Machining Processes and Metrology

Course code: **MEE2006**

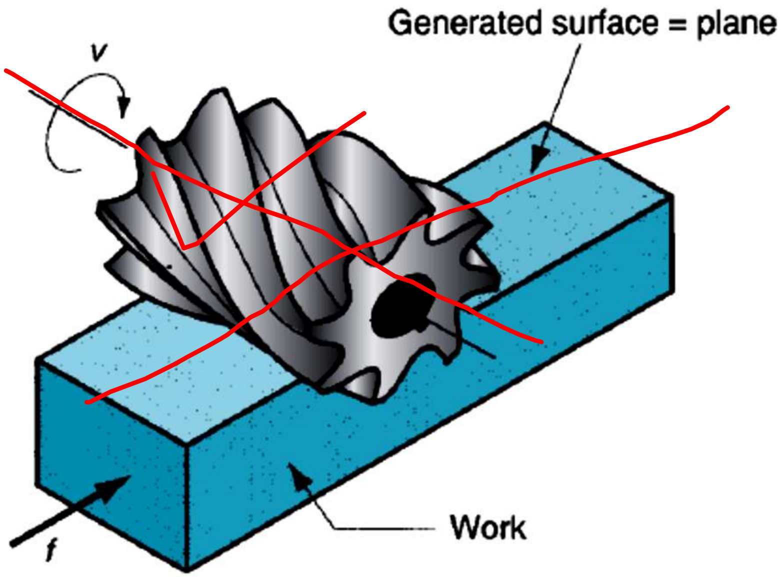
CAT 2 portion

Milling

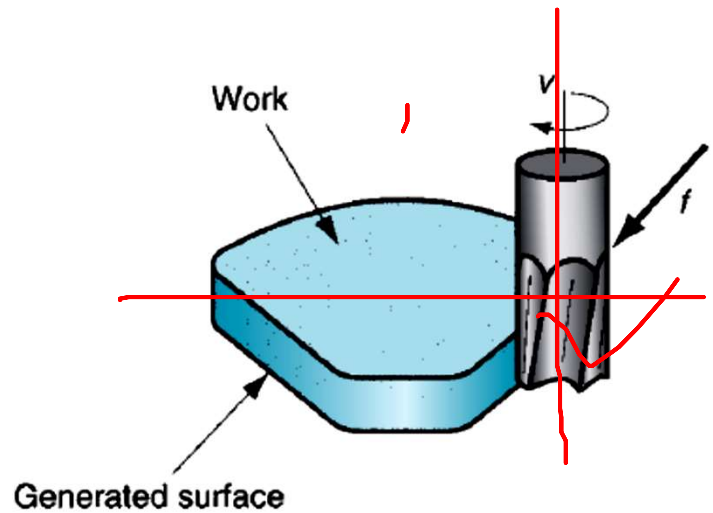
Animation - Milling Machine - Working Principle

Milling

- Milling is a machining operation in which a workpart is fed past a rotating cylindrical tool with multiple cutting edges.



Plain milling



Profile milling

Milling

- The axis of rotation of the cutting tool is perpendicular to the direction of feed.
  - This orientation between the tool axis and the feed direction is one of the features that distinguishes milling from drilling.
  - In drilling, the cutting tool is fed in a direction parallel to its axis of rotation.
- The cutting tool in milling is called a **milling cutter** and the cutting edges are called **teeth**.
- The geometric form created by milling is a plane surface.
- Other work geometries can be created either by means of the cutter path or the cutter shape.
- Owing to the variety of shapes possible and its high production rates, milling is one of the most versatile and widely used machining operations.

Milling

- Milling is an interrupted cutting operation; the teeth of the milling cutter enter and exit the work during each revolution.
- This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation.
- The tool material and cutter geometry must be designed to withstand these conditions.

Animation - Milling Operations

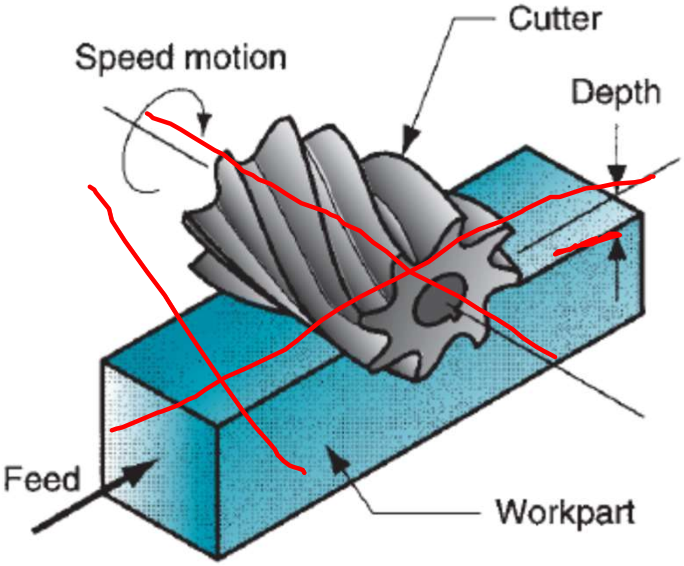
Types of milling operations

Peripheral Milling (Plain milling)

- The axis of the tool is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter.

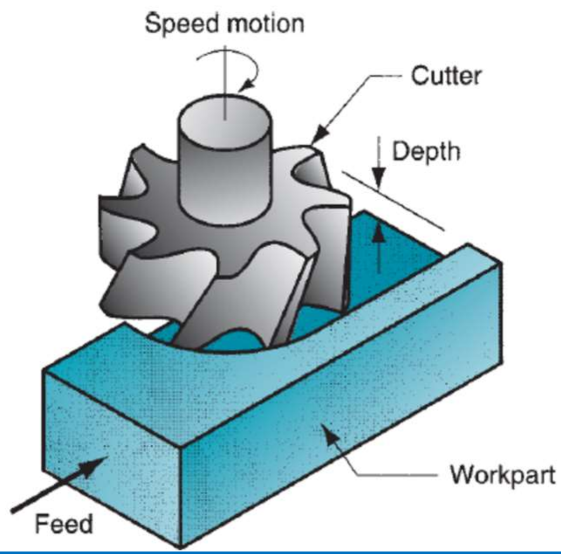
Face Milling

- The axis of the cutter is perpendicular to the surface being milled, and machining is performed by cutting edges on both the end and outside periphery of the cutter.



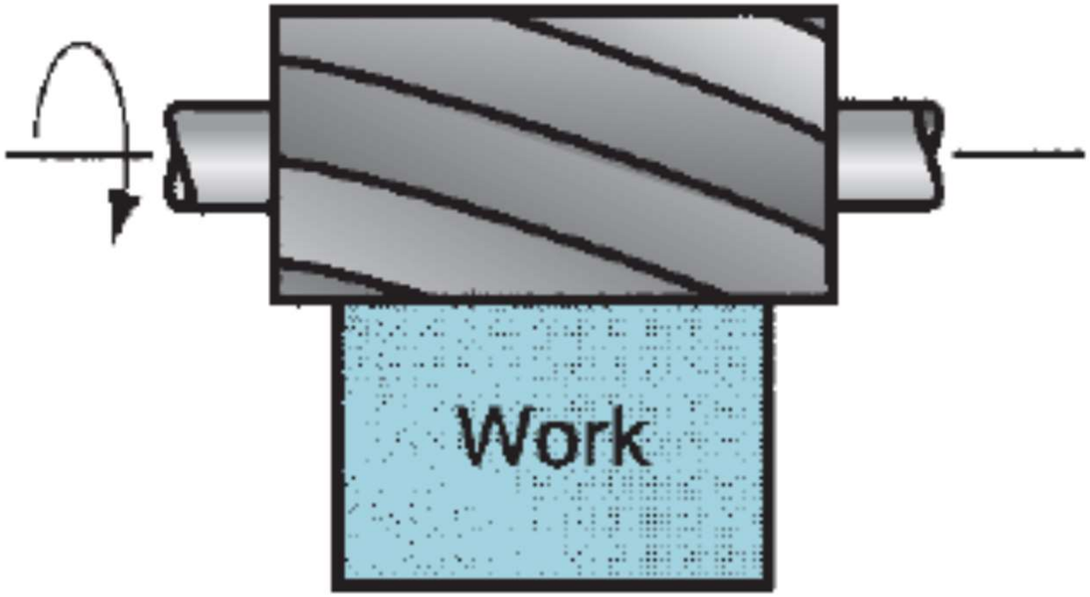
Peripheral Milling

Face Milling



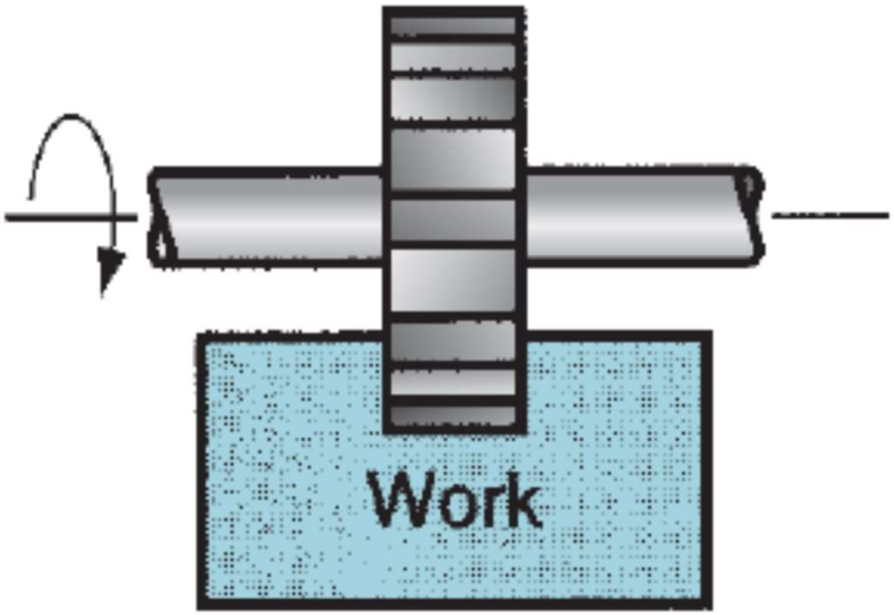
(a) slab milling

The basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides



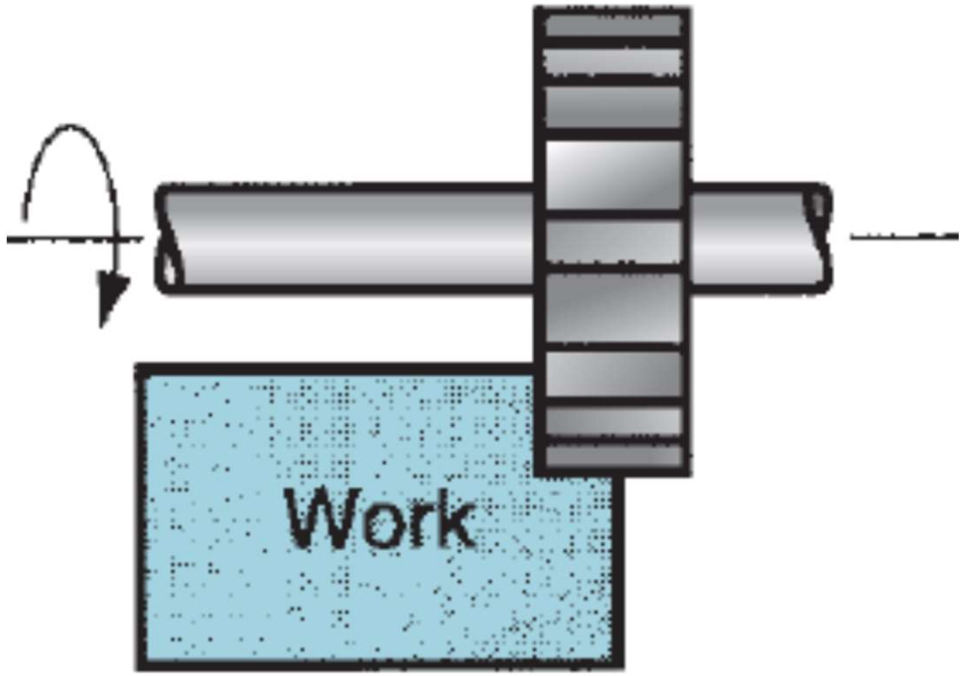
(b) Slotting (also called as slot milling)

- In which the width of the cutter is less than the workpiece width, creating a slot in the work
- when the cutter is very thin, this operation can be used to mill narrow slots or cut a workpart in two, called saw milling



