely batch-tested for quality control by the manufacturers, and often undergo Q/A several more times by the distributor and ultimate end users.

As for the SRBs themselves, NASA and Morton-Thiokol redesigned them with a new joint design, which now incorporated three O-rings instead of two, with the joints themselves having onboard heaters which can be turned on when temperatures drop below 50 °F (10 °C). No O-ring issues have occurred since *Challenger*, and they did not play a role in the Space Shuttle Columbia disaster of 2003.

Future

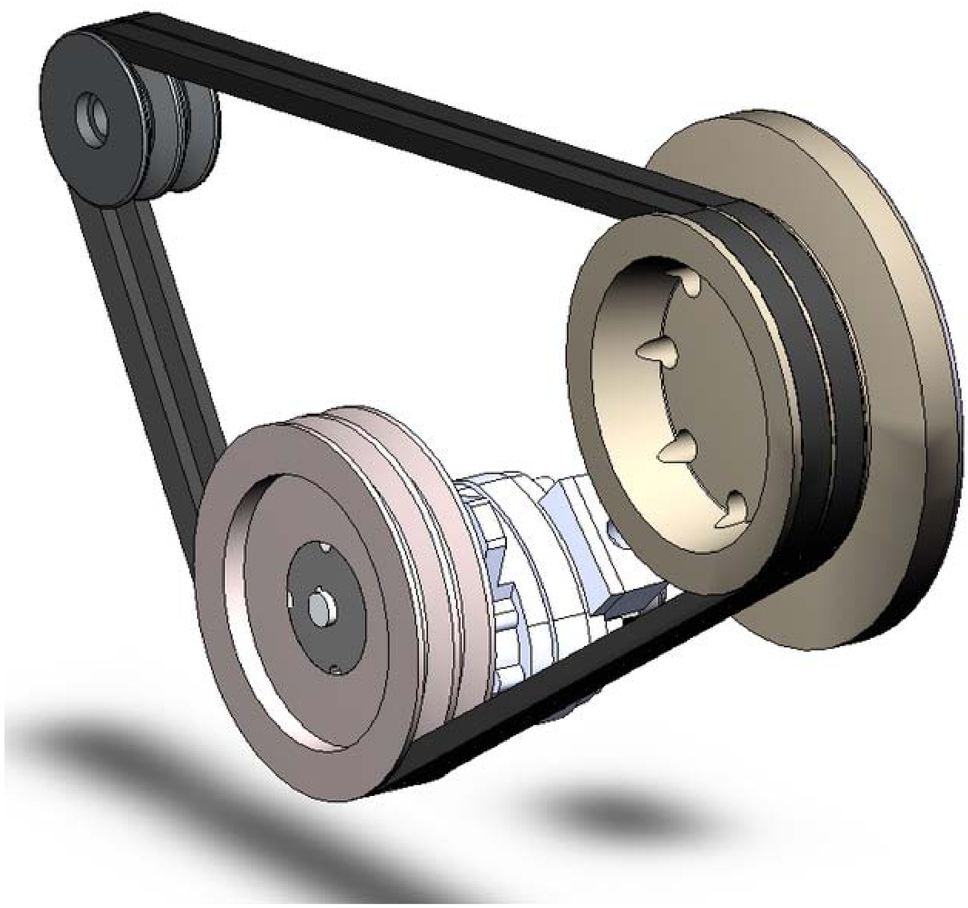
An O-ring is one of the most simple, yet highly critical, precision mechanical components ever developed. But, there are new advances that may take some of the burden of critical sealing away from the exclusive domain of O-rings. There are cottage industries of elastomer consultants assisting in designing O-ring-less pressure vessels. Nano-technology-rubber is one such new frontier. Presently, these advancements are increasing the importance of O-rings. Since O-rings encompass the areas of chemistry and material science, any advancement in nano-rubber will affect the O-ring industry.

Already, there are elastomers filled with nano-carbon and nano-PTFE and molded into O-rings used in high-performance applications. For example, carbon nanotubes are used in electrostatic dissipative applications and nano-PTFE is used in ultra pure semiconductor applications. The use of nano-PTFE in fluoroelastomers and perfluoroelastomers improves abrasion resistance, lowers friction, lowers permeation, and can act as clean filler.

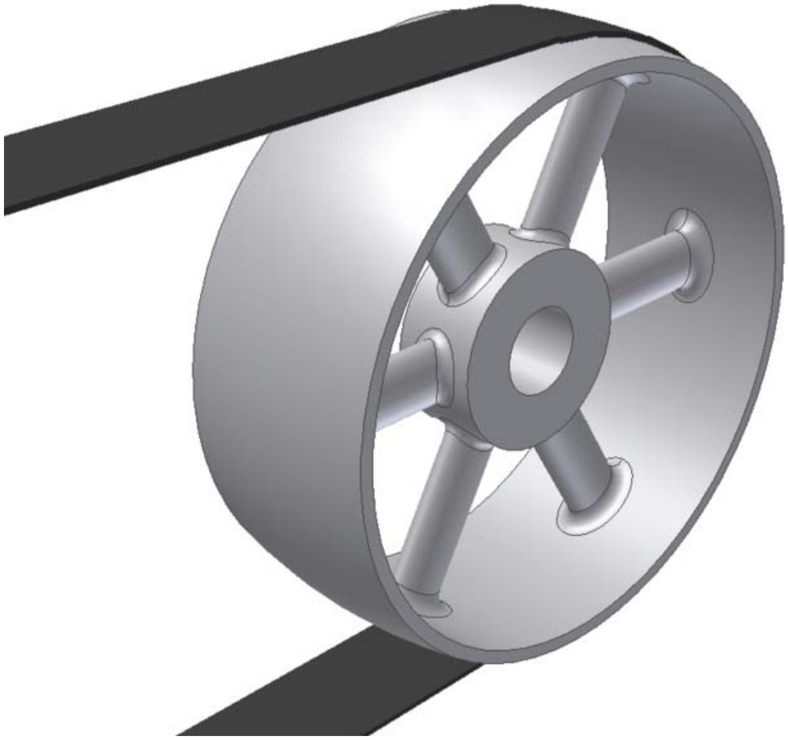
Using conductive carbon black or other fillers can exhibit the useful properties of conductive rubber, namely preventing electrical arcing, static sparks, and the overall build-up of charge within rubber that may cause it to behave like a capacitor (electrostatic dissipative). By dissipating these charges, these materials, which include doped carbon-black and rubber with metal filling additives, reduce the risk of ignition, which can be useful for fuel lines.

Chapter- 9

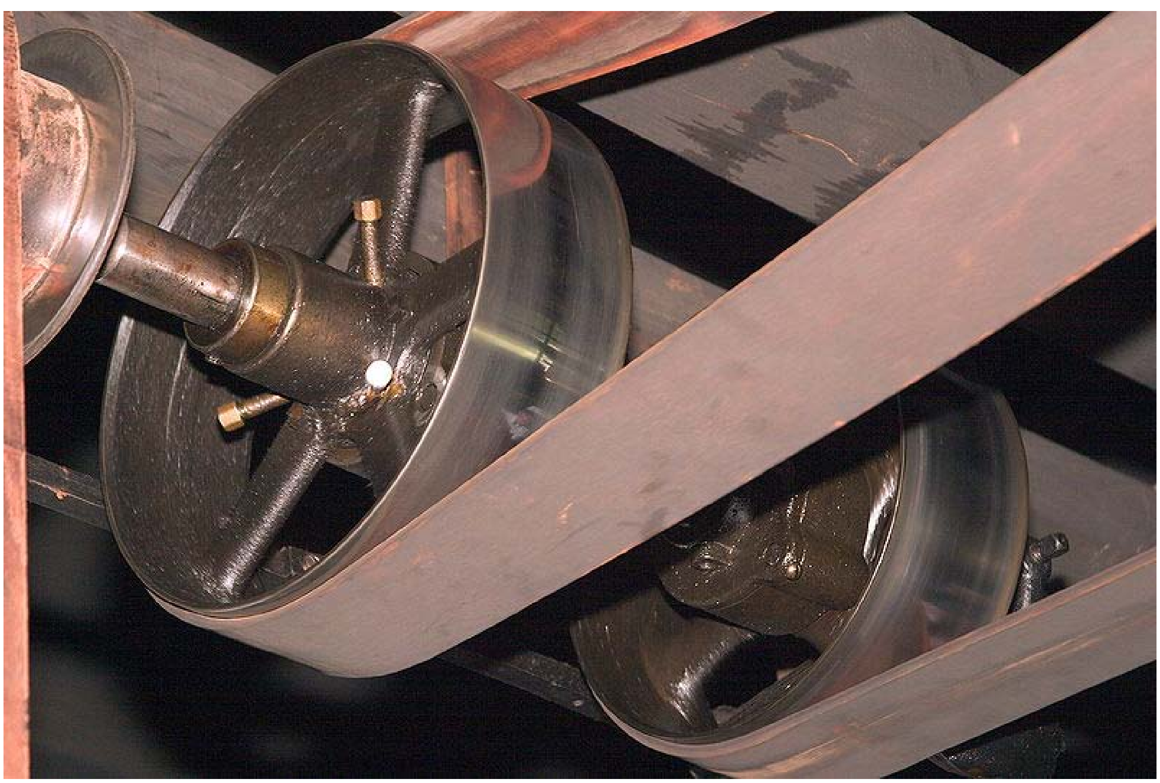
Belt (mechanical)



A pair of vee-belts



flat belt



Flat belt drive in the machine shop at the Hagley Museum

A **belt** is a loop of flexible material used to link two or more rotating shafts mechanically. Belts may be used as a source of motion, to transmit power efficiently, or to track relative movement. Belts are looped over pulleys. In a two pulley system, the belt can either drive the pulleys in the same direction, or the belt may be crossed, so that the direction of the shafts is opposite. As a source of motion, a conveyor belt is one application where the belt is adapted to continually carry a load between two points.

Power transmission

Belts are the cheapest utility for power transmission between shafts that may not be axially aligned. Power transmission is achieved by specially designed belts and pulleys. The demands on a belt drive transmission system are large and this has led to many variations on the theme. They run smoothly and with little noise, and cushion motor and bearings against load changes, albeit with less strength than gears or chains. However, improvements in belt engineering allow use of belts in systems that only formerly allowed chains or gears.

Pros and cons

Belt drive, moreover, is simple, inexpensive, and does not require axially aligned shafts. It helps protect the machinery from overload and jam, and damps and isolates noise and vibration. Load fluctuations are shock-absorbed (cushioned). They need no lubrication and minimal maintenance. They have high efficiency (90-98%, usually 95%), high tolerance for misalignment, and are inexpensive if the shafts are far apart. Clutch action is activated by releasing belt tension. Different speeds can be obtained by step or tapered pulleys.

The angular-velocity ratio may not be constant or equal to that of the pulley diameters, due to slip and stretch. However, this problem has been largely solved by the use of toothed belts. Temperatures ranges from −31 °F (−35 °C) to 185 °F (85 °C). Adjustment of center distance or addition of an idler pulley is crucial to compensate for wear and stretch.

