

Gear

A **gear** 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.

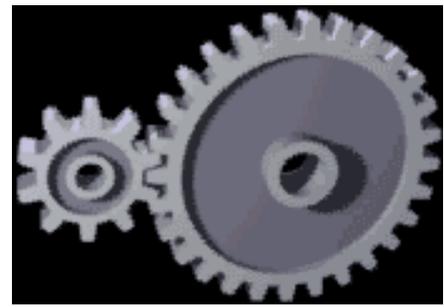
In transmissions which offer multiple gear ratios, such as bicycles and cars, the term **gear**, as in *first gear*, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission.^[1]

The earliest known reference to gears was circa A.D. 50 by Hero of Alexandria,^[2] 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.).^[3]

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.

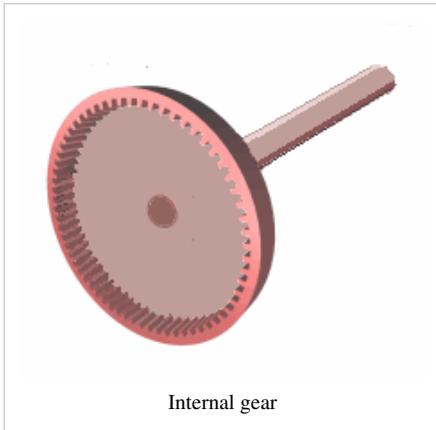
The automobile transmission allows selection between gears to give various mechanical advantages.



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.

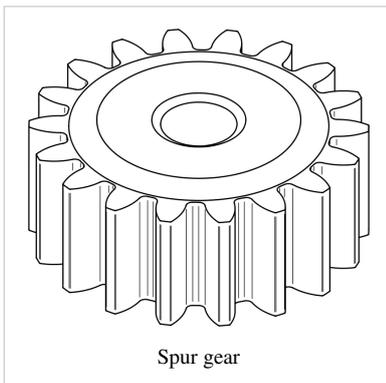
Types

External vs. internal gears



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.^[4]

Spur



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 axles.

Helical



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.

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.^[5]

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:^[6]

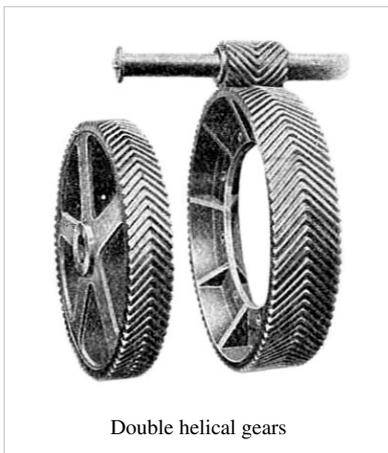
$$E = \beta_1 + \beta_2 \text{ for gears of the same handedness}$$

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

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.^[6]

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, 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.

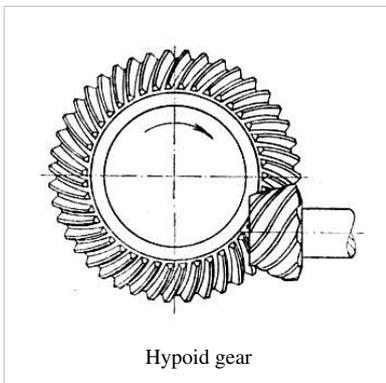
Bevel



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*.

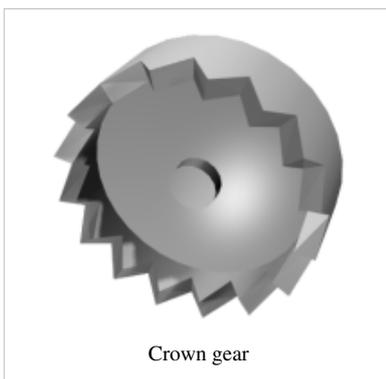
The teeth of a bevel gear may be straight-cut as with spur gears, or they may be cut in a variety of other shapes. *Spiral bevel gear* teeth are curved along the tooth's length and set at an angle, analogously to the way helical gear teeth are set at an angle compared to spur gear teeth. *Zerol bevel 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.^[7]

Hypoid



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.^{[8] [9]} 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.^[10] This style of gear is most commonly found in mechanical differentials.

