

**Hardware
Mechanical Engineering**
Meda Lance

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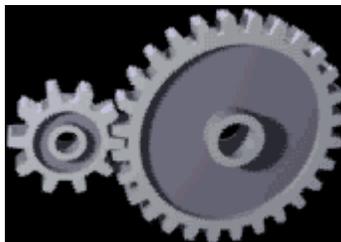
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Chapter- 1

Gear



Two meshing gears transmitting rotational motion. Note that the smaller gear is rotating faster. Although the larger gear is rotating less quickly, its torque is proportionally greater.

A **gear** or more correctly a "gear wheel" is a rotating machine part having cut *teeth*, or *cogs*, which *mesh* with another toothed part in order to transmit torque. Two or more gears working in tandem are called a *transmission* and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, magnitude, and direction of a power source. The most common situation is for a gear to mesh with another gear, however a gear can also mesh a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.

The gears in a transmission are analogous to the wheels in a pulley. An advantage of gears is that the teeth of a gear prevent slipping.

When two gears of unequal number of teeth are combined a mechanical advantage is produced, with both the rotational speeds and the torques of the two gears differing in a simple relationship.

In transmissions which offer multiple gear ratios, such as bicycles and cars, the term **gear**, as in *first gear*, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission.

The earliest known reference to gears was circa A.D. 50 by Hero of Alexandria, but they can be traced back to the Greek mechanics of the Alexandrian school in the 3rd century B.C. and were greatly developed by the Greek polymath Archimedes (287–212 B.C.). The Antikythera mechanism is an example of a very early and intricate geared device, designed to calculate astronomical positions. Its time of construction is now estimated between 150 and 100 BC.

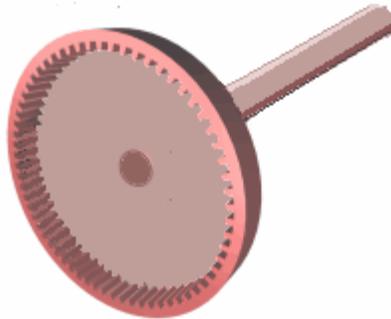
Comparison with other drive mechanisms

The definite velocity ratio which results from having teeth gives gears an advantage over other drives (such as traction drives and V-belts) in precision machines such as watches that depend upon an exact velocity ratio. In cases where driver and follower are in close proximity gears also have an advantage over other drives in the reduced number of parts required; the downside is that gears are more expensive to manufacture and their lubrication requirements may impose a higher operating cost.

The automobile transmission allows selection between gears to give various mechanical advantages.

Types

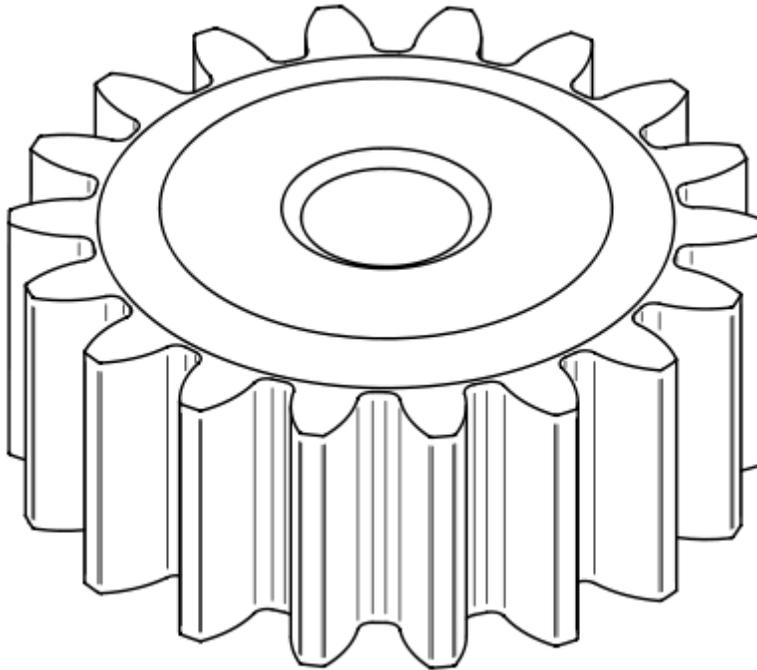
External vs. internal gears



Internal gear

An *external gear* is one with the teeth formed on the outer surface of a cylinder or cone. Conversely, an *internal gear* is one with the teeth formed on the inner surface of a cylinder or cone. For bevel gears, an internal gear is one with the pitch angle exceeding 90 degrees. Internal gears do not cause direction reversal.

Spur



Spur gear

Spur gears or *straight-cut gears* are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radially, and although they are not straight-sided in form, the edge of each tooth is straight and aligned parallel to the axis of rotation. These gears can be meshed together correctly only if they are fitted to parallel shafts.

Helical



Helical gears
Top: parallel configuration
Bottom: crossed configuration

Helical gears offer a refinement over spur gears. The leading edges of the teeth are not parallel to the axis of rotation, but are set at an angle. Since the gear is curved, this angling causes the tooth shape to be a segment of a helix. Helical gears can be meshed in a *parallel* or *crossed* orientations. The former refers to when the shafts are parallel to each other; this is the most common orientation. In the latter, the shafts are non-parallel, and in this configuration are sometimes known as "skew gears".

The angled teeth engage more gradually than do spur gear teeth causing them to run more smoothly and quietly. With parallel helical gears, each pair of teeth first make contact at a single point at one side of the gear wheel; a moving curve of contact then grows gradually across the tooth face to a maximum then recedes until the teeth break contact at a single point on the opposite side. In spur gears teeth suddenly meet at a line contact

across their entire width causing stress and noise. Spur gears make a characteristic whine at high speeds and can not take as much torque as helical gears. Whereas spur gears are used for low speed applications and those situations where noise control is not a problem, the use of helical gears is indicated when the application involves high speeds, large power transmission, or where noise abatement is important. The speed is considered to be high when the pitch line velocity exceeds 25 m/s.

A disadvantage of helical gears is a resultant thrust along the axis of the gear, which needs to be accommodated by appropriate thrust bearings, and a greater degree of sliding friction between the meshing teeth, often addressed with additives in the lubricant.

For a crossed configuration the gears must have the same pressure angle and normal pitch, however the helix angle and handedness can be different. The relationship between the two shafts is actually defined by the helix angle(s) of the two shafts and the handedness, as defined:

$$E = \beta_1 + \beta_2 \text{ for gears of the same handedness}$$

$$E = \beta_1 - \beta_2 \text{ for gears of opposite handedness}$$

Where β is the helix angle for the gear. The crossed configuration is less mechanically sound because there is only a point contact between the gears, whereas in the parallel configuration there is a line contact.

Quite commonly helical gears are used with the helix angle of one having the negative of the helix angle of the other; such a pair might also be referred to as having a right-handed helix and a left-handed helix of equal angles. The two equal but opposite angles add to zero: the angle between shafts is zero – that is, the shafts are *parallel*. Where the sum or the difference (as described in the equations above) is not zero the shafts are *crossed*. For shafts *crossed* at right angles the helix angles are of the same hand because they must add to 90 degrees.

Double helical



Double helical gears

Double helical gears, or *herringbone gear*, overcome the problem of axial thrust presented by "single" helical gears by having two sets of teeth that are set in a V shape. Each gear in a double helical gear can be thought of as two standard mirror image helical gears stacked. This cancels out the thrust since each half of the gear thrusts in the opposite direction. Double helical gears are more difficult to manufacture due to their more complicated shape.

For each possible direction of rotation, there are two possible arrangements of two oppositely-oriented helical gears or gear faces. In one possible orientation, the helical gear faces are oriented so that the axial force generated by each is in the axial direction away from the center of the gear; this arrangement is unstable. In the second possible orientation, which is stable, the helical gear faces are oriented so that each axial force is toward the mid-line of the gear. In both arrangements, when the gears are aligned correctly, the total (or *net*) axial force on each gear is zero. If the gears become misaligned in the axial direction, the unstable arrangement generates a net force for disassembly of the gear train, while the stable arrangement generates a net corrective force. If the direction of rotation is reversed, the direction of the axial thrusts is reversed, a stable configuration becomes unstable, and *vice versa*.

Stable double helical gears can be directly interchanged with spur gears without any need for different bearings.

Bevel

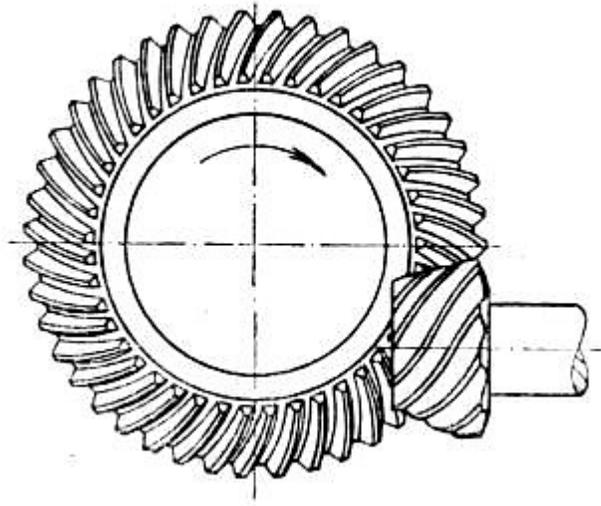


Bevel gear

A bevel gear is shaped like a right circular cone with most of its tip cut off. When two bevel gears mesh their imaginary vertices must occupy the same point. Their shaft axes also intersect at this point, forming an arbitrary non-straight angle between the shafts. The angle between the shafts can be anything except zero or 180 degrees. Bevel gears with equal numbers of teeth and shaft axes at 90 degrees are called *miter gears*.

The teeth of a bevel gear may be straight-cut as with spur gears, or they may be cut in a variety of other shapes. *Spiral bevel gear* teeth are curved along the tooth's length and set at an angle, analogously to the way helical gear teeth are set at an angle compared to spur gear teeth. *Zerol bevel gears* have teeth which are curved along their length, but not angled. Spiral bevel gears have the same advantages and disadvantages relative to their straight-cut cousins as helical gears do to spur gears. Straight bevel gears are generally used only at speeds below 5 m/s (1000 ft/min), or, for small gears, 1000 r.p.m.

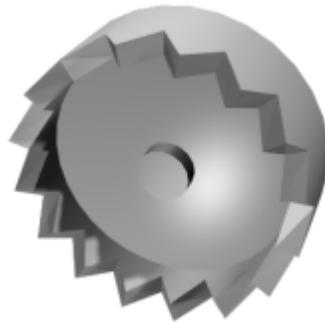
Hypoid



Hypoid gear

Hypoid gears resemble spiral bevel gears except the shaft axes do not intersect. The pitch surfaces appear conical but, to compensate for the offset shaft, are in fact hyperboloids of revolution. Hypoid gears are almost always designed to operate with shafts at 90 degrees. Depending on which side the shaft is offset to, relative to the angling of the teeth, contact between hypoid gear teeth may be even smoother and more gradual than with spiral bevel gear teeth. Also, the pinion can be designed with fewer teeth than a spiral bevel pinion, with the result that gear ratios of 60:1 and higher are feasible using a single set of hypoid gears. This style of gear is most commonly found driving mechanical differentials; which are normally straight cut bevel gears; in motor vehicle axles.

Crown



Crown gear

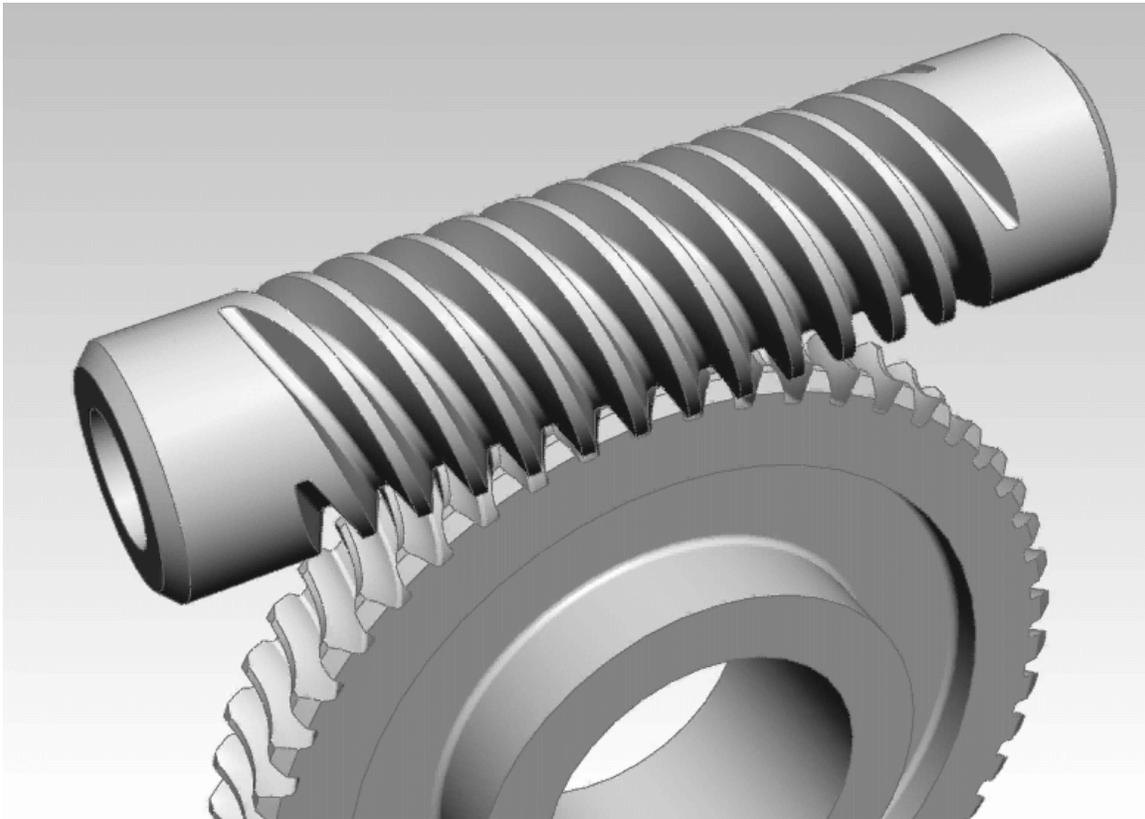
Crown gears or *contrate gears* are a particular form of bevel gear whose teeth project at right angles to the plane of the wheel; in their orientation the teeth resemble the points on a crown. A crown gear can only mesh accurately with another bevel gear, although crown

gears are sometimes seen meshing with spur gears. A crown gear is also sometimes meshed with an escapement such as found in mechanical clocks.

Worm



Worm gear



4-start worm and wheel

Worm gears resemble screws. A worm gear is usually meshed with an ordinary looking, disk-shaped gear, which is called the *gear*, *wheel*, or *worm wheel*.

Worm-and-gear sets are a simple and compact way to achieve a high torque, low speed gear ratio. For example, helical gears are normally limited to gear ratios of less than 10:1 while worm-and-gear sets vary from 10:1 to 500:1. A disadvantage is the potential for considerable sliding action, leading to low efficiency.

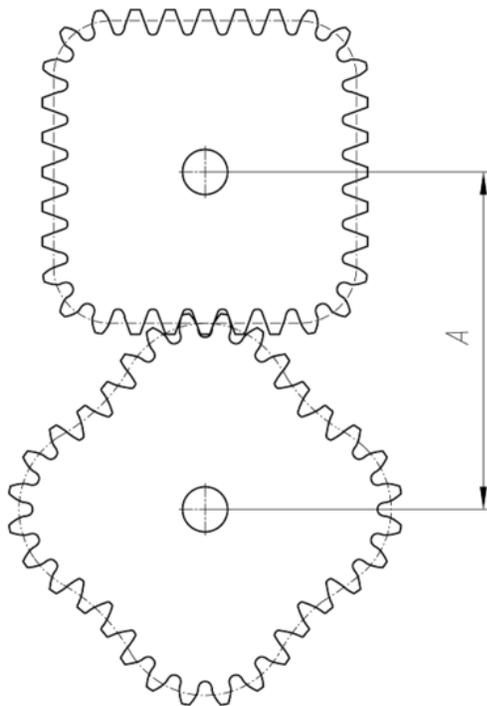
Worm gears can be considered a species of helical gear, but its helix angle is usually somewhat large (close to 90 degrees) and its body is usually fairly long in the axial direction; and it is these attributes which give it its screw like qualities. The distinction between a worm and a helical gear is made when at least one tooth persists for a full rotation around the helix. If this occurs, it is a 'worm'; if not, it is a 'helical gear'. A worm may have as few as one tooth. If that tooth persists for several turns around the helix, the worm will appear, superficially, to have more than one tooth, but what one in fact sees is the same tooth reappearing at intervals along the length of the worm. The usual screw nomenclature applies: a one-toothed worm is called *single thread* or *single start*; a worm with more than one tooth is called *multiple thread* or *multiple start*. The helix angle of a worm is not usually specified. Instead, the lead angle, which is equal to 90 degrees minus the helix angle, is given.

In a worm-and-gear set, the worm can always drive the gear. However, if the gear attempts to drive the worm, it may or may not succeed. Particularly if the lead angle is small, the gear's teeth may simply lock against the worm's teeth, because the force component circumferential to the worm is not sufficient to overcome friction. Worm-and-gear sets that do lock are called **self locking**, which can be used to advantage, as for instance when it is desired to set the position of a mechanism by turning the worm and then have the mechanism hold that position. An example is the machine head found on some types of stringed instruments.

If the gear in a worm-and-gear set is an ordinary helical gear only a single point of contact will be achieved. If medium to high power transmission is desired, the tooth shape of the gear is modified to achieve more intimate contact by making both gears partially envelop each other. This is done by making both concave and joining them at a saddle point; this is called a **cone-drive**.

Worm gears can be right or left-handed following the long established practice for screw threads.

Non-circular

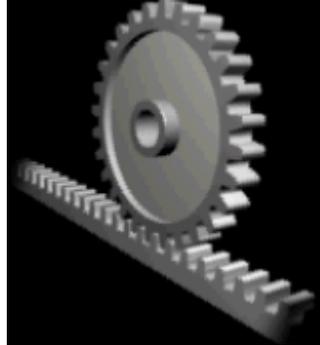


Non-circular gears

Non-circular gears are designed for special purposes. While a regular gear is optimized to transmit torque to another engaged member with minimum noise and wear and maximum efficiency, a non-circular gear's main objective might be ratio variations, axle

displacement oscillations and more. Common applications include textile machines, potentiometers and continuously variable transmissions.

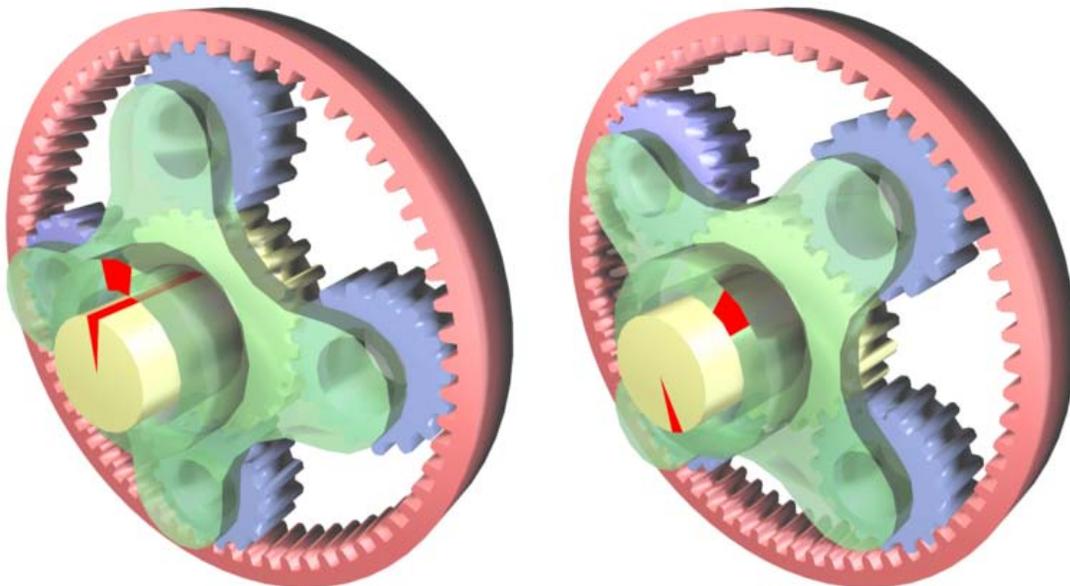
Rack and pinion



Rack and pinion gearing

A rack is a toothed bar or rod that can be thought of as a sector gear with an infinitely large radius of curvature. Torque can be converted to linear force by meshing a rack with a pinion: the pinion turns; the rack moves in a straight line. Such a mechanism is used in automobiles to convert the rotation of the steering wheel into the left-to-right motion of the tie rod(s). Racks also feature in the theory of gear geometry, where, for instance, the tooth shape of an interchangeable set of gears may be specified for the rack (infinite radius), and the tooth shapes for gears of particular actual radii then derived from that. The rack and pinion gear type is employed in a rack railway.

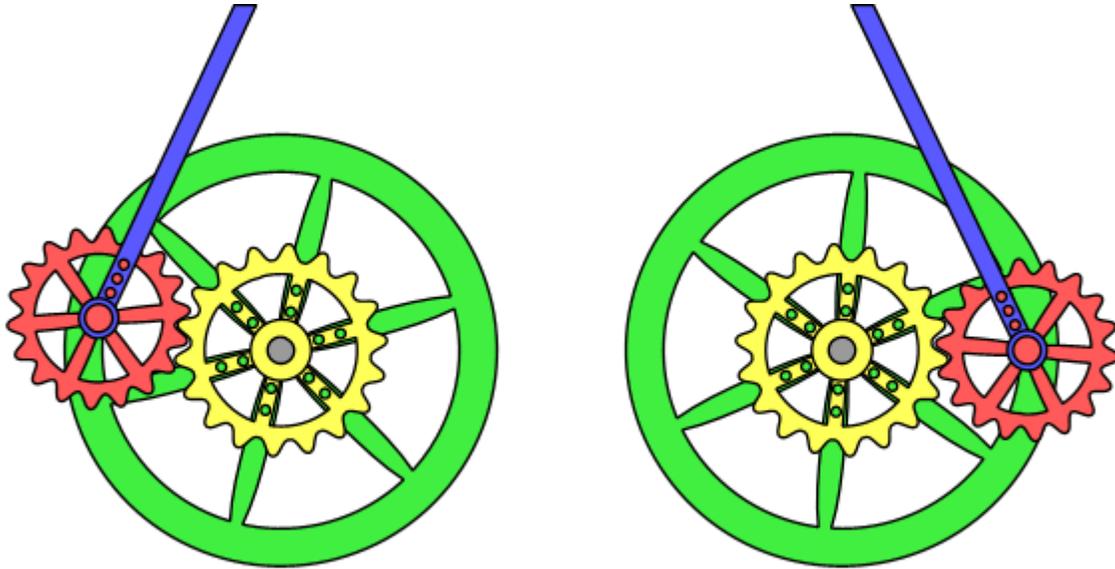
Epicyclic



Epicyclic gearing

In epicyclic gearing one or more of the gear axes moves. Examples are sun and planet gearing and mechanical differentials.

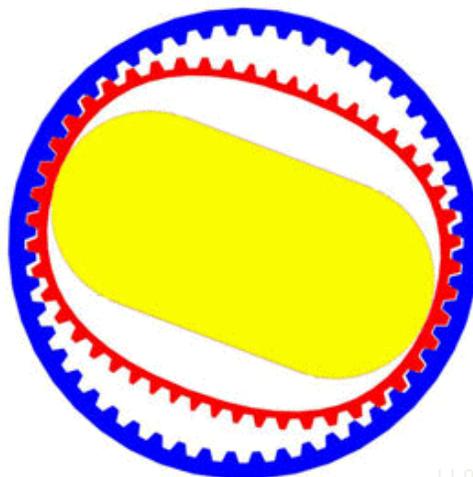
Sun and planet



Sun (yellow) and planet (red) gearing

Sun and planet gearing was a method of converting reciprocal motion into rotary motion in steam engines. It played an important role in the Industrial Revolution. The Sun is yellow, the planet red, the reciprocating crank is blue, the flywheel is green and the driveshaft is grey.