Flat belts

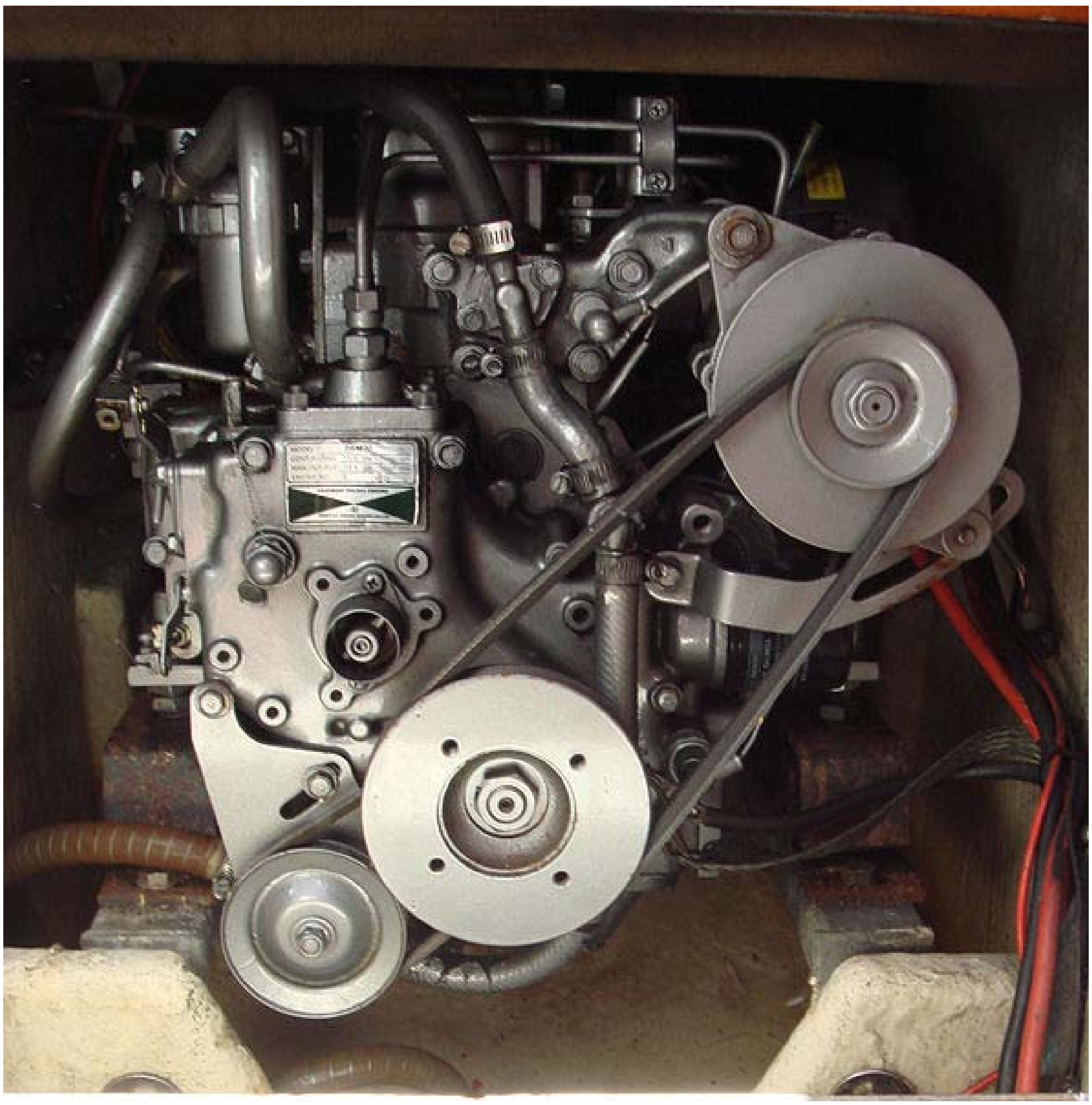
The drive belt: used to transfer power from the engine's flywheel. Here shown driving a threshing machine.

Flat belts were used early in line shafting to transmit power in factories. They were also used in countless farming, mining, and logging applications, such as bucksaws, sawmills, threshers, silo blowers, conveyors for filling corn cribs or haylofts, balers, water pumps (for wells, mines, or swampy farm fields), and electrical generators. The flat belt is a simple system of power transmission that was well suited for its day. It delivered high power for high speeds (500 hp for 10,000 ft/min), in cases of wide belts and large pulleys. These drives are bulky, requiring high tension leading to high loads, so vee belts have mainly replaced the flat-belts except when high speed is needed over power. The Industrial Revolution soon demanded more from the system, and flat belt pulleys needed to be carefully aligned to prevent the belt from slipping off. Because flat belts tend to climb towards the higher side of the pulley, pulleys were made with a slightly convex or "crowned" surface (rather than flat) to keep the belts centered. Flat belts also tend to slip on the pulley face when heavy loads are applied and many proprietary dressings were available that could be applied to the belts to increase friction, and so power transmission. Grip was better if the belt was assembled with the hair (i.e. outer) side of the leather against the pulley although belts were also often given a half-twist before joining the ends (forming a Möbius strip), so that wear was evenly distributed on both sides of the belt (DB). Belts were joined by lacing the ends together with leather thonging, or later by steel comb fasteners. A good modern use for a flat belt is with smaller pulleys and large central distances. They can connect inside and outside pulleys, and can come in both endless and jointed construction.

Round belts

Round belts are a circular cross section belt designed to run in a pulley with a circular (or near circular) groove. They are for use in low torque situations and may be purchased in various lengths or cut to length and joined, either by a staple, gluing or welding (in the case of polyurethane). Early sewing machines utilized a leather belt, joined either by a metal staple or glued, to a great effect.

Vee belts



Belts on a Yanmar 2GM20 marine diesel engine.

A multiple-V-belt drive on an air compressor.

Vee belts (also known as V-belt or wedge rope) solved the slippage and alignment problem. It is now the basic belt for power transmission. They provide the best combination of traction, speed of movement, load of the bearings, and long service life. The V-belt was developed in 1917 by John Gates of the Gates Rubber Company. They are generally endless, and their general cross-section shape is trapezoidal. The "V" shape of the belt tracks in a mating groove in the pulley (or sheave), with the result that the belt cannot slip off. The belt also tends to wedge into the groove as the load increases — the greater the load, the greater the wedging action — improving torque transmission and making the V-belt an effective solution, needing less width and tension than flat belts. V-belts trump flat belts with their small center distances and high reduction ratios. The preferred center distance is larger than the largest pulley diameter, but less than three times the sum of both pulleys. Optimal speed range is 1000–7000 ft/min. V-belts need larger pulleys for their larger thickness than flat belts. They can be supplied at various fixed lengths or as a segmented section, where the segments are linked (spliced) to form a belt of the required length. For high-power requirements, two or more vee belts can be joined side-by-side in an arrangement called a multi-V, running on matching multi-groove sheaves. The strength of these belts is obtained by reinforcements with fibers like steel, polyester or aramid (e.g. Twaron or Kevlar). This is known as a multiple-V-belt drive (or sometimes a "classical V-belt drive"). When an endless belt does not fit the need, jointed and link V-belts may be employed. However they are weaker and only usable at speeds up to 4000 ft/min. A link v-belt is a number of rubberized fabric links held together by metal fasteners. They are length adjustable by disassembling and removing links when needed.

Multi-groove belts

A multi-groove or polygroove belt is made up of usually 5 or 6 "V" shapes along side each other. This gives a thinner belt for the same drive surface, thus is more flexible, although often wider. The added flexibility offers an improved efficiency, as less energy is wasted in the internal friction of continually bending the belt. In practice this gain of efficiency is overshadowed by the reduced heating effect on the belt, as a cooler-running belt lasts longer in service.

A further advantage of the polygroove belt, and the reason they have become so popular, stems from the ability to be run over pulleys on the ungrooved back of the belt. Although this is sometimes done with vee belts and a single idler pulley for tensioning, a polygroove belt may be wrapped around a pulley on its back tightly enough to change its direction, or even to provide a light driving force.

Any vee belt's ability to drive pulleys depends on wrapping the belt around a sufficient angle of the pulley to provide grip. Where a single-vee belt is limited to a simple convex shape, it can adequately wrap at most three or possibly four pulleys, so can drive at most three accessories. Where more must be driven, such as for modern cars with power steering and air conditioning, multiple belts are required. As the polygroove belt can be bent into concave paths by external idlers, it can wrap any number of driven pulleys, limited only by the power capacity of the belt.

This ability to bend the belt at the designer's whim allows it to take a complex or "serpentine" path. This can assist the design of a compact engine layout, where the accessories are mounted more closely to the engine block and without the need to provide movable tensioning adjustments. The entire belt may be tensioned by a single idler pulley.

Ribbed belt

A ribbed belt is a power transmission belt featuring lengthwise grooves. It operates from contact between the ribs of the belt and the grooves in the pulley. Its single-piece structure it reported to offer an even distribution of tension across the width of the pulley where the belt is in contact, a power range up to 600 kW, a high speed ratio, serpentine drives (possibility to drive off the back of the belt), long life, stability and homogeneity of the drive tension, and reduced vibration. The ribbed belt may be fitted on various applications : compressors, fitness bikes, agricultural machinery, food mixers, washing machines, lawn mowers, etc.

Film belts

Though often grouped with flat belts, they are actually a different kind. They consist of a very thin belt (0.5-15 millimeters or 100-4000 micrometres) strip of plastic and occasionally rubber. They are generally intended for low-power (10 hp or 7 kW), high-speed uses, allowing high efficiency (up to 98%) and long life. These are seen in business machines, printers, tape recorders, and other light-duty operations.

Timing belts

Timing belt

Belt-drive cog on a belt-driven bicycle

Timing belts, (also known as **Toothed**, **Notch**, **Cog**, or **Synchronous** belts) are a *positive* transfer belt and can track relative movement. These belts have teeth that fit into a matching toothed pulley. When correctly tensioned, they have no slippage, run at constant speed, and are often used to transfer direct motion for indexing or timing purposes (hence their name). They are often used in lieu of chains or gears, so there is less noise and a lubrication bath is not necessary. Camshafts of automobiles, miniature timing systems, and stepper motors often utilize these belts. Timing belts need the least tension of all belts, and are among the most efficient. They can bear up to 200 hp (150 kW) at speeds of 16,000 ft/min.

Timing belts with a helical offset tooth design are available. The helical offset tooth design forms a chevron pattern and causes the teeth to engage progressively. The chevron pattern design is self-aligning. The chevron pattern design does not make the noise that some timing belts make at idiosyncratic speeds, and is more efficient at transferring power (up to 98%).

Disadvantages include a relatively high purchase cost, the need for specially fabricated toothed pulleys, less protection from overloading and jamming, and the lack of clutch action.

Specialty belts

Belts normally transmit power on the tension side of the loop. However, designs for continuously variable transmissions exist that use belts that are a series of solid metal blocks, linked together as in a chain, transmitting power on the compression side of the loop.

Rolling roads

Belts used for rolling roads for wind tunnels can be capable of 250 km/h.

Flying rope

For transmission of mechanical power over distance without electrical energy, a flying rope can be used. A wire or manila rope can be used to transmit mechanical energy from a steam engine or water wheel to a factory or pump which is located a considerable distance (10 to 100s of meters or more) from the power source. A flying rope way could be supported on poles and pulleys similar to the cable on a chair lift or aerial tramway. Transmission efficiency is generally high.

Standards for use

The open belt drive has parallel shafts rotating in the same direction, whereas the cross-belt drive also bears parallel shafts but rotate in opposite direction. The former is far more common, and the latter not appropriate for timing and standard V-belts, because the pulleys contact both the both inner and outer belt surfaces. Nonparallel shafts can be connected if the belt's center line is aligned with the center plane of the pulley. Industrial belts are usually reinforced rubber but sometimes leather types, non-leather non-reinforced belts, can only be used in light applications.