Crown



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

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.^[11] A disadvantage is the potential for considerable sliding action, leading to low efficiency.^[12]

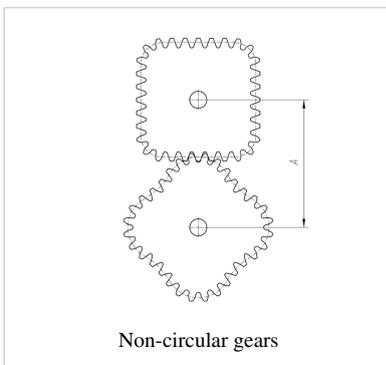
Worm gears can be considered a species of helical gear, but its helix angle is usually somewhat large (close to 90 degrees) and its body is usually fairly long in the axial direction; and it is these attributes which give it its screw like qualities. The distinction between a worm and a helical gear 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.^[13] 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**.^[14]

Worm gears can be right or left-handed following the long established practice for screw threads.^[4]

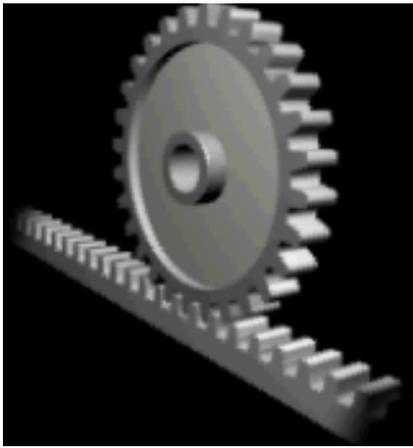
Non-circular



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.

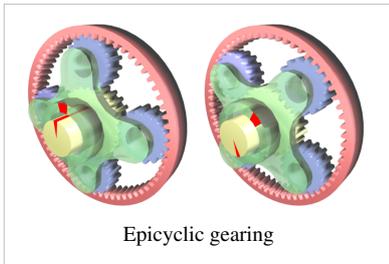
Rack and pinion



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.

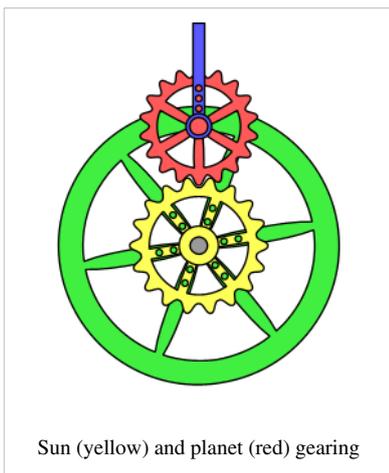
Epicyclic



Epicyclic gearing

In epicyclic gearing one or more of the gear axes moves. Examples are sun and planet gearing (see below) 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.

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:

$$d = \frac{Nm_n}{\cos\psi} \text{ in metric units or } d = \frac{N}{P_d \cos\psi} \text{ in imperial units.}^{[15]}$$

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.^[15] 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.^[4] 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. Is zero in the limiting case of a spur gear.

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

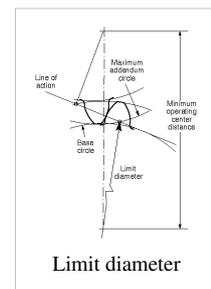
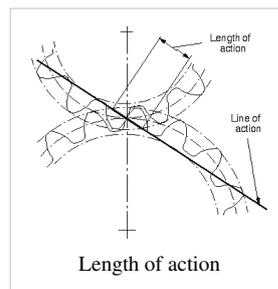
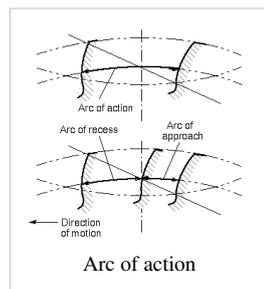
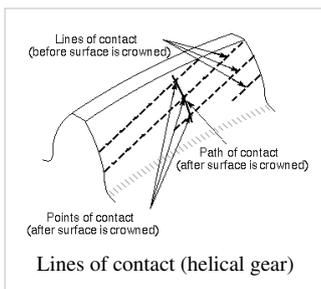
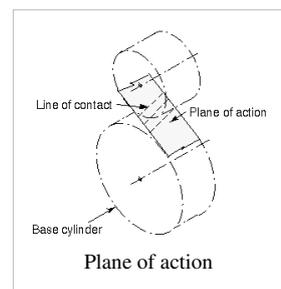
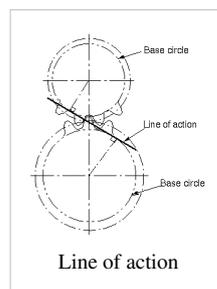
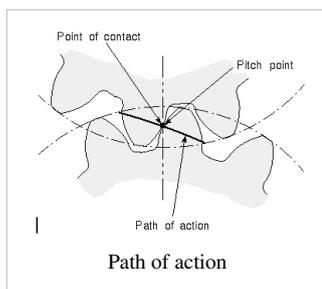
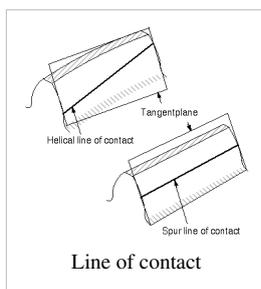
Angle between a tangent to the helix and a plane perpendicular to the axis. Note that it is the complement of the helix angle which is usually given for helical gears.