Harmonic drive



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Harmonic drive gearing

A *harmonic drive* is a specialized proprietary gearing mechanism.

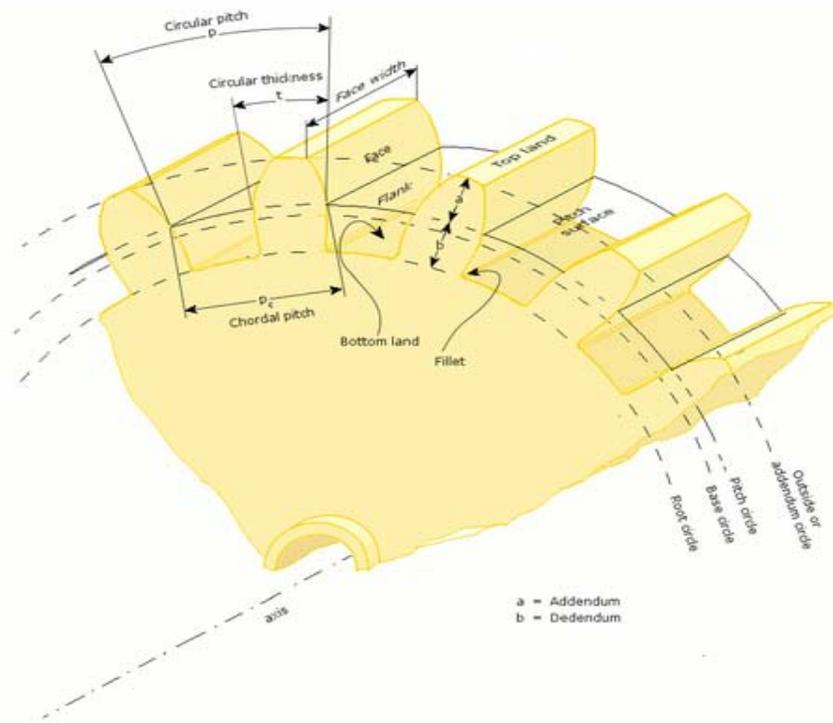
Cage gear

Cage gear in Pantigo Windmill, Long Island

A *cage gear*, also called a *lantern gear* or *lantern pinion* has cylindrical rods for teeth, parallel to the axle and arranged in a circle around it, much as the bars on a round bird cage or lantern. The assembly is held together by disks at either end into which the tooth rods and axle are set.

Nomenclature

General nomenclature



Rotational frequency, n

Measured in rotation over time, such as RPM.

Angular frequency, ω

Measured in radians per second. $1RPM = \pi / 30$ rad/second

Number of teeth, N

How many teeth a gear has, an integer. In the case of worms, it is the number of thread starts that the worm has.

Gear, wheel

The larger of two interacting gears or a gear on its own.

Pinion

The smaller of two interacting gears.

Path of contact

Path followed by the point of contact between two meshing gear teeth.

Line of action, pressure line

Line along which the force between two meshing gear teeth is directed. It has the same direction as the force vector. In general, the line of action changes from moment to moment during the period of engagement of a pair of teeth. For involute gears, however, the tooth-to-tooth force is always directed along the same line—that is, the line of action is constant. This implies that for involute gears the path of contact is also a straight line, coincident with the line of action—as is indeed the case.

Axis

Axis of revolution of the gear; center line of the shaft.

Pitch point, p

Point where the line of action crosses a line joining the two gear axes.

Pitch circle, pitch line

Circle centered on and perpendicular to the axis, and passing through the pitch point. A predefined diametral position on the gear where the circular tooth thickness, pressure angle and helix angles are defined.

Pitch diameter, d

A predefined diametral position on the gear where the circular tooth thickness, pressure angle and helix angles are defined. The standard pitch diameter is a basic dimension and cannot be measured, but is a location where other measurements are made. Its value is based on the number of teeth, the normal module (or normal diametral pitch), and the helix angle. It is calculated as:

$$d = \frac{Nm_n}{\cos\psi} \text{ in metric units or } d = \frac{N}{P_d \cos\psi} \text{ in imperial units.}$$

Module, m

A scaling factor used in metric gears with units in millimeters whose effect is to enlarge the gear tooth size as the module increases and reduce the size as the module decreases. Module can be defined in the normal (m_n), the transverse (m_t), or the axial planes (m_a) depending on the design approach employed and the type of gear being designed. Module is typically an input value into the gear design and is seldom calculated.

Operating pitch diameters

Diameters determined from the number of teeth and the center distance at which gears operate. Example for pinion:

$$d_w = \frac{2a}{u + 1} = \frac{2a}{\frac{z_2}{z_1} + 1}.$$

Pitch surface

In cylindrical gears, cylinder formed by projecting a pitch circle in the axial direction. More generally, the surface formed by the sum of all the pitch circles as one moves along the axis. For bevel gears it is a cone.

Angle of action

Angle with vertex at the gear center, one leg on the point where mating teeth first make contact, the other leg on the point where they disengage.

Arc of action

Segment of a pitch circle subtended by the angle of action.

Pressure angle, θ

The complement of the angle between the direction that the teeth exert force on each other, and the line joining the centers of the two gears. For involute gears, the teeth always exert force along the line of action, which, for involute gears, is a straight line; and thus, for involute gears, the pressure angle is constant.

Outside diameter, D_o

Diameter of the gear, measured from the tops of the teeth.

Root diameter

Diameter of the gear, measured at the base of the tooth.

Addendum, a

Radial distance from the pitch surface to the outermost point of the tooth. $a = (D_o - D) / 2$

Dedendum, b

Radial distance from the depth of the tooth trough to the pitch surface. $b = (D - \text{rootdiameter}) / 2$

Whole depth, h_t

The distance from the top of the tooth to the root; it is equal to addendum plus dedendum or to working depth plus clearance.

Clearance

Distance between the root circle of a gear and the addendum circle of its mate.

Working depth

Depth of engagement of two gears, that is, the sum of their operating addendums.

Circular pitch, p

Distance from one face of a tooth to the corresponding face of an adjacent tooth on the same gear, measured along the pitch circle.

Diametral pitch, p_d

Ratio of the number of teeth to the pitch diameter. Could be measured in teeth per inch or teeth per centimeter.

Base circle

In involute gears, where the tooth profile is the involute of the base circle. The radius of the base circle is somewhat smaller than that of the pitch circle.

Base pitch, normal pitch, p_b

In involute gears, distance from one face of a tooth to the corresponding face of an adjacent tooth on the same gear, measured along the base circle.

Interference

Contact between teeth other than at the intended parts of their surfaces.

Interchangeable set

A set of gears, any of which will mate properly with any other.

Helical gear nomenclature

Helix angle, ψ

Angle between a tangent to the helix and the gear axis. It is zero in the limiting case of a spur gear, albeit it can be considered as the hypotenuse angle as well.

Normal circular pitch, p_n

Circular pitch in the plane normal to the teeth.

Transverse circular pitch, p

Circular pitch in the plane of rotation of the gear. Sometimes just called "circular pitch". $p_n = p \cos(\psi)$

Several other helix parameters can be viewed either in the normal or transverse planes. The subscript n usually indicates the normal.

Worm gear nomenclature

Lead

Distance from any point on a thread to the corresponding point on the next turn of the same thread, measured parallel to the axis.

Linear pitch, p

Distance from any point on a thread to the corresponding point on the adjacent thread, measured parallel to the axis. For a single-thread worm, lead and linear pitch are the same.

Lead angle, λ

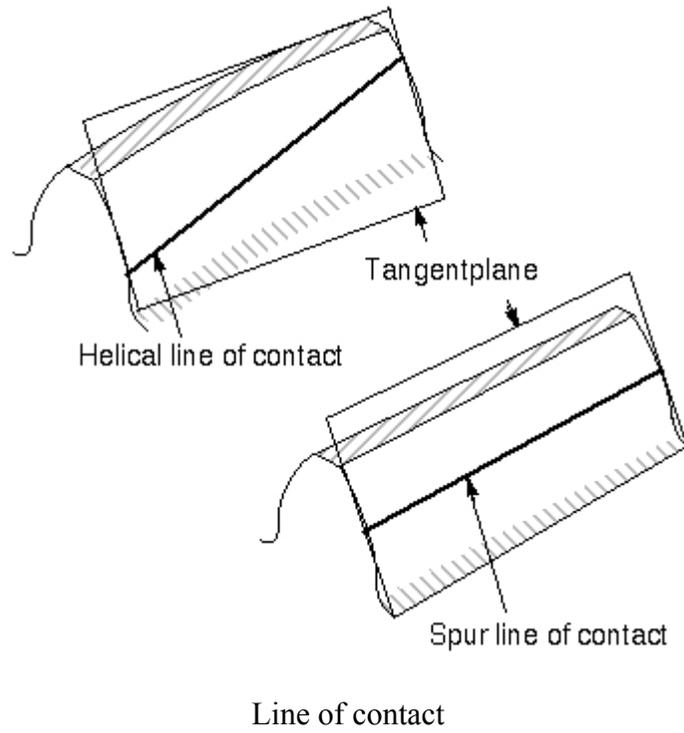
Angle between a tangent to the helix and a plane perpendicular to the axis. Note that it is the complement of the helix angle which is usually given for helical gears.

Pitch diameter, d_w

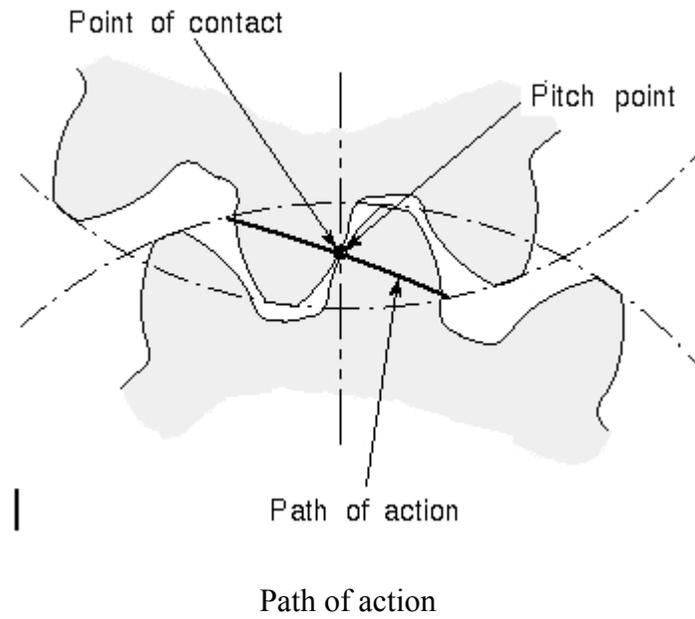
Same as described earlier in this list. Note that for a worm it is still measured in a plane perpendicular to the gear axis, not a tilted plane.

Subscript w denotes the worm, subscript g denotes the gear.

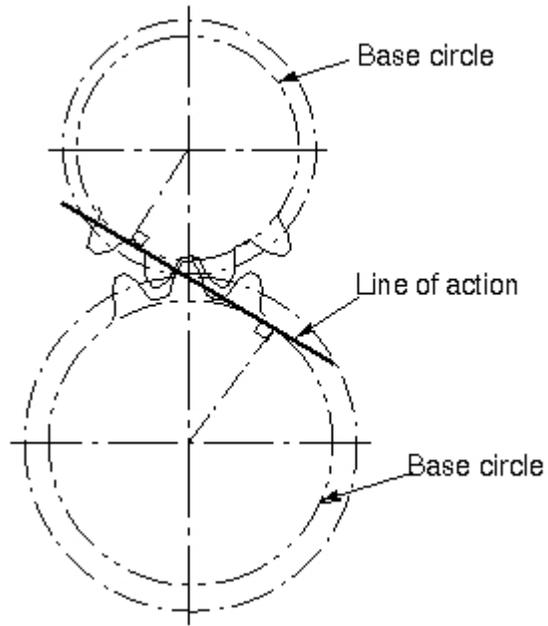
Tooth contact nomenclature



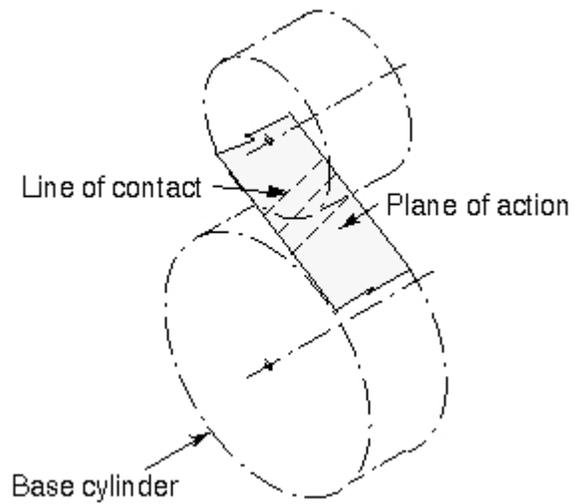
Line of contact



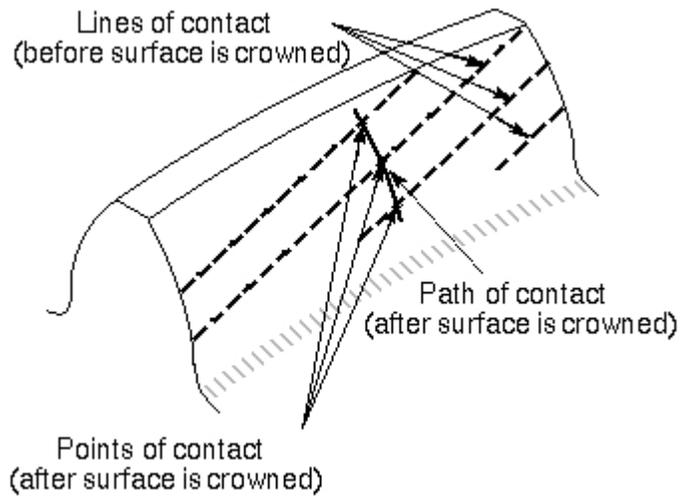
Path of action



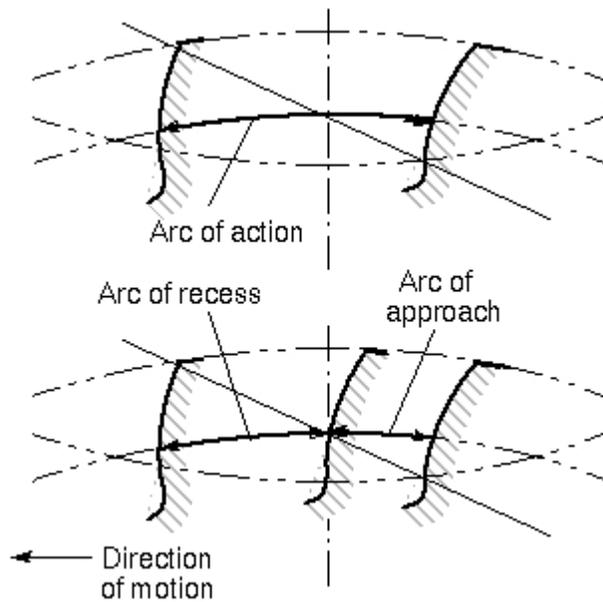
Line of action



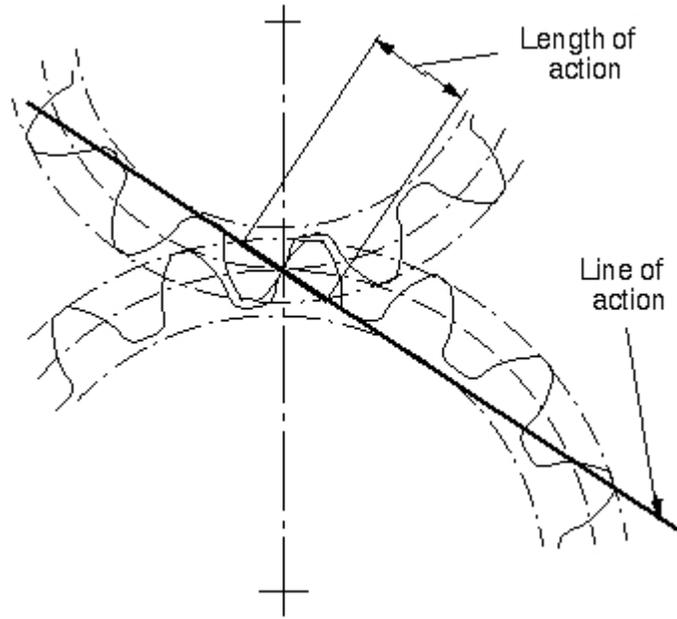
Plane of action



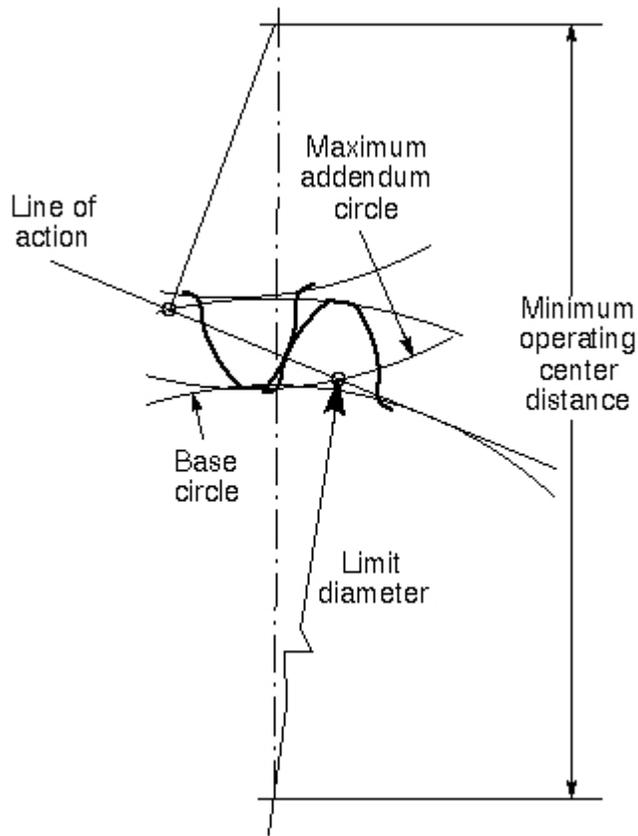
Lines of contact (helical gear)



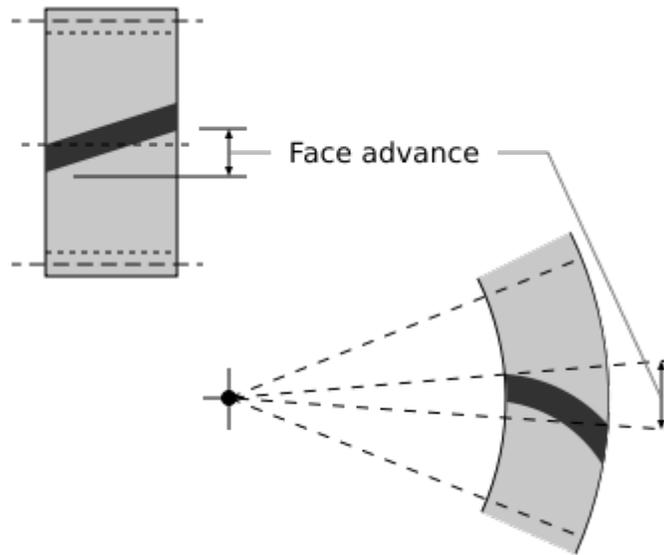
Arc of action



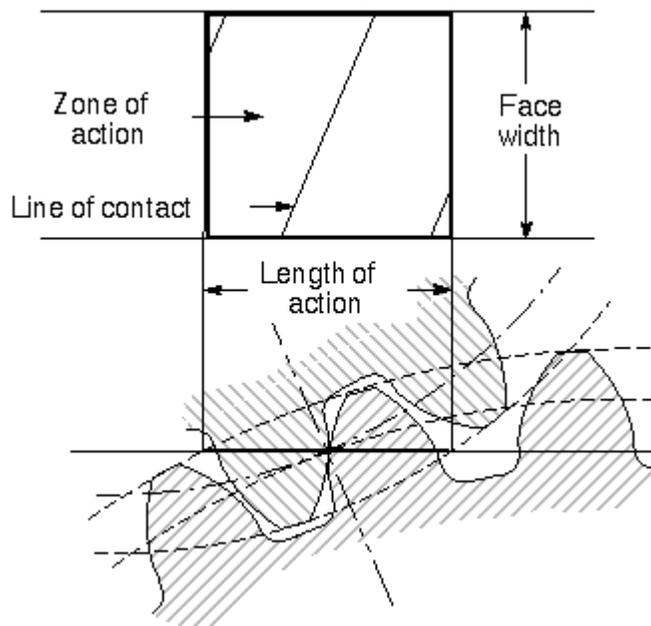
Length of action



Limit diameter



Face advance



Zone of action

Point of contact

Any point at which two tooth profiles touch each other.

Line of contact

A line or curve along which two tooth surfaces are tangent to each other.

Path of action

- The locus of successive contact points between a pair of gear teeth, during the phase of engagement. For conjugate gear teeth, the path of action passes through the pitch point. It is the trace of the surface of action in the plane of rotation.
- Line of action**
The path of action for involute gears. It is the straight line passing through the pitch point and tangent to both base circles.
- Surface of action**
The imaginary surface in which contact occurs between two engaging tooth surfaces. It is the summation of the paths of action in all sections of the engaging teeth.
- Plane of action**
The surface of action for involute, parallel axis gears with either spur or helical teeth. It is tangent to the base cylinders.
- Zone of action (contact zone)**
For involute, parallel-axis gears with either spur or helical teeth, is the rectangular area in the plane of action bounded by the length of action and the effective face width.
- Path of contact**
The curve on either tooth surface along which theoretical single point contact occurs during the engagement of gears with crowned tooth surfaces or gears that normally engage with only single point contact.
- Length of action**
The distance on the line of action through which the point of contact moves during the action of the tooth profile.
- Arc of action, Q_t**
The arc of the pitch circle through which a tooth profile moves from the beginning to the end of contact with a mating profile.
- Arc of approach, Q_a**
The arc of the pitch circle through which a tooth profile moves from its beginning of contact until the point of contact arrives at the pitch point.
- Arc of recess, Q_r**
The arc of the pitch circle through which a tooth profile moves from contact at the pitch point until contact ends.
- Contact ratio, m_c, ϵ**
The number of angular pitches through which a tooth surface rotates from the beginning to the end of contact. In a simple way, it can be defined as a measure of the average number of teeth in contact during the period in which a tooth comes and goes out of contact with the mating gear.
- Transverse contact ratio, m_p, ϵ_α**
The contact ratio in a transverse plane. It is the ratio of the angle of action to the angular pitch. For involute gears it is most directly obtained as the ratio of the length of action to the base pitch.
- Face contact ratio, m_F, ϵ_β**
The contact ratio in an axial plane, or the ratio of the face width to the axial pitch. For bevel and hypoid gears it is the ratio of face advance to circular pitch.
- Total contact ratio, m_t, ϵ_γ**

The sum of the transverse contact ratio and the face contact ratio.

$$\varepsilon_{\gamma} = \varepsilon_{\alpha} + \varepsilon_{\beta}$$

$$m_t = m_p + m_F$$

Modified contact ratio, m_o

For bevel gears, the square root of the sum of the squares of the transverse and face contact ratios.

$$m_o = (m_p^2 + m_F^2)^{0.5}$$

Limit diameter

Diameter on a gear at which the line of action intersects the maximum (or minimum for internal pinion) addendum circle of the mating gear. This is also referred to as the start of active profile, the start of contact, the end of contact, or the end of active profile.

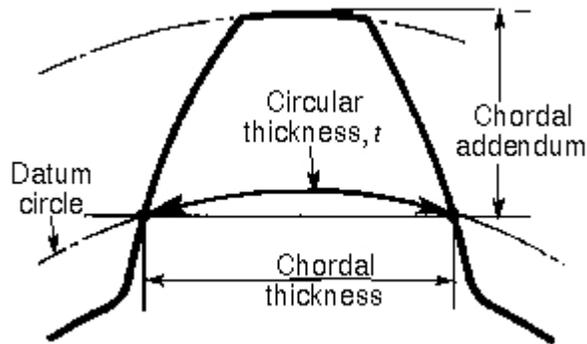
Start of active profile (SAP)

Intersection of the limit diameter and the involute profile.