The pitch line is the line between the inner and outer surfaces that is neither subject to tension (like the outer surface) nor compression (like the inner). It is midway through the surfaces in film and flat belts and dependent on cross-sectional shape and size in timing and V-belts. The angular speed is inversely proportional to size, so the larger the one wheel, the less angular velocity, and vice versa. Actual pulley speeds tend to be 0.5–1% less than generally calculated because of belt slip and stretch. In timing belts, the inverse ratio teeth of the belt contributes to the exact measurement. The speed of the belt is:

Speed = Circumference based on pitch diameter × angular speed in rpm

Selection criteria

Belt drives are built under the following required conditions: speeds of and power transmitted between drive and driven unit; suitable distance between shafts; and appropriate operating conditions. The equation for power is:

power (kW) = (torque in newton-meters) × (rpm) × (2π radians)/(60 sec × 1000 W)

Factors of power adjustment include speed ratio; shaft distance (long or short); type of drive unit (electric motor, internal combustion engine); service environment (oily, wet, dusty); driven unit loads (jerky, shock, reversed); and pulley-belt arrangement (open, crossed, turned). These are found in engineering handbooks and manufacturer's literature. When corrected, the horsepower is compared to rated horsepowers of the standard belt cross sections at particular belt speeds to find a number of arrays that will perform best. Now the pulley diameters are chosen. It is generally either large diameters or large cross section that are chosen, since, as stated earlier, larger belts transmit this same power at low belt speeds as smaller belts do at high speeds. To keep the driving part at its smallest, minimum-diameter pulleys are desired. Minimum pulley diameters are limited by the elongation of the belt's outer fibers as the belt wraps around the pulleys. Small pulleys increase this elongation, greatly reducing belt life. Minimum pulley diameters are often listed with each cross section and speed, or listed separately by belt cross section. After the cheapest diameters and belt section are chosen, the belt length is computed. If endless belts are used, the desired shaft spacing may need adjusting to accommodate standard length belts. It is often more economical to use two or more juxtaposed V-belts, rather than one larger belt.

In large speed ratios or small central distances, the angle of contact between the belt and pulley may be less than 180°. If this is the case, the drive power must be further increased, according to manufacturer's tables, and the selection process repeated. This is because power capacities are based on the standard of a 180° contact angle. Smaller contact angles mean less area for the belt to obtain traction, and thus the belt carries less power.

Belt friction

Belt drives depend on friction to operate but, if the friction is excessive, there will be waste of energy and rapid wear of the belt. Factors which affect belt friction include belt tension, contact angle and the materials from which the belt and pulleys are made.

Belt tension

Power transmission is a function of belt tension. However, also increasing with tension is stress (load) on the belt and bearings. The ideal belt is that of the lowest tension which does not slip in high loads. Belt tensions should also be adjusted to belt type, size, speed, and pulley diameters. Belt tension is determined by measuring the force to deflect the belt a given distance per inch of pulley. Timing belts need only adequate tension to keep the belt in contact with the pulley.

Belt wear

Fatigue, more so than abrasion, is the culprit for most belt problems. This wear is caused by stress from rolling around the pulleys. High belt tension; excessive slippage; adverse environmental conditions; and belt overloads caused by shock, vibration, or belt slapping all contribute to belt fatigue.

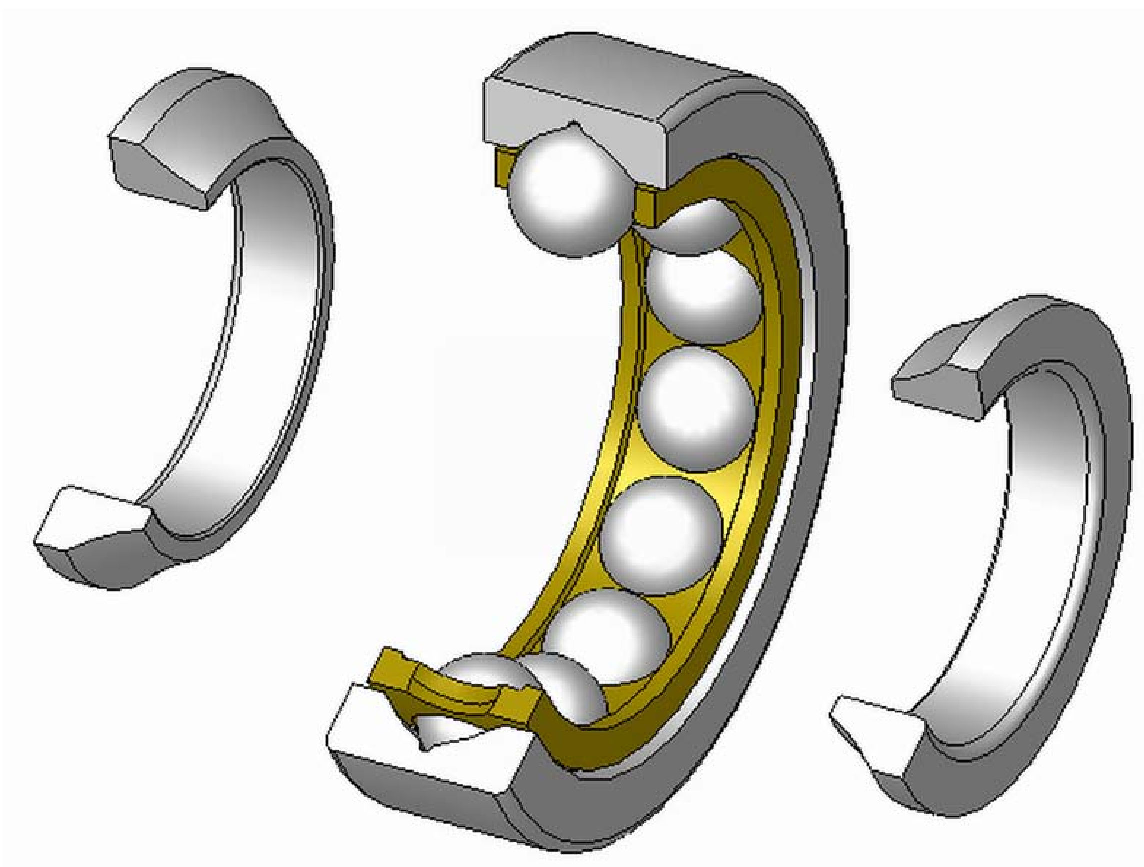
Specifications

To fully specify a belt, the material, length, and cross-section size and shape are required. Timing belts, in addition, require that the size of the teeth be given. The length of the belt is the sum of the central length of the system on both sides, half the circumference of both pulleys, and the square of the sum (if crossed) or the difference (if open) of the radii. Thus, when dividing by the central distance, it can be visualized as the central distance times the height that gives the same squared value of the radius difference on, of course, both sides. When adding to the length of either side, the length of the belt increases, in a similar manner to the Pythagorean theorem. One important concept to remember is that as D_1 gets closer to D_2 there is less of a distance (and therefore less addition of length) until its approaches zero.

On the other hand, in a crossed belt drive the *sum* rather than the difference of radii is the basis for computation for length. So the wider the small drive increases, the belt length is higher.

Chapter- 10

Bearing (mechanical)



A cutaway example of a four-point contact ball bearing

A **bearing** is a device to allow constrained relative motion between two or more parts, typically rotation or linear movement. Bearings may be classified broadly according to the motions they allow and according to their principle of operation as well as by the directions of applied loads they can handle.

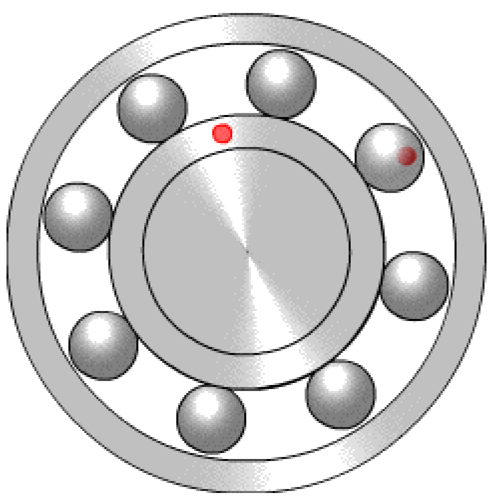
Overview

Plain bearings use surfaces in rubbing contact, often with a lubricant such as oil or graphite. A plain bearing may or may not be a discrete device. It may be nothing more than the bearing surface of a hole with a shaft passing through it, or of a planar surface that bears another (in these cases, not a discrete device); or it may be a layer of bearing metal either fused to the substrate (semi-discrete) or in the form of a separable sleeve (discrete). With suitable lubrication, plain bearings often give entirely acceptable accuracy, life, and friction at minimal cost. Therefore, they are very widely used.

However, there are many applications where a more suitable bearing can improve efficiency, accuracy, service intervals, reliability, speed of operation, size, weight, and costs of purchasing and operating machinery.

Thus, there are many types of bearings, with varying shape, material, lubrication, principle of operation, and so on. For example, rolling-element bearings use spheres or drums rolling between the parts to reduce friction; reduced friction allows tighter tolerances and thus higher precision than a plain bearing, and reduced wear extends the time over which the machine stays accurate. Plain bearings are commonly made of varying types of metal or plastic depending on the load, how corrosive or dirty the environment is, and so on. In addition, bearing friction and life may be altered dramatically by the type and application of lubricants. For example, a lubricant may improve bearing friction and life, but for food processing a bearing may be lubricated by an inferior food-safe lubricant to avoid food contamination; in other situations a bearing may be run without lubricant because continuous lubrication is not feasible, and lubricants attract dirt that damages the bearings.

Principles of operation



Ball bearing

There are at least six common principles of operation:

- plain bearing, also known by the specific styles: bushings, journal bearings, sleeve bearings, rifle bearings
- rolling-element bearings such as ball bearings and roller bearings
- jewel bearings, in which the load is carried by rolling the axle slightly off-center
- fluid bearings, in which the load is carried by a gas or liquid
- magnetic bearings, in which the load is carried by a magnetic field
- flexure bearings, in which the motion is supported by a load element which bends.

Motions

Common motions permitted by bearings are:

- Axial rotation e.g. shaft rotation
- Linear motion e.g. drawer
- spherical rotation e.g. ball and socket joint
- hinge motion e.g. door, elbow, knee

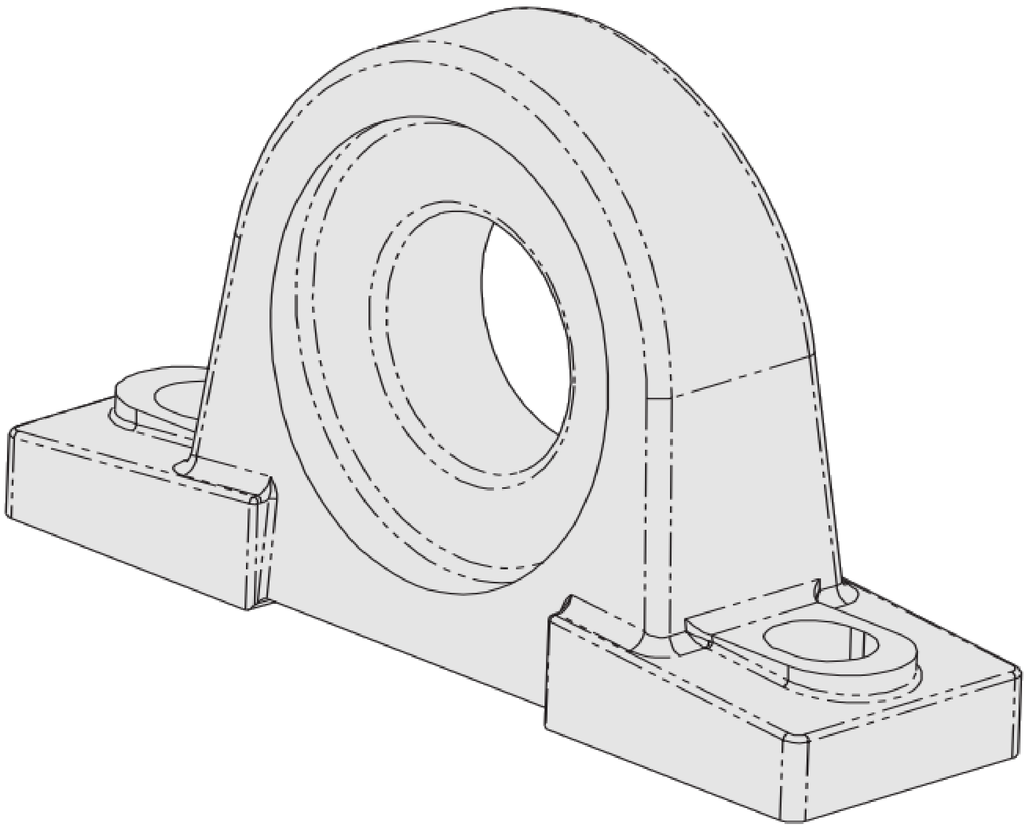
Friction

Reducing friction in bearings is often important for efficiency, to reduce wear and to facilitate extended use at high speeds and to avoid overheating and premature failure of the bearing. Essentially, a bearing can reduce friction by virtue of its shape, by its material, or by introducing and containing a fluid between surfaces or by separating the surfaces with an electromagnetic field.