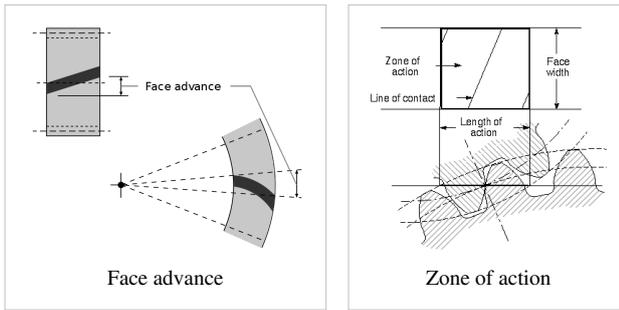
Pitch diameter, d_w

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





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.

$$\epsilon_\gamma = \epsilon_\alpha + \epsilon_\beta$$

$$m_t = m_p + m_F$$

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.

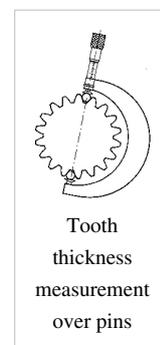
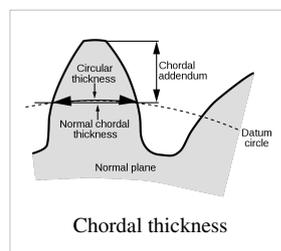
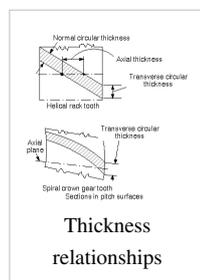
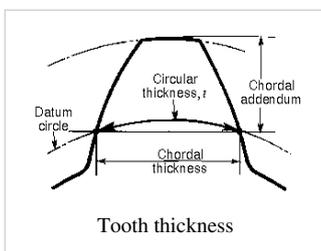
Start of active profile (SAP)

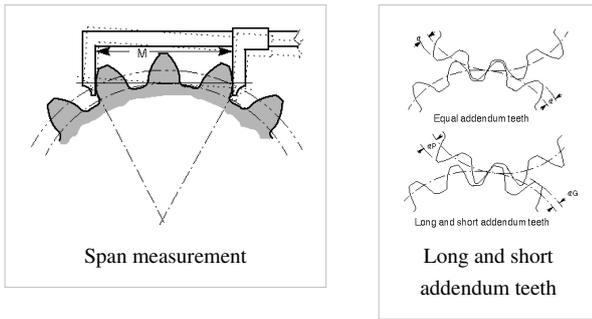
Intersection of the limit diameter and the involute profile.

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





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

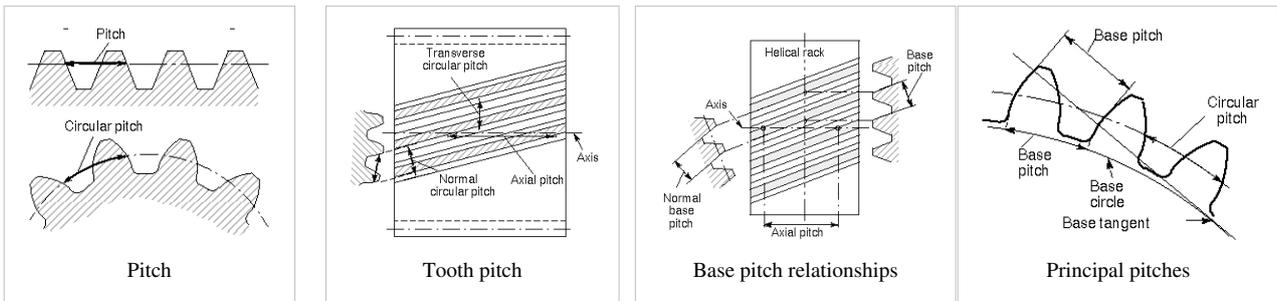
Teeth in which two engaging gears have equal addendums.

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.^[4] 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.