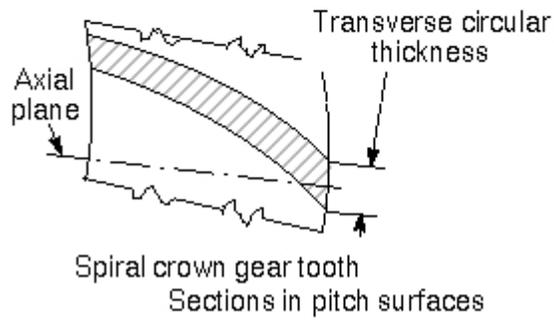
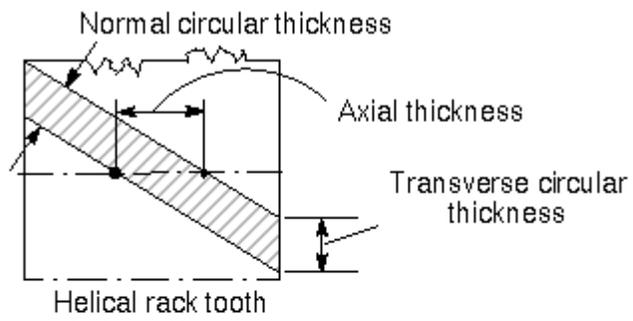
Face advance

Distance on a pitch circle through which a helical or spiral tooth moves from the position at which contact begins at one end of the tooth trace on the pitch surface to the position where contact ceases at the other end.

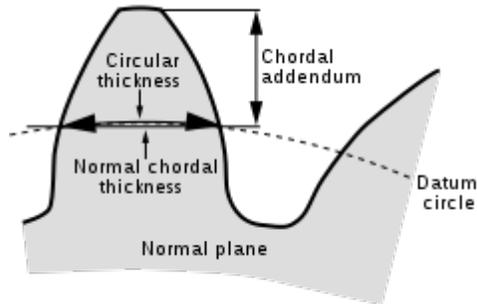
Tooth thickness nomenclature



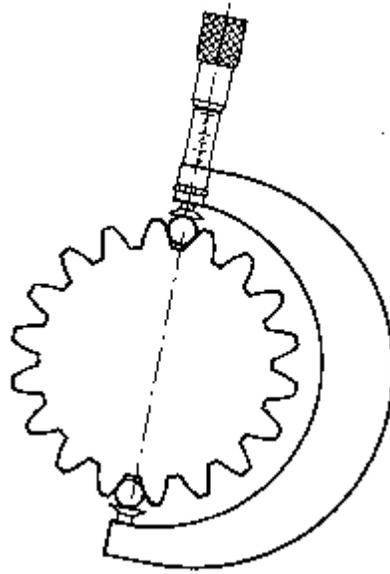
Tooth thickness



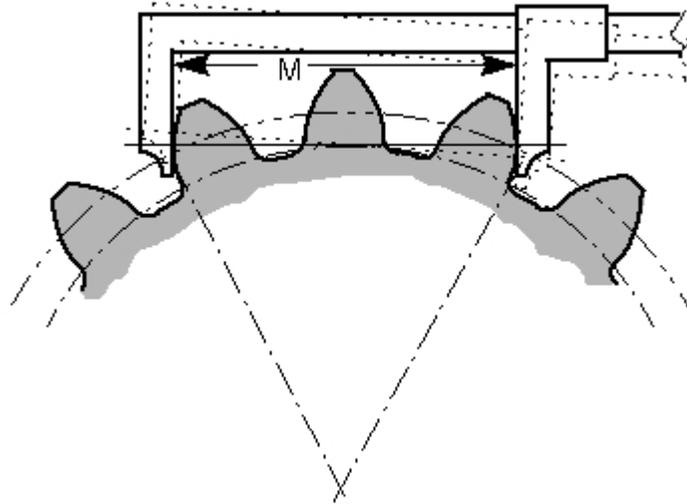
Thickness relationships



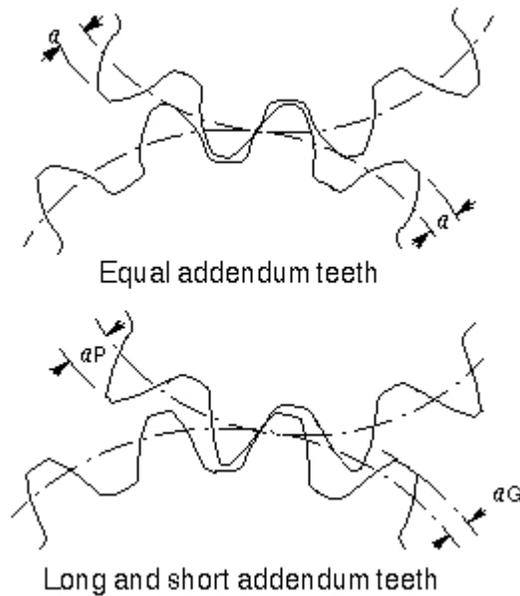
Chordal thickness



Tooth thickness measurement over pins



Span measurement



Circular thickness

Length of arc between the two sides of a gear tooth, on the specified datum circle.

Transverse circular thickness

Circular thickness in the transverse plane.

Normal circular thickness

Circular thickness in the normal plane. In a helical gear it may be considered as the length of arc along a normal helix.

Axial thickness

In helical gears and worms, tooth thickness in an axial cross section at the standard pitch diameter.

Base circular thickness

In involute teeth, length of arc on the base circle between the two involute curves forming the profile of a tooth.

Normal chordal thickness

Length of the chord that subtends a circular thickness arc in the plane normal to the pitch helix. Any convenient measuring diameter may be selected, not necessarily the standard pitch diameter.

Chordal addendum (chordal height)

Height from the top of the tooth to the chord subtending the circular thickness arc. Any convenient measuring diameter may be selected, not necessarily the standard pitch diameter.

Profile shift

Displacement of the basic rack datum line from the reference cylinder, made non-dimensional by dividing by the normal module. It is used to specify the tooth thickness, often for zero backlash.

Rack shift

Displacement of the tool datum line from the reference cylinder, made non-dimensional by dividing by the normal module. It is used to specify the tooth thickness.

Measurement over pins

Measurement of the distance taken over a pin positioned in a tooth space and a reference surface. The reference surface may be the reference axis of the gear, a datum surface or either one or two pins positioned in the tooth space or spaces opposite the first. This measurement is used to determine tooth thickness.

Span measurement

Measurement of the distance across several teeth in a normal plane. As long as the measuring device has parallel measuring surfaces that contact on an unmodified portion of the involute, the measurement will be along a line tangent to the base cylinder. It is used to determine tooth thickness.

Modified addendum teeth

Teeth of engaging gears, one or both of which have non-standard addendum.

Full-depth teeth

Teeth in which the working depth equals 2.000 divided by the normal diametral pitch.

Stub teeth

Teeth in which the working depth is less than 2.000 divided by the normal diametral pitch.

Equal addendum teeth

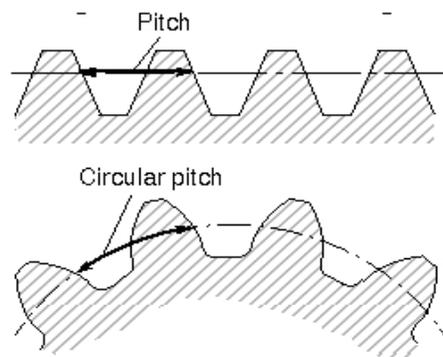
Teeth in which two engaging gears have equal addendums.

Long and short-addendum teeth

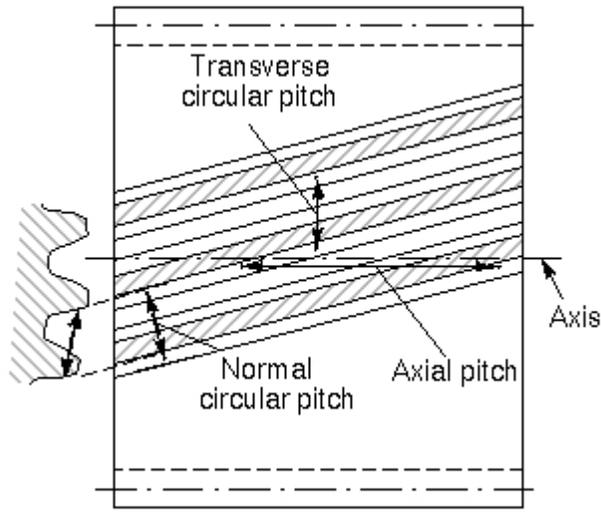
Teeth in which the addendums of two engaging gears are unequal.

Pitch nomenclature

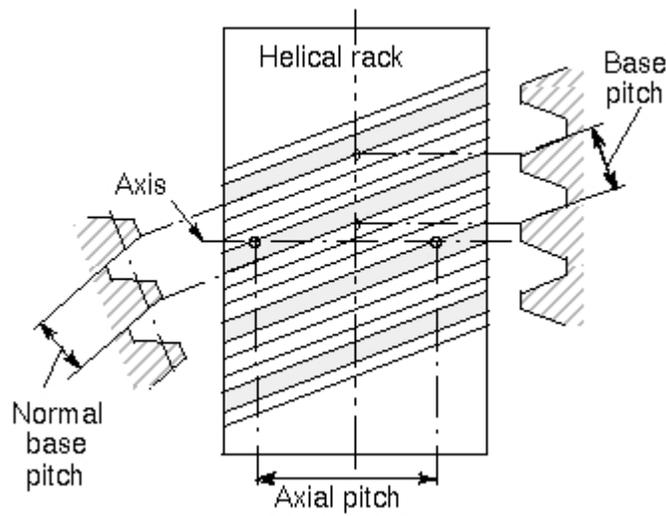
Pitch is the distance between a point on one tooth and the corresponding point on an adjacent tooth. It is a dimension measured along a line or curve in the transverse, normal, or axial directions. The use of the single word *pitch* without qualification may be ambiguous, and for this reason it is preferable to use specific designations such as transverse circular pitch, normal base pitch, axial pitch.



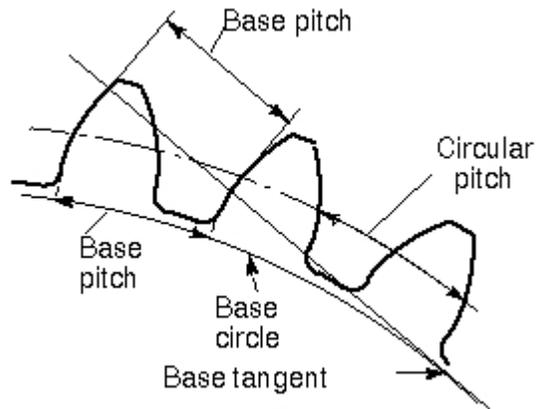
Pitch



Tooth pitch



Base pitch relationships



Principal pitches

Circular pitch, p

Arc distance along a specified pitch circle or pitch line between corresponding profiles of adjacent teeth.

Transverse circular pitch, p_t

Circular pitch in the transverse plane.

Normal circular pitch, p_n, p_e

Circular pitch in the normal plane, and also the length of the arc along the normal pitch helix between helical teeth or threads.

Axial pitch, p_x

Linear pitch in an axial plane and in a pitch surface. In helical gears and worms, axial pitch has the same value at all diameters. In gearing of other types, axial pitch may be confined to the pitch surface and may be a circular measurement. The term axial pitch is preferred to the term linear pitch. The axial pitch of a helical worm and the circular pitch of its worm gear are the same.

Normal base pitch, p_N, p_{bn}

An involute helical gear is the base pitch in the normal plane. It is the normal distance between parallel helical involute surfaces on the plane of action in the normal plane, or is the length of arc on the normal base helix. It is a constant distance in any helical involute gear.

Transverse base pitch, p_b, p_{bt}

In an involute gear, the pitch on the base circle or along the line of action. Corresponding sides of involute gear teeth are parallel curves, and the base pitch is the constant and fundamental distance between them along a common normal in a transverse plane.

Diametral pitch (transverse), P_d

Ratio of the number of teeth to the standard pitch diameter in inches.

$$P_d = \frac{N}{d} = \frac{25.4}{m} = \frac{\pi}{p}$$

Normal diametral pitch, P_{nd}

Value of diametral pitch in a normal plane of a helical gear or worm.

$$P_{nd} = \frac{P_d}{\cos \psi}$$

Angular pitch, θ_N , τ

Angle subtended by the circular pitch, usually expressed in radians.

$$\tau = \frac{360}{z} \text{ degrees or } \frac{2\pi}{z} \text{ radians}$$

Backlash

Backlash is the error in motion that occurs when gears change direction. It exists because there is always some gap between the trailing face of the driving tooth and the leading face of the tooth behind it on the driven gear, and that gap must be closed before force can be transferred in the new direction. The term "backlash" can also be used to refer to the size of the gap, not just the phenomenon it causes; thus, one could speak of a pair of gears as having, for example, "0.1 mm of backlash." A pair of gears could be designed to have zero backlash, but this would presuppose perfection in manufacturing, uniform thermal expansion characteristics throughout the system, and no lubricant. Therefore, gear pairs are designed to have some backlash. It is usually provided by reducing the tooth thickness of each gear by half the desired gap distance. In the case of a large gear and a small pinion, however, the backlash is usually taken entirely off the gear and the pinion is given full sized teeth. Backlash can also be provided by moving the gears farther apart.

For situations, such as instrumentation and control, where precision is important, backlash can be minimised through one of several techniques. For instance, the gear can be split along a plane perpendicular to the axis, one half fixed to the shaft in the usual manner, the other half placed alongside it, free to rotate about the shaft, but with springs between the two halves providing relative torque between them, so that one achieves, in effect, a single gear with expanding teeth. Another method involves tapering the teeth in the axial direction and providing for the gear to be slid in the axial direction to take up slack.

Shifting of gears

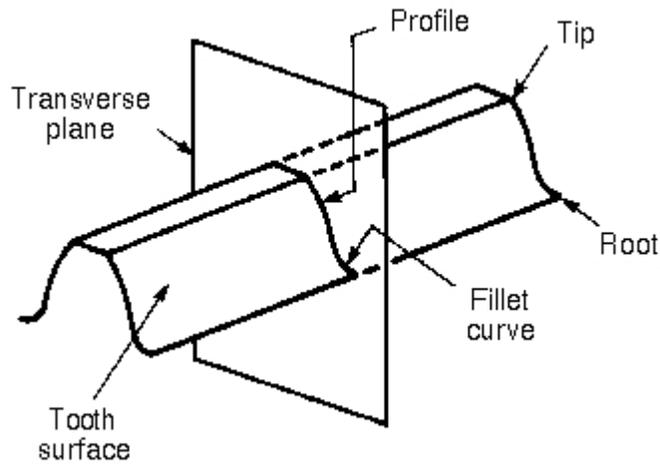
In some machines (e.g., automobiles) it is necessary to alter the gear ratio to suit the task. There are several methods of accomplishing this. For example:

- Manual transmission
- Automatic transmission
- Deraillieur gears which are actually sprockets in combination with a roller chain
- Hub gears (also called epicyclic gearing or sun-and-planet gears)

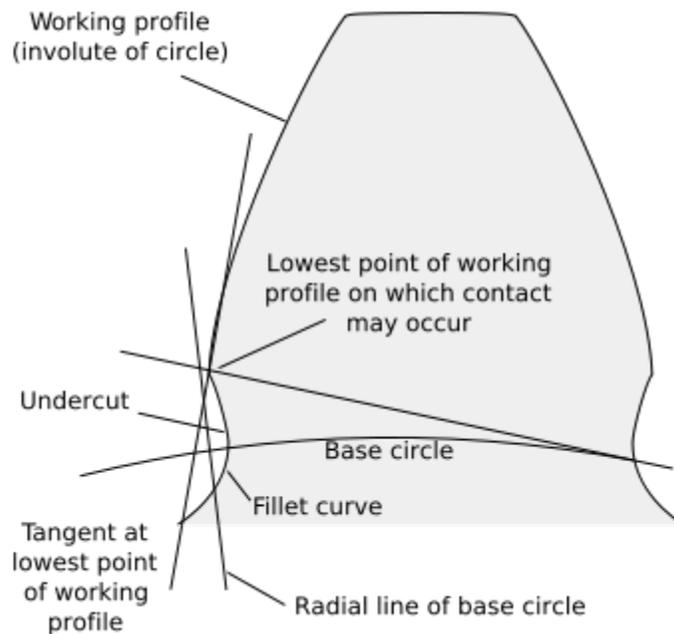
There are several outcomes of gear shifting in motor vehicles. In the case of vehicle noise emissions, there are higher sound levels emitted when the vehicle is engaged in lower gears. The design life of the lower ratio gears is shorter so cheaper gears may be used (i.e.

spur for 1st and reverse) which tends to generate more noise due to smaller overlap ratio and a lower mesh stiffness etc than the helical gears used for the high ratios. This fact has been utilized in analyzing vehicle generated sound since the late 1960s, and has been incorporated into the simulation of urban roadway noise and corresponding design of urban noise barriers along roadways.

Tooth profile



Profile of a spur gear



Undercut

A profile is one side of a tooth in a cross section between the outside circle and the root circle. Usually a profile is the curve of intersection of a tooth surface and a plane or surface normal to the pitch surface, such as the transverse, normal, or axial plane.

The fillet curve (root fillet) is the concave portion of the tooth profile where it joins the bottom of the tooth space.

As mentioned in the beginning, the attainment of a non fluctuating velocity ratio is dependent on the profile of the teeth. Friction and wear between two gears is also dependent on the tooth profile. There are a great many tooth profiles that will give a constant velocity ratio, and in many cases, given an arbitrary tooth shape, it is possible to develop a tooth profile for the mating gear that will give a constant velocity ratio. However, two constant velocity tooth profiles have been by far the most commonly used in modern times. They are the cycloid and the involute. The cycloid was more common until the late 1800s; since then the involute has largely superseded it, particularly in drive train applications. The cycloid is in some ways the more interesting and flexible shape; however the involute has two advantages: it is easier to manufacture, and it permits the center to center spacing of the gears to vary over some range without ruining the constancy of the velocity ratio. Cycloidal gears only work properly if the center spacing is exactly right. Cycloidal gears are still used in mechanical clocks.

An undercut is a condition in generated gear teeth when any part of the fillet curve lies inside of a line drawn tangent to the working profile at its point of juncture with the fillet. Undercut may be deliberately introduced to facilitate finishing operations. With undercut the fillet curve intersects the working profile. Without undercut the fillet curve and the working profile have a common tangent.

Gear materials



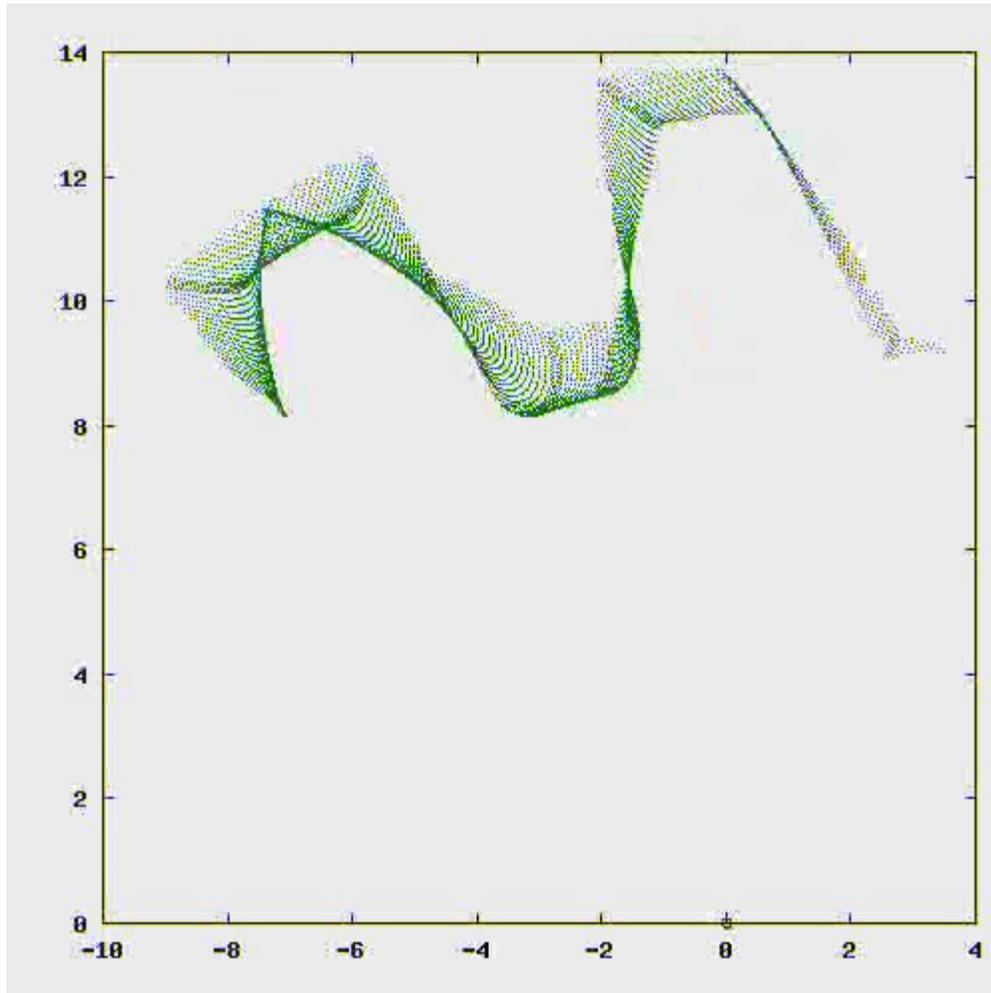
Wooden gears of a historic windmill

Numerous nonferrous alloys, cast irons, powder-metallurgy and even plastics are used in the manufacture of gears. However steels are most commonly used because of their high strength to weight ratio and low cost. Plastic is commonly used where cost or weight is a concern. A properly designed plastic gear can replace steel in many cases because it has many desirable properties, including dirt tolerance, low speed meshing, and the ability to "skip" quite well. Manufacturers have employed plastic gears to make consumer items affordable in items like copy machines, optical storage devices, VCRs, cheap dynamos, consumer audio equipment, servo motors, and printers.

The module system

Countries which have adopted the metric system generally use the module system. As a result, the term module is usually understood to mean the pitch diameter in millimeters divided by the number of teeth. When the module is based upon inch measurements, it is known as the *English module* to avoid confusion with the metric module. Module is a direct dimension, whereas diametral pitch is an inverse dimension (like "threads per inch"). Thus, if the pitch diameter of a gear is 40 mm and the number of teeth 20, the module is 2, which means that there are 2 mm of pitch diameter for each tooth.

Manufacture



Gear Cutting simulation (length 1m35s) faster, high bitrate version.

Gears are most commonly produced via hobbing, but they are also shaped, broached, cast, and in the case of plastic gears, injection molded. For metal gears the teeth are usually heat treated to make them hard and more wear resistant while leaving the core soft and tough. For large gears that are prone to warp a quench press is used.

Inspection

Gear geometry can be inspected and verified using various methods such as industrial CT scanning, coordinate-measuring machines, white light scanner or laser scanning.

Particularly useful for plastic gears, industrial CT scanning can inspect internal geometry and imperfections such as porosity.

Gear model in modern physics

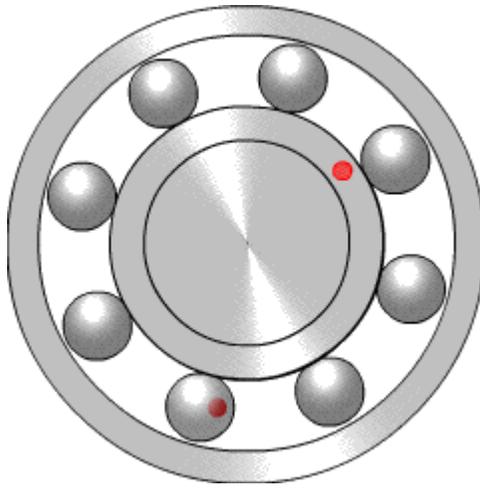
Modern physics adopted the gear model in different ways. In the nineteenth century, James Clerk Maxwell developed a model of electromagnetism in which magnetic field lines were rotating tubes of incompressible fluid. Maxwell used a gear wheel and called it an "idle wheel" to explain the electrical current as a rotation of particles in opposite directions to that of the rotating field lines.