- **By shape**, gains advantage usually by using spheres or rollers, or by forming flexure bearings.
- **By material**, exploits the nature of the bearing material used. (An example would be using plastics that have low surface friction.)
- **By fluid**, exploits the low viscosity of a layer of fluid, such as a lubricant or as a pressurized medium to keep the two solid parts from touching, or by reducing the normal force between them.
- **By fields**, exploits electromagnetic fields, such as magnetic fields, to keep solid parts from touching.

Combinations of these can even be employed within the same bearing. An example of this is where the cage is made of plastic, and it separates the rollers/balls, which reduce friction by their shape and finish.

Loads



A block bearing with provisions for fixing it

Bearings vary greatly over the size and directions of forces that they can support.

Forces can be predominately radial, axial (thrust bearings) or Bending moments perpendicular to the main axis.

Speeds

Different bearing types have different operating speed limits. Speed is typically specified as maximum relative surface speeds, often specified ft/s or m/s. Rotational bearings typically describe performance in terms of the product *DN* where *D* is the diameter (often in mm) of the bearing and *N* is the rotation rate in revolutions per minute.

Generally there is considerable speed range overlap between bearing types. Plain bearings typically handle only lower speeds, rolling element bearings are faster, followed by fluid bearings and finally magnetic bearings which are limited ultimately by centripetal force overcoming material strength.

Play

Some applications apply bearing loads from varying directions and accept only limited play or "slop" as the applied load changes. One source of motion is gaps or "play" in the bearing. For example, a 10 mm shaft in a 12 mm hole has 2 mm play.

Allowable play varies greatly depending on the use. As example, a wheelbarrow wheel supports radial and axial loads. Axial loads may be hundreds of newtons force left or right, and it is typically acceptable for the wheel to wobble by as much as 10 mm under the varying load. In contrast, a lathe may position a cutting tool to ±0.02 mm using a ball lead screw held by rotating bearings. The bearings support axial loads of thousands of newtons in either direction, and must hold the ball lead screw to ±0.002 mm across that range of loads.

Stiffness

A second source of motion is elasticity in the bearing itself. For example, the balls in a ball bearing are like stiff rubber, and under load deform from round to a slightly flattened shape. The race is also elastic and develops a slight dent where the ball presses on it.

The stiffness of a bearing is how the distance between the parts which are separated by the bearing varies with applied load. With rolling element bearings this is due to the strain of the ball and race. With fluid bearings it is due to how the pressure of the fluid varies with the gap (when correctly loaded, fluid bearings are typically stiffer than rolling element bearings).

Service life

Fluid and magnetic bearings can have practically indefinite service lives. In practice, there are fluid bearings supporting high loads in hydroelectric plants that have been in nearly continuous service since about 1900 and which show no signs of wear.

Rolling element bearing life is determined by load, temperature, maintenance, lubrication, material defects, contamination, handling, installation and other factors. These factors can all have a significant effect on bearing life. For example, the service life of bearings in one application was extended dramatically by changing how the bearings were stored before installation and use, as vibrations during storage caused lubricant failure even when the only load on the bearing was its own weight; the resulting damage is often false brinelling. Bearing life is statistical: several samples of a given bearing will often exhibit a bell curve of service life, with a few samples showing significantly better or worse life. Bearing life varies because microscopic structure and contamination vary greatly even where macroscopically they seem identical.

For plain bearings some materials give much longer life than others. Some of the John Harrison clocks still operate after hundreds of years because of the *lignum vitae* wood employed in their construction, whereas his metal clocks are seldom run due to potential wear.

Flexure bearings bend a piece of material repeatedly. Some materials fail after repeated bending, even at low loads, but careful material selection and bearing design can make flexure bearing life indefinite.

Although long bearing life is often desirable, it is sometimes not necessary. Harris describes a bearing for a rocket motor oxygen pump that gave several hours life, far in excess of the several tens of minutes life needed.

Bearings are often manufactured to what is called an "L10" life factor.

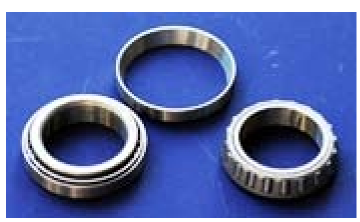
Maintenance

Many bearings require periodic maintenance to prevent premature failure, although some such as fluid or magnetic bearings may require little maintenance.

Most bearings in high cycle operations need periodic lubrication and cleaning, and may require adjustment to minimise the effects of wear.

Bearing life is often much better when the bearing is kept clean and well-lubricated. However, many applications make good maintenance difficult. For example bearings in the conveyor of a rock crusher are exposed continually to hard abrasive particles. Cleaning is of little use because cleaning is expensive, yet the bearing is contaminated again as soon as the conveyor resumes operation. Thus, a good maintenance program might lubricate the bearings frequently but clean them never.

History



Tapered bearings

Early Timken tapered roller bearing with notched rollers

The oldest instance of the bearing principle dates to the Egyptians when they used tree trunks under sleds. There are also Egyptian drawings of bearings used with hand drills.

The earliest recovered example of a bearing is a wooden ball bearing supporting a rotating table from the remains of the Roman Nemi ships in Lake Nemi, Italy. The wrecks were dated to 40 AD.

Leonardo da Vinci is often credited with drawing the first roller bearing around the year 1500. However, Agostino Ramelli is the first to have published sketches of roller and thrust bearings. An issue with ball and roller bearings is that the balls or rollers rub against each other causing additional friction which can be prevented by enclosing the balls or rollers in a cage. The captured, or caged, ball bearing was originally described by Galileo in the 17th century. The mounting of bearings into a set was not accomplished for many years after that. The first patent for a ball race was by Philip Vaughan of Carmarthen in 1794.

Bearings saw use for holding wheel and axles. The bearings used there were plain bearings that were used to greatly reduce friction over that of dragging an object by making the friction act over a shorter distance as the wheel turned.

The first plain and rolling-element bearings were wood closely followed by bronze. Over their history bearings have been made of many materials including ceramic, sapphire, glass, steel, bronze, other metals and plastic (e.g., nylon, polyoxymethylene, polytetrafluoroethylene, and UHMWPE) which are all used today.

Watch makers produced "jeweled" pocket watches using sapphire plain bearings to reduce friction thus allowing more precise time keeping.

Even basic materials can have good durability. As examples, wooden bearings can still be seen today in old clocks or in water mills where the water provides cooling and lubrication.

The first practical caged-roller bearing was invented in the mid-1740s by horologist John Harrison for his H3 marine timekeeper. This uses the bearing for a very limited oscillating motion but Harrison also used a similar bearing in a truly rotary application in a contemporaneous regulator clock.

A patent on ball bearings, reportedly the first, was awarded to Jules Suriray, a Parisian bicycle mechanic, on 3 August 1869. The bearings were then fitted to the winning bicycle ridden by James Moore in the world's first bicycle road race, Paris-Rouen, in November 1869.

Friedrich Fischer's idea from the year 1883 for milling and grinding balls of equal size and exact roundness by means of a suitable production machine formed the foundation for creation of an independent bearing industry.

The modern, self-aligning design of ball bearing is attributed to Sven Wingquist of the SKF ball-bearing manufacturer in 1907, when he was awarded Swedish patent No. 25406 on its design.

Henry Timken, a 19th century visionary and innovator in carriage manufacturing, patented the tapered roller bearing, in 1898. The following year, he formed a company to produce his innovation. Through a century, the company grew to make bearings of all types, specialty steel and an array of related products and services.

Erich Franke invented and patented the wire race bearing in 1934. His focus was on a bearing design with a cross section as small as possible and which could be integrated into the enclosing design. After World War II he founded together with Gerhard Heydrich the company Franke & Heydrich KG (today Franke GmbH) to push the development and production of wire race bearings.

Richard Stribeck's extensive research on ball bearing steels identified the metallurgy of the commonly used 100Cr6 (AISI 52100) showing coefficient of friction as a function of pressure.

Designed in 1968 and later patented in 1972, Bishop-Wisecarver's co-founder Bud Wisecarver created vee groove bearing guide wheels, a type of linear motion bearing consisting of both an external and internal 90 degree vee angle.

In the early 1980s, Pacific Bearing's founder, Robert Schroeder, invented the first bi-material plain bearing which was size interchangeable with linear ball bearings. This bearing had a metal shell (aluminum, steel or stainless steel) and a layer of Teflon-based material connected by a thin adhesive layer.

Today ball and roller bearings are used in many applications which include a rotating component. Examples include ultra high speed bearings in dental drills, aerospace bearings in the Mars Rover, gearbox and wheel bearings on automobiles, flexure bearings in optical alignment systems and bicycle wheel hubs.

Types

There are many different types of bearings.

Type	Description	Friction	Stiffness†	Speed	Life	Notes
Plain bearing	Rubbing surfaces, usually with lubricant; some bearings use pumped lubrication and behave similarly to fluid bearings.	Depends on materials and construction, PTFE has coefficient of friction ~0.05-0.35, depending upon fillers added	Good, provided wear is low, but some slack is normally present	Low to very high	Low to very high - depends upon application and lubrication	Widely used, relatively high friction, suffers from stiction in some applications. Depending upon the application, lifetime can be higher or lower than rolling element bearings.
Rolling element bearing	Ball or rollers are used to prevent or minimise rubbing	Rolling coefficient of friction with steel can be ~0.005 (adding resistance due to seals, packed grease, preload and misalignment can increase friction to as much as 0.125)	Good, but some slack is usually present	Moderate to high (often requires cooling)	Moderate to high (depends on lubrication, often requires maintenance)	Used for higher moment loads than plain bearings with lower friction

Jewel bearing	Off-center bearing rolls in seating	Low	Low due to flexing	Low	Adequate (requires maintenance)	Mainly used in low-load, high precision work such as clocks. Jewel bearings may be very small.
Fluid bearing	Fluid is forced between two faces and held in by edge seal	Zero friction at zero speed, low	Very high	Very high (usually limited to a few hundred feet per second at/by seal)	Virtually infinite in some applications, may wear at startup/shutdown in some cases. Often negligible maintenance.	Can fail quickly due to grit or dust or other contaminants. Maintenance free in continuous use. Can handle very large loads with low friction.
Magnetic bearings	Faces of bearing are kept separate by magnets (electromagnets or eddy currents)	Zero friction at zero speed, but constant power for levitation, eddy currents are often induced when movement occurs, but may be negligible if magnetic field is quasi-static	Low	No practical limit	Indefinite. Maintenance free. (with electromagnets)	Active magnetic bearings (AMB) need considerable power. Electrodynamic bearings (EDB) do not require external power.
Flexure bearing	Material flexes to give and constrain movement	Very low	Low	Very high.	Very high or low depending on materials and strain in application. Usually maintenance free.	Limited range of movement, no backlash, extremely smooth motion

†Stiffness is the amount that the gap varies when the load on the bearing changes, it is distinct from the friction of the bearing.

Chapter- 11

Rolling-element Bearing

A **rolling-element bearing** is a bearing which carries a load by placing round elements between the two pieces. The relative motion of the pieces causes the round elements to roll with very little rolling resistance and with little sliding.