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

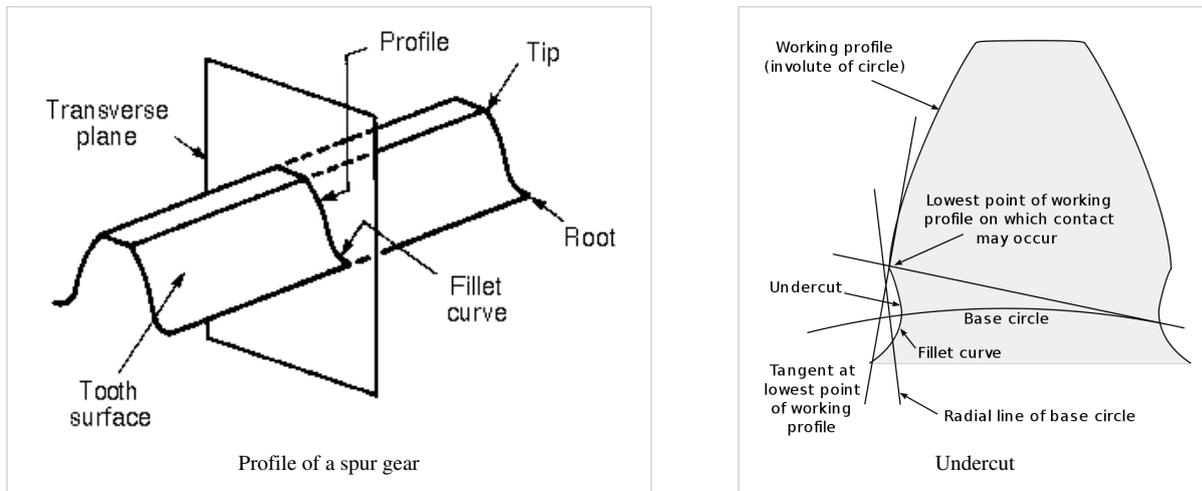
In some machines (e.g., automobiles) it is necessary to alter the gear ratio to suit the task. There are several methods of accomplishing this. For example:

- Manual transmission
- Automatic gearbox
- Derailleur 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 air pollution emissions, there are higher pollutant emissions generated in the lower gears, when the engine is working harder than when higher gears have been attained. In the case of vehicle noise emissions, there are higher sound levels emitted when the vehicle is engaged in lower gears. 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.^[16]

Tooth profile



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.

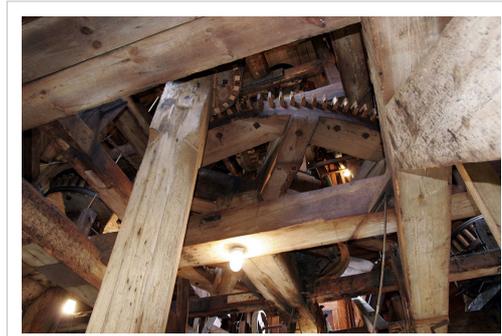
The fillet curve (root fillet) is the concave portion of the tooth profile where it joins the bottom of the tooth space.²

As mentioned near the beginning of the article, 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

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.



Wooden gears of a historic windmill

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.^[17]

Manufacture

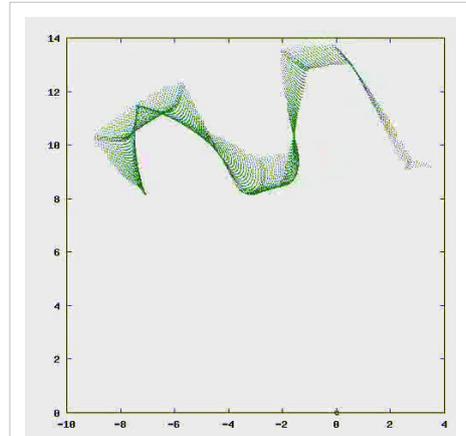
Gears are most commonly produced via hobbing, but they are also shaped, broached, cast, and in the case of plastic gears, injection molded. For metal gears the teeth are usually heat treated to make them hard and more wear resistant while leaving the core soft and tough. For large gears that are prone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

Gear model in modern physics

Modern physics adopted the gear model in different ways. In nineteenth century James Clerk Maxwell developed a model of electromagnetism in which magnetic field lines were rotating tubes of incompressible fluid. Maxwell used gear wheel and called it "idle wheel" to explain the electrical current as a rotation of particles in opposite direction to that of the rotating field lines.^[18]

A new consideration of gear in quantum physics is regarded as a quantum gears. 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.^[19]

It has been shown that the Three Wave Hypothesis may be represented in a bevel gear form.^[20]



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