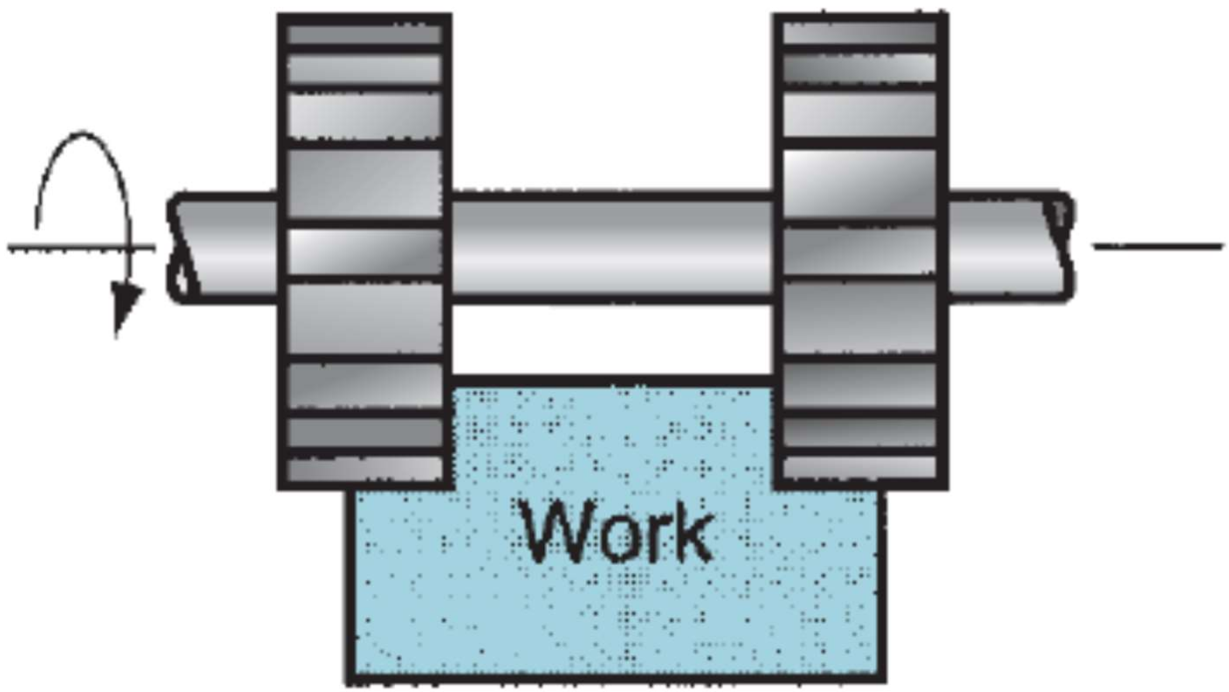
(c) Side milling

The cutter machines the side of the workpiece



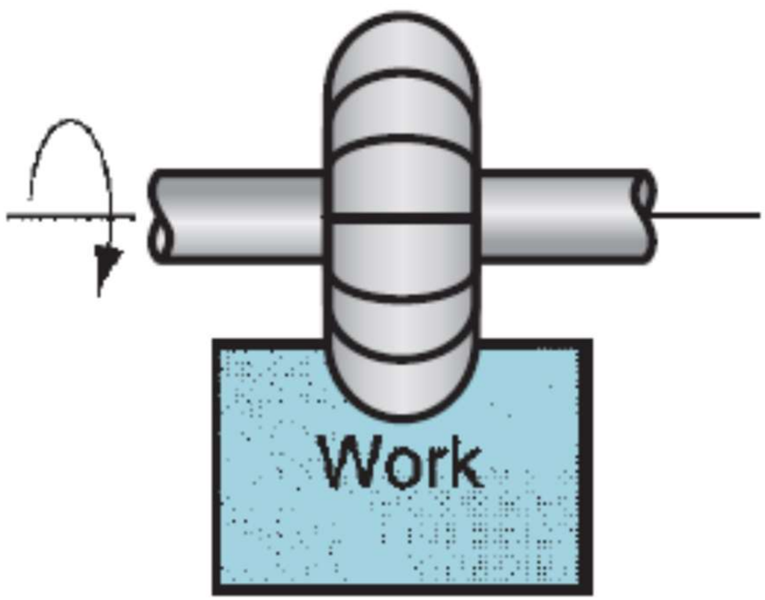
(d) Straddle milling

- The same as side milling, only cutting takes place on both sides of the work



(e) Form milling

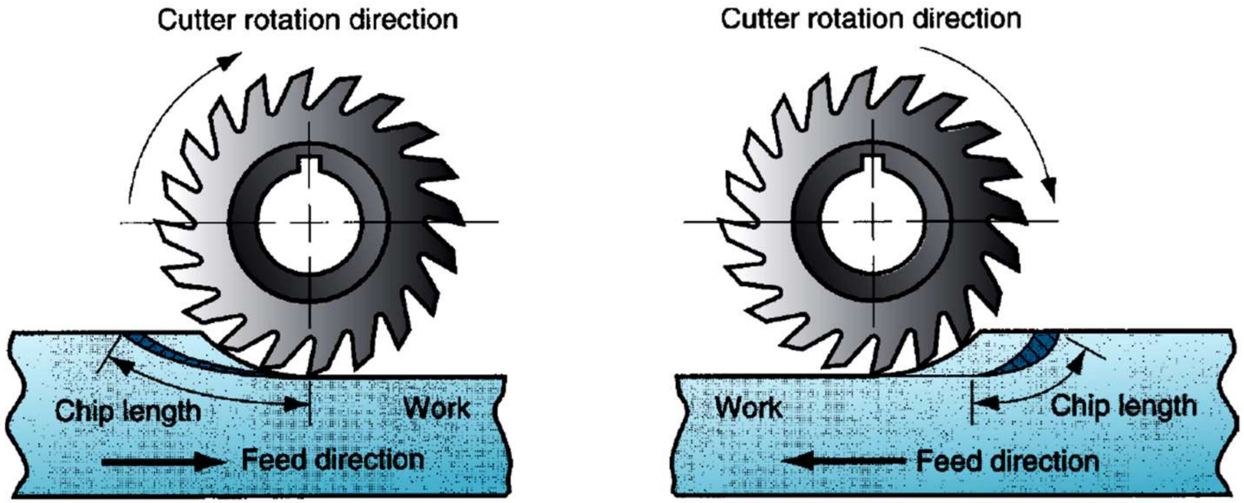
- The milling teeth have a special profile that determines the shape of the slot that is cut in the work. Form milling is therefore classified as a *forming operation*



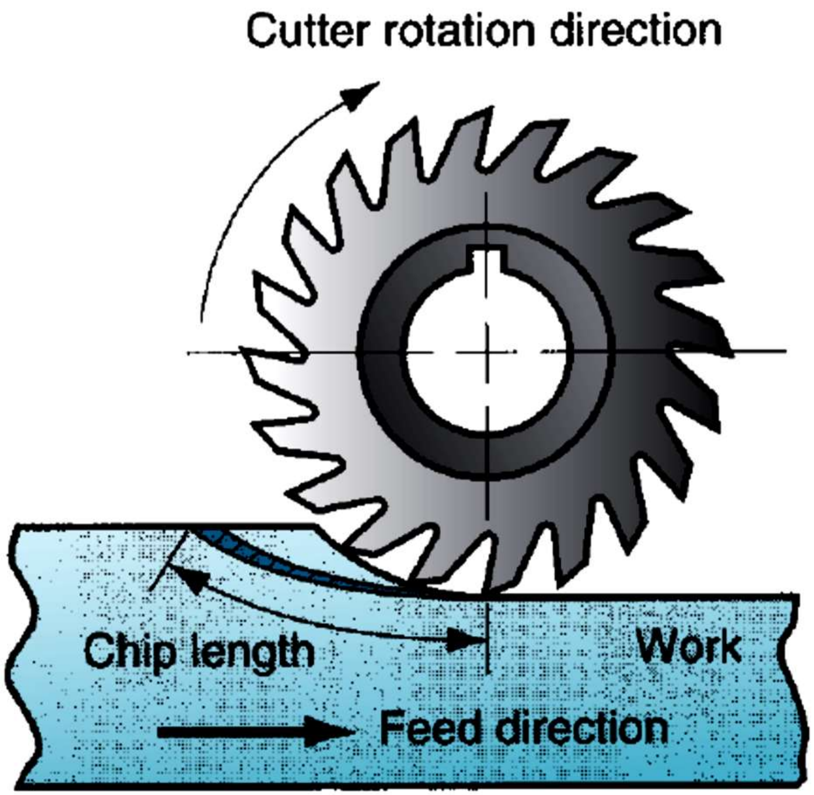
Peripheral milling

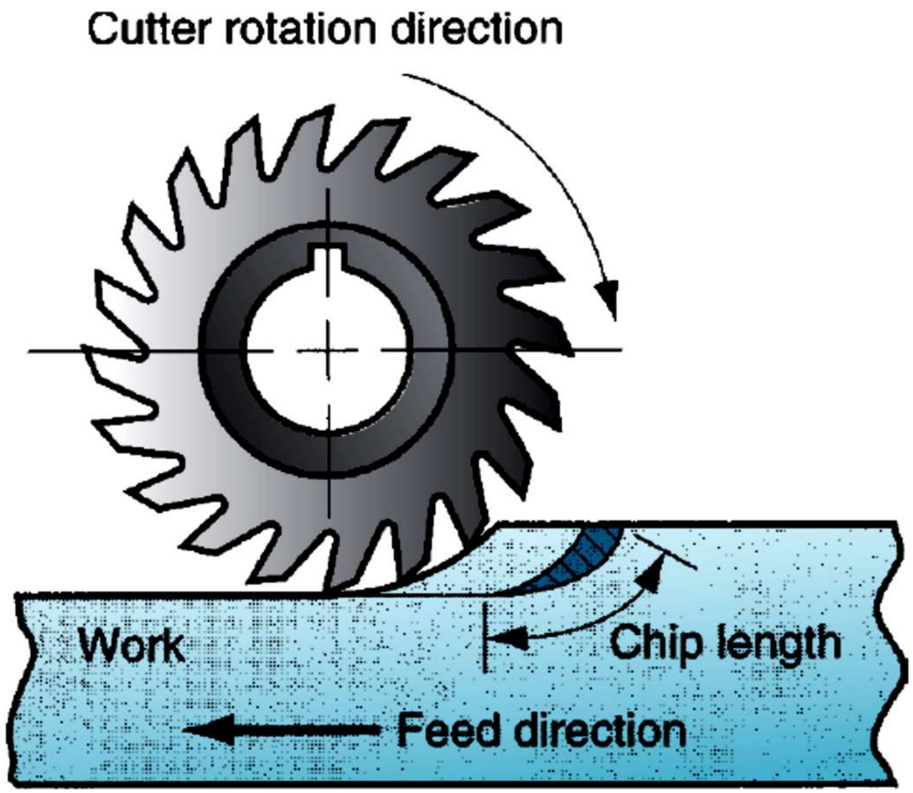
In **peripheral milling**, the direction of cutter rotation distinguishes two forms of milling: ***up milling*** and ***down milling***

1. In ***up milling***, also called ***conventional milling***, the direction of motion of the cutter teeth is ***opposite the feed*** direction when the teeth cut into the work. It is milling ''***against the feed***.''
2. In ***down milling***, also called ***climb milling***, the direction of cutter motion is the ***same as the feed*** direction when the teeth cut the work. It is milling ''***with the feed.***''



Up milling vs. Down milling

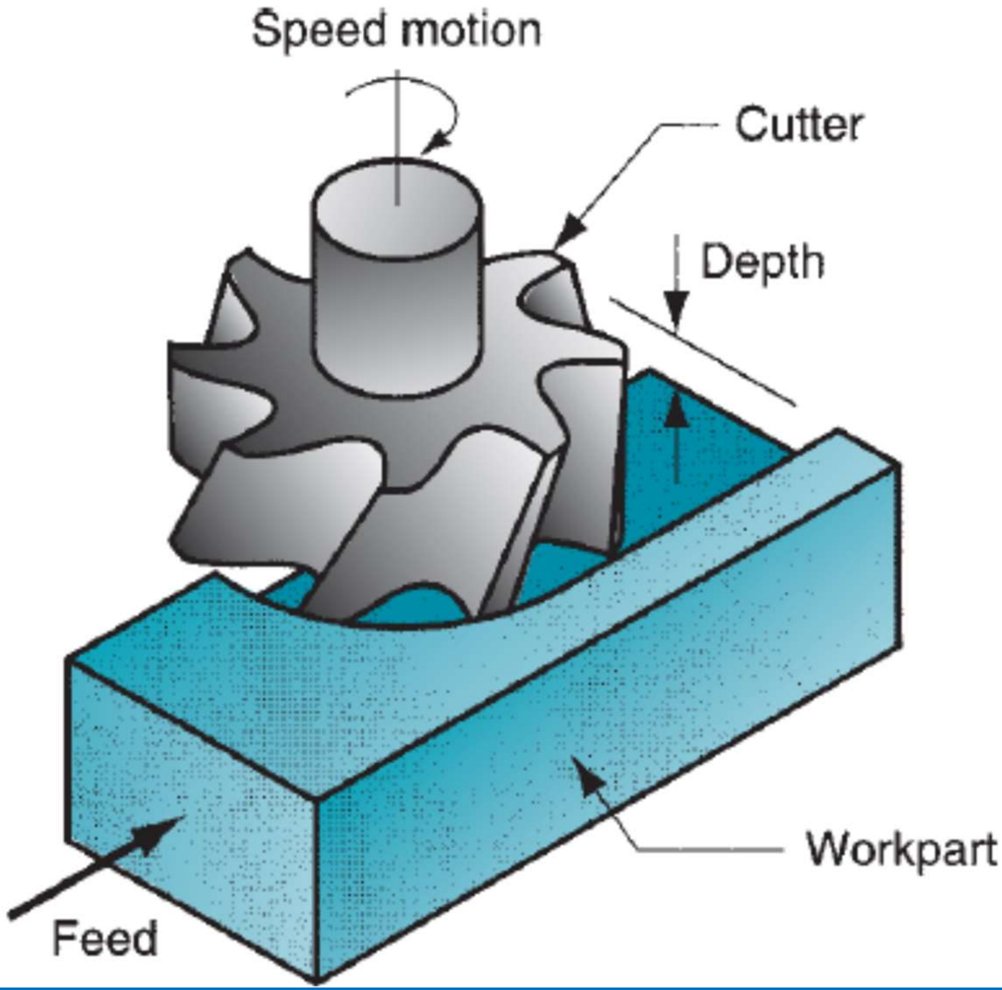




Up milling vs. Down milling

Up milling (This is the more common method of milling)	Down milling
The maximum chip thickness is at the end of the cut	Cutting starts at the surface of the workpiece where the chip is thickest.
Advantage: 1. Tooth engagement is not a function of workpiece surface characteristics	Advantage: The downward component of the cutting force holds the workpiece in place, particularly for slender parts.
2. Contamination or scale (oxide layer) on the surface does not adversely affect tool life	must have a rigid work-holding setup to withstand impact load, and gear backlash must be eliminated in the table feed mechanism
The cutting process is smooth smooth, provided that the cutter teeth are sharp. Otherwise, the tooth will rub against and smear the surface for some distance before it begins to cut.	not suitable for the machining of workpieces having surface scale, such as hot-worked metals, forgings, and castings
There may be a tendency for the tool to chatter, and the workpiece has a tendency to be pulled upward (because of the cutter rotation direction), necessitating proper clamping	The scale is hard and abrasive and causes excessive wear and damage to the cutter teeth, thus shortening tool life.

