

6.6 GEAR MANUFACTURING

Introduction

Because of their capability for transmitting motion and power, gears are among the most important of all machine elements. Special attention is paid to gear manufacturing because of the specific requirements to the gears. The gear tooth flanks have a complex and precise shape with high requirements to the surface finish.

Gears can be manufactured by most of manufacturing processes discussed so far (casting, forging, extrusion, powder metallurgy, blanking). But as a rule, machining is applied to achieve the final dimensions, shape and surface finish in the gear. The initial operations that produce a semifinishing part ready for gear machining as referred to as *blanking operations*; the starting product in gear machining is called a *gear blank*.

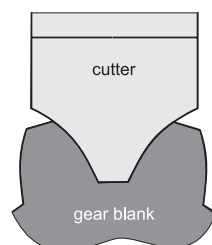
Two principal methods of gear manufacturing include

- ① gear forming, and
- ② gear generation.

Each method includes a number of machining processes, the major of them included in this section.

Gear forming

In gear form cutting, the cutting edge of the cutting tool has a shape identical with the shape of the space between the gear teeth.

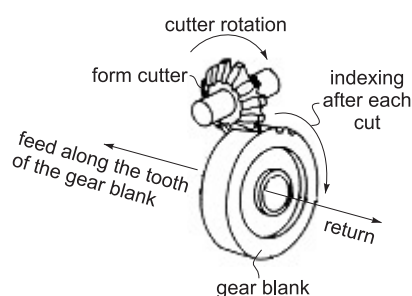


The principle of gear forming.

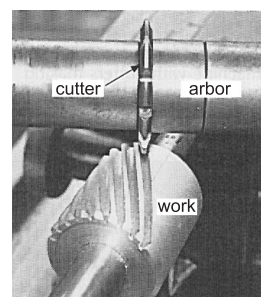
Two machining operations, milling and broaching can be employed to form cut gear teeth.

Form milling

In *form milling*, the cutter called a *form cutter* travels axially along the length of the gear tooth at the appropriate depth to produce the gear tooth. After each tooth is cut, the cutter is withdrawn, the gear blank is rotated (*indexed*), and the cutter proceeds to cut another tooth. The process continues until all teeth are cut.

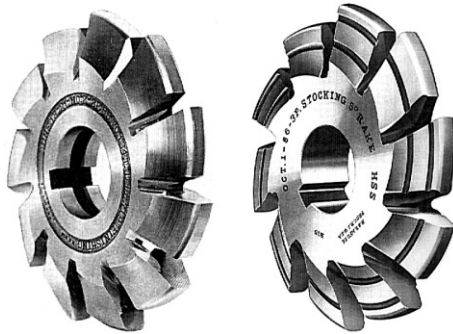


Setup of form milling.

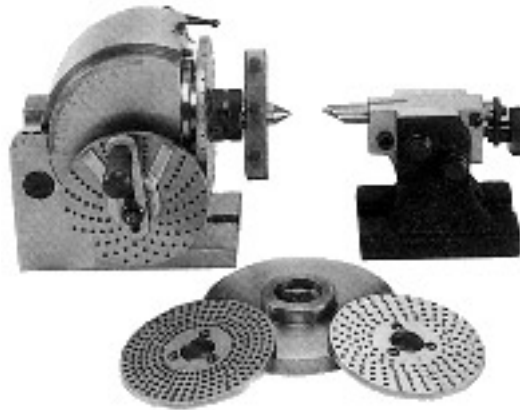


Form milling of a helical gear.

Each cutter is designed to cut a range of tooth numbers. The precision of the form-cut tooth profile depends on the accuracy of the cutter and the machine and its stiffness.



Form cutters for finishing cutting (*Left*) and for rough cuts (*Right*).



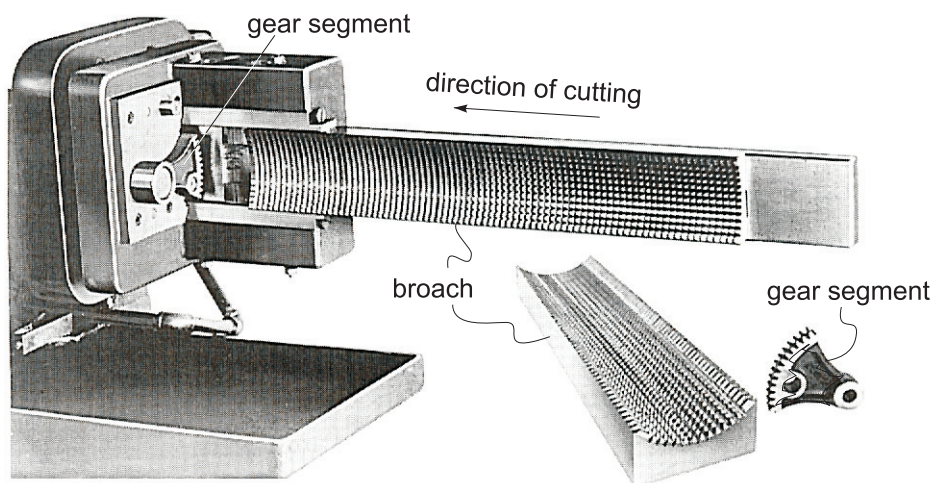
Dividing head (*Left*), and footstock (*Right*) used to index the gear blank in form milling.