One of the earliest and best-known rolling-element bearings are sets of logs laid on the ground with a large stone block on top. As the stone is pulled, the logs roll along the ground with little sliding friction. As each log comes out the back, it is moved to the front where the block then rolls on to it. It is possible to imitate such a bearing by placing several pens or pencils on a table and placing an item on top of them.

A rolling-element rotary bearing uses a shaft in a much larger hole, and cylinders called "rollers" tightly fill the space between the shaft and hole. As the shaft turns, each roller acts as the logs in the above example. However, since the bearing is round, the rollers never fall out from under the load.

Rolling-element bearings have the advantage of a good tradeoff between cost, size, weight, carrying capacity, durability, accuracy, friction, and so on. Other bearing designs are often better on one specific attribute, but worse in most other attributes, although fluid bearings can sometimes simultaneously outperform on carrying capacity, durability, accuracy, friction, rotation rate and sometimes cost. Only plain bearings are used as widely as rolling-element bearings.

Design

Typical rolling-element bearings range in size from 10 mm diameter to a few metres diameter, and have load-carrying capacity from a few tens of grams to many thousands of tonnes.

A particularly common kind of rolling-element bearing is the ball bearing. The bearing has inner and outer *races* and a set of balls. Each race is a ring with a groove where the balls rest. The groove is usually shaped so the ball is a slightly loose fit in the groove. Thus, in principle, the ball contacts each race at a single point. However, a load on an infinitely small point would cause infinitely high contact pressure. In practice, the ball deforms (flattens) slightly where it contacts each race, much as a tire flattens where it touches the road. The race also dents slightly where each ball presses on it. Thus, the contact between ball and race is of finite size and has finite pressure. Note also that the deformed ball and race do not roll entirely smoothly because different parts of the ball are moving at different speeds as it rolls. Thus, there are opposing forces and sliding motions at each ball/race contact. Overall, these cause bearing drag.

Most rolling element bearings use *cages* to keep the balls separate. This reduces wear and friction, since it avoids the balls rubbing against each other as they roll, and precludes them from jamming. Caged roller bearings were invented by John Harrison in the mid-18th century as part of his work on chronometers.

Types of rolling elements

There are five types of rolling-elements that are used in rolling element bearings: balls, cylindrical rollers, tapered rollers, spherical rollers, and needles.

Ball

A ball bearing

Ball bearings use balls instead of cylinders. Ball bearings can support both radial (perpendicular to the shaft) and axial loads (parallel to the shaft). For lightly-loaded bearings, balls offer lower friction than rollers. Ball bearings can operate when the bearing races are misaligned. Precision balls are typically cheaper to produce than shapes such as rollers; combined with high-volume use, ball bearings are often much cheaper than other bearings of similar dimensions. Ball bearings may have high point loads, limiting total load capacity compared to other bearings of similar dimensions.

Cylindrical roller

A roller bearing

Common roller bearings use cylinders of slightly greater length than diameter. Roller bearings typically have higher load capacity than ball bearings, but a lower capacity and higher friction under loads perpendicular to the primary supported direction. If the inner and outer races are misaligned, the bearing capacity often drops quickly compared to either a ball bearing or a spherical roller bearing.

Roller bearings are the earliest known type of rolling-element-bearing, dating back to at least 40 BC.

Needle

A needle roller bearing

Needle roller bearings use very long and thin cylinders. Often the ends of the rollers taper to points, and these are used to keep the rollers captive, or they may be hemispherical and not captive but held by the shaft itself or a similar arrangement. Since the rollers are thin, the outside diameter of the bearing is only slightly larger than the hole in the middle. However, the small-diameter rollers must bend sharply where they contact the races, and thus the bearing fatigues relatively quickly.

Tapered roller

Tapered roller bearings

Tapered roller bearings use conical rollers that run on conical races. Most roller bearings only take radial or axial loads, but tapered roller bearings support both radial and axial loads, and generally can carry higher loads than ball bearings due to greater contact area. Taper roller bearings are used, for example, as the wheel bearings of most cars, trucks, buses, and so on. The downsides to this bearing is that due to manufacturing complexities, tapered roller bearings are usually more expensive than ball bearings; and additionally under heavy loads the tapered roller is like a wedge and bearing loads tend to try to eject the roller; the force from the collar which keeps the roller in the bearing adds to bearing friction compared to ball bearings.

Spherical roller

Spherical roller bearings

Spherical roller bearings use rollers that are thicker in the middle and thinner at the ends; the race is shaped to match. Spherical roller bearings can thus adjust to support misaligned loads. However, spherical rollers are difficult to produce and thus expensive, and the bearings have higher friction than a comparable ball bearing since different parts of the spherical rollers run at different speeds on the rounded race and thus there are opposing forces along the bearing/race contact.

Configurations

The configuration of the races determine the types of motions and loads that a bearing can best support. A given configuration can serve multiple of the following types of loading.

Thrust loadings

A thrust roller bearing

Thrust bearings are used to support axial loads, such as vertical shafts. Commonly spherical, conical or cylindrical rollers are used; but non-rolling element bearings such as hydrostatic or magnetic bearings see some use where particularly heavy loads or low friction is needed.

Radial loadings

Rolling element bearings are often used for axles due to their low rolling friction. For light loads, such as bicycles, ball bearings are often used. For heavy loads and where the loads can greatly change during cornering, such as cars and trucks, tapered rolling bearings are used.

Linear motion

Linear motion roller-element bearings are typically designed for either shafts or flat surfaces. Flat surface bearings often consist of rollers and are mounted in a cage, which is then placed between the two flat surfaces; a common example is drawer-support hardware. Roller-element bearing for a shaft use bearing balls in a groove designed to recirculate them from one end to the other as the bearing moves; as such, they are called *linear ball bearings* or *recirculating bearings*.

Bearing failure

A prematurely failed rear bearing cone from a mountain bicycle, caused by a combination of pitting due to wet conditions, improper lubrication, and fatigue from frequent shock loading.

Rolling-element bearings often work well in non-ideal conditions, but sometimes minor problems cause bearings to fail quickly and mysteriously. For example, with a stationary (non-rotating) load, small vibrations can gradually press out the lubricant between the races and rollers or balls (false brinelling). Without lubricant the bearing fails, even though it is not rotating and thus is apparently not being used. For these sorts of reasons, much of bearing design is about failure analysis.

There are three usual limits to the lifetime or load capacity of a bearing: abrasion, fatigue and pressure-induced welding. Abrasion is when the surface is eroded by hard contaminants scraping at the bearing materials. Fatigue is when a material breaks after it is repeatedly loaded and released. Where the ball or roller touches the race there is always some deformation, and hence a risk of fatigue. Smaller balls or rollers deform more sharply, and so tend to fatigue faster. Pressure-induced welding is when two metal pieces are pressed together at very high pressure and they become one. Although balls, rollers and races may look smooth, they are microscopically rough. Thus, there are high-pressure spots which push away the bearing lubricant. Sometimes, the resulting metal-to-metal contact welds a microscopic part of the ball or roller to the race. As the bearing continues to rotate, the weld is then torn apart, but it may leave race welded to bearing or bearing welded to race.

Although there are many other apparent causes of bearing failure, most can be reduced to these three. For example, a bearing which is run dry of lubricant fails not because it is "without lubricant", but because lack of lubrication leads to fatigue and welding, and the resulting wear debris can cause abrasion. Similar events occur in false brinelling damage. In high speed applications, the oil flow also reduces the bearing metal temperature by convection. The oil becomes the heat sink for the friction losses generated by the bearing.

Constraints and trade-offs

Caged radial ball bearings

All parts of a bearing are subject to many design constraints. For example, the inner and outer races are often complex shapes, making them difficult to manufacture. Balls and rollers, though simpler in shape, are small; since they bend sharply where they run on the races, the bearings are prone to fatigue. The loads within a bearing assembly are also affected by the speed of operation: rolling-element bearings may spin over 100,000 rpm, and the principal load in such a bearing may be momentum rather than the applied load. Smaller rolling elements are lighter and thus have less momentum, but smaller elements also bend more sharply where they contact the race, causing them to fail more rapidly from fatigue. Maximum rolling element bearing speeds are often specified in 'DN', which is the product of the diameter (in mm) and the maximum RPM. For angular contact bearings DNs over 2.1 million have been found to be reliable in high performance rocketry applications.

There are also many material issues: a harder material may be more durable against abrasion but more likely to suffer fatigue fracture, so the material varies with the application, and while steel is most common for rolling-element bearings, plastics, glass, and ceramics are all in common use. A small defect (irregularity) in the material is often responsible for bearing failure; one of the biggest improvements in the life of common bearings during the second half of the 20th century was the use of more homogeneous materials, rather than better materials or lubricants (though both were also significant). Lubricant properties vary with temperature and load, so the best lubricant varies with application.

Although bearings tend to wear out with use, designers can make tradeoffs of bearing size and cost versus lifetime. A bearing can last indefinitely—longer than the rest of the machine—if it is kept cool, clean, lubricated, is run within the rated load, and if the bearing materials are sufficiently free of microscopic defects. Note that cooling, lubrication, and sealing are thus important parts of the bearing design.

The needed bearing lifetime also varies with the application. For example, Tedric A. Harris reports in his *Rolling Bearing Analysis* on an oxygen pump bearing in the U.S.

Space Shuttle which could not be adequately isolated from the liquid oxygen being pumped. All lubricants reacted with the oxygen, leading to fires and other failures. The solution was to lubricate the bearing with the oxygen. Although liquid oxygen is a poor lubricant, it was adequate, since the service life of the pump was just a few hours.

The operating environment and service needs are also important design considerations. Some bearing assemblies require routine addition of lubricants, while others are factory sealed, requiring no further maintenance for the life of the mechanical assembly. Although seals are appealing, they increase friction, and in a permanently-sealed bearing the lubricant may become contaminated by hard particles, such as steel chips from the race or bearing, sand, or grit that gets past the seal. Contamination in the lubricant is abrasive and greatly reduces the operating life of the bearing assembly. Another major cause of bearing failure is the presence of water in the lubrication oil. Online water-in-oil monitors have been introduced in recent years to monitor the effects of both particles and the presence of water in oil and their combined effect.

Chapter- 12

Screw

Screws come in a variety of shapes and sizes for different purposes. U.S. quarter coin (diameter 24 mm) shown for scale.

A **screw**, or **bolt**, is a type of fastener characterized by a helical ridge, known as an *external thread* or just *thread*, wrapped around a cylinder. Some screw threads are designed to mate with a complementary thread, known as an *internal thread*, often in the form of a nut or an object that has the internal thread formed into it. Other screw threads are designed to cut a helical groove in a softer material as the screw is inserted. The most common uses of screws are to hold objects together and to position objects.

Often screws have a *head*, which is a specially formed section on one end of the screw that allows it to be turned, or *driven*. Common tools for driving screws include screwdrivers and wrenches. The head is usually larger than the body of the screw, which keeps the screw from being driven deeper than the length of the screw and to provide a *bearing surface*. There are exceptions; for instance, carriage bolts have a domed head that is not designed to be driven; set screws have a head smaller than the outer diameter of the screw; J-bolts have a J-shaped head which is not designed to be driven, but rather is usually sunk into concrete allowing it to be used as an anchor bolt. The cylindrical portion of the screw from the underside of the head to the tip is known as the *shank*; it may be fully threaded or partially threaded.

The majority of screws are tightened by clockwise rotation, which is termed a *right-hand thread*. Screws with left-hand threads are used in exceptional cases. For example, when the screw will be subject to anticlockwise forces (which would work to undo a right-hand thread), a left-hand-threaded screw would be an appropriate choice. The left side pedal of a bicycle has a left-hand thread.

Differentiation between bolt and screw

A carriage bolt with square nut

A structural bolt with a nut and washer

There is no universally accepted distinction between a screw and a bolt. The *Machinery's Handbook* describes the distinction as follows:

A bolt is an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by torquing a nut. A screw is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread, and of being tightened or released by torquing the head. An externally threaded fastener which is prevented from being turned during assembly and which can be tightened or released only by torquing a nut is a bolt. (Example: round head bolts, track bolts, plow bolts.) An externally threaded fastener that has thread form which prohibits assembly with a nut having a straight thread of multiple pitch length is a screw. (Example: wood screws, tapping screws.)