More recently, quantum physics uses "quantum gears" in their model. A group of gears can serve as a model for several different systems, such as an artificially constructed nanomechanical device or a group of ring molecules.

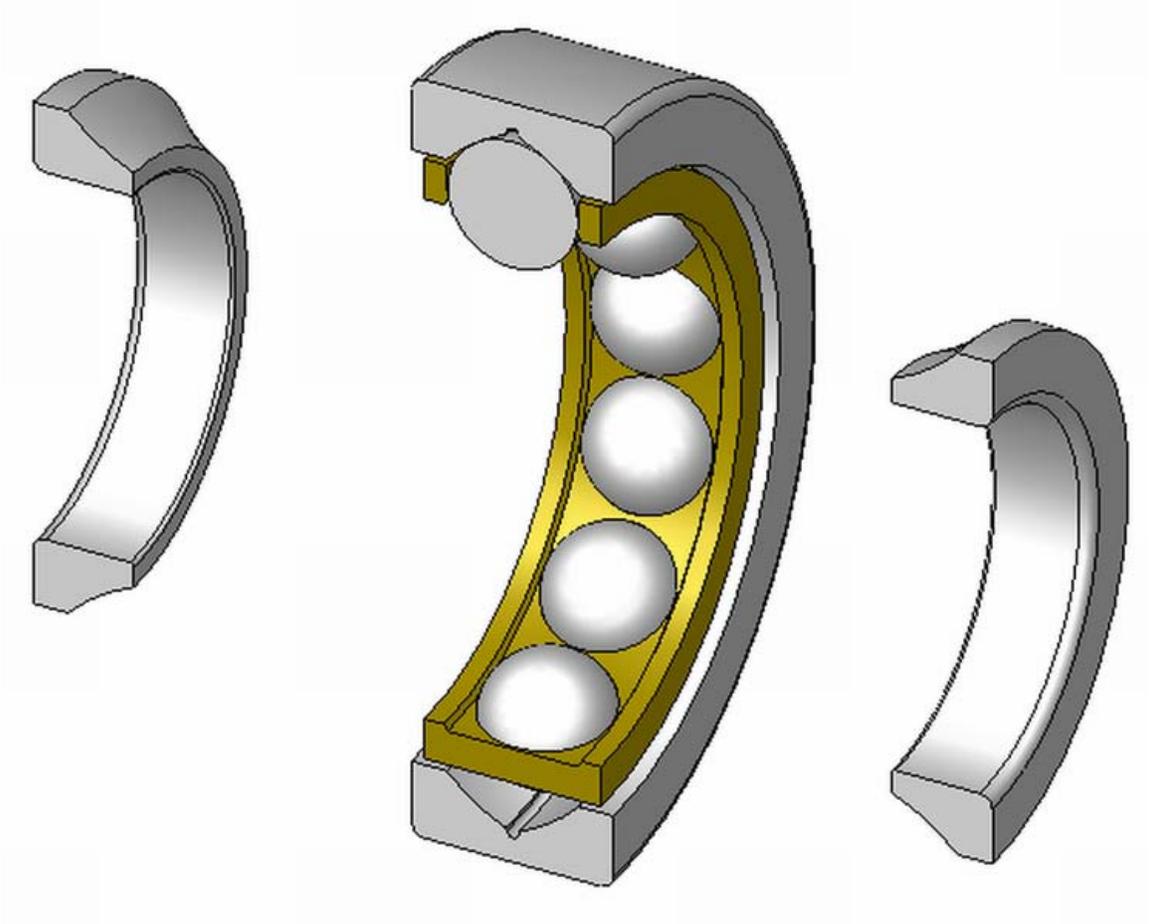
The Three Wave Hypothesis compares the wave–particle duality to a bevel gear.

Chapter- 2

Ball Bearing



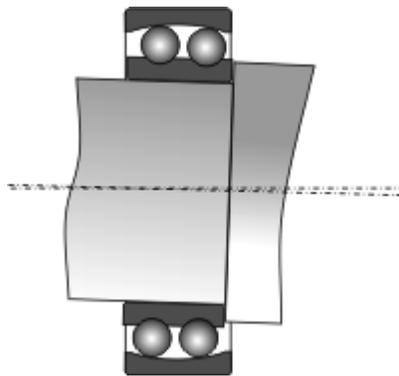
Working principle for a ball bearing.



A 4 point angular contact ball bearing



A ball bearing with a semi transparent cage.



Wingquist's and SKF's self-aligning ball bearing.

A **ball bearing** is a type of rolling-element bearing that uses balls to maintain the separation between the moving parts of the bearing.

The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two *races* to contain the balls and transmit the loads through the balls. Usually one of the races is held fixed. As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were rotating on each other.

Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the smaller contact area between the balls and races. However, they can tolerate some misalignment of the inner and outer races.

Compared to other rolling-element bearings, the ball bearing is the least expensive, primarily because of the low cost of producing the balls used in the bearing.

Common designs

There are several common designs of ball bearing, each offering various trade-offs. They can be made from many different materials, including: stainless steel, chrome steel, and ceramic (silicon nitride (Si_3N_4)). A hybrid ball bearing is a bearing with ceramic balls and races of metal.

Angular contact

An *angular contact* ball bearing uses axially asymmetric races. An axial load passes in a straight line through the bearing, whereas a radial load takes an oblique path that tends to want to separate the races axially. So the angle of contact on the inner race is the same as that on the outer race. Angular contact bearings better support "combined loads" (loading in both the radial and axial directions) and the contact angle of the bearing should be matched to the relative proportions of each. The larger the contact angle (typically in the range 10 to 45 degrees), the higher the axial load supported, but the lower the radial load. In high speed applications, such as turbines, jet engines, and dentistry equipment, the centrifugal forces generated by the balls changes the contact angle at the inner and outer race. Ceramics such as silicon nitride are now regularly used in such applications due to their low density (40% of steel). These materials significantly reduce centrifugal force and function well in high temperature environments. They also tend to wear similarly way to bearing steel—rather than cracking or shattering like glass or porcelain.

Most bicycles use angular-contact bearings in the headsets because the forces on these bearings are in both the radial and axial direction.

Axial

An *axial* ball bearing uses side-by-side races. An axial load is transmitted directly through the bearing, while a radial load is poorly-supported, tends to separate the races, and anything other than a small radial load is likely to damage the bearing.

Deep-groove

In a *deep-groove* radial bearing, the race dimensions are close to the dimensions of the balls that run in it. Deep-groove bearings have higher load ratings for their size than shallow-groove , but are also less tolerant of misalignment of the inner and outer races. A misaligned shallow-groove bearing may support a larger load than the same sized deep-groove bearing with similar misalignment.

Construction types

Conrad

A *Conrad* bearing is assembled by placing the inner and outer races radially offset, so the races touch at one point and have a large gap on the radially opposite side. The bearing is then filled by placing balls in to the large gap, then distributing them around the bearing assembly. The act of distributing the balls causes the inner and outer races to become concentric. If the balls were left free, the balls could resume their offset locations and the bearing could disassemble itself. Thus, a cage is inserted to hold the balls in their distributed positions. The cage supports no bearing load; it serves to keep the balls located. Conrad bearings have the advantage that they take both radial and axial loads, but the disadvantage they cannot be filled to a full complement and thus have reduced load-carrying capacity compared to a full-complement bearing. The Conrad bearing is named for its inventor, Robert Conrad, who got British patent 12,206 in 1903 and U.S. patent 822,723 in 1906. Probably the most familiar industrial ball bearing is the deep-groove Conrad style. The bearing is used in most of the mechanical industries.

Slot-fill

In a *slot-fill* radial bearing, the inner and outer races are notched so that when they are aligned, balls can be slipped in the slot to fill the bearing. A slot-fill bearing has the advantage that the entire groove is filled with balls, called a *full complement*. A slot-fill bearing has the disadvantages that it handles axial loads poorly, and the notches weaken the races. Note that an angular contact bearing can be disassembled axially and so can easily be filled with a full complement.

Split-race

The outer race may be split axially or radially, or a hole drilled in it for filling. These approaches allow a full complement to be used, but also limit the orientation of loads or the amount of misalignment the bearing can tolerate. Thus, these designs find much less use.

Rows

There are two *row* designs: *single-row* bearings and *double-row* bearings. Most ball bearings are a single-row design, which means there is one row of bearing balls. This design works with radial and thrust loads.

A *double-row* design has two rows of bearing balls. Their disadvantage is they need better alignment than single-row bearings.

Flanged

Bearings with a flange on the outer ring simplify axial location. The housing for such bearings can consist of a through-hole of uniform diameter, but the entry face of the housing (which may be either the outer or inner face) must be machined truly normal to the hole axis. However such flanges are very expensive to manufacture. A more cost effective arrangement of the bearing outer ring, with similar benefits, is a snap ring groove at either or both ends of the outside diameter. The snap ring assumes the function of a flange.

Caged

Cages are typically used to secure the balls in a Conrad style ball bearing. In other construction types they may decrease the number of balls depending on the specific cage shape, and thus reduce the load capacity. Without cages the tangential position is stabilized by sliding of two convex surfaces on each other. With a cage the tangential position is stabilized by a sliding of a convex surface in a matched concave surface, which avoids dents in the balls and has lower friction. Caged roller bearings were invented by John Harrison in the mid 18th century as part of his work on chronographs. Caged bearings were used more frequently during wartime steel shortages for bicycle wheel bearings married to replaceable cups.

Ceramic hybrid ball bearings using ceramic balls

Ceramic bearing balls can weigh up to 40% less than steel bearing balls, depending on size and material. This reduces centrifugal loading and skidding, so hybrid ceramic bearings can operate 20% to 40% faster than conventional bearings. This means that the outer race groove exerts less force inward against the ball as the bearing spins. This reduction in force reduces the friction and rolling resistance. The lighter ball allows the bearing to spin faster, and uses less energy to maintain its speed.

Ceramic hybrid ball bearings use these ceramic balls in place of steel balls. They are constructed with steel inner and outer rings, but ceramic balls; hence the *hybrid* designation.

Self-aligning

Self-aligning ball bearings are constructed with the inner ring and ball assembly contained within an outer ring that has a spherical raceway. This construction allows the bearing to tolerate a small angular misalignment resulting from deflection or improper mounting.

Series

Ball bearings are produced in various series, independent of the manufacturer:

- Series 100: Extra light series
- Series 200: Light series
- Series 300: Medium series
- Series 400: Heavy series

The ball size increases as the series increases, for any given inner diameter or outer diameter (not both). The larger the ball the greater the load carrying capacity. Series 200 and 300 are the most common.

Operating conditions

Lifespan

The calculated life for a bearing is based on the load it carries and its operating speed. The industry standard usable bearing lifespan is inversely proportional to the bearing load cubed. Nominal maximum load of a bearing (as specified for example in SKF datasheets), is for a lifespan of 1 million rotations, which at 50 Hz (i.e., 3000 RPM) is a lifespan of 5.5 working hours. 90% of bearings of that type have at least that lifespan, and 50% of bearings have a lifespan at least 5 times as long.

The industry standard life calculation is based upon the work of Lundberg and Palmgren performed in 1947. The formula assumes the life to be limited by metal fatigue and that the life distribution can be described by a Weibull distribution. Many variations of the formula exist that include factors for material properties, lubrication, and loading. Factoring for loading may be viewed as a tacit admission that modern materials demonstrate a different relationship between load and life than Lundberg and Palmgren determined .

Failure modes

If a bearing is not rotating, maximum load is determined by force that causes non-elastic deformation of balls. If the balls are flattened, the bearing does not rotate. Maximum load for not or very slowly rotating bearings is called "static" maximum load.

If that same bearing is rotating, that deformation tends to knead the ball into roughly a ball shape, so the bearing can still rotate, but if this continues for a long time, the ball fails due to metal fatigue. Maximum load for rotating bearing is called "dynamic" maximum load, and is roughly two or three times as high as static maxload.

If a bearing is rotating, but experiences heavy load that lasts shorter than one revolution, static maxload must be used in computations, since the bearing does not rotate during the maximum load.

Maximum load

In general, maximum load on a ball bearing is proportional to outer diameter of bearing times width of bearing (where width is measured in direction of axle).

Lubrication

For a bearing to have its nominal lifespan at its nominal maximum load, it must be lubricated with a lubricant (oil or grease) that has at least the minimum dynamic viscosity (usually denoted with the Greek letter ν) recommended for that bearing.

The recommended dynamic viscosity is inversely proportional to diameter of bearing.

The recommended dynamic viscosity decreases with rotating frequency. As a rough indication: for less than 3000 RPM, recommended viscosity increases with factor 6 for a factor 10 decrease in speed, and for more than 3000 RPM, recommended viscosity decreases with factor 3 for a factor 10 increase in speed.

For a bearing where average of outer diameter of bearing and diameter of axle hole is 50 mm, and that is rotating at 3000 RPM, recommended dynamic viscosity is 12 mm²/s.

Note that dynamic viscosity of oil varies strongly with temperature: a temperature increase of 50 - 70°C causes the viscosity to decrease by factor 10.

If the viscosity of lubricant is higher than recommended, lifespan of bearing increases, roughly proportional to square root of viscosity. If the viscosity of the lubricant is lower than recommended, the lifespan of the bearing decreases, and by how much depends on which type of oil being used. For oils with EP ('extreme pressure') additives, the lifespan is proportional to the square root of dynamic viscosity, just as it was for too high viscosity, while for ordinary oil's lifespan is proportional to the square of the viscosity if a lower-than-recommended viscosity is used.

Lubrication can be done with a grease, which has advantages that grease sticks to the bearing and protects bearing metal from environment, but has disadvantages that this grease must be replaced periodically, and maximum load of bearing decreases (because if bearing gets too warm, grease melts and runs out of bearing). Time between grease replacements decreases very strongly with diameter of bearing: for a 40 mm bearing,

grease should be replaced every 5000 working hours, while for a 100 mm bearing it should be replaced every 500 working hours.

Lubrication can also be done with an oil, which has advantage of higher maximum load, but needs some way to keep oil in bearing, as it normally tends to run out of it. For oil lubrication it is recommended that for applications where oil does not become warmer than 50 °C, oil should be replaced once a year, while for applications where oil does not become warmer than 100 °C, oil should be replaced 4 times per year. For car engines, oil becomes 100 °C but the engine has an oil filter to continually improve oil quality; therefore, the oil is usually changed less frequently than the oil in bearings.

Direction of load

Most bearings are meant for supporting loads perpendicular to axle ("radial loads"). Whether they can also bear axial loads, and if so, how much, depends on the type of bearing. Thrust bearings (commonly found on lazy susans) are specifically designed for axial loads.

For single-row deep-groove ball bearings, SKF's documentation says that maximum axial load is circa 50 % of maximum radial load, but it also says that "light" and/or "small" bearings can take axial loads that are 25 % of maximum radial load.

For single-row edge-contact ball bearings, axial load can be circa 2 times max radial load, and for cone-bearings maximum axial load is between 1 and 2 times maximum radial load.

If both axial and radial loads are present, they can be added vectorially, to result in total load on bearing, which in combination with nominal maximum load can be used to predict lifespan.

Avoiding undesirable axial load

The part of a bearing that rotates (either axle hole or outer circumference) must be fixed, while for a part that does not rotate this is not necessary (so it can be allowed to slide). If a bearing is loaded axially, both sides must be fixed.

If an axle has two bearings, and temperature varies, axle shrinks or expands, therefore it is not admissible for both bearings to be fixed on both their sides, since expansion of axle would exert axial forces that would destroy these bearings. Therefore, at least one of bearings must be able to slide.

A 'freely sliding fit' is one where there is at least a 4 µm clearance, presumably because surface-roughness of a surface made on a lathe is normally between 1.6 and 3.2 µm.

Fit

Bearings can only withstand their maximum load if the mating parts are properly sized. Bearing manufacturers supply tolerances for the fit of the shaft and the housing so this can be achieved. The material and hardness may also be specified.

Fittings that are not allowed to slide are therefore made to have diameters that make sure they can not slide, for whatever real diameter of mating surface of bearing is, and consequently these mating surfaces can not be brought into position without using considerable force. For small bearings this can be done by using a press (because tapping with a hammer to press-fit the bearing pre-damages both the bearing and the shaft), while for large bearings forces are so large that there is no alternative to heating one part before fitting, so thermal expansion causes a (temporary) sliding fit.

Avoiding torsional loads

If an axle is supported by two bearings, and center-lines of rotation of these bearings are not same, then large forces are exerted on the bearing that destroy it. Some very small amount of misalignment is acceptable, and how much depends on type of bearing. For bearings that are specifically made to be 'self-aligning', acceptable misalignment is between 1.5 and 3 degrees of arc. Bearings that are not designed to be self-aligning can accept misalignment of only 2–10 minutes of arc.

Applications

Today the ball bearing is used in numerous everyday applications. Ball bearings are used for dental and medical instruments. In dental and medical hand pieces, it is necessary for the pieces to withstand sterilization and corrosion. Because of this requirement, dental and medical hand pieces are made from 440C stainless steel, which allows smooth rotations at fast speeds.

- Hard drive bearings used to be highly spherical, and were said to be the best spherical manufactured shapes, but this is no longer true, and more and more are being replaced with fluid bearings.
- German ball bearing factories were often a target of allied aerial bombings during World War II; such was the importance of the ball bearing to the German war industry.
- In horology, the company Jean Lassale designed a watch movement that used ball bearings to reduce the thickness of the movement. Using 0.20 mm balls, the Calibre 1200 was only 1.2 mm thick, which still is the thinnest mechanical watch movement.
- Aerospace bearings are used in many applications on commercial, private and military aircraft including pulleys, gearboxes and jet engine shafts. Materials include M50 tool steel (AMS6491), Carbon chrome steel (AMS6444), the corrosion resistant AMS5930, 440C stainless steel, silicon nitride (ceramic) and titanium carbide-coated 440C.

- Skateboarding. The wheels in a skateboard contain two bearings in each of the four wheels.
- Yo-Yo's, there are Ball bearings in the center of high quality Yo-Yo's.
- Agricultural Equipment. The many moving parts in a piece of farm machinery depend on several different types of bearings to operate. Under the heavy loads and dusty conditions, these bearings need to be lubricated, repaired, or replaced often.

History

Although roller bearings had been developing since ancient Egyptian times, the first recorded patent on ball bearings 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.

Ball bearings were first produced in Europe so they were standardized to metric dimensions. American manufacturers came along later so they produced ball bearings in metric dimensions prior to the early-1990s.

Chapter- 3

Wire

A **wire** is a single, usually cylindrical, string of metal. Wires are used to bear mechanical loads and to carry electricity and telecommunications signals. Wire is commonly formed by drawing the metal through a hole in a die or draw plate. Standard sizes are determined by various wire gauges. The term *wire* is also used more loosely to refer to a bundle of such strands, as in 'multistranded wire', which is more correctly termed a wire rope in mechanics, or a cable in electricity.

History

In antiquity, jewellery often contains, in the form of chains and applied decoration, large amounts of wire that is accurately made and which must have been produced by some efficient, if not technically advanced, means. In some cases, strips cut from metal sheet were made into wire by pulling them through perforations in stone beads. This causes the strips to fold round on themselves to form thin tubes. This strip drawing technique was in use in Egypt by the 2nd Dynasty. From the middle of the 2nd millennium BC most of the gold wires in jewellery are characterised by seam lines that follow a spiral path along the wire. Such twisted strips can be converted into solid round wires by rolling them between flat surfaces or the strip wire drawing method. The strip twist wire manufacturing method was superseded by drawing in the ancient Old World sometime between about the 8th and 10th centuries AD. There is some evidence for the use of drawing further East prior to this period.

Square and hexagonal wires were possibly made using a swaging technique. In this method a metal rod was struck between grooved metal blocks, or between a grooved punch and a grooved metal anvil. Swaging is of great antiquity, possibly dating to the beginning of the 2nd millennium BC in Egypt and in the Bronze and Iron Ages in Europe for torches and fibulae.

Twisted square section wires are a very common filigree decoration in early Etruscan jewellery.

In about the middle of the 2nd millennium BC a new category of decorative tube was introduced which imitated a line of granules. True beaded wire, produced by mechanically distorting a round-section wire, appeared in the Eastern Mediterranean and Italy in the seventh century BC, perhaps disseminated by the Phoenicians. Beaded wire continued to be used in jewellery into modern times, although it largely fell out of favour in about the tenth century AD when two drawn round wires, twisted together to form what are termed 'ropes', provided a simpler-to-make alternative. A forerunner to beaded wire may be the notched strips and wires which first occur from around 2000 BC in Anatolia.

Wire was drawn in England from the medieval period. The wire was used to make wool cards and pins, manufactured goods whose import was prohibited by Edward IV in 1463. The first wire mill in Great Britain was established at Tintern in about 1568 by the founders of the Company of Mineral and Battery Works, who had a monopoly on this. Apart from their second wire mill at nearby Whitebrook, there were no other wire mills before the second half of the 17th century. Despite the existence of mills, the drawing of wire down to fine sizes continued to be done manually.

Wire is usually drawn of cylindrical form; but it may be made of any desired section by varying the outline of the holes in the draw-plate through which it is passed in the process of manufacture. The draw-plate or die is a piece of hard cast-iron or hard steel, or for fine work it may be a diamond or a ruby. The object of utilising precious stones is to enable the dies to be used for a considerable period without losing their size, and so producing wire of incorrect diameter. Diamond dies must be rebored when they have lost their original diameter of hole, but the metal dies are brought down to size again by hammering up the hole and then drifting it out to correct diameter with a punch.

Uses

Wire has many uses. It forms the raw material of many important manufacturers, such as the wire-net industry, wire-cloth making and wire-rope spinning, in which it occupies a place analogous to a textile fiber. Wire-cloth of all degrees of strength and fineness of mesh is used for sifting and screening machinery, for draining paper pulp, for window screens, and for many other purposes. Vast quantities of aluminium, copper, nickel and steel wire are employed for telephone and data wires and cables, and as conductors in electric power transmission, and heating. It is in no less demand for fencing, and much is consumed in the construction of suspension bridges, and cages, etc. In the manufacture of stringed musical instruments and scientific instruments wire is again largely used. Among its other sources of consumption it is sufficient to mention pin and hair-pin making, the needle and fish-hook industries, nail, peg and rivet making, and carding machinery; indeed there are few industries into which it does not enter.

Not all metals and metallic alloys possess the physical properties necessary to make useful wire. The metals must in the first place be ductile and strong in tension, the quality on which the utility of wire principally depends. The metals suitable for wire, possessing almost equal ductility, are platinum, silver, iron, copper, aluminium and gold; and it is

only from these and certain of their alloys with other metals, principally brass and bronze, that wire is prepared. By careful treatment extremely thin wire can be produced. Special purpose wire is however made from other metals (e.g. tungsten wire for light bulb and vacuum tube filaments, because of its high melting temperature). Copper wires are also plated with other metals, such as tin, nickel, and silver to handle different temperatures, provide lubrication, provide easier stripping of rubber from copper.

Production



Wire mill, 1913.