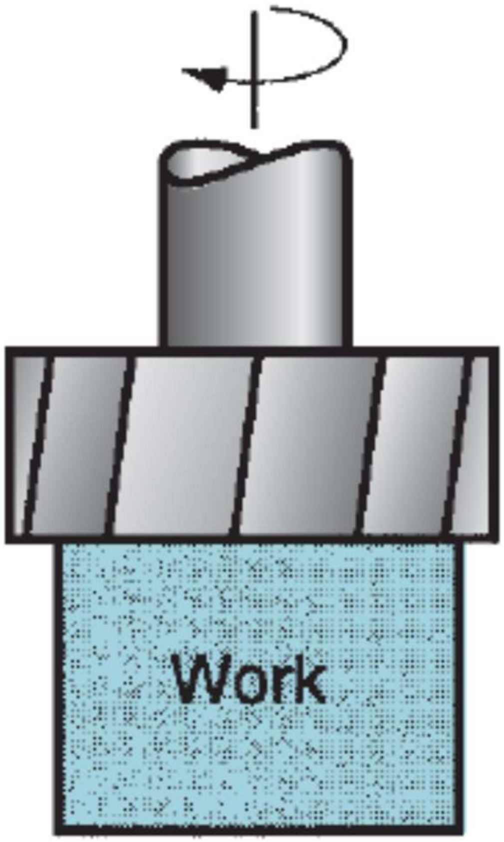
In face milling, the axis of the cutter is perpendicular to the surface being milled, and machining is performed by cutting edges on both the end and outside periphery of the cutter.



Face Milling

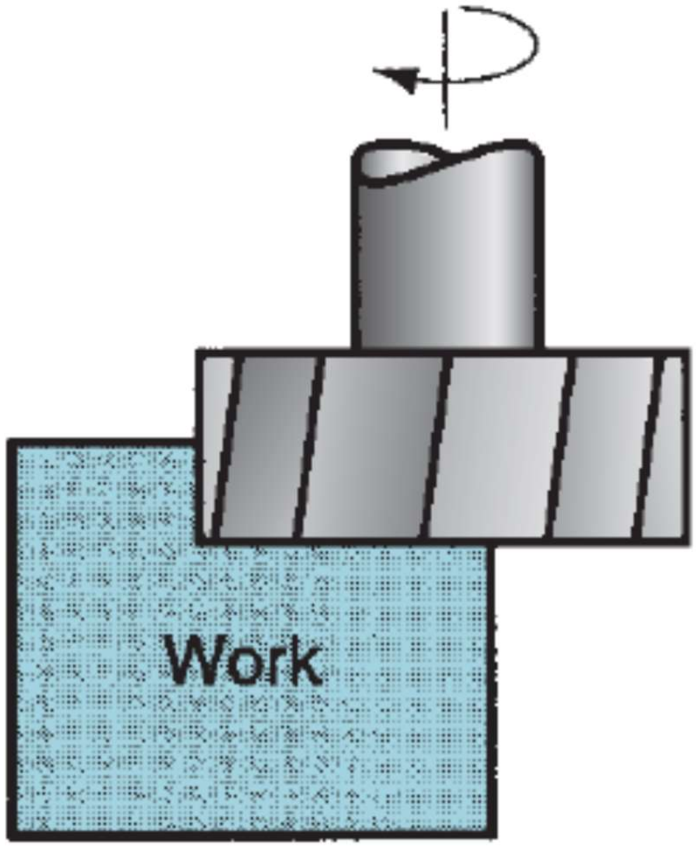
Conventional face milling

- The diameter of the cutter is greater than the workpart width, so the cutter overhangs the work on both sides



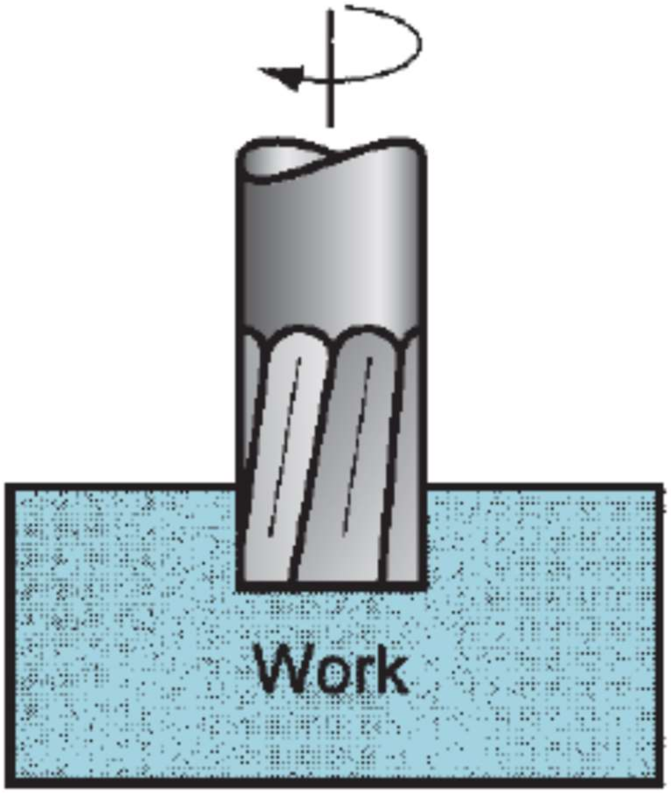
Partial face milling

- The cutter overhangs the work on only one side



End milling

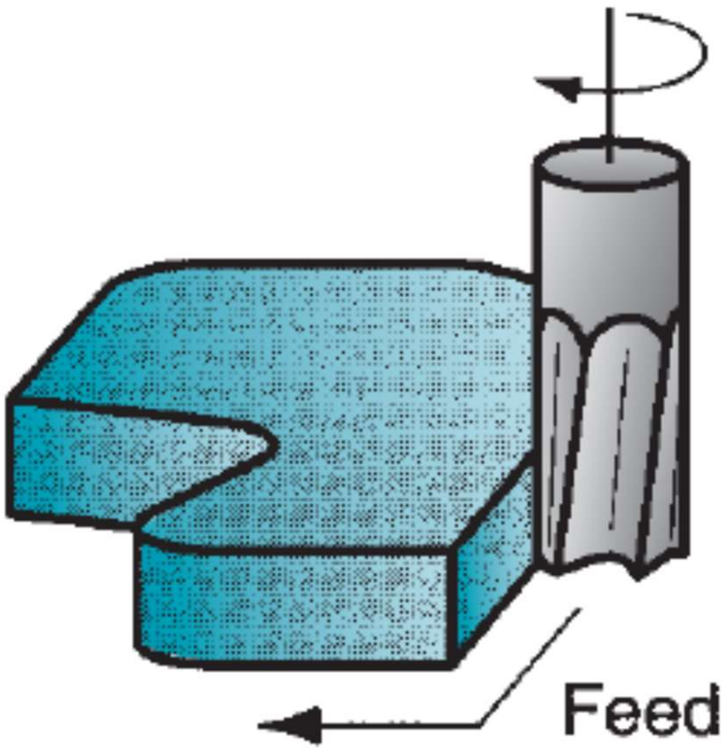
- The cutter diameter is less than the work width, so a slot is cut into the part