This distinction is consistent with ASME B18.2.1 and some dictionary definitions for *screw* and *bolt*.

The issue of what is a screw and what is a bolt is not completely resolved with *Machinery's Handbook* distinction, however, because of confounding terms, the ambiguous nature of some parts of the distinction, and usage variations. Some of these issues are discussed below:

Machine screws

ASME standards specify a variety of "Machine Screws" in diameters ranging up to 0.75 in (19.05 mm). These fasteners are often used with nuts as well as often driven into tapped holes. They might be considered a screw or a bolt based on the *Machinery's Handbook* distinction. In practice, they tend to be mostly available in smaller sizes and the smaller sizes are referred to as screws or less ambiguously as machine screws, although some kinds of machine screws can be referred to as stove bolts.

Hex cap screws

ASME standard B18.2.1 -1996 specifies Hex Cap Screws that range in size from 0.25–3 in (6.35–76.20 mm) in diameter. These fasteners are very similar to hex bolts. They differ mostly in that they are manufactured to tighter tolerances than the corresponding bolts. The *Machinery's Handbook* refers parenthetically to these fasteners as "Finished Hex Bolts". Reasonably, these fasteners might be referred to as bolts but based on the US government document, Distinguishing Bolts from Screws, the US government might classify them as screws because of the tighter tolerance. In 1991 responding to an influx of counterfeit fasteners Congress passed PL 101-592 "Fastener Quality Act" This resulted in the rewriting of specifications by the ASME B18 committee. B18.2.1 was re-written and as a result they eliminated the "Finished Hex Bolts" and renamed them the "Hex Cap Screw".

Lug bolts & head bolts

These terms refer to fasteners that are designed to be threaded into a tapped hole that is in part of the assembly and so based on the *Machinery's Handbook* distinction they would be screws. Here common terms are at variance with *Machinery's Handbook* distinction.

Lag bolt

Lag bolts : These are clearly screws based on the *Machinery's Handbook* distinction. The term has been replaced by "Lag Screw" in the *Machinery's Handbook*

Government standards

The US government made an effort to formalize the difference between a bolt and a screw because different tariffs apply to each. The document seems to have no significant effect on common usage and does not eliminate the ambiguous nature of the distinction between screws and bolts for some threaded fasteners.

Historical issue

Old USS and SAE standards defined cap screws as fasteners with shanks that were threaded to the head and bolts as fasteners with shanks that were partially unthreaded. This is now an obsolete distinction.

Controlled vocabulary versus natural language

The distinctions delineated above are enforced in the controlled vocabulary of standards organizations. Nevertheless, there are sometimes differences between the controlled vocabulary and the natural-language usage of the words among machinists, auto mechanics, and other workers. These differences reflect linguistic evolution shaped by the changing of technology over centuries. The words *bolt* and *screw* have both existed since before today's modern mix of fastener types existed, and the natural usage of those words has evolved retronymously in response to the technological change. (That is, the use of words as names for objects changes as the objects themselves change.) Nonthreaded fasteners predominated in fastening technology until the advent of practical, inexpensive screw-cutting in the early 19th century. The basic meaning of the word *screw* has long involved the idea of a helical screw thread, but the Archimedes screw and the screw gimlet (like a corkscrew) preceded the fastener.

> The word *bolt* is also a very old word, and it was used for centuries to refer to metal rods that passed through the substrate to be fastened on the other side, often via nonthreaded means (clinching, forge welding, pinning, wedging, etc.). The connection of this sense to the sense of a door bolt or the crossbow bolt is apparent. In the 19th century, bolts fastened via screw threads were often called *screw bolts* in contradistinction to *clench bolts*.

In common usage, the distinction is often that screws are smaller than bolts, and that screws are generally tapered and bolts are not. This distinction is not rigorous.

Other distinctions

Bolts have been defined as headed fasteners having external threads that meet an exacting, uniform bolt thread specification (such as M, MJ, UN, UNR, and UNJ) such that they can accept a nontapered nut. Screws are then defined as headed, externally threaded fasteners that do not meet the above definition of bolts. These definitions of screw and bolt eliminate the ambiguity of the *Machinery's handbook* distinction. And it is for that reason, perhaps, that some people favor them. However, they are neither compliant with common usage of the two words nor are they compliant with formal specifications.

Types of screws and bolts

Threaded fasteners either have a tapered shank or a non-tapered shank. Fasteners with tapered shanks are designed to either be driven into a substrate directly or into a pilot hole in a substrate. Mating threads are formed in the substrate as these fasteners are driven in. Fasteners with a non-tapered shank are designed to mate with a nut or to be driven into a tapped hole.

Fasteners with a tapered shank (self-threading screws)

A Phillips wood screw being driven into a board with a driver.

Wood screw

A **wood screw** is defined as a male screw made of a metal with a slotted head and sharp point. A wood screw is commonly furnished with a flat, round or oval-head. A wood screw generally has an unthreaded shank below the head. It is designed to attach two pieces of wood together.

Twinfast screw

A Twinfast screw : is a type of wood screw with two threads (i.e. a lead of 2), so that it can be driven twice as fast.

Coach screw (UK) or lag screw/bolt (US)

Coach screw or lag screw/bolt is similar to a wood screw except that it is generally much larger running to lengths up to 15 in (381 mm) with diameters from 0.25–0.5 in (6.35–12.70 mm) in commonly available (hardware store) sizes (not counting larger mining and civil engineering lags and lag bolts) and it generally has a hexagonal drive head. Lag bolts are designed for securely fastening heavy timbers (post and beams, timber railway trestles and bridges) to one another, or to fasten wood to masonry or concrete.

> Lag bolts are usually used with an expanding insert called a lag in masonry or concrete walls, the lag manufactured with a hard metal jacket that bites into the sides of the drilled hole, and the inner metal in the lag being a softer alloy of lead, or zinc alloyed with soft iron. The coarse thread of a lag bolt and lag mesh and deform slightly making a secure near water tight anti-corroding mechanically strong fastening.

Sheet metal screw

A Sheet metal screw (self-tapping screw, thread cutting screws) has sharp threads that cut into a material such as sheet metal, plastic or wood. They are sometimes notched at the tip to aid in chip removal during thread cutting. The shank is usually threaded up to the head. Sheet metal screws make excellent fasteners for attaching metal hardware to wood because the fully threaded shank provides good retention in wood.

Concrete screw

A concrete screw is a stainless or carbon steel screw for fastening wood, metal, or other materials into concrete or masonry. Concrete screws are commonly blue in color, with or without corrosion coating. They may either have a Phillips flat head or a slotted hex washer head. Heads sizes range from 0.1875 to 0.375 in (4.763 to 9.525 mm) and lengths from 1.25 to 5 in (32 to 127 mm).

> Typically an installer uses a hammer drill to make a pilot hole for each concrete screw.

> In the United States, concrete screws are commonly called *Tapcons* which refers to the brand name created from the definition of "an anchor that taps its own threads into concrete." Other commercial names for the fastener are *masonry screw*, *confast screw*, *blue screw*, *self-tapping screw*, and *Titen*.

Drywall screw

A drywall screw is a specialized screw with a bugle head that is designed to attach drywall to wood or metal studs, however it is a versatile construction fastener with many uses. The diameter of drywall screw threads is larger than the shaft diameter.

Particle board screw (chipboard screw)

A particle board screw is similar to a drywall screw except that it has a thinner shaft and provides better resistance to pull-out in particle board, while offset against a lower shear strength. The threads on particle board screws are asymmetrical.

Deck screw

A deck screw is similar to drywall screw except that it has improved corrosion resistance and is generally supplied in a larger gauge. Most deck screws have a type-17 (auger type) thread cutting tip for installation into decking materials.

Double ended screw (dowel screw)

A double ended screw (dowel screw) is similar to a wood screw but with two pointed ends and no head, used for making hidden joints between two pieces of wood.

Screw eye (eye screw)

A screw eye (eye screw) is a screw with a looped head. Larger ones are sometimes call lag eye screws. Designed to be used as attachment point, particularly for something that is hung from it.

Mirror screws

Mirror screws are flat head wood screws with a tapped hole in the head, which is designed to receive a separate screw-in chrome-plated cover. They are usually used to mount mirrors.

Thread rolling screws

Thread rolling screws have a lobed (usually triangular) cross-section. They form threads in a pre-drilled hole in the mating workpiece by pushing the material outward during installation.

Self-drilling screw (Teks screw)

A self-drilling screw is similar to a sheet metal screw, but it has a drill-shaped point to cut through the substrate to eliminate the need for drilling a pilot hole. Designed for use in soft steel or other metals. The points are numbered from 1 through 5, the larger the number, the thicker metal it can go through without a pilot hole. A 5 point can drill a 0.5 in (12.7 mm) of steel, for example.

Fasteners with a non-tapered shank

Breakaway bolt

A Breakaway bolt is a bolt with a hollow threaded shank, which is designed to break away upon impact. Typically used to fasten fire hydrants, so they will *break away* when hit by a car. Also used in aircraft to reduce weight.

Cap screw

The term *cap screw* refers to many different things at different times and places. Currently, it most narrowly refers to a style of head. More broadly, and more commonly, it refers to the group of screws: shoulder screws, hex heads, counter-sunk heads, button heads, and fillister heads. In the US, cap screws are defined by ASME B18.6.2 and ASME B18.3. In the past, the term *cap screw*, in general, referred to screws that were supposed to be used in applications where a nut was not used, however the characteristics that differentiated it from a bolt vary over time. In 1910, Anthony defined it as screw with a hex head that was thicker than a bolt head, but the distance across the flats was less than a bolt's. In 1913, Woolley and Meredith defined them like Anthony, but gave the following dimensions: hex head cap screws up to and including $\frac{7}{16}$ inches (11.1125 mm) have a head that is $\frac{3}{16}$ inches (4.7625 mm) larger than the shank diameter; screws greater than $\frac{1}{2}$ inches (12.7 mm) in diameter have a head that is $\frac{1}{4}$ inches (6.35 mm) larger than the shank. Square head cap screws up to and including $\frac{3}{4}$ inches (19.05 mm) have a head $\frac{1}{8}$ inches (3.175 mm) larger than the shank; screws larger than $\frac{3}{4}$ inches (19.05 mm) have a head $\frac{1}{4}$ inches (6.35 mm) larger than the shank. In 1919, Dyke defined them as screws that are threaded all the way to the head.

Cap screws (wide definition)

Hex cap screw

A hex cap screw is a cap screw with a hexagonal head, designed to be driven by a wrench (spanner). An ASME B18.2.1 compliant cap screw has somewhat tighter tolerances than a hex bolt for the head height and the shank length. The nature of the tolerance difference allows an ASME B18.2.1 hex cap screw to always fit where a hex bolt is installed but a hex bolt could be slightly too large to be used where a hex cap screw is designed in.

Hex bolt

At times the term *hex bolt* is used interchangeably with *hex cap screw*. An ASME B18.2.1 compliant hex bolt is built to different tolerances than a hex cap screw.

Socket cap screw

A socket cap screw, also known as a *socket head cap screw*, *socket screw* or *Allen bolt*, this is a type of cap screw with a hexagonal recessed drive. The most common types in use have a cylindrical head whose diameter is nominally 1.5 times (1960 series design) that of the screw shank (major) diameter. Counterbored holes in parts allow the screw head to be flush with the surface or recessed. Other head designs include *button* head and *flat* head, the latter designed to be seated into countersunk holes. A hex key (sometimes referred to as an *Allen wrench* or *Allen key*) or *hex driver* is required to tighten or loosen a socket screw. Socket screws are commonly used in assemblies that do not provide sufficient clearance for a conventional wrench or socket.