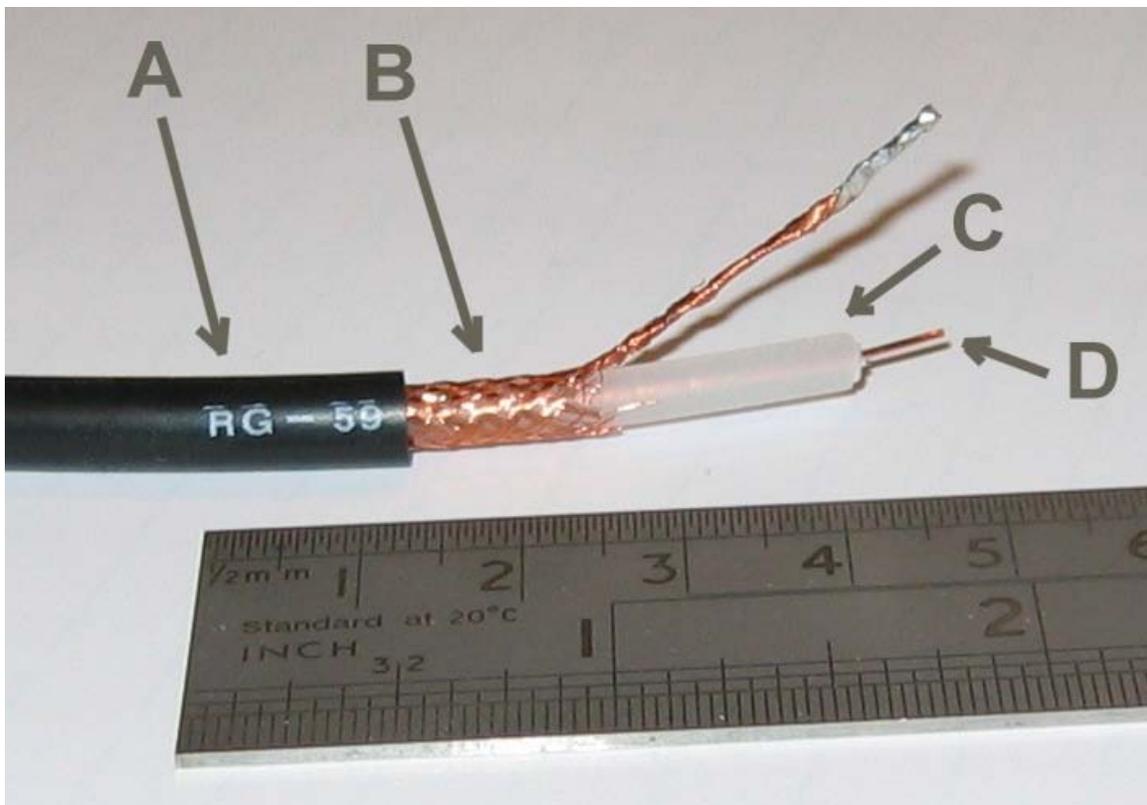
Wire is often reduced to the desired diameter and properties by repeated drawing through progressively smaller dies, or traditionally holes in draw plates. After a number of passes the wire may be annealed to facilitate more drawing or, if it is a finished product, to maximise ductility and conductivity.

Finishing, jacketing, and insulating

Electrical wires are usually covered with insulating materials, such as plastic, rubber-like polymers, or varnish. Insulating and jacketing of wires and cables is nowadays done by

passing them through an extruder. Formerly, materials used for insulation included treated cloth or paper, and various oil-based products. Since the mid-1960s, plastic and polymers exhibiting properties similar to rubber have predominated.

Two or more wires may be wrapped concentrically, separated by insulation, to form coaxial cable. The wire or cable may be further protected with substances like paraffin, some kind of preservative compound, bitumen, lead, aluminum sheathing, or steel taping. Stranding or covering machines wind material onto wire which passes through quickly. Some of the smallest machines for cotton covering have a large drum, which grips the wire and moves it through toothed gears; the wire passes through the centre of disks mounted above a long bed, and the disks carry each a number of bobbins varying from six to twelve or more in different machines. A supply of covering material is wound on each bobbin, and the end is led on to the wire, which occupies a central position relatively to the bobbins; the latter being revolved at a suitable speed bodily with their disks, the cotton is consequently served on to the wire, winding in spiral fashion so as to overlap. If a large number of strands are required the disks are duplicated, so that as many as sixty spools may be carried, the second set of strands being laid over the first.

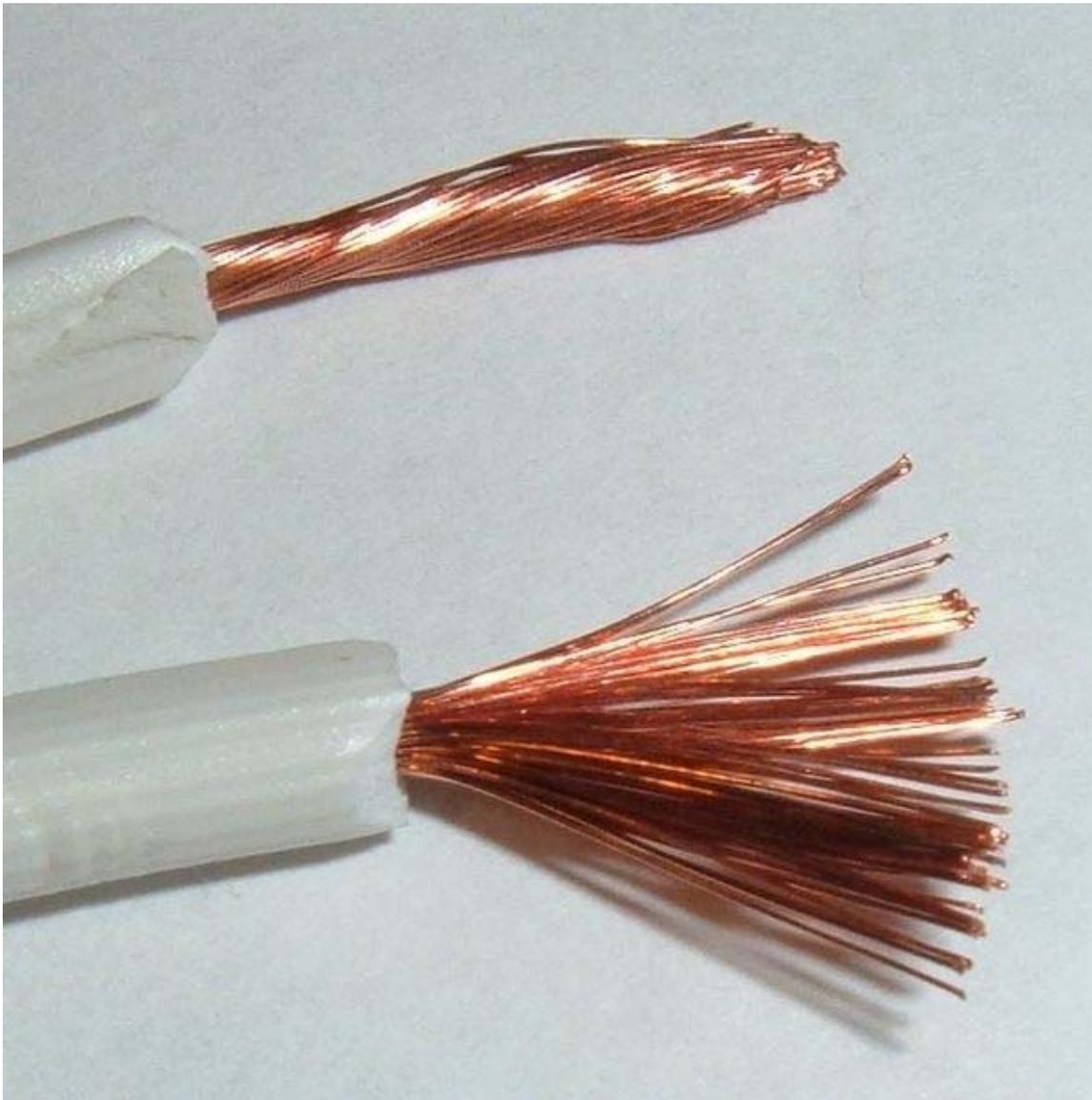


Coaxial Cable, one example of a jacketed and insulated **wire**.

For heavier cables, used for electric light and power, and submarine cables, the machines are somewhat different in construction. The wire is still carried through a hollow shaft, but the bobbins or spools of covering material are set with their spindles at right angles to

the axis of the wire, and they lie in a circular cage which rotates on rollers below. The various strands coming from the spools at various parts of the circumference of the cage all lead to a disk at the end of the hollow shaft. This disk has perforations through which each of the strands pass, thence being immediately wrapped on the cable, which slides through a bearing at this point. Toothed gears having certain definite ratios are used to cause the winding drum for the cable and the cage for the spools to rotate at suitable relative speeds which do not vary. The cages are multiplied for stranding with a large number of tapes or strands, so that a machine may have six bobbins on one cage and twelve on the other.

Solid versus stranded



Stranded copper wire

Solid wire, also called solid-core or single-strand wire, consists of one piece of metal wire. Stranded wire is composed of a bundle of small-gauge wires to make a larger conductor.

Stranded wire is more flexible than solid wire of the same total cross-sectional area. Solid wire is cheaper to manufacture than stranded wire and is used where there is little need for flexibility in the wire. Solid wire also provides mechanical ruggedness; and, because it has relatively less surface area which is exposed to attack by corrosives, protection against the environment. Stranded wire is used when higher resistance to metal fatigue is required. Such situations include connections between circuit boards in multi-printed-circuit-board devices, where the rigidity of solid wire would produce too much stress as a result of movement during assembly or servicing; A.C. line cords for appliances; musical instrument cables; computer mouse cables; welding electrode cables; control cables connecting moving machine parts; mining machine cables; trailing machine cables; and numerous others.

At high frequencies, current travels near the surface of the wire because of the *skin effect*, resulting in increased power loss in the wire. Stranded wire might seem to reduce this effect, since the total surface area of the strands is greater than the surface area of the equivalent solid wire, but in fact a simple stranded wire will not improve skin effect since all the strands are short-circuited together and still behave as a single conductor. A stranded wire will have higher resistance than a solid wire of the same diameter because the cross-section of the stranded wire is not all copper, there are unavoidable gaps between the strands (this is the circle packing problem for circles within a circle). A stranded wire with the same cross-section of conductor as a solid wire is said to have the same equivalent gauge and is always a larger diameter.

However, for many high-frequency applications, *proximity effect* is more severe than skin effect, and in some limited cases, simple stranded wire can reduce proximity effect. For better performance at high frequencies, litz wire, which has the individual strands insulated and twisted in special patterns, may be used.

Number of strands

The more individual wire strands in a wire bundle the more flexible, kink resistant, break resistant, and stronger the wire is. But more strands cost more.

The lowest number of strands is 7: one in the middle, 6 surrounding it.

The next level up is 19, which is another layer of 12 strands on top of the 7. After that the number varies, but 37 and 49 are common, then in the 70 to 100 range (the number is no longer exact). Even larger numbers than that are typically found only in very large wires.

For application where the wire moves 19 is the lowest that should be used (7 should only be used in applications where the wire is placed and then doesn't move), and 49 is much

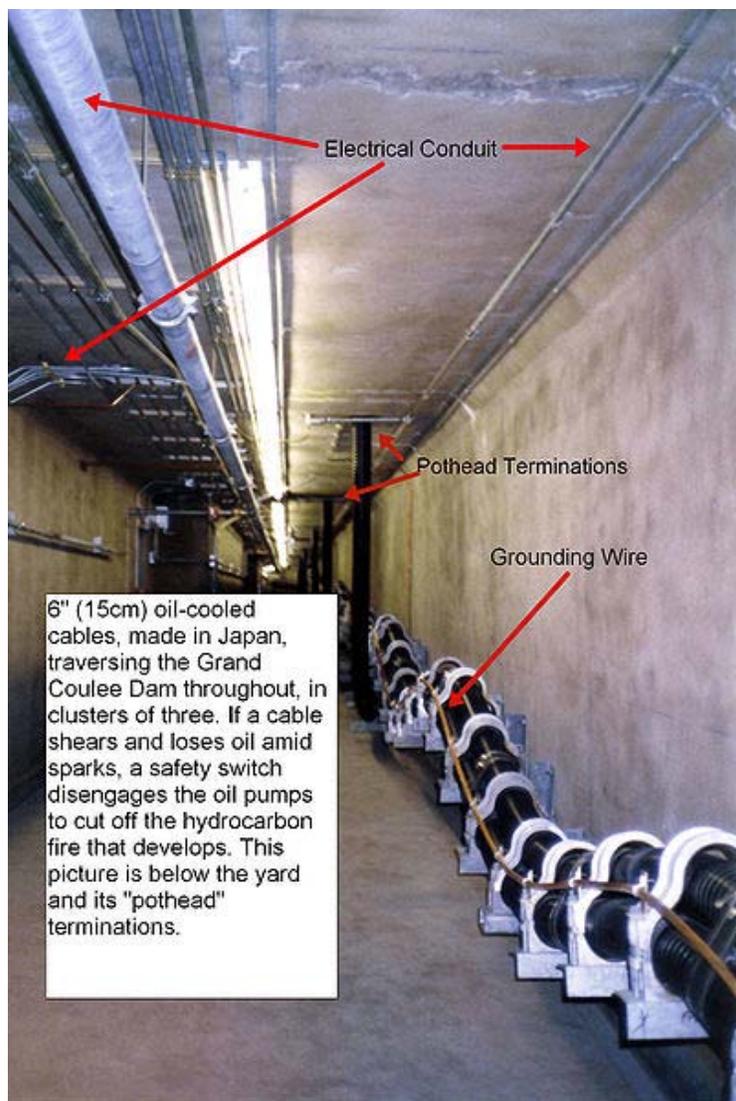
better. For applications with constant repeated movement, such as assembly robots, and headphone wires, 70 to 100 is mandatory.

Varieties

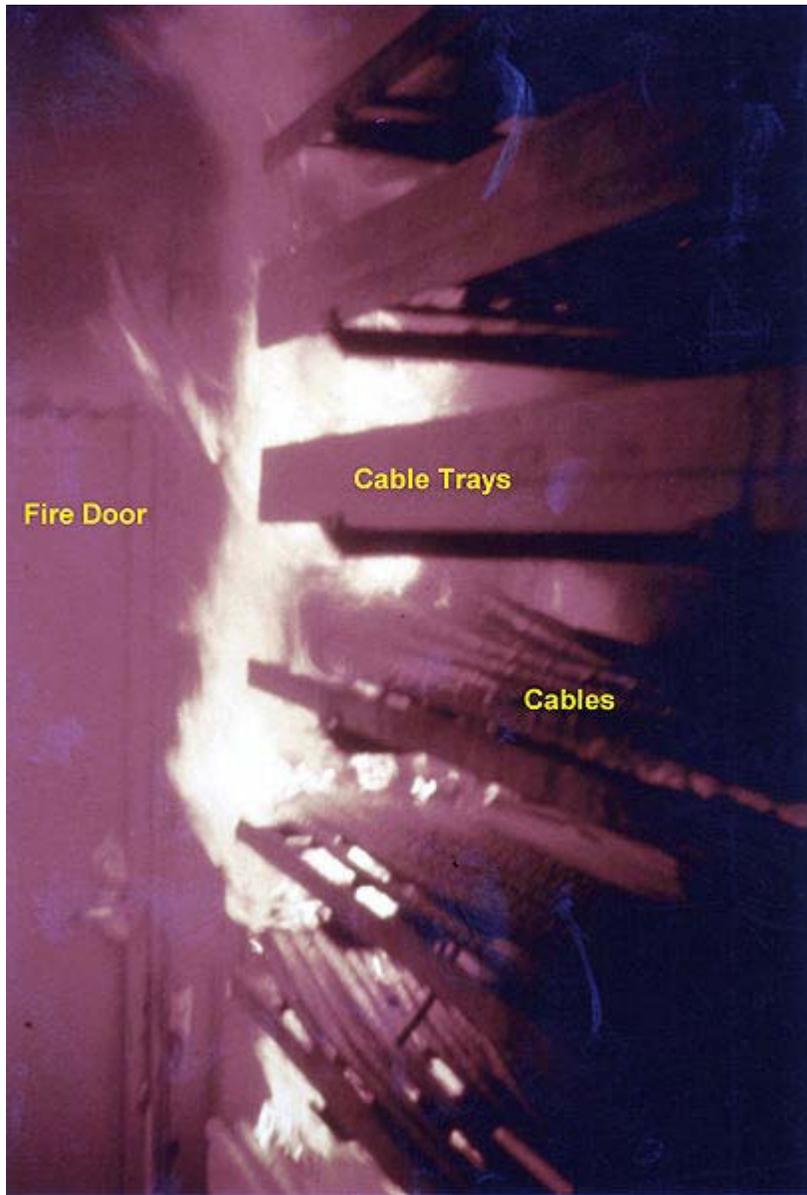
- *Hook-up wire* is small-to-medium gauge, solid or stranded, insulated wire, used for making internal connections inside electrical or electronic devices. It is often tin-plated to facilitate soldering.
- *Magnet wire* is solid wire, usually copper, which, to allow closer winding when making electromagnetic coils, is insulated only with varnish, rather than the thicker plastic or other insulation commonly used on electrical wire. It is used for the winding of electric motors, transformers, inductors, generators, speaker coils, etc.
- *Resistance wire* is wire with higher than normal resistivity, often used for heating elements or for making wire-wound resistors. Nichrome wire is the most common type.

Chapter- 4

Cable



6 inch (15 cm) outside diameter, oil-cooled cables, traversing the Grand Coulee Dam throughout. An example of a heavy cable for power transmission.



Fire test in Sweden, showing rapid fire spread through burning of cable jackets. Of great importance for cables used in installations.



500 MCM single conductor power cable

A **cable** is two or more wires running side by side and bonded, twisted or braided together to form a single assembly. In mechanics cables, otherwise known as wire ropes, are used for lifting, hauling and towing or conveying force through tension. In electrical engineering cables are used to carry electric currents. An optical cable contains one or more optical fibers in a protective jacket that supports the fibers.

Electric cables discussed here are mainly meant for installation in buildings and industrial sites.

History

Ropes made of multiple strands of natural fibers such as hemp, sisal, manila, and cotton have been used for millennia for hoisting and hauling. By the 19th century, deepening of mines and construction of large ships increased demand for stronger cables. Invention of improved steelmaking techniques made high quality steel available at lower cost, and so wire ropes became common in mining and other industrial applications. By the middle of the 19th century, manufacture of large submarine telegraph cables was done using machines similar to those used for manufacture of mechanical cables.

In the 19th century and early 20th century, electrical cable was often insulated using cloth, rubber and paper. Plastic materials are generally used today, except for high reliability power cables.

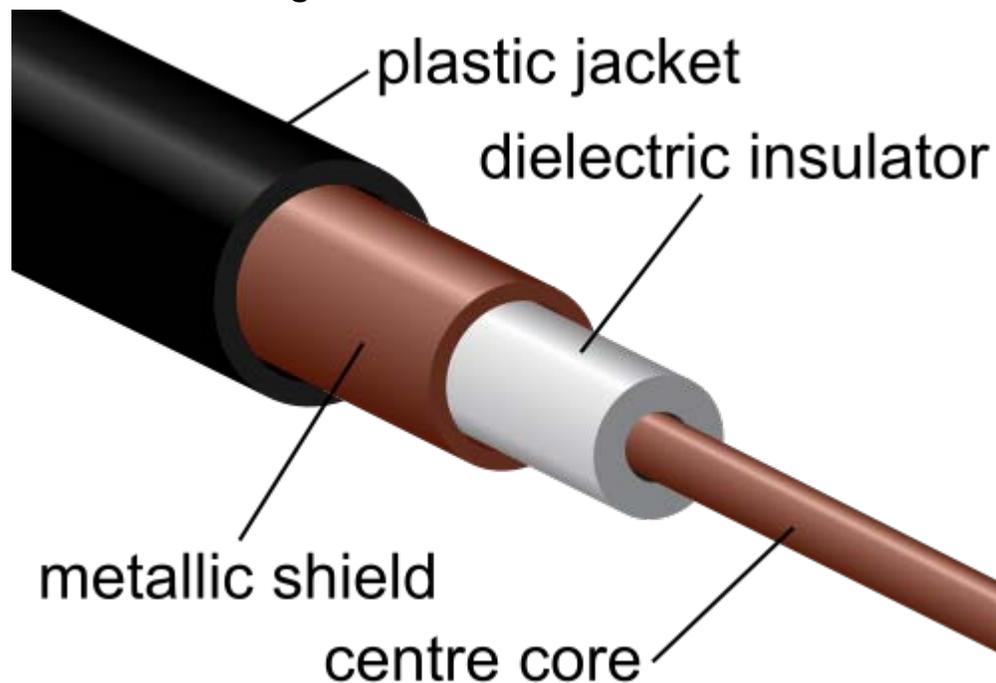
Electrical cables

Electrical cables may be made more flexible by stranding the wires. In this process, smaller individual wires are twisted or braided together to produce larger wires that are more flexible than solid wires of similar size. Bunching small wires before concentric stranding adds the most flexibility. Copper wires in a cable may be bare, or they may be plated with a thin layer of another metal, most often tin but sometimes gold, silver or some other material. Tin, gold, and silver are much less prone to oxidation than copper, which may lengthen wire life, and makes soldering easier. Tinning is also used to provide lubrication between strands. Tinning was used to help removal of rubber insulation. Tight lays during stranding makes the cable extensible (CBA - as in telephone handset cords).

Cables can be securely fastened and organized, such as by using trunking, cable trays, cable ties or cable lacing. Continuous-flex or flexible cables used in moving applications within cable carriers can be secured using strain relief devices or cable ties.

At high frequencies, current tends to run along the surface of the conductor. This is known as the skin effect.

Cables and electromagnetic fields



Coaxial cable.



Twisted pair.

Any current-carrying conductor, including a cable, radiates an electromagnetic field. Likewise, any conductor or cable will pick up energy from any existing electromagnetic field around it. These effects are often undesirable, in the first case amounting to unwanted transmission of energy which may adversely affect nearby equipment or other parts of the same piece of equipment; and in the second case, unwanted pickup of noise which may mask the desired signal being carried by the cable, or, if the cable is carrying power supply or control voltages, pollute them to such an extent as to cause equipment malfunction.

The first solution to these problems is to keep cable lengths in buildings short, since pickup and transmission are essentially proportional to the length of the cable. The second solution is to route cables away from trouble. Beyond this, there are particular cable designs that minimize electromagnetic pickup and transmission. Three of the principal design techniques are shielding, coaxial geometry, and twisted-pair geometry.

Shielding makes use of the electrical principle of the Faraday cage. The cable is encased for its entire length in foil or wire mesh. All wires running inside this shielding layer will

be to a large extent decoupled from external electric fields, particularly if the shield is connected to a point of constant voltage, such as earth. Simple shielding of this type is not greatly effective against low-frequency magnetic fields, however - such as magnetic "hum" from a nearby power transformer. A grounded shield on cables operating at 2 kV or more gathers leakage current and capacitive current, protecting people from electric shock and equalizing stress on the cable insulation.

Coaxial design helps to further reduce low-frequency magnetic transmission and pickup. In this design the foil or mesh shield is perfectly tubular - i.e. with a circular cross section - and the inner conductor (there can only be one) is situated exactly at its center. This causes the voltages induced by a magnetic field between the shield and the core conductor to consist of two nearly equal magnitudes which cancel each other.

The twisted pair is a simple expedient where two wires of a cable, rather than running parallel to each other, are twisted around each other, forming a pair of intertwined helices. This can be achieved by putting one end of the pair in a hand drill and turning while maintaining moderate tension on the line. Field cancellation between successive twists of the pair considerably reduces electromagnetic pickup and transmission.

Power-supply cables feeding sensitive electronic devices are sometimes fitted with a series-wired inductor called a choke which blocks high frequencies that may have been picked up by the cable, preventing them from passing into the device.

Fire protection

In building construction, electrical cable jacket material is a potential source of fuel for fires. To limit the spread of fire along cable jacketing, one may use cable coating materials or one may use cables with jacketing that is inherently fire retardant. The plastic covering on some metal clad cables may be stripped off at installation to reduce the fuel source for accidental fires. In Europe in particular, it is often customary to place inorganic wraps and boxes around cables in order to safeguard the adjacent areas from the potential fire threat associated with unprotected cable jacketing. However, this fire protection also traps heat generated from conductor losses, so the protection must be thin.