In form milling, indexing of the gear blank is required to cut all the teeth. *Indexing* is the process of evenly dividing the circumference of a gear blank into equally spaced divisions. The index head of the indexing fixture is used for this purpose.

The *index fixture* consists of an *index head* (also *dividing head*, *gear cutting attachment*) and *footstock*, which is similar to the tailstock of a lathe. The index head and footstock attach to the worktable of the milling machine. An *index plate* containing graduations is used to control the rotation of the index head spindle. Gear blanks are held between centers by the index head spindle and footstock. Workpieces may also be held in a chuck mounted to the index head spindle or may be fitted directly into the taper spindle recess of some indexing fixtures.

Broaching

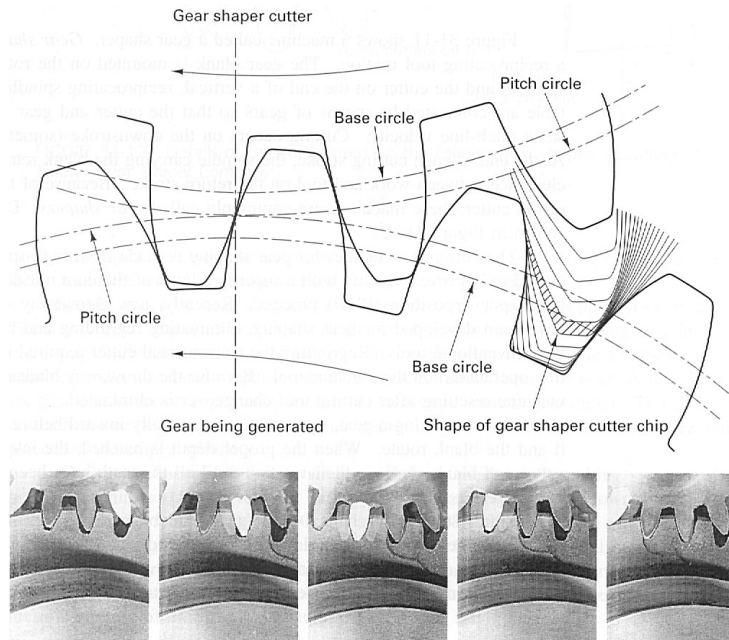
Broaching can also be used to produce gear teeth and is particularly applicable to internal teeth. The process is rapid and produces fine surface finish with high dimensional accuracy. However, because broaches are expensive-and a separate broach is required for each size of gear-this method is suitable mainly for high-quantity production.



Broaching the teeth of a gear segment by horizontal external broaching in one pass.

Gear generation

In *gear generating*, the tooth flanks are obtained (generated) as an outline of the subsequent positions of the cutter, which resembles in shape the mating gear in the gear pair:



Generating action of a gear-shaper cutter; (*Bottom*) series of photographs showing various stages in generating one tooth in a gear by means of a gear shaper, action taking place from right to left, corresponding to a diagram above. One tooth of the cutter was painted white.

In gear generating, two machining processes are employed, shaping and milling. There are several modifications of these processes for different cutting tool used,

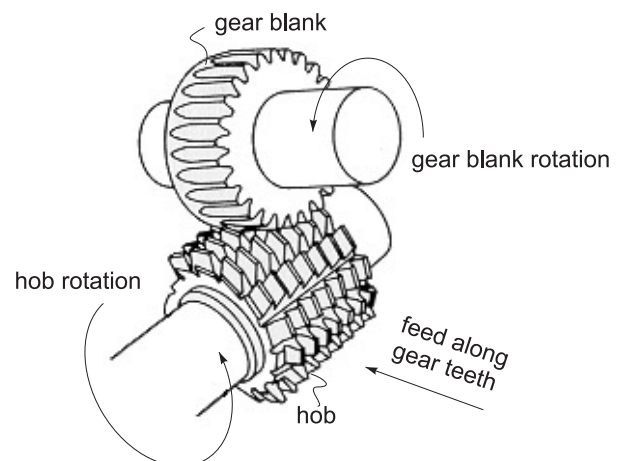
- ❖ milling with a *hob* (*gear hobbing*),
- ❖ gear shaping with a *pinion-shaped cutter*, or
- ❖ gear shaping with a *rack-shaped cutter*.

Cutters and blanks rotate in a timed relationship: a proportional feed rate between them is maintained. Gear generating is used for high production runs and for finishing cuts.