Face Milling

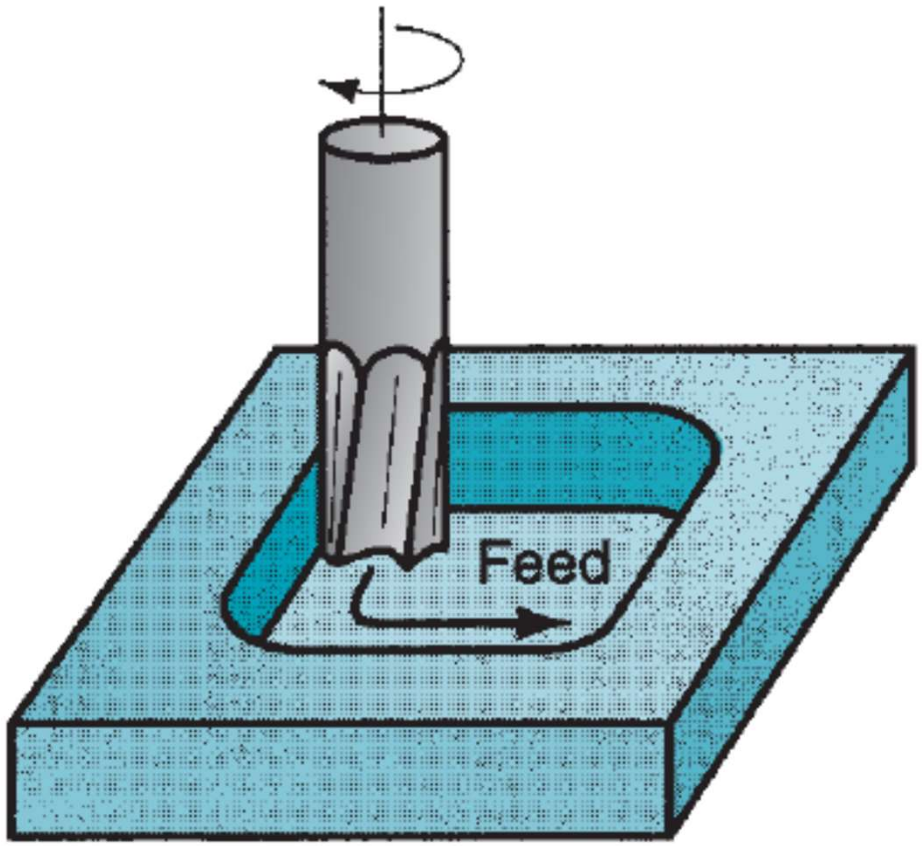
Profile milling

- A form of end milling in which the outside periphery of a flat part is cut



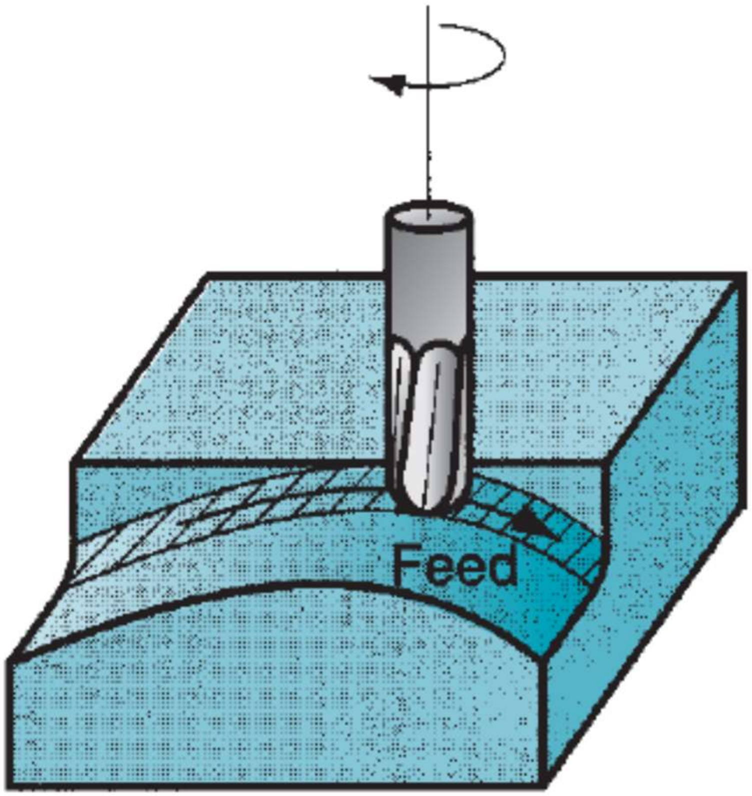
Pocket milling

- Another form of end milling used to mill shallow pockets into flat parts



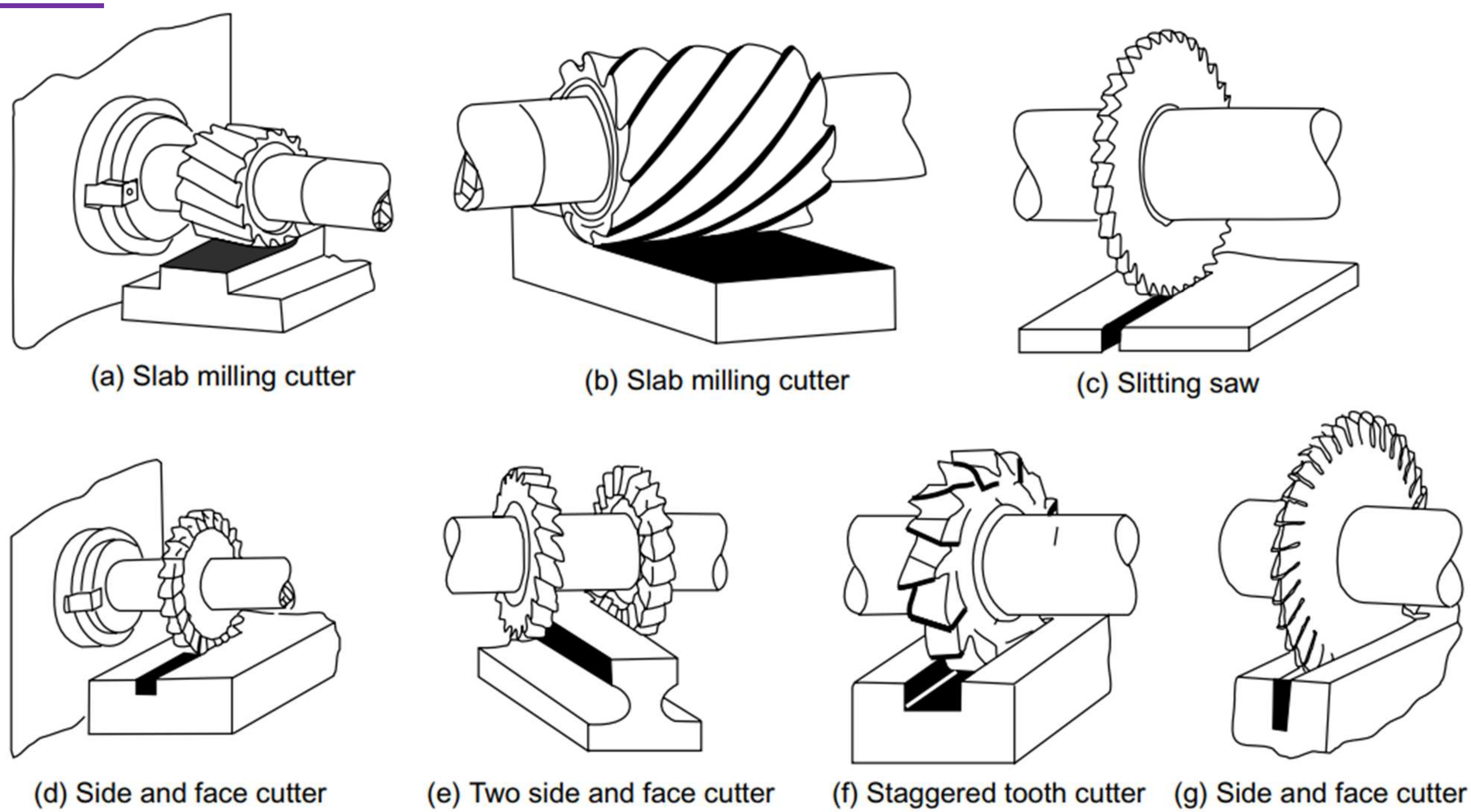
Surface contouring

A ball-nose cutter (rather than square-end cutter) is fed back and forth across the work along a curvilinear path at close intervals to create a three dimensional surface form.

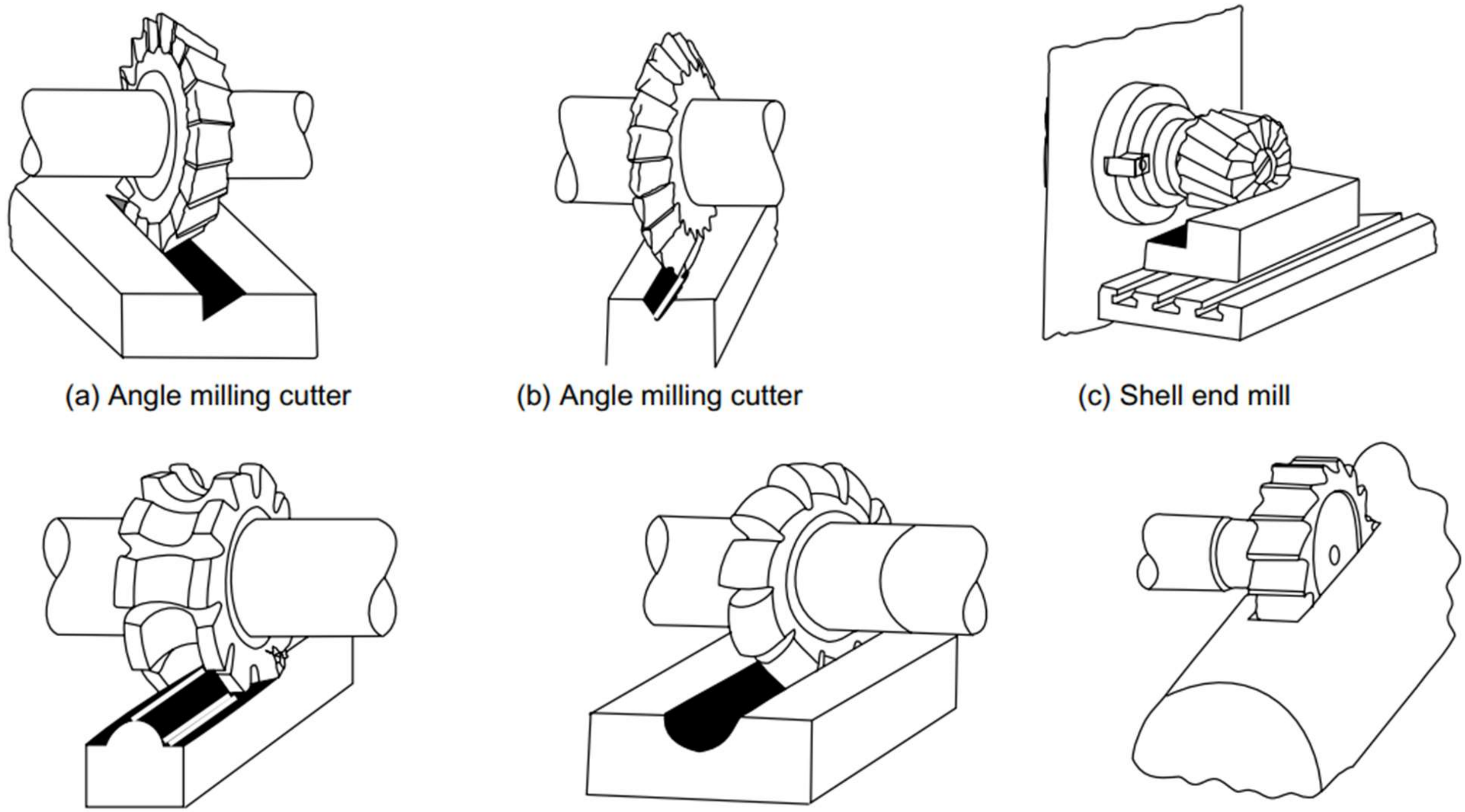


Animation - Milling Cutter

CUTTERS



Arbor mounted milling cutters general purpose



(a) Angle milling cutter
(b) Angle milling cutter
(c) Shell end mill
(d) Form relieved circular cutter
(e) Form relieved circular cutter
(f) Woodruff key cutter

Arbor mounted milling cutters special forms

Cutting conditions in milling

1. The cutting speed is determined at the outside diameter of a milling cutter. This can be converted to spindle rotation speed using a formula that should now be familiar:

$$N = \frac{v}{\pi D}$$

2. The feed f in milling is usually given as a feed per cutter tooth; called the chip load, it represents the size of the chip formed by each cutting edge.

$$f_r = N n_t f$$

where f_r = feed rate, mm/min; N = spindle speed, rev/min;

n_t = number of teeth on the cutter; and f = chip load in mm/tooth (in/tooth).

Material removal rate in milling

- Material removal rate in milling determined using the product of the cross sectional area of the cut and the feed rate
- if a slab-milling operation is cutting a workpiece with width w at a depth d, the material removal rate is

$$R_{MR} = wdf_r$$

The time required to mill a workpiece

- The time required to mill a workpiece of length L must account for the approach distance required to fully engage the cutter
- First, consider the case of slab milling as shown here.
- approach distance A to reach full cutter depth is given by

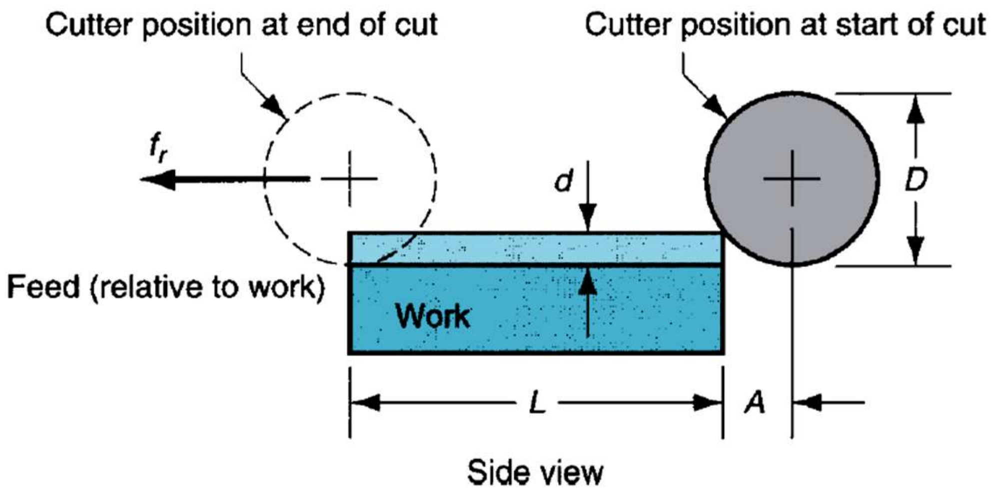
$$A = \sqrt{d(D - d)}$$

where d = depth of cut, mm.

D = diameter of the milling cutter,mm.

The time T_m in which the cutter is engaged milling the workpiece is therefore

$$T_m = \frac{L + A}{f_r}$$



- A peripheral milling operation is performed on the top surface of a rectangular workpart which is 400 mm long and 60 mm wide. The milling cutter, which is 80 mm in diameter and has five teeth, overhangs the width of the part on both sides. Cutting speed = 70 m/min, chip load = 0.25 mm/tooth, and depth of cut = 5.0 mm. Determine (a) the actual machining time to make one pass across the surface and (b) the maximum material removal rate during the cut.

Solution: (a) $N = v/\pi D = 70{,}000 \text{ mm}/80\pi = 279$ rev/min

$f_r = N n_t f = 279(5)(0.25) = 348$ mm/min

$A = (d(D-d))^{0.5} = (5(80-5))^{0.5} = 19.4$ mm

$T_m = (400 + 19.4)/348 = \mathbf{1.20\ min}$

(b) $R_{MR} = w d f_r = 60(5)(348) = \mathbf{104{,}400\ mm^3/min}$

Problems: milling

- A face milling operation is used to machine 6.0 mm from the top surface of a rectangular piece of aluminum 300 mm long by 125 mm wide in a single pass. The cutter follows a path that is centered over the workpiece. It has four teeth and is 150 mm in diameter. Cutting speed = 2.8 m/s, and chip load = 0.27 mm/tooth. Determine (a) the actual machining time to make the pass across the surface and (b) the maximum metal removal rate during cutting.