There are two methods of providing fire protection to a cable:

1. Insulation material is deliberately added up with fire retardant materials
2. The copper conductor itself is covered with mineral insulation (MICC cables)

Electrical cable types

Basic cable types are as follows:

Shape

- Ribbon cable

Construction

Based on construction and cable properties it can be sorted into the following:

- Coaxial cable
- Mineral-insulated copper-clad cable
- Twinax cable
- Flexible cables
- Non-metallic sheathed cable (or nonmetallic building wire, NM, NM-B)
- Metallic sheathed cable (or armored cable, AC, or BX)
- Multicore cable (consist of more than one wire and is covered by cable jacket)
- Shielded cable
- Single cable (from time to time this name is used for wire)
- Twisted pair
- Twisting cable

Special

- Arresting cable
- Bowden cable
- Heliac cable
- Direct-buried cable
- Heavy-lift cable
- Elevator cable

Application



A 250V, 16A electrical cable on a reel.

- Audiovisual cable
- Bicycle cable
- Communications cable
- Computer cable
- Mechanical cable
- Sensing cable
- Submersible cable
- Wire rope (wire cable)

Chapter- 5

Spring



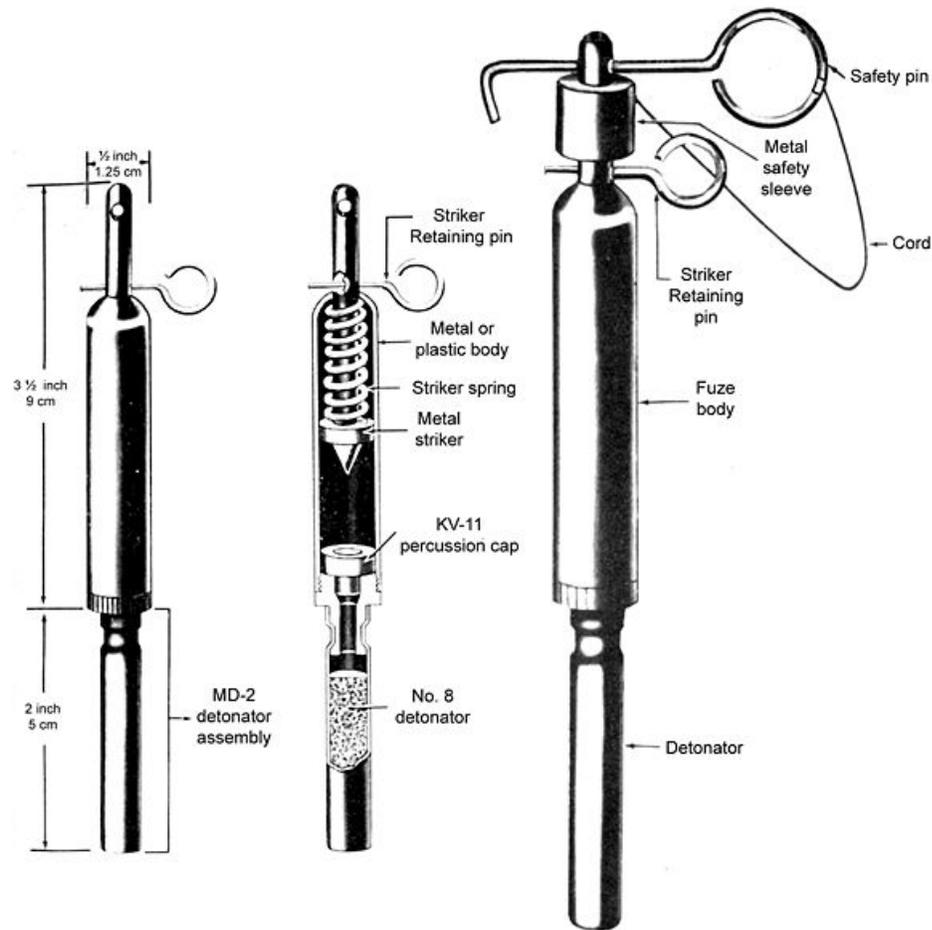
Helical or *coil* springs designed for tension



Compression springs store energy when compressed



The English longbow - a simple but very powerful spring made of yew, measuring 2 m (6 ft 6 in) long, with a 470 N (105 lbf) draw force



Military boobytrap firing device from USSR (normally connected to a tripwire) showing spring-loaded firing pin

A **spring** is an elastic object used to store mechanical energy. Springs are usually made out of hardened steel. Small springs can be wound from pre-hardened stock, while larger ones are made from annealed steel and hardened after fabrication. Some non-ferrous metals are also used including phosphor bronze and titanium for parts requiring corrosion resistance and beryllium copper for springs carrying electrical current (because of its low electrical resistance).

When a spring is compressed or stretched, the force it exerts is proportional to its change in length. The *rate* or *spring constant* of a spring is the change in the force it exerts, divided by the change in deflection of the spring. That is, it is the gradient of the force versus deflection curve. An extension or compression spring has units of force divided by distance, for example lbf/in or N/m. Torsion springs have units of force multiplied by distance divided by angle, such as N·m/rad or ft·lbf/degree. The inverse of spring rate is compliance, that is: if a spring has a rate of 10 N/mm, it has a compliance of 0.1 mm/N. The stiffness (or rate) of springs in parallel is additive, as is the compliance of springs in series.

Depending on the design and required operating environment, any material can be used to construct a spring, so long as the material has the required combination of rigidity and elasticity: technically, a wooden bow is a form of spring.

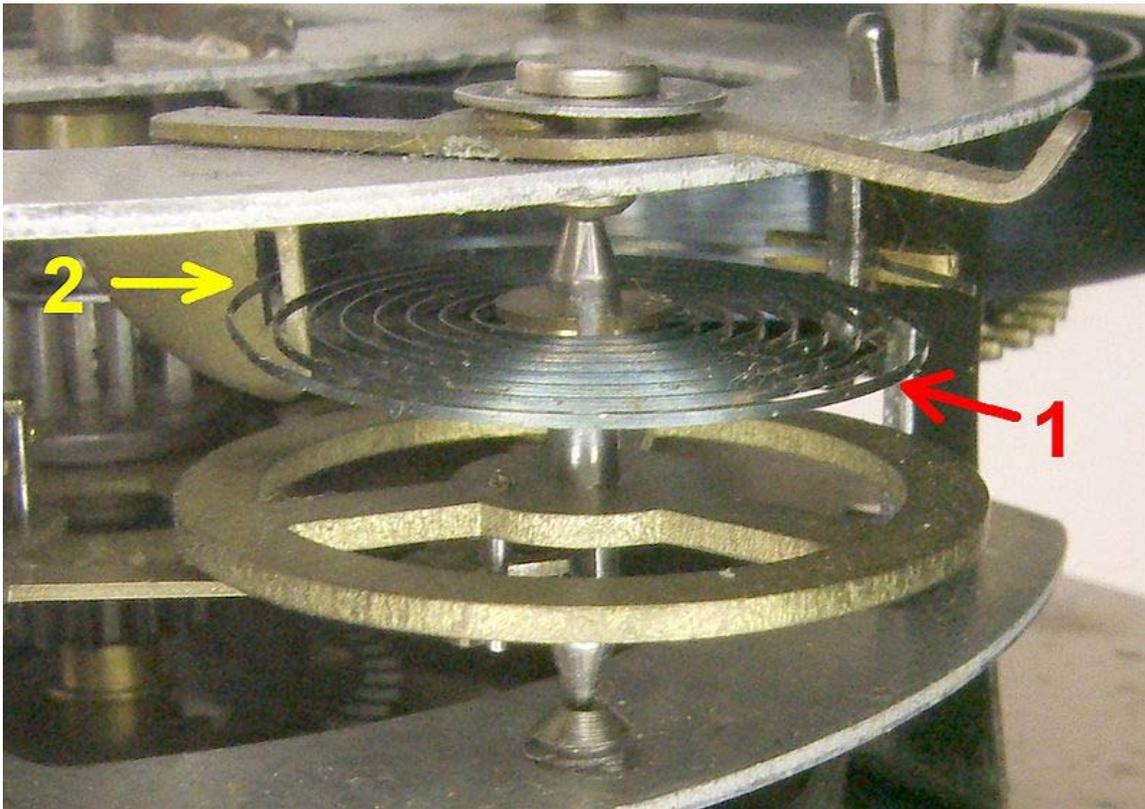
History

Simple non-coiled springs were used throughout human history e.g. the bow (and arrow). In the Bronze Age more sophisticated spring devices were used, as shown by the spread of tweezers in many cultures. Ctesibius of Alexandria developed a method for making bronze with spring-like characteristics by producing an alloy of bronze with an increased proportion of tin, and then hardening it by hammering after it is cast.

Coiled springs appeared early in the 15th century, in door locks. The first spring powered-clocks appeared in that century and evolved into the first large watches by the 16th century.

In 1676 British physicist Robert Hooke discovered the principle behind springs' action, that the force it exerts is proportional to its extension, now called Hooke's law.

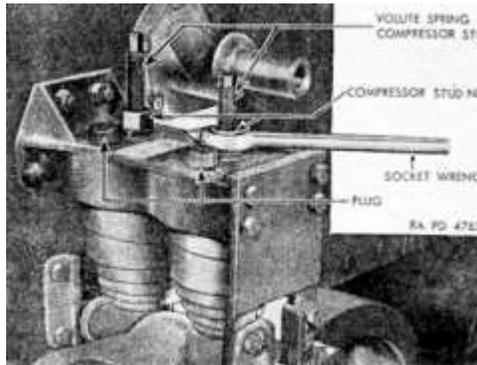
Types



A spiral torsion spring, or hairspring, in an alarm clock.



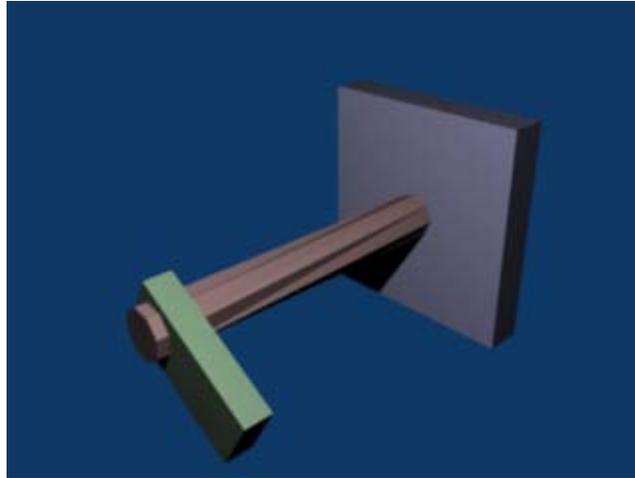
A volute spring. Under compression the coils slide over each other, so affording longer travel.



Vertical volute springs of Stuart tank



Tension springs in a folded line reverberation device.



A torsion bar twisted under load



Leaf spring on a truck

Springs can be classified depending on how the load force is applied to them:

- Tension/Extension spring - the spring is designed to operate with a tension load, so the spring stretches as the load is applied to it.

- Compression spring - is designed to operate with a compression load, so the spring gets shorter as the load is applied to it.
- Torsion spring - unlike the above types in which the load is an axial force, the load applied to a torsion spring is a torque or twisting force, and the end of the spring rotates through an angle as the load is applied.

They can also be classified based on their shape:

- Coil spring - this type is made of a coil or helix of wire
- Flat spring - this type is made of a flat or conical shaped piece of metal.

The most common types of spring are:

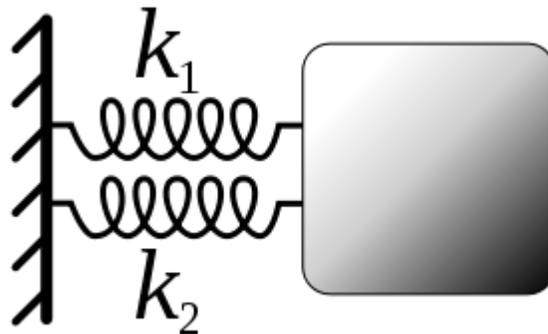
- Cantilever spring - a spring which is fixed only at one end.
- Coil spring or helical spring - a spring (made by winding a wire around a cylinder) and the conical spring - these are types of torsion spring, because the wire itself is twisted when the spring is compressed or stretched. These are in turn of two types:
 - *Compression springs* are designed to become shorter when loaded. Their turns (loops) are not touching in the unloaded position, and they need no attachment points.
 - A *volute spring* is a compression spring in the form of a cone, designed so that under compression the coils are not forced against each other, thus permitting longer travel.
 - *Tension or extension springs* are designed to become longer under load. Their turns (loops) are normally touching in the unloaded position, and they have a hook, eye or some other means of attachment at each end.
- Hairspring or balance spring - a delicate spiral torsion spring used in watches, galvanometers, and places where electricity must be carried to partially-rotating devices such as steering wheels without hindering the rotation.
- Leaf spring - a flat springy sheet, used in vehicle suspensions, electrical switches, bows.
- V-spring - used in antique firearm mechanisms such as the wheellock, flintlock and percussion cap locks.

Other types include:

- Belleville washer or Belleville spring - a disc shaped spring commonly used to apply tension to a bolt (and also in the initiation mechanism of pressure-activated landmines).
- Constant-force spring — a tightly rolled ribbon that exerts a nearly constant force as it is unrolled.
- Gas spring - a volume of gas which is compressed.
- Ideal Spring - the notional spring used in physics: it has no weight, mass, or damping losses.

- Mainspring - a spiral ribbon shaped spring used as a power source in watches, clocks, music boxes, windup toys, and mechanically powered flashlights
- Negator spring - a thin metal band slightly concave in cross-section. When coiled it adopts a flat cross-section but when unrolled it returns to its former curve, thus producing a constant force throughout the displacement and *negating* any tendency to re-wind. The commonest application is the retracting steel tape rule.
- Progressive rate coil springs - A coil spring with a variable rate, usually achieved by having unequal pitch so that as the spring is compressed one or more coils rests against its neighbour.
- Rubber band - a tension spring where energy is stored by stretching the material.
- Spring washer - used to apply a constant tensile force along the axis of a fastener.
- Torsion spring - any spring designed to be twisted rather than compressed or extended. Used in torsion bar vehicle suspension systems.
- Wave spring - a thin spring-washer into which waves have been pressed.

Physics



Two springs attached to a wall and a mass. In a situation like this, the two springs can be replaced by one with a spring constant of $k_{eq}=k_1+k_2$.

Hooke's law

Most springs (not stretched or compressed beyond the elastic limit) obey Hooke's law, which states that the force with which the spring pushes back is linearly proportional to the distance from its equilibrium length:

$$F = -kx,$$

where

x is the displacement vector - the distance and direction in which the spring is deformed

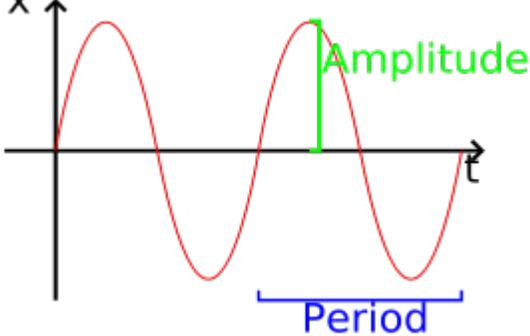
F is the resulting force vector - the magnitude and direction of the restoring force the spring exerts

k is the **spring constant** or **force constant** of the spring.

Coil springs and other common springs typically obey Hooke's law. There are useful springs that don't: springs based on beam bending can for example produce forces that vary nonlinearly with displacement.

Simple harmonic motion

Since force is equal to mass, m , times acceleration, a , the force equation for a spring obeying Hooke's law looks like:

$$F = ma \Rightarrow -kx = ma.$$


The displacement, x , as a function of time. The amount of time that passes between peaks is called the period.

The mass of the spring is assumed small in comparison to the mass of the attached mass and is ignored. Since acceleration is simply the second derivative of x with respect to time,

$$-kx = m \frac{d^2x}{dt^2}.$$

This is a second order linear differential equation for the displacement x as a function of time. Rearranging:

$$\frac{d^2x}{dt^2} + \frac{k}{m}x = 0,$$

the solution of which is the sum of a sine and cosine:

$$x(t) = A \sin \left(t \sqrt{\frac{k}{m}} \right) + B \cos \left(t \sqrt{\frac{k}{m}} \right).$$

A and B are arbitrary constants that may be found by considering the initial displacement and velocity of the mass. The graph of this function with $B = 0$ (zero initial position with some positive initial velocity) is displayed in the image on the right.

Theory

In classical physics, a spring can be seen as a device that stores potential energy, specifically elastic potential energy, by straining the bonds between the atoms of an elastic material.

Hooke's law of elasticity states that the extension of an elastic rod (its distended length minus its relaxed length) is linearly proportional to its tension, the force used to stretch it. Similarly, the contraction (negative extension) is proportional to the compression (negative tension).

This law actually holds only approximately, and only when the deformation (extension or contraction) is small compared to the rod's overall length. For deformations beyond the elastic limit, atomic bonds get broken or rearranged, and a spring may snap, buckle, or permanently deform. Many materials have no clearly defined elastic limit, and Hooke's law can not be meaningfully applied to these materials.

Hooke's law is a mathematical consequence of the fact that the potential energy of the rod is a minimum when it has its relaxed length. Any smooth function of one variable approximates a quadratic function when examined near enough to its minimum point; and therefore the force — which is the derivative of energy with respect to displacement — will approximate a linear function.

Force of fully compressed spring

$$F_{max} = \frac{Ed^4(L - nd)}{16(1 + \nu)(D - d)^3n}$$

where

- E - Young's modulus
- d - spring wire diameter
- L - free length of spring
- n - number of active windings
- ν - Poisson ratio
- D - spring outer diameter

Zero-length springs

"Zero-length spring" is a term for a specially-designed coil spring that would exert zero force if it had zero length. That is, in a line graph of the spring's force versus its length, the line passes through the origin. Obviously a coil spring cannot contract to zero length

because at some point the coils will touch each other and the spring will not be able to shorten any more. Zero length springs are made by manufacturing a coil spring with built-in tension, so if it *could* contract further, the equilibrium point of the spring, the point at which its restoring force is zero, occurs at a length of zero. In practice, zero length springs are made by combining a "negative length" spring, made with even more tension so its equilibrium point would be at a "negative" length, with a piece of inelastic material of the proper length so the zero force point would occur at zero length.

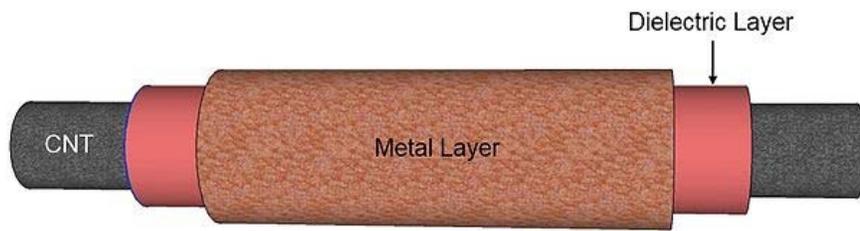
A spring with zero length can be attached to a mass on a hinged boom in such a way that the force on the mass is almost exactly balanced by the vertical component of the force from the spring, whatever the position of the boom. This creates a pendulum with very long period. Long-period pendulums enable seismometers to sense the slowest waves from earthquakes. The LaCoste suspension with zero-length springs is also used in gravimeters because it is very sensitive to changes in gravity. Springs for closing doors are often made to have roughly zero length so that they will exert force even when the door is almost closed, so it will close firmly.

Uses

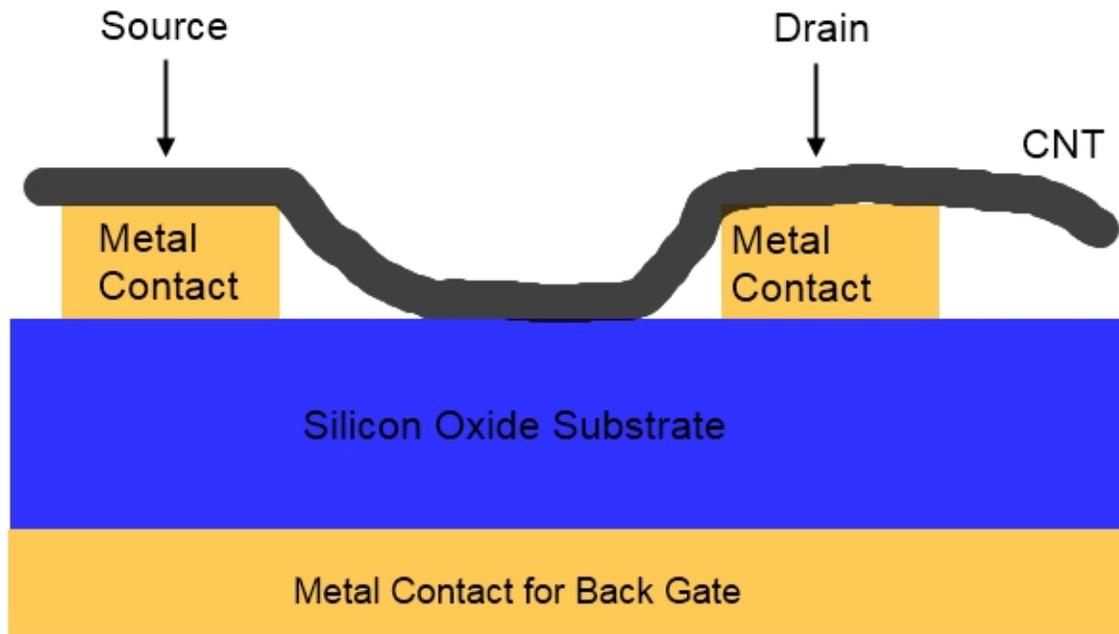
- Balance springs mechanical timepieces
- Buckling spring keyboards
- In CD players
- Inside a pen
- Mattress
- Pogo Stick
- Slinky
- Trampoline
- Vehicle suspension

Chapter- 6

Electrical Conductor



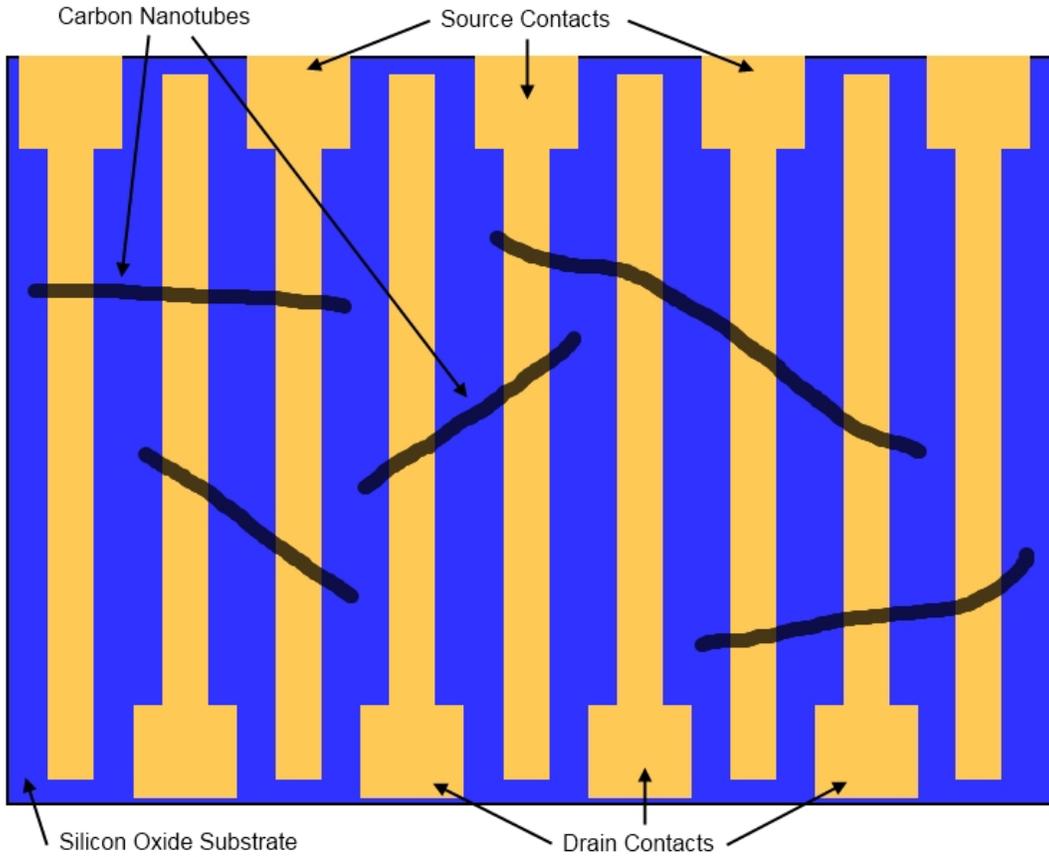
CNT Sheathed



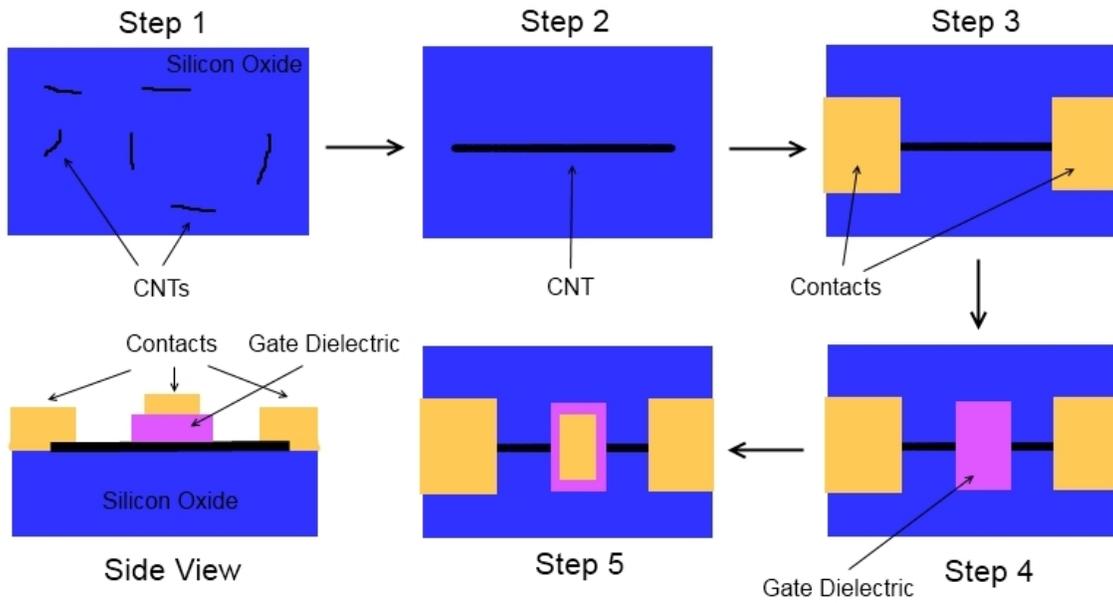
CNTFET Backgate Sideview

In physics and electrical engineering, a **conductor** is a material which contains movable electric charges. In metallic conductors, such as copper or aluminum, the movable charged particles are electrons. Positive charges may also be mobile in the form of atoms in a lattice that are missing electrons (known as holes), or in the form of ions, such as in the electrolyte of a battery. Insulators are non-conducting materials with fewer mobile charges, which resist the flow of electric current.