Gear hobbing

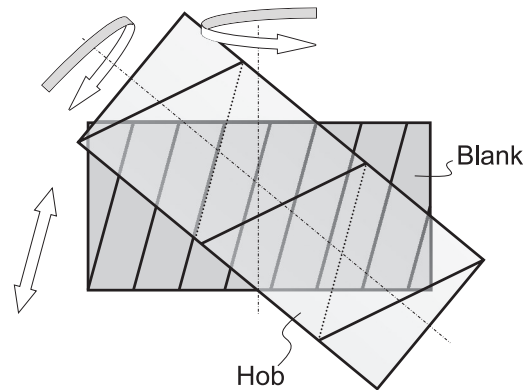
Gear hobbing is a machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (*hob*).

All motions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshing until all teeth are cut.



Setup of gear hobbing operation.

When hobbing a spur gear, the angle between the hob and gear blank axes is 90° minus the lead angle at the hob threads. For helical gears, the hob is set so that the helix angle of the hob is parallel with the tooth direction of the gear being cut. Additional movement along the tooth length is necessary in order to cut the whole tooth length:



Kinematics of the gear hobbing operation for cutting of a helical gear.

The action of the hobbing machine (also *gear hobber*) is shown in the figures. The cutting of a gear by means of a hob is a continuous operation. The hob and the gear blank are connected by a proper gearing so that they rotate in mesh. To start cutting a gear, the rotating hob is fed inward until the proper setting for tooth depth is achieved, then cutting continues until the entire gear is finished.

Machines for cutting precise gears are generally CNC-type and often are housed in temperature controlled rooms to avoid dimensional deformations.



Gear hobbing of a spur gear (*Left*), and an operator adjusting a CNC gear hobber (*Right*).

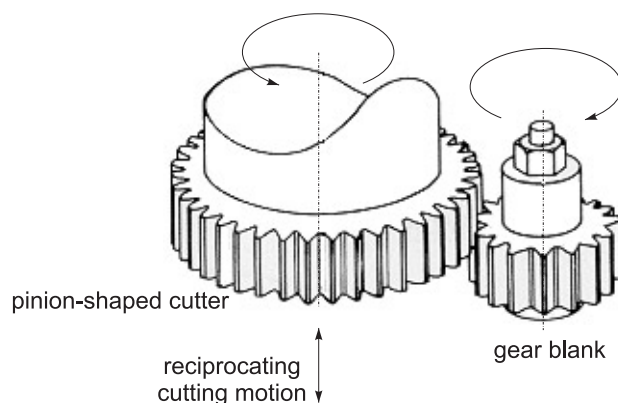
The *gear hob* is a formed tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges.



Coated HSS gear hob.

Shaping with a pinion-shaped cutter

This modification of the gear shaping process is defined as a process for generating gear teeth by a rotating and reciprocating pinion-shaped cutter:



Setup of gear shaping operation with a pinion-shaped cutter.



Coated HSS pinion-shaped gear cutter.

The cutter axis is parallel to the gear axis. The cutter rotates slowly in timed relationship with the gear blank at the same pitch-cycle velocity, with an axial primary reciprocating motion, to produce the gear teeth.

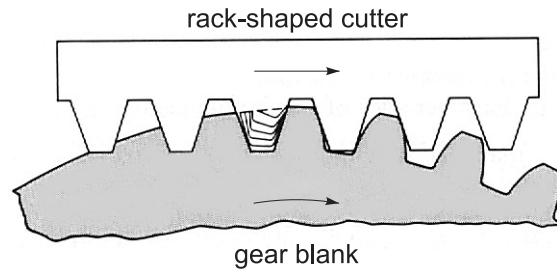
A train of gears provides the required relative motion between the cutter shaft and the gear-blank shaft. Cutting may take place either at the downstroke or upstroke of the machine. Because the clearance required for cutter travel is small, gear shaping is suitable for gears that are located close to obstructing surfaces such as flanges.

The tool is called gear cutter and resembles in shape the mating gear from the conjugate gear pair, the other gear being the blank.

Gear shaping is one of the most versatile of all gear cutting operations used to produce internal gears, external gears, and integral gear-pinion arrangements. Advantages of gear shaping with pinion-shaped cutter are the high dimensional accuracy achieved and the not too expensive tool. The process is applied for finishing operation in all types of production rates.

Shaping with a rack-shaped cutter

In the gear shaping with a rack-shaped cutter, gear teeth are generated by a cutting tool called a *rack shaper*. The rack shaper reciprocates parallel to the axis of the gear axis. It moves slowly linearly with the gear blank rotation at the same pitch-cycle velocity:



Setup of gear shaping operation with a rack-shaped cutter.

The rack shaper is actually a segment of a rack. Because it is not practical to have more than 6-12 teeth on a rack cutter, the cutter must be disengaged at suitable intervals and returned to the starting point, the gear blank meanwhile remaining fixed.

Advantages of this method involve a very high dimensional accuracy and cheap cutting tool (the rack shaper's teeth blanks are straight, which makes sharpening of the tool easy). The process can be used for low-quantity as well as high-quantity production of spur and helix external gears.

Finishing operations

As produced by any of the process described, the surface finish and dimensional accuracy may not be accurate enough for certain applications. Several *finishing* operations are available, including the conventional process of *shaving*, and a number of abrasive operations, including *grinding*, *honoring*, and *lapping*.