Solution: (a) $N = v/\pi D = (2800 \text{ mm/s})/150\pi = 5.94$ rev/s

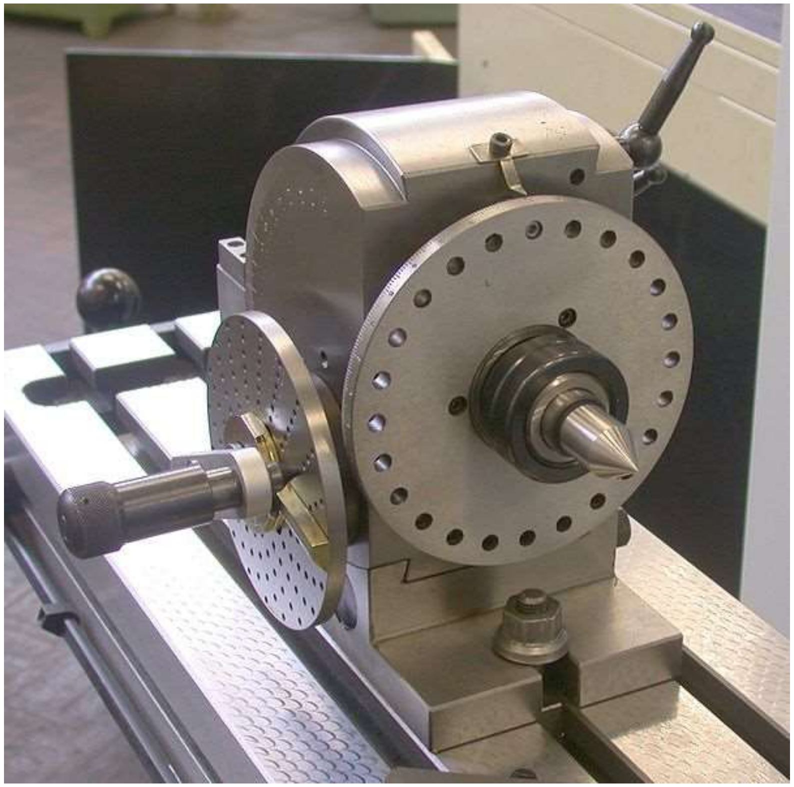
$f_r = Nn_t f = 5.94(4)(0.27) = 6.42$ mm/s

$A = D/2 = 150/2 = 75$ mm

$T_m = (L + 2A)/f_r = (300 + 2(75))/6.42 =$ **70 s = 1.17 min**

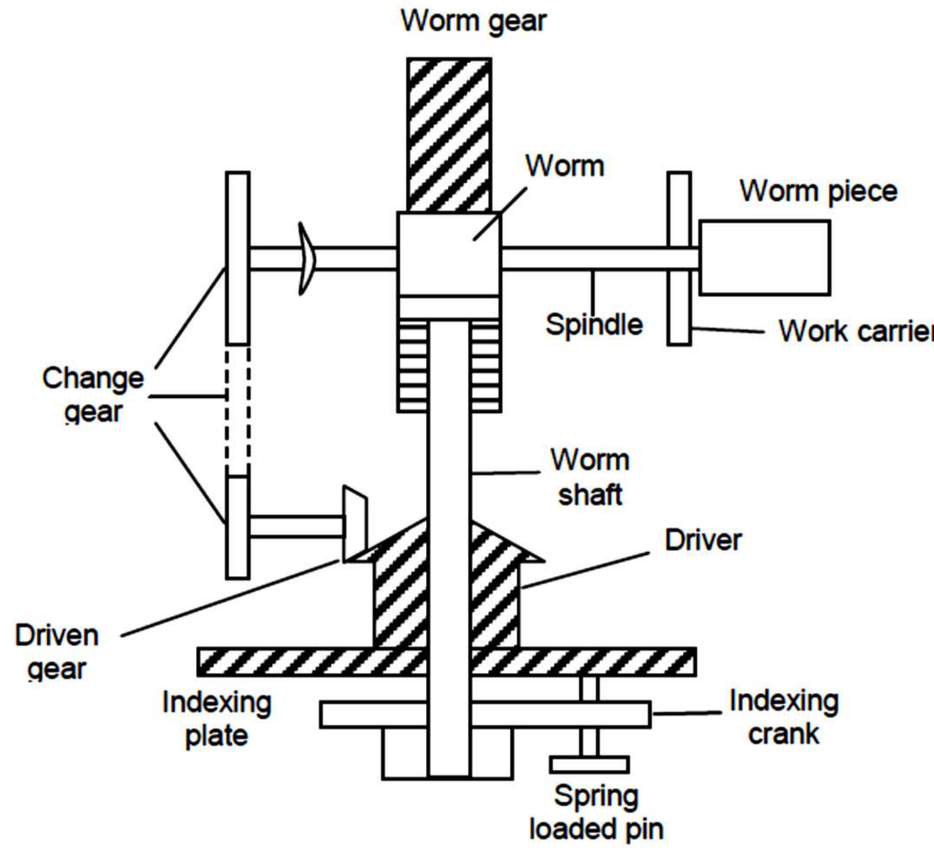
(b) $R_{MR} = wdf_r = 125(6)(6.42) =$ **4813 mm³/s**

Indexing is an operation of dividing a periphery of a cylindrical workpiece into equal number of divisions by the help of index crank and index plate.



Universal Dividing Head

- It is most popular and common type of indexing arrangement.
- Used to do all types of indexing on a milling machine
- Can set the workpiece in vertical, horizontal, or in inclined position relative to the worktable



Universal Dividing Head

- If we revolve crank by 40 revolutions the spindle attached with worm gear will revolve by only one revolution and one complete turn of the crank will revolve the spindle only by 1/40th revolution (turn).
- In order to turn the crank precisely a fraction of a revolution, an indexing plate is used. An indexing plate is like a circular disc having concentric rings of different number of equally spaced holes.

Indexing Methods

1. Direct indexing
2. Simple indexing
3. Compound indexing
4. Differential indexing

Direct indexing

- It is also named as rapid indexing
- Direct indexing plate is usually consists of 24 equally spaced holes in a circle
- It is possible to divide the surface of workpiece into any number of equal divisions out of
  - 2, 3, 4, 6, 8, 12, 24 parts

Example: If we want to divide the surface into 6 parts?

Number of holes by which pin is to be moved $= \frac{24}{N}$

$$= \frac{26}{6} = 4$$

that is after completing one pair of milling, whole surface of workpiece we have to move the pin by 4 holes before next milling operation

Simple Indexing

- It is also named as plain indexing.
- One complete turn of indexing crank revolves the workpiece by 1/ 40th revolution.
- Three indexing plates are used. These plates have concentric circles of holes with their different numbers as described below:

Plate No. 1	15	16	17	18	19	20
Plate No. 2	21	23	27	29	31	33
Plate No. 3	37	39	41	43	47	49

These are the standard indexing plates followed by all machine tool manufacturers.

Simple Indexing (continued…)

Indexing procedure:

1. Divide 40 by the number of divisions to be done on the circumference of workpiece. This gives movement of indexing crank.

   Indexing crank movement $= \dfrac{40}{N}$

   N is the number of divisions to be made on the circumference of workpiece.

2. If the above number is a whole number, then crank is rotated by that much number of revolutions after each milling operations, till the completion of the work.

Simple Indexing (continued…)

- For example, if we want to divide the circumference into 10 number of parts.
- Indexing crank movement $= \frac{40}{10} = 4$ revolutions.
- That is the indexing crank is given 4 revolutions after each of milling operation for 9 more milling operations.
- If indexing crank movement calculated by $\frac{40}{N}$ is not whole number,

  it is simplified and then expressed as a whole number and a fraction.

- The fractional part of the above number is further processed by multiplying its denominator and numerator by a suitable common number so that the denominator will turn to a number equal to any number of holes available on the any of indexing plates.
- That particular holes circle is selected for the movement of crank pin.
- The numerator of the process fraction stands for the number of holes to be moved by the indexing crank in the selected hole circle in addition to complete turns of indexing crank equal to whole number part of $\frac{40}{N}$.

Simple Indexing (continued…)

1. Let us do the indexing to cut 30 teeth on a spur gear blank that means we need to divide the circumference of gear blank into 30 identical, parts.
2. Crank movement $= \dfrac{40}{N} = \dfrac{40}{30}$

$$= 1\frac{10}{30} = 1\frac{1}{3}$$

$$= 1\frac{5}{15}$$

1. Let us do the indexing to cut 22 teeth on a spur gear blank that means we need to divide the circumference of gear blank into 22 identical, parts.

= 40/N = 40/22 = 1 + 18/22 = 1+ 9/11

Plate No. 1	15	16	17	18	19	20
Plate No. 2	21	23	27	29	31	33
Plate No. 3	37	39	41	43	47	49

= 1+ 27/33

Limitations of this method:

This method can used for indexing upto 50 for any number of divisions after 50 this method is not capable for some numbers like 96, etc. Compound indexing overcomes the limitations.

Milling Machines

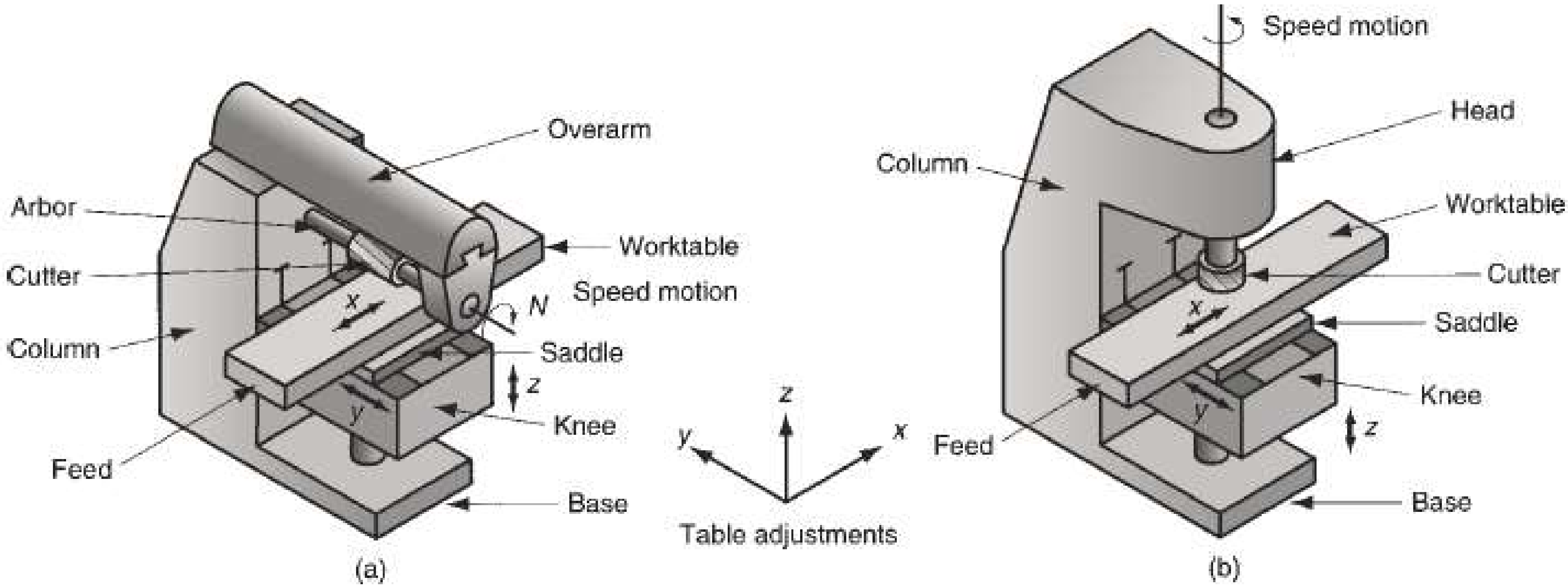
- Milling machines can be classified as horizontal or vertical
- A horizontal milling machine
  - has a horizontal spindle,
  - well suited for performing peripheral milling (e.g., slab milling, slotting, side and straddle milling) on workparts that are roughly cube shaped
- A vertical milling machine
  - has a vertical spindle,
  - this orientation is appropriate for face milling, end milling, surface contouring, and die sinking on relatively flat workparts.