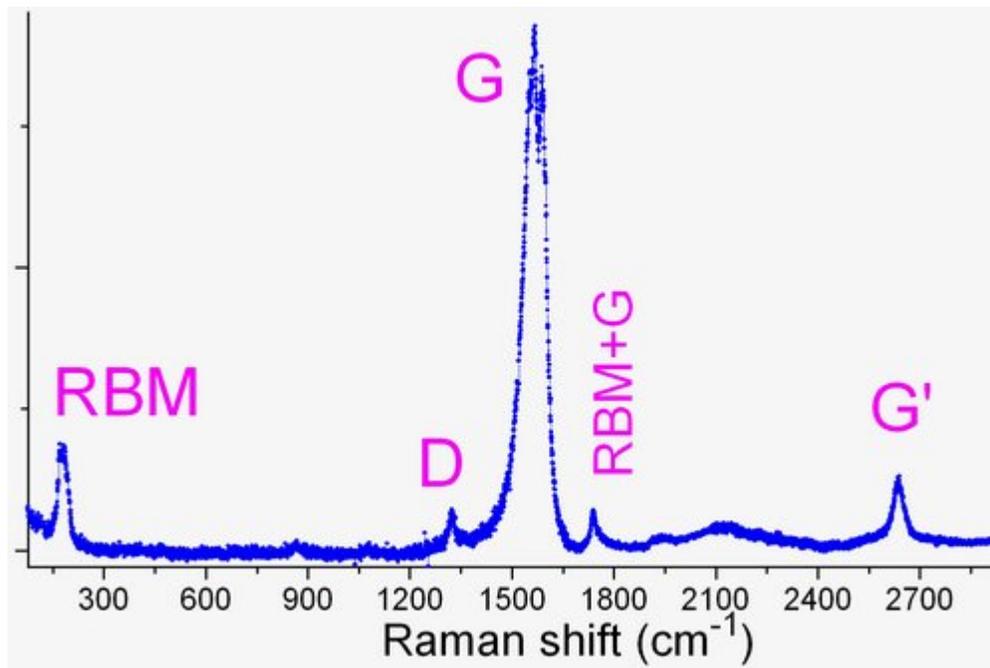
All conductors contain electric charges which will move when an electric potential difference (measured in volts) is applied across separate points on the material. This flow of charge (measured in amperes) is what is meant by *electric current*. In most materials, the direct current is proportional to the voltage (as determined by Ohm's law), provided the temperature remains constant and the material remains in the same shape and state.



CNTFET Backgate



CNTFET Topgate Fab

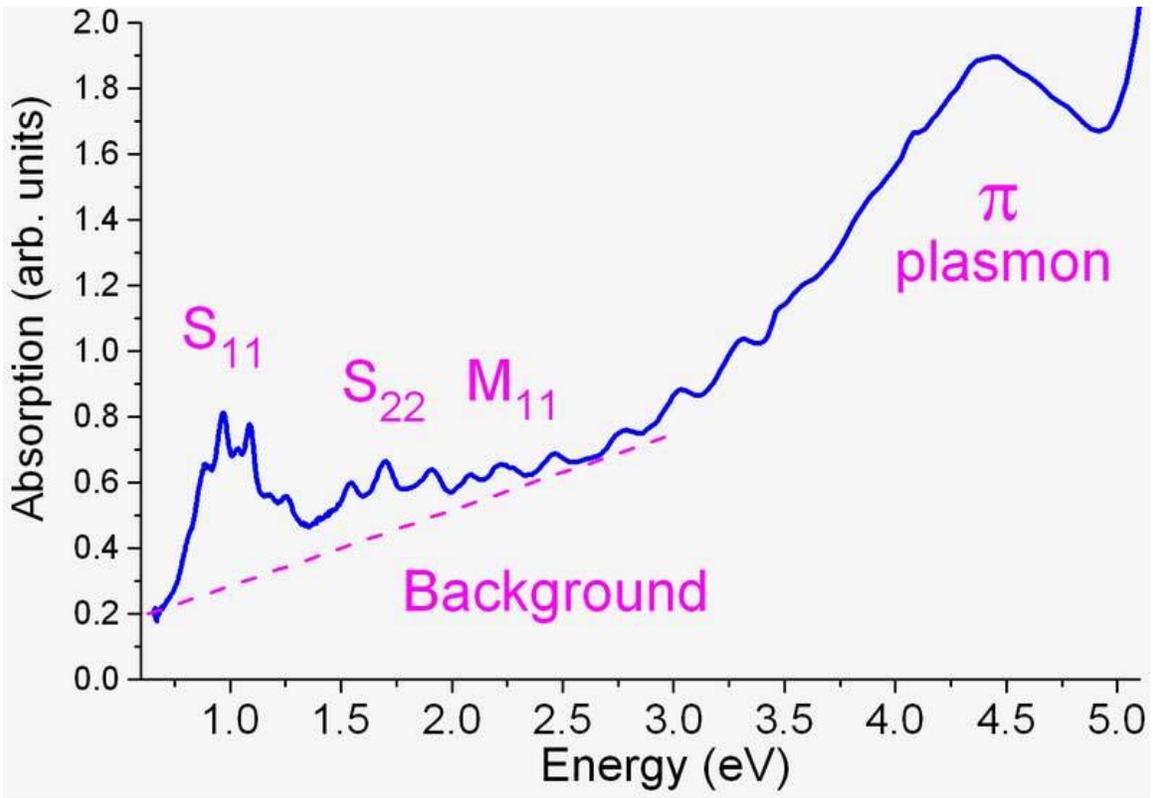


CNTRaman

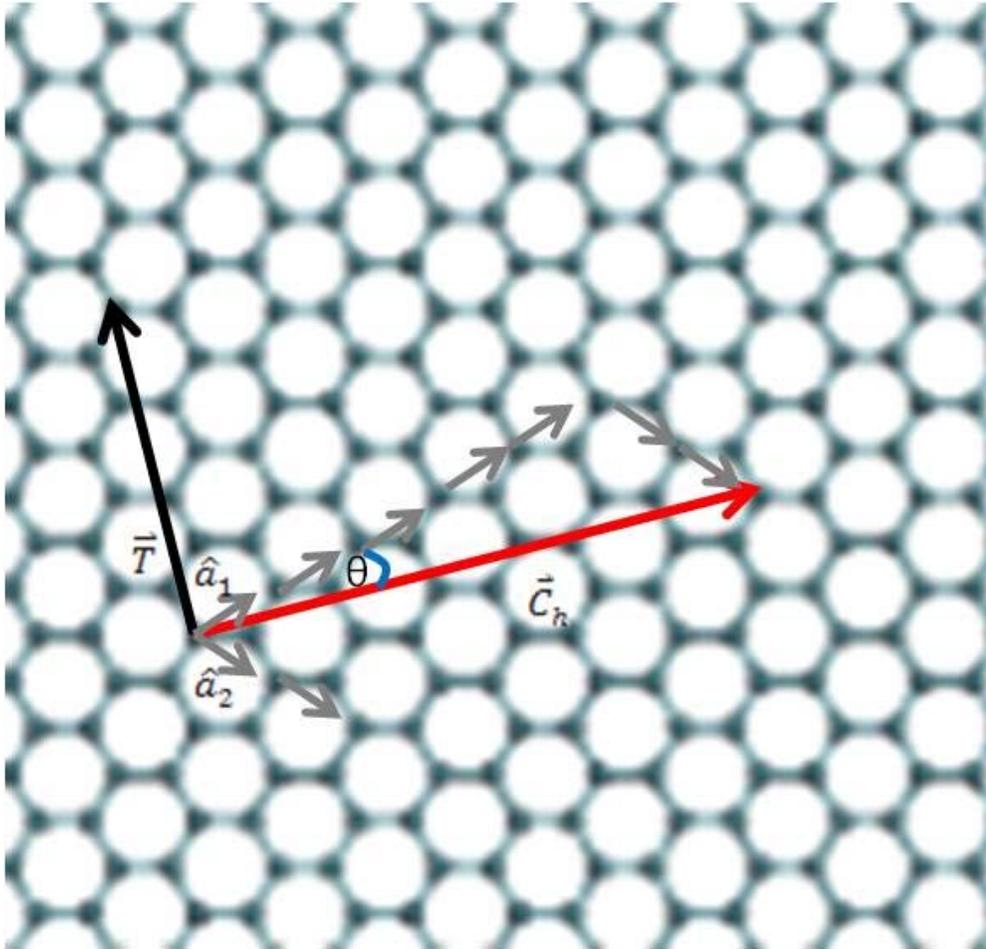
Most familiar conductors are metallic. Copper is the most common material used for electrical wiring. Silver is the best conductor, but is expensive. Because it does not corrode, gold is used for high-quality surface-to-surface contacts. However, there are also many non-metallic conductors, including graphite, solutions of salts, and all plasmas. There are even conductive polymers.

All non-superconducting materials offer some resistance and warm up when a current flows. Thus, proper design of an electrical conductor takes into account the temperature that the conductor needs to be able to endure without damage, as well as the quantity of electric current. The motion of charges also creates an electromagnetic field around the conductor that exerts a mechanical radial squeezing force on the conductor. A conductor of a given material and volume (length \times cross-sectional area) has no real limit to the current it can carry without being destroyed as long as the heat generated by the resistive loss is removed and the conductor can withstand the radial forces. This effect is especially critical in printed circuits, where conductors are relatively small and close together, and inside an enclosure: the heat produced, if not properly removed, can cause fusing (melting) of the tracks.

Thermal and electrical conductivity often go together. For instance, most metals are both electrical and thermal conductors. However, some materials are practical electrical conductors without being good thermal conductors.



CNTabsorption



Chiral vector

Conductor size

In many countries, conductors are measured by their cross section in square millimeters. However, in the United States, conductors are measured by American wire gauge for smaller ones, and circular mils for larger ones.

Conductor materials

Of the metals commonly used for conductors, copper has a high conductivity. Silver is more conductive, but due to cost it is not practical in most cases. However, it is used in specialized equipment, such as satellites, and as a thin plating to mitigate skin effect losses at high frequencies. Because of its ease of connection by soldering or clamping, copper is still the most common choice for most light-gauge wires.

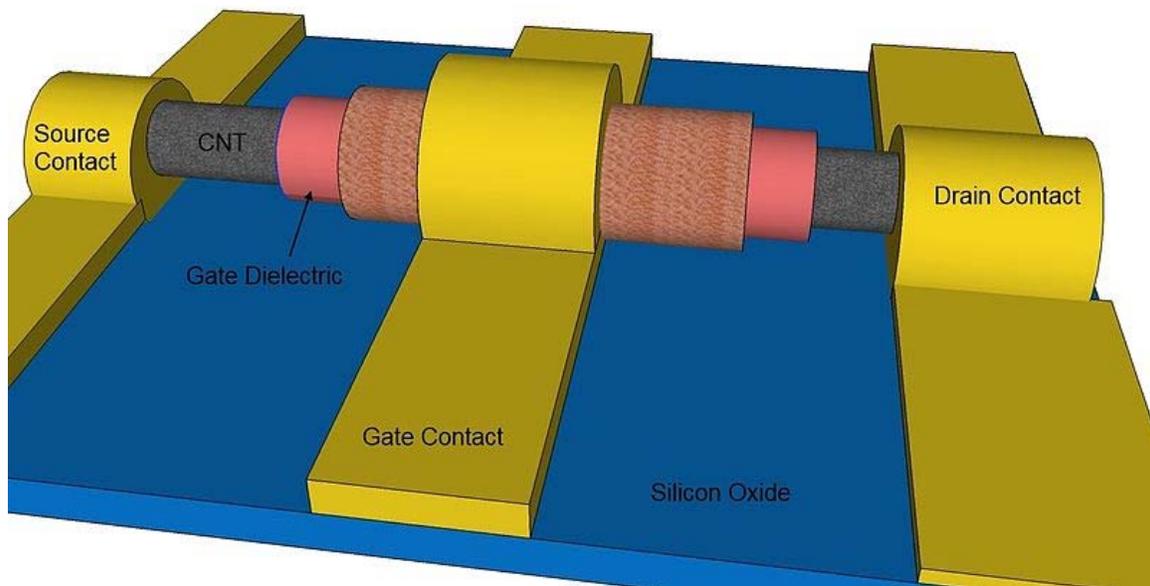
Aluminium has been used as a conductor in housing applications for cost reasons. It is actually more conductive than copper when compared by unit weight, but it has technical

problems that have led to problems when used for household and similar wiring, sometimes having led to structural fires:

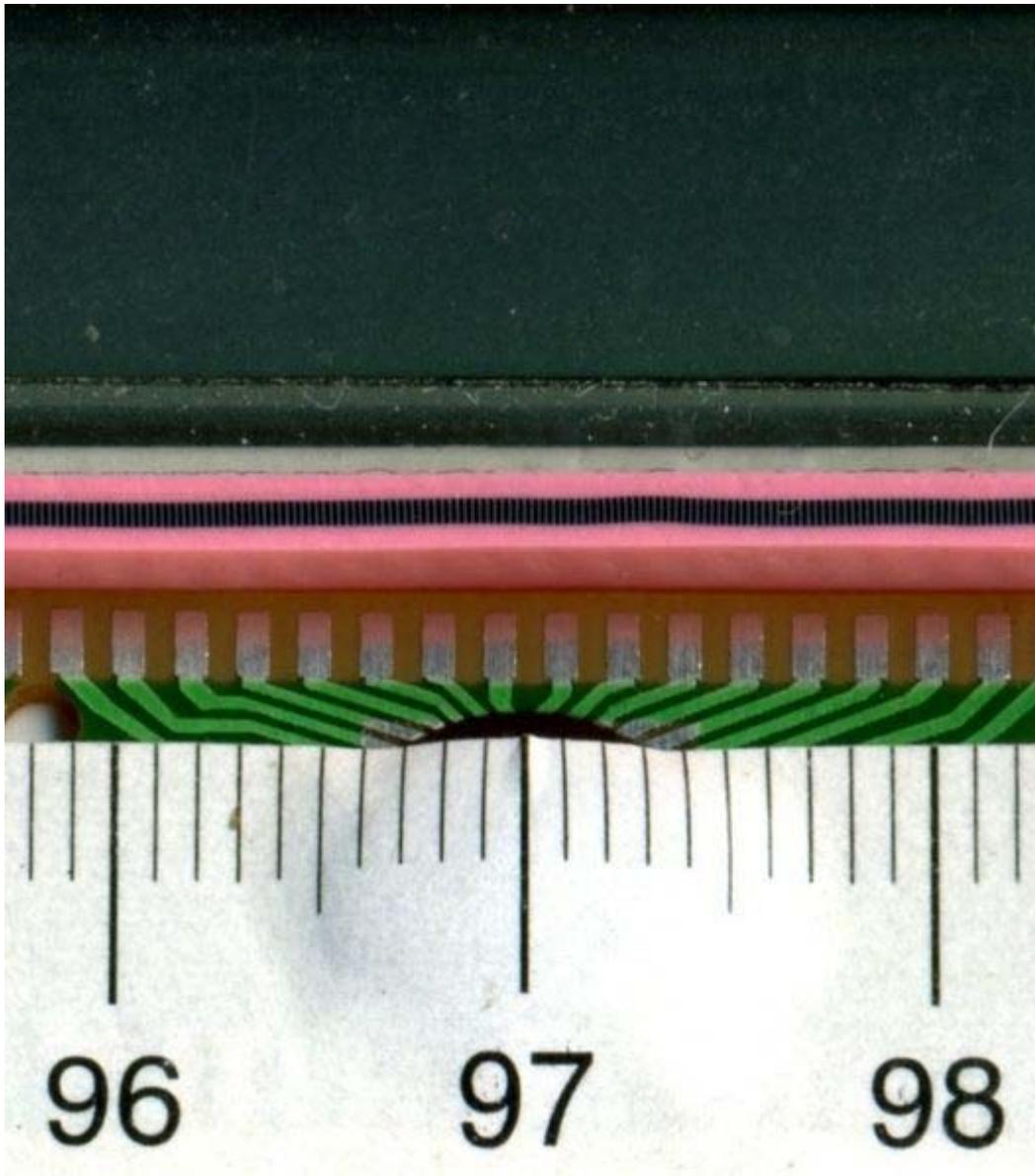
- a tendency to form an electrically resistive surface oxide within connections, leading to heat cycling of the connection (unless protected by a well-maintained protective paste);
- a tendency to "creep" under thermal cycling, causing connections to get looser due to a low mechanical yield point of the aluminium; and
- a coefficient of thermal expansion sufficiently different from the materials used for connections, accelerating the creep problem and addressed by using only plugs, switches, and splices rated specifically for aluminium.

These problems do not affect other uses, and aluminium is commonly used for the low voltage "drop" between a power pole and the household meter. It is also the most common metal used in high-voltage transmission lines, in combination with steel as structural reinforcement.

The surface of anodized aluminium does not conduct electricity, and sometimes this must be considered when aluminium enclosures are to be electrically bonded for safety or to enclose or exclude electromagnetic radiation.



WraparoundCNTFET



Zebra connector

Conductor ampacity

The ampacity of a conductor, that is, the amount of current it can carry, is related to its electrical resistance: a lower-resistance conductor can carry more current. The resistance, in turn, is determined by the material the conductor is made from (as described above) and the conductor's size. For a given material, conductors with a larger cross-sectional area have less resistance than conductors with a smaller cross-sectional area.

For bare conductors, the ultimate limit is the point at which power lost to resistance causes the conductor to melt. Aside from fuses, most conductors in the real world are operated far below this limit, however. For example, household wiring is usually

insulated with PVC insulation that is only rated to operate to about 60 °C, therefore, the current flowing in such wires must be limited so that it never heats the copper conductor above 60 °C, causing a risk of fire. Other, more expensive insulations such as Teflon or fiberglass may allow operation at much higher temperatures.

The American wire gauge article contains a table showing allowable ampacities for a variety of copper wire sizes.

Isotropy

If an electric field is applied to a material, and the resulting induced electric current is in the same direction, the material is said to be an *isotropic electrical conductor*. If the resulting electric current is in a different direction from the applied electric field, the material is said to be an *anisotropic electrical conductor*.

Chapter- 7

Latch



Window latch



Door latch

A **latch** (called **sneck** in Northern England) is a type of mechanical fastener that is used to join two (or more) objects or surfaces together while allowing for the regular or eventual separation of the objects or surfaces.

Note that a latch is not the same as the locking mechanism of a door or window, although often they are found together in the same product.

A latch typically engages another piece of hardware on the other mounting surface. Depending upon the type and design of the latch, this engaged bit of hardware may be known as a *keeper* or *strike*.

Latches range in complexity from flexible one piece flat springs of metal or plastic, such as are used to keep blow molded plastic power tool cases closed, to multi-point cammed latches used to keep large doors closed.

Common types

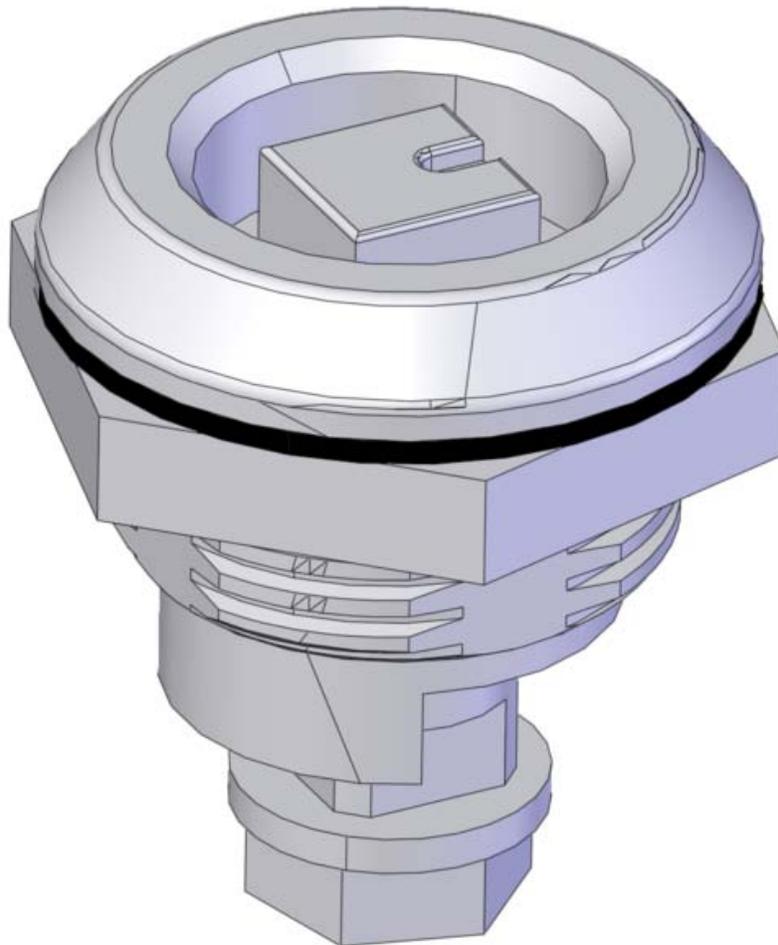
Spring latch

- Passage/Privacy
- Deadlatch (entry) includes an extra tongue
- Deadbolt latch (single throw bolt)

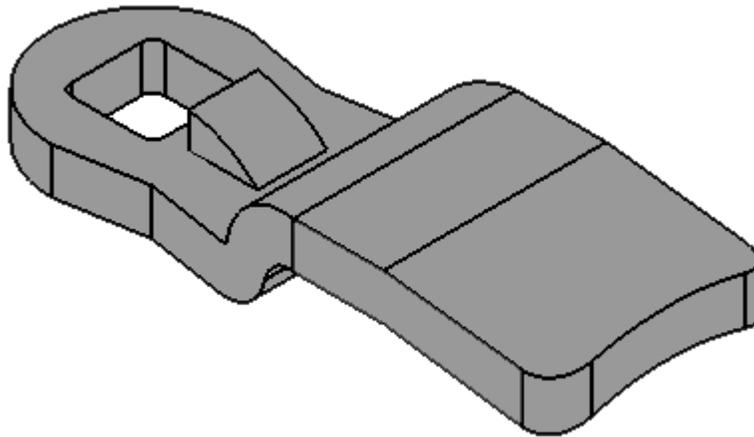
Slam latch

A slam latch uses a spring and is activated by the shutting or slamming of a door. Like all latches, a slam latch is a mechanism to hold a door closed. Slam latch derives its name from its ability to slam doors and drawers shut without damaging the latch. A slam latch is rugged and ideal for industrial, agricultural and construction applications.