Machine screw

A machine screw is generally a smaller fastener (less than ¼ inches (6.35 mm) in diameter) threaded the entire length of its shank that usually has a recessed drive type (slotted, Phillips, etc.). Machine screws are also made with socket heads, in which case they may be referred to as socket head machine screws.

Self-tapping machine screw

A self-tapping machine screw is similar to a machine screw except the lower part of the shank is designed to cut threads as the screw is driven into an untapped hole. The advantage of this screw type over a self-tapping screw is that, if the screw is reinstalled, new threads are not cut as the screw is driven.

Set screw

A set screw (grub screw) is generally a headless screw but can be any screw used to fix a rotating part to a shaft. The set screw is driven through a threaded hole in the rotating part until it is tight against the shaft. The most often used type is the socket set screw, which is tightened or loosened with a hex key.

Set bolt

A set bolt (tap bolt) is a bolt that is threaded all the way to the head. An ASME B18.2.1 compliant set/tap bolt has the same tolerances as an ASME B18.2.1 compliant hex cap screw.

Stud

Studs (threaded rods) are head-less screws. They may be threaded at both ends and unthreaded in the middle or completely threaded; the latter is usually referred to as a threaded rod, especially when it has a large aspect ratio (that is, quite long compared to diameter). Completely threaded round stock is available in bar stock form and is then usually referred to as "all-thread".

Eye bolt

An eye bolt is a bolt with a looped head.

Toggle bolt

A toggle bolt is a bolt with a special nut known as a wing. It is designed to be used where there is no access to side of the material where the nut is located. Usually the wing is spring loaded and expands after being inserted into the hole.

Carriage bolt

A carriage bolt (coach bolt) has a domed or countersunk head, and the shank is topped by a short square section under the head. The square section grips into the part being fixed (typically wood), preventing the bolt from turning when the nut is tightened. A rib neck carriage bolt has several longitudinal ribs instead of the square section, to grip into a metal part being fixed.

Elevator bolt

An elevator bolt is a bolt similar to a carriage bolt, except the head is thin and flat. There are many variations. Some do not have a square base, but rather triangular sections of the flat head are folded down to form "fangs" that cut into wood and hold it secure.

Stove bolt

A stove bolt is a type of machine screw that has a round or flat head and is threaded to the head. They are usually made of low grade steel, have a slot or Phillips drive, and are used to join sheet metal parts using a hex or square nut.

Shoulder screw

A shoulder screw (stripper bolt) differs from machine screws in that the shank is ground to a precise diameter, known as the *shoulder*, and the threaded portion is smaller in diameter than the shoulder. Shoulder bolt specifications call out the shoulder diameter, shoulder length, and threaded diameter; the threaded length is fixed, based on the threaded diameter, and usually quite short. It is usually used for revolving joints in mechanisms and linkages; when used as a guide for the stripper plate in a die set its called a stripper bolt.

Thumb screw

A thumb screw is a threaded fastener designed to be twisted into a tapped hole by hand without the use of tools.

Security screw

A security screw is similar to a standard screw except that once inserted it cannot be easily removed.

Tension control bolt

A tension control bolt (TC bolt) is a heavy duty bolt used in steel frame construction. The head is usually domed and is not designed to be driven. The end of the shank has a spline on it which is engaged by a special power wrench which prevents the bolt from turning while the nut is tightened. When the appropriate torque is reached the spline shears off.

Plow bolt

A plow bolt is bolt similar to a carriage bolt, except the head is flat or concave, and the underside of the head is a cone designed to fit in a countersunk recess. There are many variations, with some not using a square base, but rather a key, a locking slot, or other means. The recess in the mating part must be designed to accept the particular plow bolt.

Spring bolt

A spring bolt is a bolt which must be pulled back and which is brought back into place by the spring when the pressure is released. Spring bolts are used in Rubik's Snakes, for example, the wedges of which are pulled apart slightly when twisted and are pulled back together by the spring bolt when shifted back into position.

Other threaded fasteners

Superbolt, or multi-jackbolt tensioner

A superbolt, or multi-jackbolt tensioner is an alternative type of fastener that retrofits or replaces existing nuts, bolts, or studs. Tension in the bolt is developed by torquing individual jackbolts, which are threaded through the body of the nut and push against a hardened washer. Because of this, the amount of torque required to achieve a given preload is reduced. Installation and removal of any size tensioner is achieved with hand tools, which can be advantageous when dealing with large diameter bolting applications.

Hanger screw

A hanger screw is a headless fastener that has machine screw threads on one end and self-tapping threads on the other designed to be driven into wood or another soft substrate. Often used for mounting legs on tables.

Materials

Screws and bolts are made from a wide range of materials, with steel being perhaps the most common, in many varieties. Where great resistance to weather or corrosion is required, stainless steel, titanium, brass (steel screws can discolor oak and other woods), bronze, monel or silicon bronze may be used, or a coating such as brass, zinc or chromium applied. Electrolytic action from dissimilar metals can be prevented with aluminium screws for double-glazing tracks, for example. Some types of plastic, such as nylon or polytetrafluoroethylene (PTFE), can be threaded and used for fastening requiring moderate strength and great resistance to corrosion or for the purpose of electrical insulation.

Bolted joints

Rusty hexagonal bolt heads

The American Institute of Steel Construction (AISC) 13th Edition Steel Design Manual section 16.1 chapter J-3 specifies the requirements for bolted structural connections. Structural bolts replaced rivets due to decreasing cost and increasing strength of structural bolts in the 20th century. Connections are formed with two types of joints: slip-critical connections and bearing connections. In slip-critical connections, movement of the connected parts is a serviceability condition and bolts are tightened to a minimum required pretension. Slip is prevented through friction of the "faying" surface, that is the plane of shear for the bolt and where two members make contact. Because friction is proportional to the normal force, connections must be sized with bolts numerous and large enough to provide the required load capacity. However, this greatly decreases the shear capacity of each bolt in the connection. The second type and more common connection is a bearing connection. In this type of connection the bolts carry the load through shear and are only tightened to a "snug-fit." These connections require fewer bolts than slip-critical connections and therefore are a less expensive alternative. Slip-critical connections are more common on flange plates for beam and column splices and moment critical connections. Bearing type connections are used in light weight structures and in member connections where slip is not important and prevention of structural failure is the design constraint. Common bearing type connections include: shear tabs, beam supports, gusset plates in trusses.

Mechanical classifications

The numbers stamped on the head of the bolt are referred to the grade of the bolt used in certain application with the strength of a bolt. High-strength steel bolts usually have a hexagonal head with an ISO strength rating (called *property class*) stamped on the head. And the absence of marking/number indicates a lower grade bolt with low strength. The property classes most often used are 5.8, 8.8, and 10.9. The number before the point is the tensile ultimate strength in MPa divided by 100. The number after the point is 10 times the ratio of tensile yield strength to tensile ultimate strength. For example, a property class 5.8 bolt has a nominal (minimum) tensile ultimate strength of 500 MPa, and a tensile yield strength of 0.8 times tensile ultimate strength or 0.8(500) = 400 MPa.

Tensile ultimate strength is the stress at which the bolt fails. Tensile yield strength is the stress at which the bolt will receive a permanent set (an elongation from which it will not recover when the force is removed) of 0.2 % offset strain. When elongating a fastener prior to reaching the yield point, the fastener is said to be operating in the elastic region; whereas elongation beyond the yield point is referred to as operating in the plastic region, since the fastener has suffered permanent plastic deformation.

Mild steel bolts have property class 4.6. High-strength steel bolts have property class 8.8 or above.

The same type of screw or bolt can be made in many different grades of material. For critical high-tensile-strength applications, low-grade bolts may fail, resulting in damage or injury. On SAE-standard bolts, a distinctive pattern of marking is impressed on the heads to allow inspection and validation of the strength of the bolt. However, low-cost counterfeit fasteners may be found with actual strength far less than indicated by the markings. Such inferior fasteners are a danger to life and property when used in aircraft, automobiles, heavy trucks, and similar critical applications.

Inch

SAE J429 defines the bolt grades for inch-system sized bolts and screws. It defines them by *grade*, which ranges from 0 to 8, with 8 being the strongest. Higher grades do not exist within the specification. SAE grades 5 and 8 are the most common.

Metric

The international standard for metric screws is defined by ISO 898, specifically ISO 898-1. SAE J1199 and ASTM F568M are two North American metric standards that closely mimic the ISO standard. In case of inch sizes the grade is dictated by the number of radial shapes plus a value of two. Inch-system bolts use integer values to indicate grades but metric bolts use numbers with one decimal. The two North American standards use the same property class markings as defined by ISO 898. The ASTM standard only includes the following property classes from the ISO standard: 4.6, 4.8, 5.8, 8.8, 9.8, 10.9, and 12.9; it also includes two extra property classes: 8.8.3 and 10.9.3. ASTM property classes are to be stamped on the top of screws and it is preferred that the marking is raised.

Screw head shapes

(a) pan, (b) button, (c) round, (d) truss, (e) flat (countersunk), (f) oval

Combination flanged-hex/Phillips-head screw used in computers

Pan head
    A low disc with chamfered outer edge

Button or dome head
    Cylindrical with a rounded top

Round head
    A dome-shaped head used for decoration.

Truss head
    Lower-profile dome designed to prevent tampering

Countersunk or flat head
    Conical, with flat outer face and tapering inner face allowing it to sink into the material. The *angle* of the screw is measured as the full angle of the cone.

Oval or raised head
    A decorative screw head with a countersunk bottom and rounded top.

Bugle head

Similar to countersunk, but there is a smooth progression from the shank to the angle of the head, similar to the bell of a bugle

Cheese head

Disc with cylindrical outer edge, height approximately half the head diameter

Fillister head

Cylindrical, but with a slightly convex top surface. Height to diameter ratio is larger than cheese head.

Flanged head

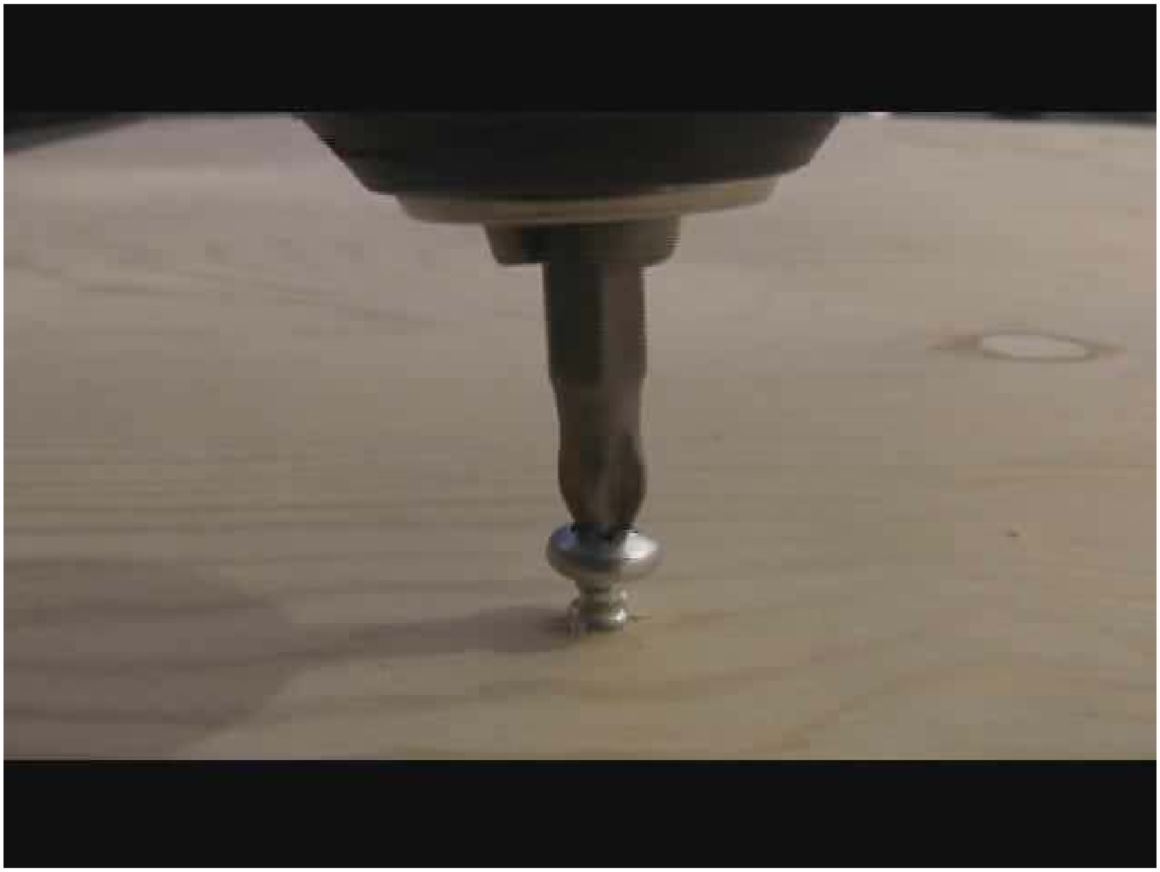
A flanged head can be any of the above head styles with the addition of an integrated flange at the base of the head. This eliminates the need for a flat washer.