Types of Milling Machines

Types of Milling Machines

- Milling machines can be classified as **horizontal** or **vertical**.
- A **horizontal milling machine** has a horizontal spindle, and this design is well suited for performing peripheral milling (e.g., slab milling, slotting, side and straddle milling) on workparts that are roughly cube shaped.
- A **vertical milling machine** has a vertical spindle, and this orientation is appropriate for face milling, end milling, surface contouring, and die sinking on relatively flat workparts.
- Other than spindle orientation, milling machines can be classified into the following…
  - **knee-and-column,**
  - **bed type,**
  - **planer type,**
  - **tracer mills, and**
  - **CNC milling machines**

Knee-and-column type milling machines



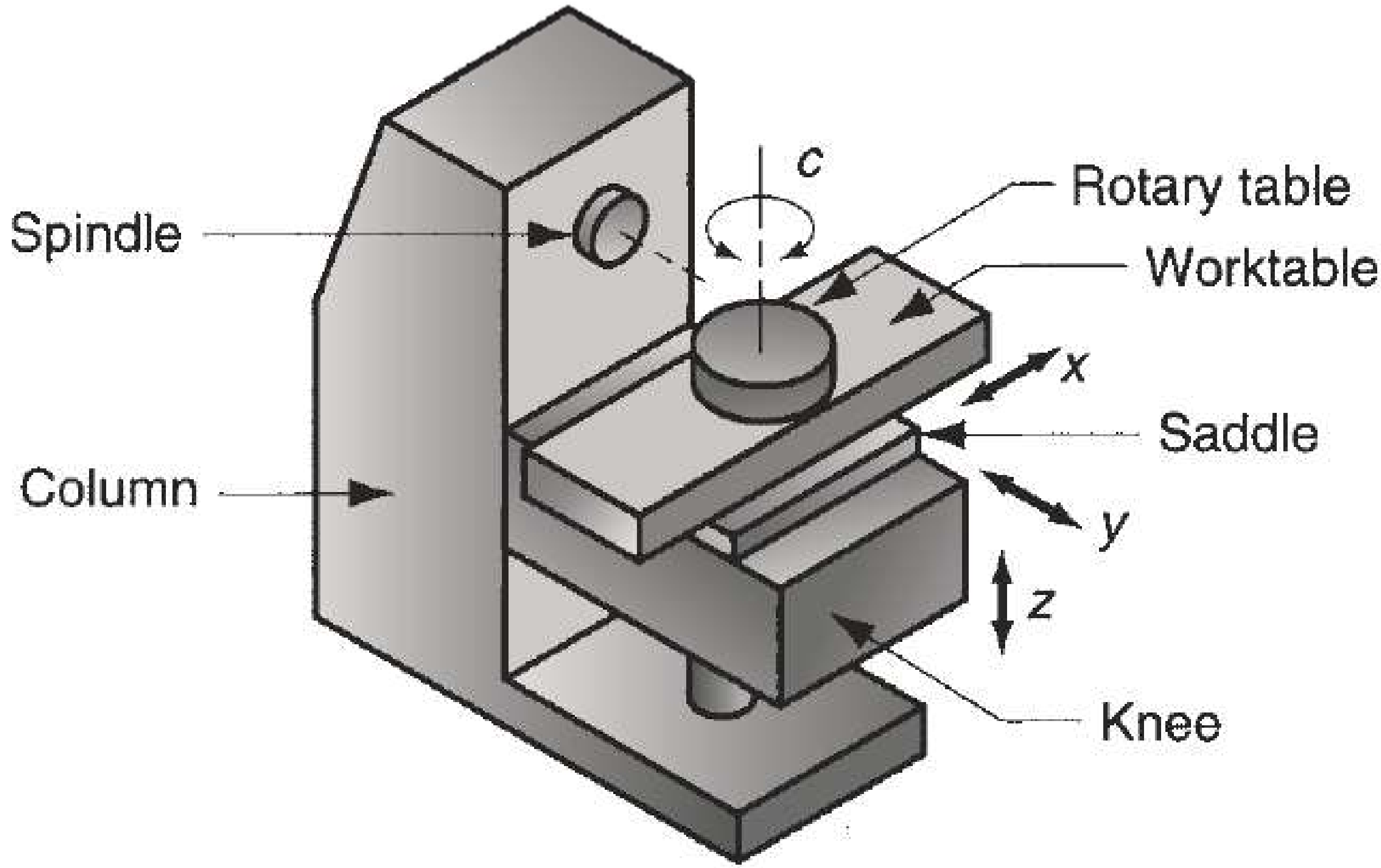
Two basic types of knee-and-column milling machine: (a) horizontal and (b) vertical.

1. Knee-and-column type milling machines

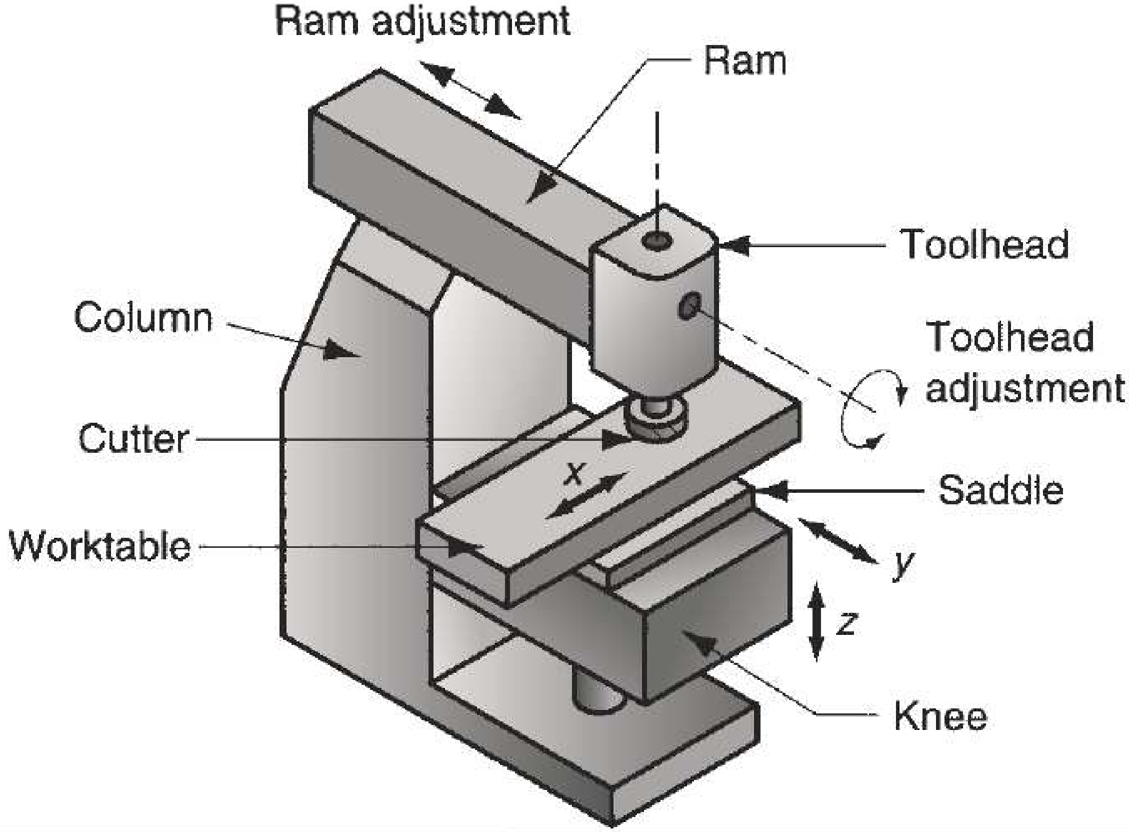
a. Has a column that supports the spindle, and
b. Has a knee (roughly resembling a human knee) that supports the worktable.
c. In case of horizontal type milling machine, the arbor is basically a shaft that holds the milling cutter and is driven by the spindle.
d. An overarm is provided on horizontal machines to support the arbor.
e. On vertical knee-and-column machines, milling cutters can be mounted directly in the spindle without an arbor.

- Knee-and-column milling machines are **versatile** due to their capability for worktable feed movement in any of the x–y–z axes.
  - The worktable can be moved in the x-direction, the saddle can be moved in the y-direction, and the knee can be moved vertically to achieve the z-movement.

- It has a table that can be swiveled in a horizontal plane (about a vertical axis) to any specified angle.
- This facilitates the cutting of angular shapes and helixes on workparts.

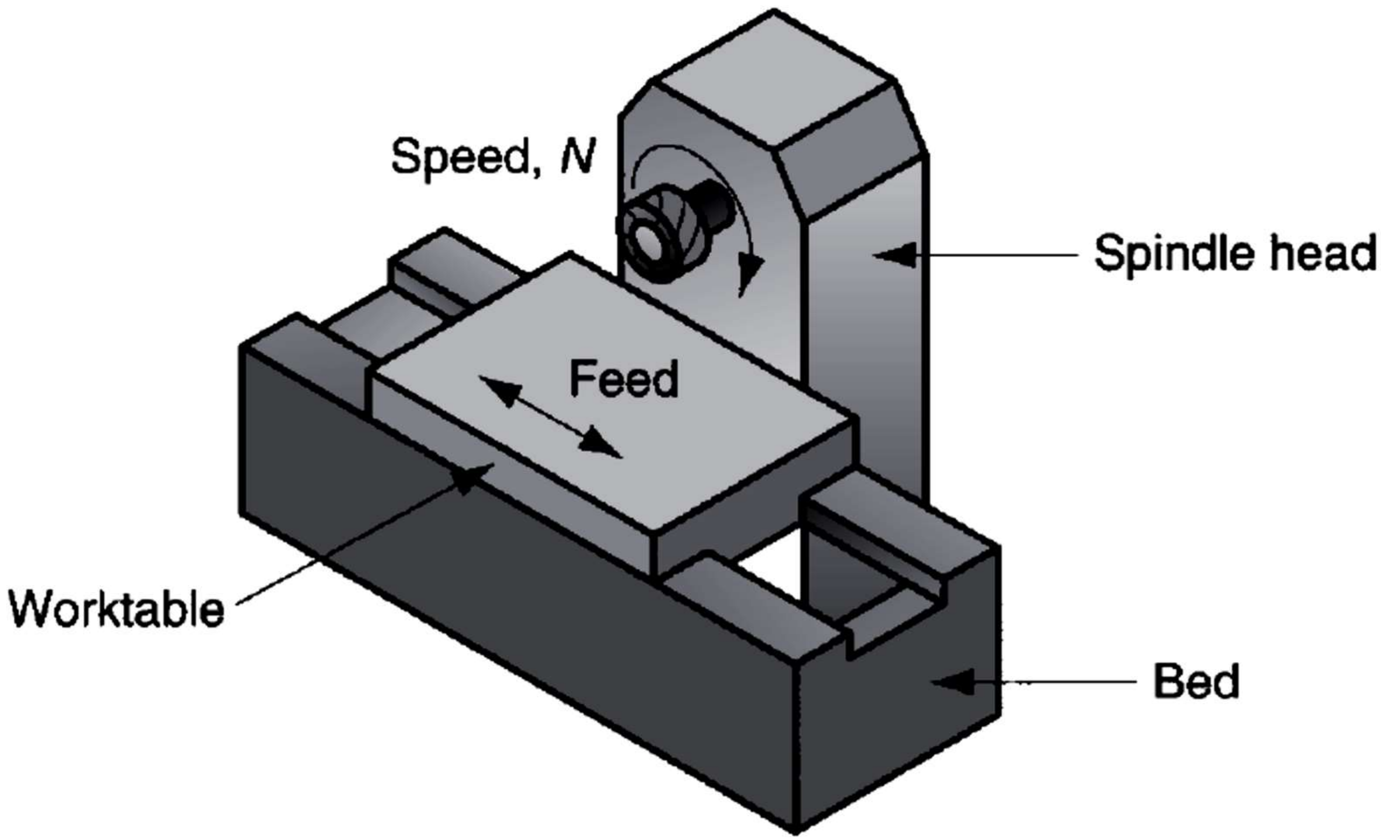


- The toolhead containing the spindle is located on the end of a horizontal ram; the ram can be adjusted in and out over the worktable to locate the cutter relative to thework.
- The toolhead can also be swiveled to achieve an angular orientation of the cutter with respect to the work. These features provide considerable versatility in machining a variety of work shapes.



2. Bed-type Milling Machines

- are designed for high production
- They are constructed with greater rigidity than knee-and-column machines, thus permitting them to achieve heavier feed rates and depths of cut needed for high material removal rates



Simplex bed-type milling machine horizontal spindle.

2. Bed-type Milling Machines

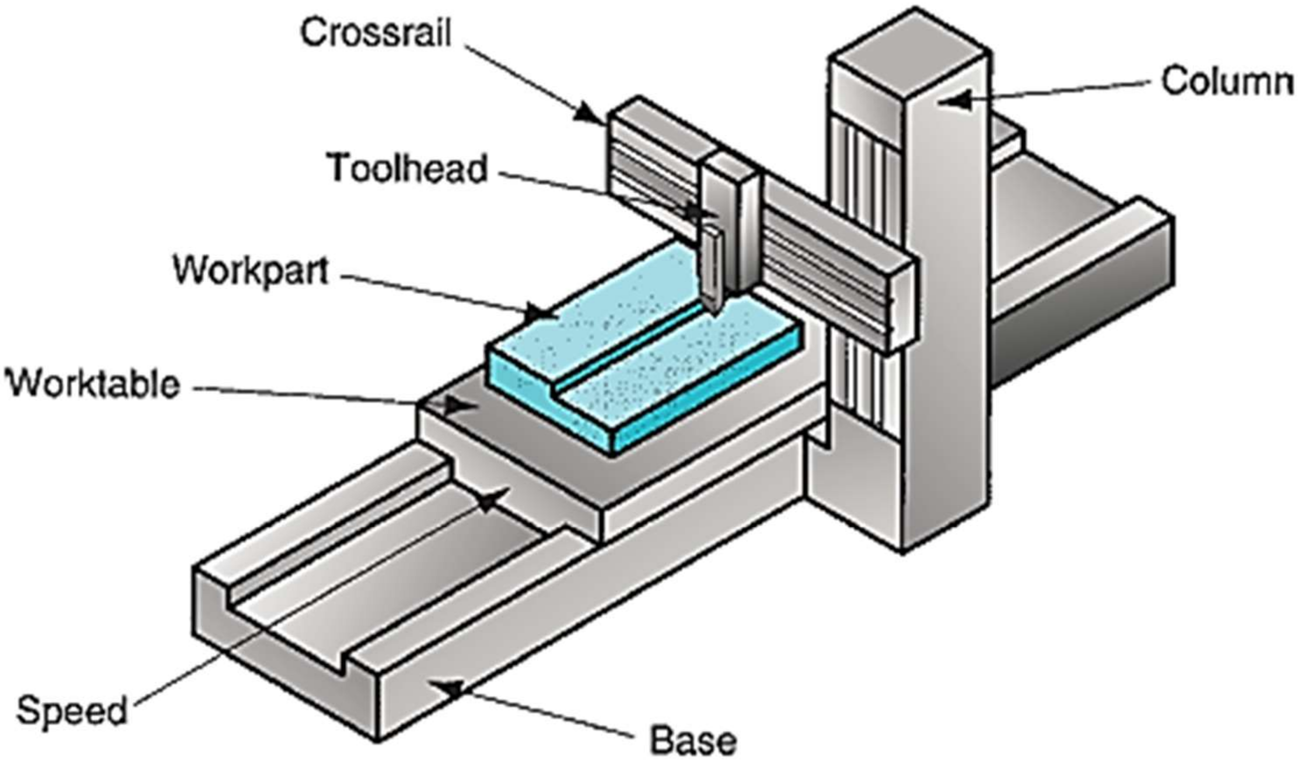
1. Single spindle bed machines are called simplex mills (available in either horizontal or vertical models)
2. Duplex mills use two spindle heads (The heads are usually positioned horizontally on opposite sides of the bed to perform simultaneous operations during one feeding pass of the work).
3. Triplex mills add a third spindle mounted vertically over the bed to further increase machining capability.