Cam lock



The base portion of a cam lock



Offset cam

A **cam lock** is a type of latch consisting of a *base* and a *cam*. The base is where the key or tool is used to rotate the cam, which is what does the latching. Cams can be straight or offset; offset cams often are reversible.

Norfolk latch

A **Norfolk latch** is a type of latch incorporating a simple thumb actuated lever and commonly used to hold wooden gates and doors closed. In a Norfolk latch, the handle is fitted to a backplate independently of the thumb piece.

Introduced around 1800 - 1820, Norfolk latches, originating in the English county of the same name, differ from the older Suffolk latch, which lacked a back plate to which the thumbpiece is attached.

Suffolk latch

A **Suffolk latch** is a type of latch incorporating a simple thumb actuated lever and commonly used to hold wooden gates and doors closed.

The Suffolk latch originated in the English county of Suffolk in the 16th century and stayed in common use until the 19th century. They have recently come back into favour, particularly on garden gates and sheds. They were common from the 17th century to around 1825, and their lack of a back plate made them different from the later, and neighbouring Norfolk latch (introduced 1800 - 1820). Many of these plates found their way into America and other parts of the world.

Crossbar



A crossbar on a door

A crossbar, sometimes called a *bolt*, is a primitive fastener consisting simply of a post barring a door. Crossbars are no longer in modern use.

Crossbars were historically common, simple fasteners consisting simply of a plank or beam mounted to one side of a door by a set of cleats. The board could be slid past the frame to block the door. Alternatively, the bar can be a separate piece that is placed into open cleats or hooks, extending across the frame on both sides. The effect of this device is essentially the opposite of the crash bar in that its operation is to permit the door to be opened inward rather than outward. On a set of double doors, the same principle works, but needn't extend past the frame. The bar simply extends into another set of cleats on the other door such as to interfere with the door opening.

Cabin hook



A cabin hook latch

A **cabin hook** is a hooked bar that engages into a staple. The bar is usually attached permanently to a ring or staple that is fixed with screws or nails to woodwork or a wall at the same level as the eye screw. The eye screw is usually screwed into the adjacent wall or onto the door itself. Used to hold a cupboard, door or gate open or shut.

A cabin hook is used in many situations to hold a door open, like on ships to prevent doors from swinging and banging against other woodwork as the ship moves due to wave action. This usage spread also to other domains, where a door was required to be held open or a self-closing device is used to close the door.

Many buildings are built with fire-resistant doors to separate different parts of buildings and to allow people to be protected from fire and smoke. When using a cabin hook in such a situation, one should keep in mind that a fire-resistant door is an expensive and

heavy item, and it only works as a fire door if it is always closed. To open the often heavy fire door easily, magnetic door holders are used that are released when the buildings electrical fire alarm system is activated by a fire. As cabin hooks must be activated manually, they are inappropriate for fire doors.

Other latches

- Bolt lock latch
- Compression latch
- Draw latch (both over- & under-center)
- Rotary latch

Applications

Weaponry

Many types of weaponry incorporate latches with designs unique to the weapon.

Firearms

Firearms require specialized latches used during loading and firing of the weapon.

A break-action firearm is one whose barrels are hinged and a latch is operated to release the two parts of the weapon to expose the breech and allow loading and unloading of ammunition. It is then closed and re-latched prior to firing. A separate operation may be required for the cocking and latching-open of a hammer to fire the new round. Break open actions are universal in double-barrelled shotguns, double-barrelled rifles and combination guns, and are also common in single shot rifles, pistols, and shotguns, and can also be found in flare guns, grenade launchers, air guns and some older revolver designs.

Several latch designs have been used for loading revolvers. In a top-break revolver, the frame is hinged at the bottom front of the cylinder. The frame is in two parts, held together by a latch on the top rear of the cylinder. For a swing out cylinder, the cylinder is mounted on a pivot that is coaxial with the chambers, and the cylinder swings out and down. Some designs, such as the Ruger Super Redhawk or the Taurus Raging Bull, use a latches at the front and rear of the cylinder to provide a secure bond between cylinder and frame.

To fire a revolver, generally the hammer is first manually cocked and latched into place. The trigger, when pulled, releases the hammer, which fires the round in the chamber.

Knives

Various types of knives with folding or retractable blades rely on latches for their function. A **switchblade** uses an internal spring to produce the blade which is held in

place by a button-activated latch. Likewise a **ballistic knife** uses a strong latch to restrain a powerful spring from firing the blade as a projectile until triggered by opening the latch. A **gravity knife** relies on a latch to hold the folding blade in an open position once released. A **balisong** uses a single latch to hold the folding blade both open and closed, depending on the position of the handles; by rotating 180 degrees the same latch can be used in either configuration. Balisong latches have numerous variations, including magnetic variants and some which can be opened via a spring when the handles are squeezed together.

Utility knives also often use a latch to hold a folding knife both open and closed. This allows it to be locked in orientation to the handle when in use, but also safely stowed otherwise. To open a knife of this type may require significantly more force than the weapons variety as an added safety feature.

Other

Crossbows incorporate a type of latch to hold the drawn bowstring prior to firing.

Automobiles

Automobiles incorporate numerous special purpose latches as components of the doors, hood/bonnet, trunk/boot, tailgate, seat belts, etc.

On passenger cars, a hood may be held down by a concealed latch. On race cars or cars with aftermarket hoods (that do not use the factory latch system) the hood may be held down by hood pins.

The term *Nader bolt* is a nickname for the bolt on vehicles that allows a hinged door to remain safely latched and closed. It is named after consumer rights advocate and politician Ralph Nader, who in 1965 released the book *Unsafe at Any Speed* which claimed that American cars were fundamentally flawed with respect to operator safety.

Latches in seatbelts typically fasten the belt which constrains the occupant to the body of the car. Particularly in rear seats slightly different latches may be used for each seat in order to prevent the seatbelts from being attached to the wrong point. Inertial seatbelt release is a potential circumstance where, in a collision, the seatbelt latch can unintentionally come loose leading to potential injury of the passenger. An additional risk of seatbelt latches is that in some cases the occupant may believe the latch is secure when in fact it has not.

Bakeware

A spring latch is used to hold the walls of a Springform pan in place.

Chapter- 8

Bucket



Hulett crane bucket



Bucket wheel detail showing actual buckets use

A **bucket** (also called a **scoop** to qualify shallower designs of tools) is a specialized container attached to a machine, as compared to a bucket adapted to the form of a human being. It is a bulk material handling component.

The bucket has an inner volume as compared to other types of machine attachments like blades or shovels.

The bucket could be attached to the lifting hook of a crane, at the end of the arm of an excavating machine, to a the wires of a dragline excavator, to the arms of a power shovel or a tractor equipped with a backhoe loader or to a loader, or to a dredge.

The name "bucket" may have been coined from buckets used in water wheels, or used in water turbines or in similar-looking devices.



Pelton wheel

Purposes

Buckets in mechanical engineering can have a distinct quality from the traditional bucket (pail) whose purpose is to contain things. Larger versions of this type of bucket equip bucket trucks to contain human beings, buckets in water-hauling systems in mines or, for instance, in helicopter buckets to hold water to combat fires.

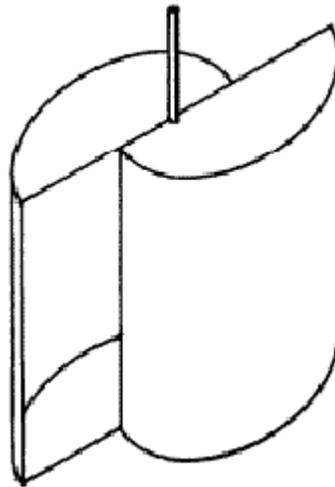
Two other types of mechanical buckets can be distinguished according to the final destination of the device they equip: energy-consumer systems like excavators or energy-capturer systems like water bucket wheels or turbines.

Size and shape

Buckets exist in a variety of sizes or shapes. They can be quite large like those equipping Hulett cranes, used to discharge ore out of cargo ships in harbours or very small such as those used by deep-sea exploration vehicles.

The shape of the bucket can vary from the truncated conical shape of an actual bucket to more scoop-like or spoon-like shapes akin to water turbines. The cross section can be round or square.

Designs



Savonius wind turbine with two scoops

Simple design

This is the same shape of a domestic form, the one-piece-standing single element, but often with an augmented size.

Helicopter bucket

An helicopter bucket allows to carry water above a fire site.



Helicopter bucket made of canvas

Concrete bucket

Concrete buckets help deliver concrete on a specific site of a building by the means of a tower crane. They have a bottom opening to allow concrete to flow out of the bucket when in-place.



An excavator bucket

Electrical trucks bucket

They are placed at the end of an excavator-like arm and have to be made from a material that provides isolation from electricity, like fiber glass, to help the workers protect themselves. There may be a door on the side of the bucket.

Excavator bucket

Excavator buckets are made of solid steel and generally present teeth protruding from the cutting edge, to disrupt hard material and avoid wear-and-tear of the bucket. Subsets of the excavator bucket are: the ditching bucket, trenching bucket, A ditching bucket is a

wider bucket with no teeth, 5–6 feet (1.5–1.8 m) used for excavating larger excavations and grading stone. A trenching excavator bucket is normally 6 to 24 in (150 to 610 mm) wide and with protruding teeth.

Clamshell bucket

The clamshell bucket is a more sophisticated articulated several-pieces device, including two elementary buckets associated on a hinged structure forming a claw-like appendage with an internal volume.

Buckets-wheel

In mining

The design is used in bucket-wheel excavators. The buckets in the wheel have to be made of solid material to withstand the resistance of the material it cuts through.

In energy production

The bucket wheel design is also used to capture the water energy in water-wheels or water turbines like Pelton wheels. The buckets also have to be made of solid material to withstand the force of the water flow. Their shape is optimized according to their purpose. Other designs include vertical shaft wind turbines designs like on the Savonius wind turbine. In this case, the buckets have to be made of a light material.

Buckets-ladders (buckets-chains)

The buckets-ladders are used in bucket elevators or in the dredge design of some dredgers.



Truck with clamshell grab on arm, south Manchester, England, 27 July 2009



Bucket wheel on a bucket-wheel excavator

Chapter- 9

Fastener



Typical fasteners (coin shown for scale)

A **fastener** is a hardware device that mechanically joins or affixes two or more objects together.

Fasteners can also be used to close a container such as a bag, a box, or an envelope; or they may involve keeping together the sides of an opening of flexible material, attaching a lid to a container, etc. There are also special-purpose closing devices, e.g. a bread clip. Fasteners used in these manners are often temporary, in that they may be fastened and unfastened repeatedly.

Some types of woodworking joints make use of separate internal reinforcements, such as dowels or biscuits, which in a sense can be considered fasteners within the scope of the joint system, although on their own they are not general purpose fasteners.

Furniture supplied in flat-pack form often uses cam dowels locked by cam locks, also known as conformat fasteners.

Items like a rope, string, wire (e.g. metal wire, possibly coated with plastic, or multiple parallel wires kept together by a plastic strip coating), cable, chain, or plastic wrap may be used to mechanically join objects; but are not generally categorized as fasteners

because they have additional common uses. Likewise, hinges and springs may join objects together, but are ordinarily not considered fasteners because their primary purpose is to allow articulation rather than rigid affixment.

Other alternative methods of joining materials include crimping, welding, soldering, brazing, taping, gluing, cementing, or the use of other adhesives. The use of force may also be used, such as with magnets, vacuum (like suction cups), or even friction.

Industry

In 2005, it is estimated that the United States fastener industry runs 350 manufacturing plants and employs 40,000. The industry is strongly tied to the production of automobiles, aircraft, appliances, agricultural machinery, commercial construction, and infrastructure. More than 200 billion fasteners are used per year in the U.S., with 26 billion by the automotive industry.

Types



Structural bolt DIN 6914 with DIN 6916 washer and UNI 5587 nut.

- batten
- brass fastener
- buckle
- button
- Captive fastener
- clamp (or cramp)
- clasp
 - Bocklebee clasp
- Cleko
- clip
 - circlip
 - paper clip
- clutch (pin fastener)
- flange
- frog
- grommet
- masonry anchor
- nail
- peg
- pin
 - clevis pin
 - clothes-pin
 - cotter pin
 - Dowel pin
 - linchpin
 - R-clip
 - Spring pin
- retaining ring
 - circlip
 - e-ring
- rivet
- rubber band (or bands of other materials)
- screw anchor
- Self-clinching
- snap
- staple
- stitches
- strap
- tack
- threaded fastener
 - captive threaded fasteners
 - nut
 - screw
 - stud
 - threaded insert
 - threaded rod

- tie
- toggle
- velcro brand hook-and-loop strips
- wedge anchor
- zipper

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.

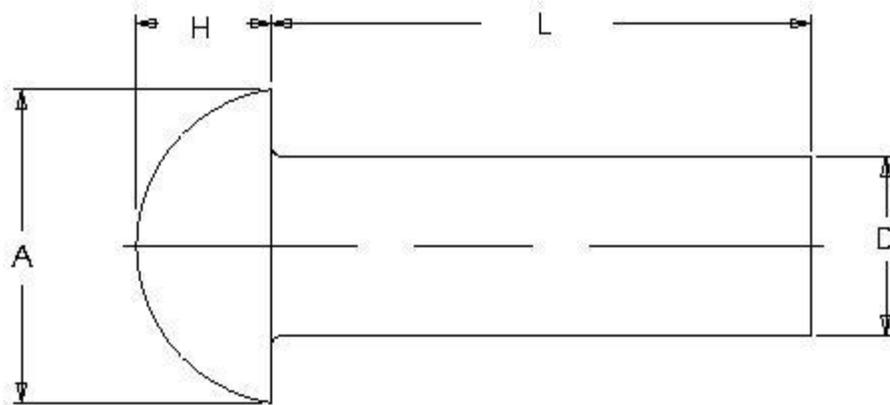
Because there is effectively a head on each end of an installed rivet, it can support tension loads (loads parallel to the axis of the shaft); however, it is much more capable of supporting shear loads (loads perpendicular to the axis of the shaft). Bolts and screws are better suited for tension applications.

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.

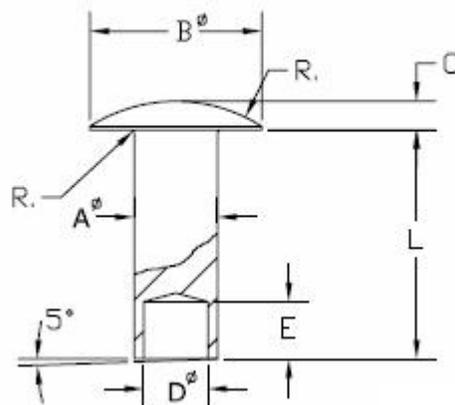
At a central location near the areas being riveted, a furnace was set up. Rivets were placed in the furnace and heated to a glowing hot temperature, at which time the furnace operator would use tongs to individually remove and throw them to catchers stationed near the joints to be riveted. The catcher 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

STANDARD SEMI-TUBULAR RIVET



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 semitubular 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
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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

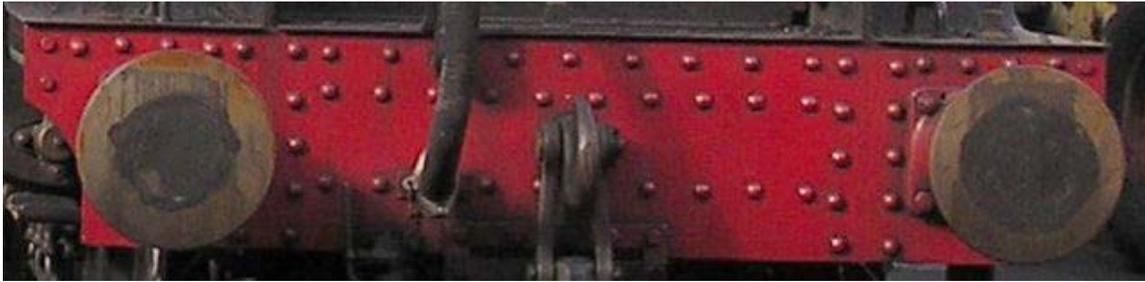


Installing rivets on M3 tank hull

Rivet diameters are commonly measured in $\frac{1}{32}$ -inch increments and their lengths in $\frac{1}{16}$ -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 $\frac{3}{32}$ -inch diameter and $\frac{4}{16}$ -inch (or $\frac{1}{4}$ -inch) length. Some rivets lengths are also available in "half sizes" and will have a dash number such as -3.5 ($\frac{7}{32}$ 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.

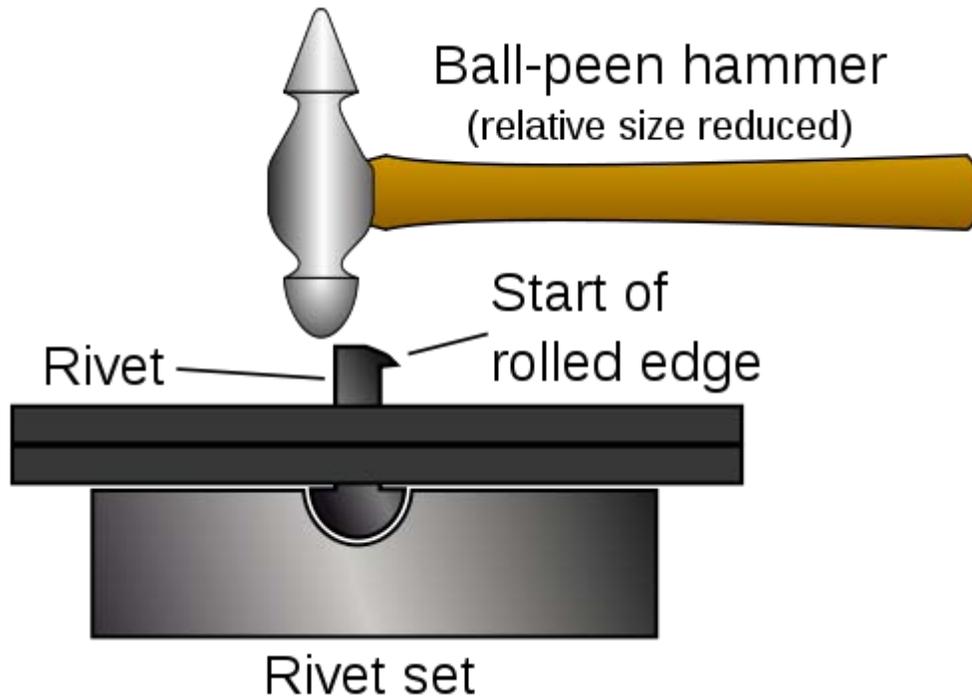
Common but more exotic uses of rivets are to reinforce jeans and to produce the distinctive sound of a sizzle cymbal.

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

Flange



Flanged railway wheel

A **flange** is an external or internal rib, or rim (lip), for strength, as the flange of an iron beam or I-beam (or a T-beam); or for a guide, as the flange of a train wheel; or for attachment to another object, as the flange on the end of a pipe, steam cylinder, etc., or on the lens mount of a camera. Thus a flanged rail is a rail with a flange on one side to keep wheels, etc., from running off. The term "flange" is also used for a kind of tool used to form flanges. Pipes with flanges can be assembled and disassembled easily.

Plumbing or piping



Surrey flange

A flange can also be a plate or ring to form a rim at the end of a pipe when fastened to the pipe (for example, a closet flange). A blind flange is a plate for covering or closing the end of a pipe. A flange joint is a connection of pipes, where the connecting pieces have flanges by which the parts are bolted together.

Although the word flange generally refers to the actual raised rim or lip of a fitting, many flanged plumbing fittings are themselves known as 'flanges':

Common flanges used in plumbing are the Surrey flange or Danzey flange, York flange, Sussex flange and Essex flange. Surrey and York flanges fit to the top of the hot water tank allowing all the water to be taken without disturbance to the tank. They are often used to ensure an even flow of water to showers. An Essex flange requires a hole to be drilled in the side of the tank.

There is also a Warix flange which is the same as a York flange but the shower output is on the top of the flange and the vent on the side. The York and Warix flange have female adapters so that they fit onto a male tank, whereas the Surrey flange connects to a female tank.

A closet flange provides the mount for a toilet.

Pipe flanges

There are many different flange standards to be found worldwide. To allow easy functionality and inter-changeability, these are designed to have standardised dimensions. Common world standards include ASA/ANSI (USA), PN/DIN (European), BS10 (British/Australian), and JIS/KS (Japanese/Korean).

In most cases these are not interchangeable (e.g. an ANSI flange will not mate against a JIS flange). Further, many of the flanges in each standard are divided into "pressure classes", allowing flanges to be capable of taking different pressure ratings. Again these are not generally interchangeable (e.g. an ANSI 150 will not mate with an ANSI 300). These pressure classes also have differing pressure and temperature ratings for different materials. Unique pressure classes for piping can also be developed for a process plant or power generating station; these may be specific to the corporation, engineering procurement and construction (EPC) contractor, or the process plant owner.

The flange faces are also made to standardized dimensions and are typically "flat face", "raised face", "tongue and groove", or "ring joint" styles, although other obscure styles are possible.

Flange designs are available as "welding neck", "slip-on", "boss", "lap joint", "socket weld", "threaded", and also "blind".

ASME standards (U.S.)



ASME type flange on a gas pipeline

Pipe flanges that are made to standards called out by ASME B16.5 or ASME B16.47 are typically made from forged materials and have machined surfaces. B16.5 refers to nominal pipe sizes (NPS) from ½" to 24". B16.47 covers NPSs from 26" to 60". Each specification further delineates flanges into pressure classes: 150, 300, 400, 600, 900, 1500 and 2500 for B16.5; B16.47 delineates its flanges into pressure classes 75, 150, 300, 400, 600, 900.

The gasket type and bolt type are generally specified by the standard(s); however, sometimes the standards refer to the ASME Boiler and Pressure Vessel Code (B&PVC) for details. These flanges are recognized by ASME Pipe Codes such as ASME B31.1 Power Piping, and ASME B31.3 Process Piping.

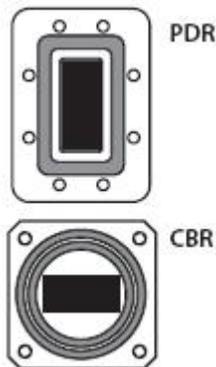
Materials for flanges are usually under ASME designation: SA-105 (Specification for Carbon Steel Forgings for Piping Applications), SA-266 (Specification for Carbon Steel Forgings for Pressure Vessel Components), or SA-182 (Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service). In addition, there are many "industry standard" flanges that in some circumstance may be used on ASME work.

Other countries

Flanges in other countries also are manufactured according to the standards for materials, pressure ratings, etc. Such standards include DIN, BS, and/or ISO standards.

Vacuum flanges

A vacuum flange is a flange at the end of a tube used to connect vacuum chambers, tubing and vacuum pumps to each other.



Form factor of PDR and CBR flanges.

Microwave RF

In microwave telecommunications, a flange is a type of cable joint which allows different types of waveguide to connect.

Several different microwave RF flange types exist, such as CAR, CBR, OPC, PAR, PBJ, PBR, PDR, UAR, UBR, UDR, icp and UPX.