Some varieties of screw are manufactured with a break-away head, which snaps off when adequate torque is applied. This prevents tampering and also provides an easily inspectable joint to guarantee proper assembly. An example of this is the shear bolts used on vehicle steering columns, to secure the ignition switch.

Types of screw drives

Modern screws employ a wide variety of drive designs, each requiring a different kind of tool to drive in or extract them. The most common screw drives are the slotted and Phillips; hex, Robertson, and torx are also common in some applications. Some types of drive are intended for automatic assembly in mass-production of such items as automobiles. More exotic screw drive types may be used in situations where tampering is undesirable, such as in electronic appliances that should not be serviced by the home repair person.

Tools



An electric driver screws a self-tapping phillips head screw into wood

The hand tool used to drive in most screws is called a *screwdriver*. A power tool that does the same job is a *power screwdriver*; power drills may also be used with screw-driving attachments. Where the holding power of the screwed joint is critical, torque-measuring and *torque-limiting screwdrivers* are used to ensure sufficient but not excessive force is developed by the screw. The hand tool for driving hex head threaded fasteners is a *spanner* (UK usage) or *wrench* (US usage).

Thread standards

There are many systems for specifying the dimensions of screws, but in much of the world the ISO metric screw thread preferred series has displaced the many older systems. Other relatively common systems include the British Standard Whitworth, BA system (British Association), and the Unified Thread Standard.

ISO metric screw thread

The basic principles of the ISO metric screw thread are defined in international standard ISO 68-1 and preferred combinations of diameter and pitch are listed in ISO 261. The smaller subset of diameter and pitch combinations commonly used in screws, nuts and bolts is given in ISO 262. The most commonly used pitch value for each diameter is the *coarse pitch*. For some diameters, one or two additional *fine pitch* variants are also specified, for special applications such as threads in thin-walled pipes. ISO metric screw threads are designated by the letter **M** followed by the major diameter of the thread in millimeters (e.g., *M8*). If the thread does not use the normal *coarse pitch* (e.g., 1.25 mm in the case of M8), then the pitch in millimeters is also appended with a multiplication sign (e.g. "M8×1" if the screw thread has an outer diameter of 8 mm and advances by 1 mm per 360° rotation).

The nominal diameter of a metric screw is the outer diameter of the thread. The tapped hole (or nut) into which the screw fits, has an internal diameter which is the size of the screw minus the pitch of the thread. Thus, an M6 screw, which has a pitch of 1 mm, is made by threading a 6 mm shank, and the nut or threaded hole is made by tapping threads into a hole of 5 mm diameter (6 mm - 1 mm).

Metric hexagon bolts, screws and nuts are specified, for example, in British Standard BS 4190 (general purpose screws) and BS 3692 (precision screws). The following table lists the relationship given in these standards between the thread size and the maximal width across the hexagonal flats (wrench size):

ISO metric thread	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10	M12	M16	M20	M24	M30	M36	M42	M48	M56	M64
Wrench size (mm)	3.2	4	5	5.5	7	8	10	13	17	19	24	30	36	46	55	65	75	85	95

In addition, the following non-preferred intermediate sizes are specified:

ISO metric thread	M7	M14	M18	M22	M27	M33	M39	M45	M52	M60	M68
Wrench size (mm)	11	22	27	32	41	50	60	70	80	90	100

Whitworth

The first person to create a standard (in about 1841) was the English engineer Sir Joseph Whitworth. Whitworth screw sizes are still used, both for repairing old machinery and where a coarser thread than the metric fastener thread is required. Whitworth became *British Standard Whitworth*, abbreviated to BSW (BS 84:1956) and the *British Standard Fine* (BSF) thread was introduced in 1908 because the Whitworth thread was too coarse for some applications. The thread angle was 55° and a depth and pitch of thread that varied with the diameter of the thread (i.e., the bigger the bolt, the coarser the thread). The spanner size is determined by the size of the bolt, not the distance between the flats.

The most common use of a Whitworth pitch nowadays is in all UK scaffolding. Additionally, the standard photographic tripod thread, which for small cameras is 1/4" Whitworth (20 tpi) and for medium/large format cameras is 3/8" Whitworth (16 tpi). It is also used for microphone stands and their appropriate clips, again in both sizes, along with "thread adapters" to allow the smaller size to attach to items requiring the larger thread.

British Association screw thread

A later standard established in the United Kingdom was the British Association (BA) screw threads, named after the British Association for Advancement of Science. Screws were described as "2BA", "4BA" etc., the odd numbers being rarely used, except in equipment made prior to the 1970s for telephone exchanges in the UK. This equipment made extensive use of odd-numbered BA screws, in order—it may be suspected—to reduce theft. BA threads are specified by British Standard BS 93:1951 "Specification for British Association (B.A.) screw threads with tolerances for sizes 0 B.A. to 16 B.A."

While not related to ISO metric screws, the sizes were actually defined in metric terms, a 0BA thread having a 6 mm diameter and 1 mm pitch. Other threads in the BA series are related to 0BA in a geometric series with the common factors 0.9 and 1.2. For example, a 4BA thread has pitch mm (0.65mm) and diameter mm (3.62mm). Although 0BA has the same diameter and pitch as ISO M6, the threads have different forms and are not compatible.

BA threads are still common in some niche applications. Certain types of fine machinery, such as moving-coil meters and clocks, tend to have BA threads wherever they are manufactured. BA sizes were also used extensively in aircraft, especially those manufactured in the United Kingdom. BA sizing is still used in railway signalling, mainly for the termination of electrical equipment and cabling.

BA threads are extensively used in Model Engineering where the smaller hex head sizes make scale fastenings easier to represent. As a result many UK Model Engineering suppliers still carry stocks of BA fasteners up to typically 8BA and 10BA. 5BA is also commonly used as it can be threaded onto 1/8 rod.

Unified Thread Standard

The Unified Thread Standard (UTS) is most commonly used in the United States of America, but is also extensively used in Canada and occasionally in other countries. The size of a UTS screw is described using the following format: **X-Y**, where **X** is the nominal size (the hole or slot size in standard manufacturing practice through which the shaft of the screw can easily be pushed) and **Y** is the threads per inch (TPI). For sizes ¼ inch and larger the size is given as a fraction; for sizes less than this an integer is used, ranging from 0 to 16. For most size screws there are multiple TPI available, with the most common being designated a Unified Coarse Thread (UNC or UN) and Unified Fine Thread (UNF or UF).

Manufacture

A schematic of the heading process

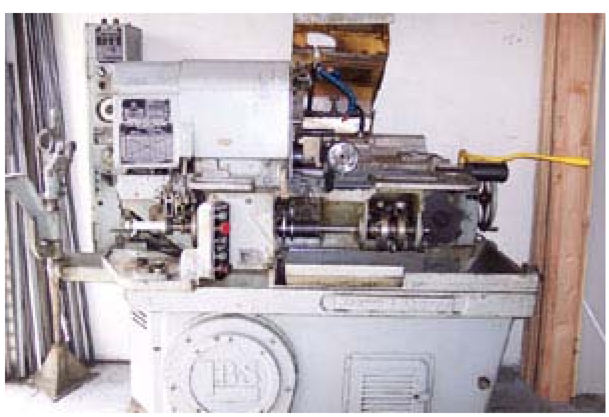
There are three steps in manufacturing a screw: *heading*, *thread rolling*, and *coating*. Screws are normally made from wire, which is supplied in large coils, or round bar stock for larger screws. The wire or rod is then cut to the proper length for the type of screw being made; this workpiece is known as a *blank*. It is then cold headed, which is a cold working process. Heading produces the *head* of the screw. The shape of the die in the machine dictates what features are pressed into the screw head; for example a flat head screw uses a flat die. For more complicated shapes two heading processes are required to get all of the features into the screw head. This production method is used because heading has a very high production rate, and produces virtually no waste material. Slotted head screws require an extra step to cut the slot in the head; this is done on a *slotting machine*. These machines are essentially stripped down milling machines designed to process as many blanks as possible.

The blanks are then polished again prior to threading. The threads are usually produced via thread rolling, however some are cut. The workpiece is then tumble finished with wood and leather media to do final cleaning and polishing. For most screws a coating, such as hot-dip galvanizing or blackening, is applied to prevent corrosion.

Different bolt sections

History

A lathe of 1871, equipped with leadscrew and change gears for single-point screw-cutting.



A Brown & Sharpe single-spindle screw machine.

While a recent hypothesis attributes the Archimedes' screw to Sennacherib, King of Assyria, archaeological finds and pictorial evidence only appear in the Hellenistic period and the standard view holds the device to be a Greek invention, most probably by the 3rd century BC polymath Archimedes himself.

The screw was later described by the Greek mathematician Archytas of Tarentum (428 – 350 BC). By the 1st century BC, wooden screws were commonly used throughout the Mediterranean world in devices such as oil and wine presses. Metal screws used as fasteners did not appear in Europe until the 15th century.

In 1744, the flat-bladed bit for the carpenter's brace was invented, the precursor to the first simple screwdriver. Handheld screwdrivers first appeared after 1800.

Prior to the mid-19th century, cotter pins or pin bolts, and "clinch bolts" (now called rivets), were used in shipbuilding.

The metal screw did not become a common fastener until machine tools for mass production were developed at the end of the 18th century. In the 1770s, English instrument maker Jesse Ramsden (1735–1800) invented the first satisfactory screw-cutting lathe. The British engineer Henry Maudslay (1771–1831) patented a screw-cutting lathe in 1797; a similar device was patented by David Wilkinson in the United States in 1798. These developments caused great increase in the use of threaded fasteners. Standardization of threadforms began almost immediately, but it was not quickly completed; it has been an evolving process ever since.

The development of the turret lathe (1840s) and of the screw machine (1870s) drastically reduced the unit cost of threaded fasteners by increasingly automating the machine tool control. This cost reduction spurred ever greater use of screws.

Throughout the 19th century, the most commonly used forms of screw head (drive) were simple internal-wrenching slots and external-wrenching squares and hexagons. These were easy to machine and served most applications adequately. The 20th century saw the development of many other types of drive. In 1908, Canadian P. L. Robertson invented the internal-wrenching square drive. The internal-wrenching hexagon drive (hex socket) shortly followed in 1911. In the early 1930s, the Phillips-head screw was invented by Henry F. Phillips.

Threadform standardization further improved in the late 1940s, when the ISO metric screw thread and the Unified Thread Standard were defined.

Other fastening methods

Alternative fastening methods are nails, rivets, roll pins, pinned shafts, welding, soldering, brazing, and gluing (including taping), and clinch fastening.