3. Planer type mills

a. are the largest milling machines.

b. Their general appearance and construction are those of a large planer

c. the difference is that milling is performed instead of planning



- Planer mills are built to machine very large parts.
- The worktable and bed of the machine are heavy and relatively low to the ground

4. Tracer mill (also called a profiling mill)

a. is designed to reproduce an irregular part geometry that has been created on a template.
b. Using either manual feed by a human operator or automatic feed by the machine tool,
c. a tracing probe is controlled to follow the template while a milling head duplicates the path taken by the probe to machine the desired shape.
d. Two types: x-y tracing and x-y-z tracing

5. Computer numerical control milling machines

a. are milling machines in which the
b. cutter path is controlled by alphanumerical data rather than a physical template.
c. They are especially suited to profile milling, pocket milling, surface contouring, and die sinking operations, in which two or three axes of the worktable must be simultaneously controlled to achieve the required cutter path.

Gear Manufacturing Processes

Gear Manufacturing

A gear is an important machine elements which is used to for transmission of power or motion or both from one shaft to other. It is normally a round blank carrying projections or teeth along its periphery which enable a positive drive.

Gears are widely used in various mechanisms and devices to transmit power and motion positively (without slip) between parallel, intersecting (axis) or non-intersecting non parallel shafts,

- without change in the direction of rotation
- with change in the direction of rotation
- without change of speed (of rotation)
- with change in speed at any desired ratio

Often some gearing system (rack – and – pinion) is also used to transform rotary motion into linear motion and vice-versa.

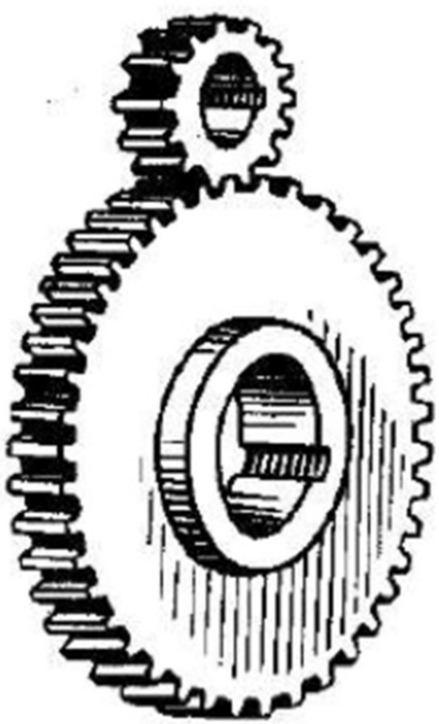
General Application of Gears

Gears of various type, size and material are widely used in several machines and systems requiring positive and stepped drive. The major applications are :

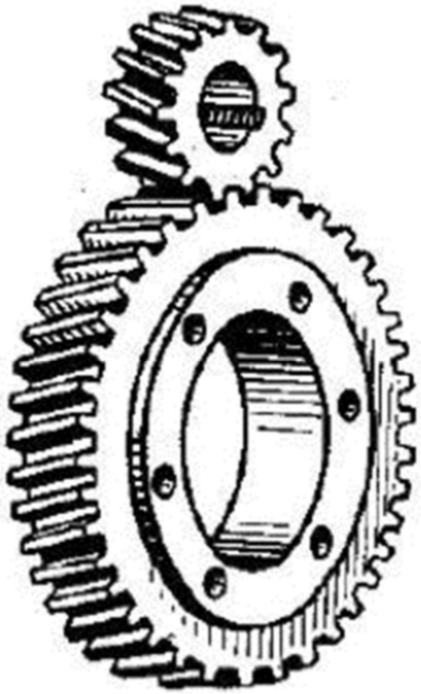
- Speed gear box, feed gear box and some other kinematic units of machine tools
- Speed drives in textile, jute and similar machineries
- Gear boxes of automobiles
- Speed and / or feed drives of several metal forming machines
- Machineries for mining, tea processing etc.
- Large and heavy duty gear boxes used in cement industries, sugar industries, cranes, conveyors etc.
- Precision equipments, clocks and watches
- Industrial robots and toys.

Depending on the specifi c application, gears can be selected from the following types:

1. <u>Spur gears:</u> These are the most common type, which transmit power or motion between parallel shafts or between a shaft and a rack. They are simple in design and measurement.

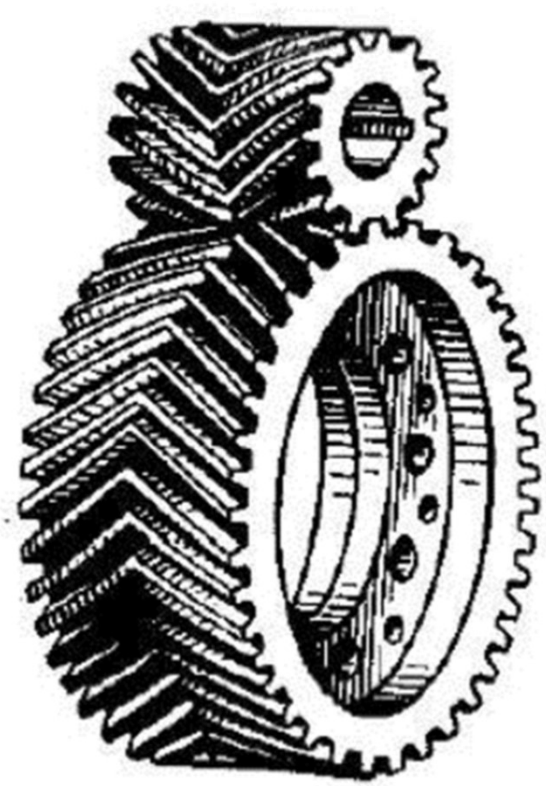


2. <u>Helical gear:</u> These are used to transmit motion between parallel or crossed shafts. These gears are more expensive and difficult in production than the former. The teeth along the periphery are at an angle to the axis of the gear. These gear are stronger and quicker than the spur gears because more number of teeth are in mesh at the same time.

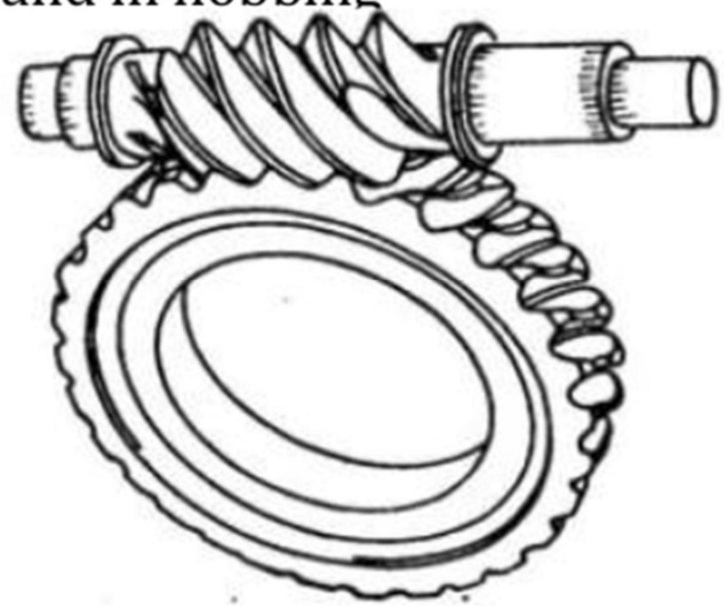


Types of Gears

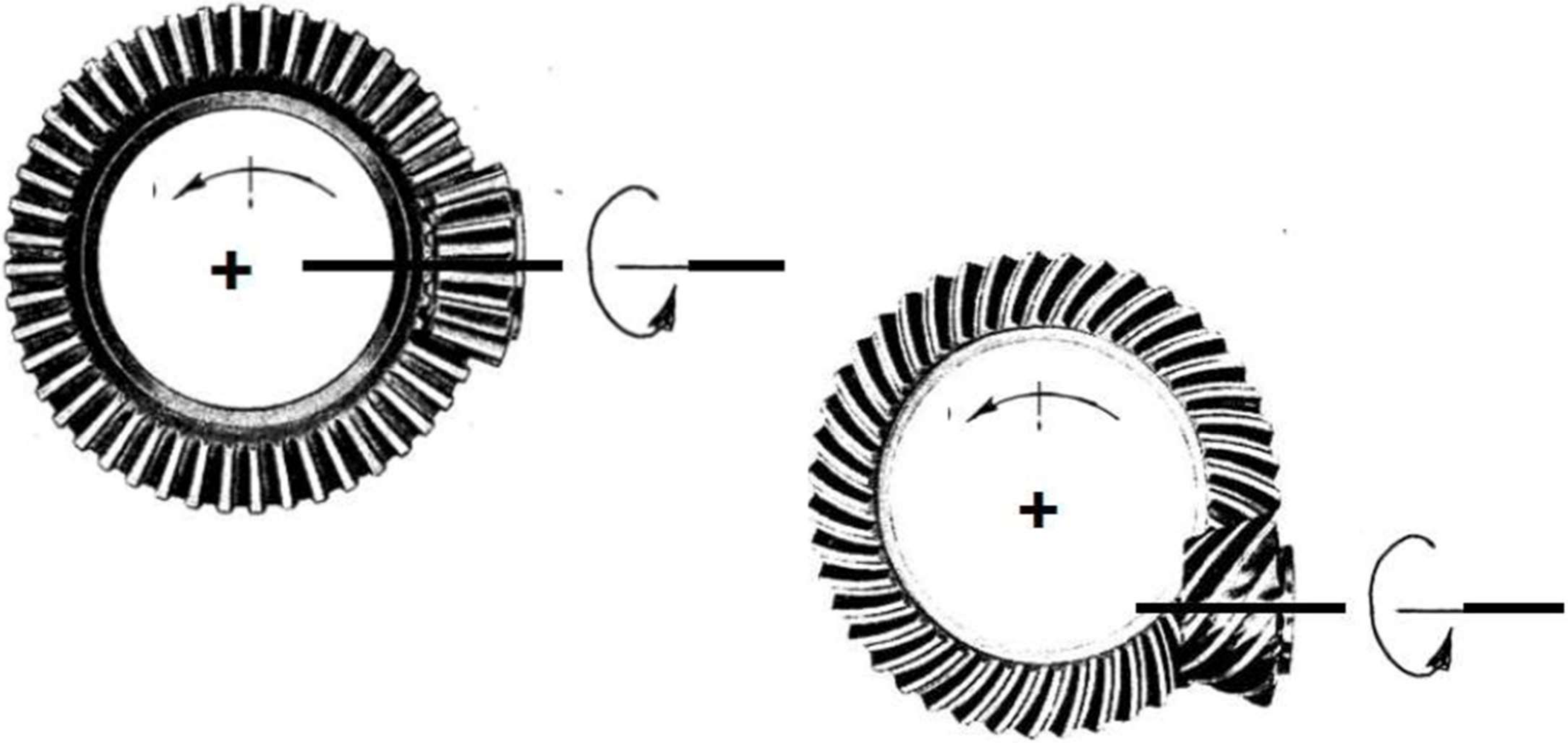
<u>3. Herringbone gear:</u> These are sometimes called double helical gears. These gears transmit motion between parallel shafts. They combine the principal advantages of spur and helical gears, because two or more teeth share the load at the same time.



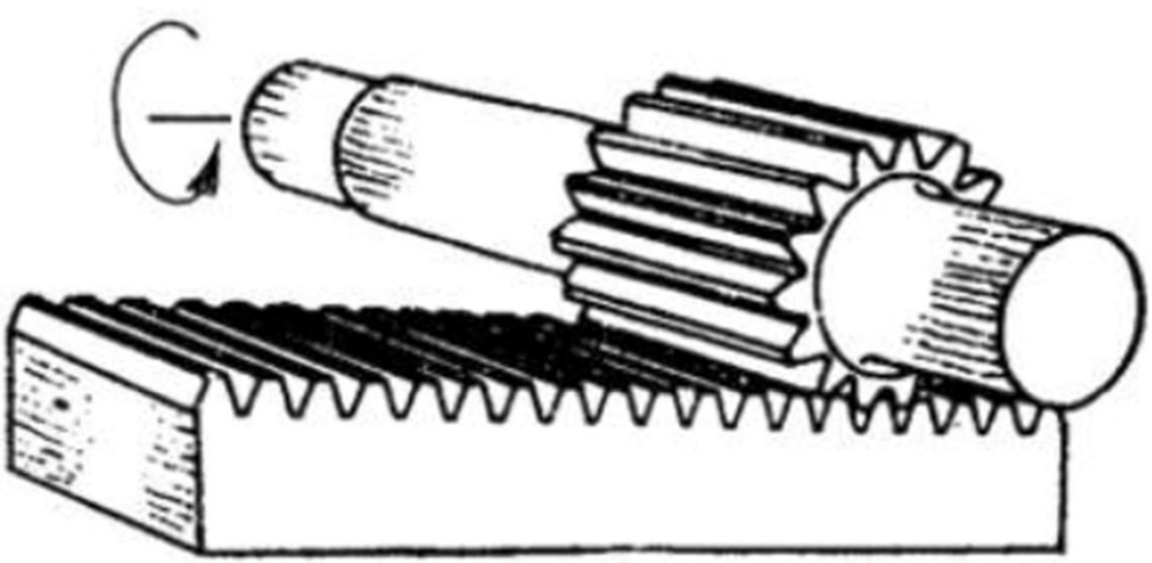
- <u>4. Worm and worm gears:</u> A worm is more or less similar to a screw having single or multiple start threads, which form the teeth of the worm. This worm drives the worm gear to enable transmission of power. Worm and worm wheel are generally used for speed reduction but are irreversible i.e., rotation can be transmitted only from the worm to the worm wheel. They are frequently used in indexing heads of milling machines and in hobbing machines.



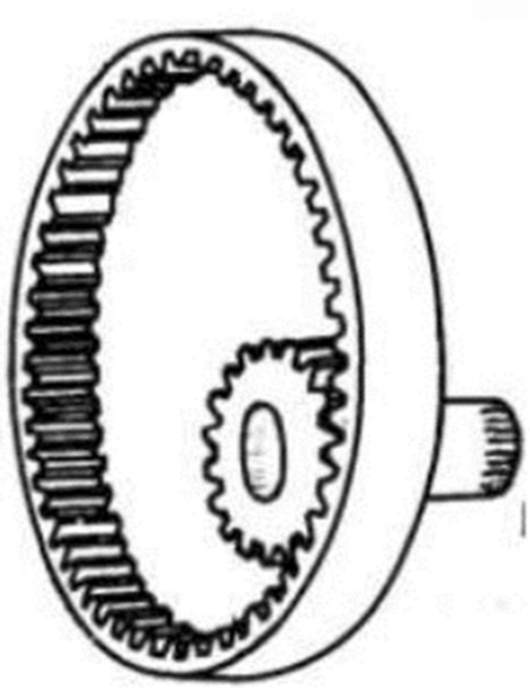
5. Bevel gear: They are used to connect shafts at any desired angle to one another, but not parallel. The most common angle is normally 90 degree.



6. Rack and pinion: A rack can be best described as a gear of infinite radius. It works in conjunction with a small gear, called pinion. . The combination provides a means to convert the reciprocating motion into rotary motion and vice-versa.

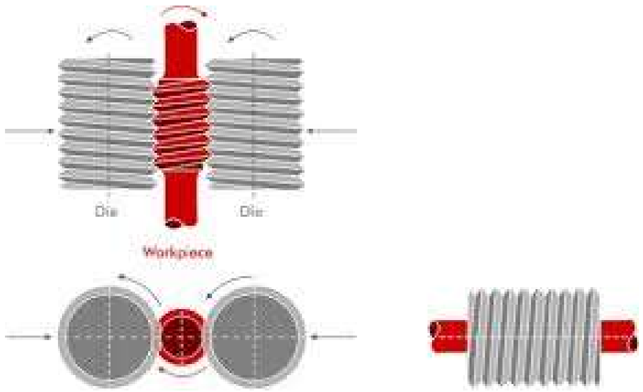


7. Internal gear:



Gear Manufacturing

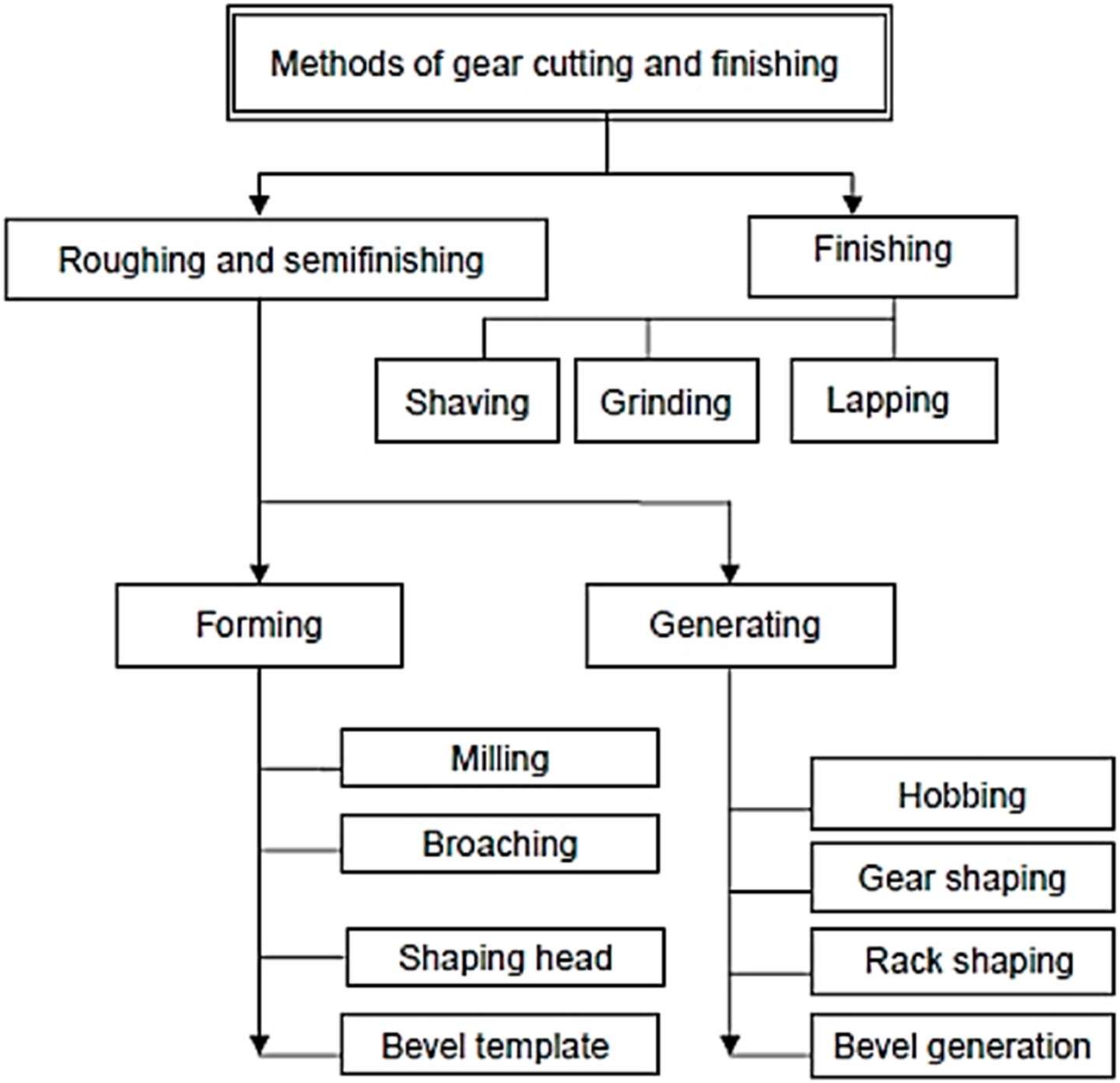
- Some of the processes for making gears or producing gear teeth are
  a. Machining
  b. Casting
  c. Stamping
  d. Coining
  e. Cold Drawing
  f. Rolling
  g. Extrusion
  h. Powder metallurgy
  i. Plastic Molding



- Blanking of sheet metal also can be used for making thin gears, such as those used in mechanical watches, clocks, and similar mechanisms.
- Plastic gears can be made by such processes as injection melding and casting.

Gears can be commercially produced by other methods like sand casting, die casting, stamping, extrusion, and powder metallurgy. All these processes are used for gears of low wear resistance, low power transmission, and relatively low accuracy of transmitted motion. When the application involves higher values for one or more of these characteristics, cut or machined gears are used.

Gear cutting is a highly complex and specialized art, that is why most of the gear cutting methods are single-purpose machines. Some of them are designed such that only a particular type of gear can be cut. Gear production by cutting involves two principal methods—forming and generating processes. Gear finishing involves four operations—shaving, grinding, lapping, and burnishing

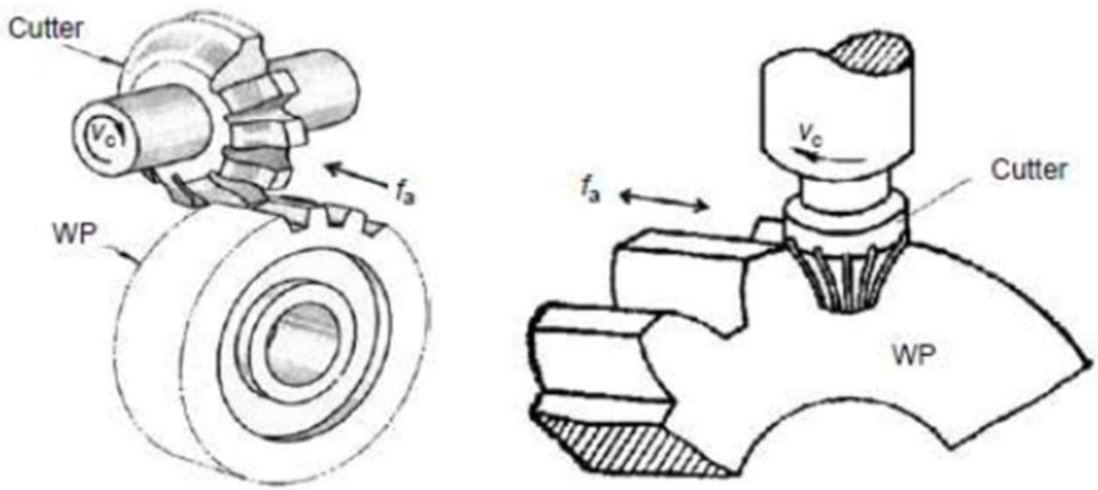

Methods of gear cutting and finishing
Roughing and semifinishing
Finishing
Shaving
Grinding
Lapping
Forming
Generating
Milling
Broaching
Shaping head
Bevel template
Hobbing
Gear shaping
Rack shaping
Bevel generation

Gear Cutting by Forming

In this processes, the cutter used has the same form as the space between the teeth to be cut. The cutters used for this purpose on planer and shaper are single point tools, on milling machine a revolving multi tooth tool and on broaching machine a broach.

1. <u>Gear milling:</u>

The usual practice in gear milling is to mill one tooth space at a time, after which the blank is indexed to the next cutting position.



Gear forming on milling machines (and shapers) has the following characteristics:

- Advantages:

General purpose equipment and machines are used.

Comparatively simple setup is needed.

Simple and cheap cutting tools are used.

It is suitable for piece and small size production.

- Drawbacks:

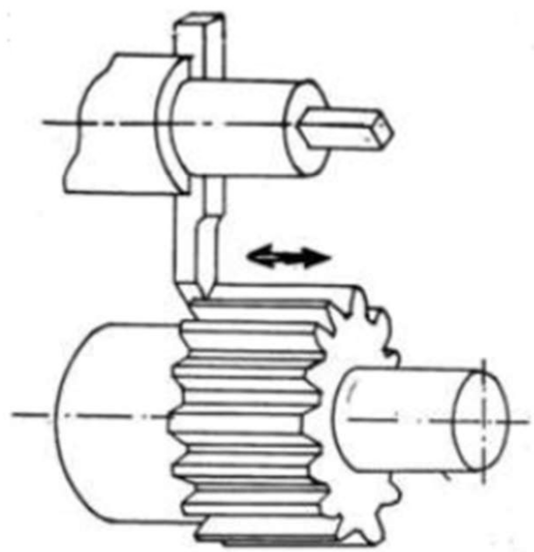
It is an inaccurate process due to profile deviations and indexing errors.

Low production capacity due to the idle time loss in indexing, approaching, and withdrawal

of the tool. However, productivity can be enhanced by multi-WP setup.

2. Shaping, planing and slotting

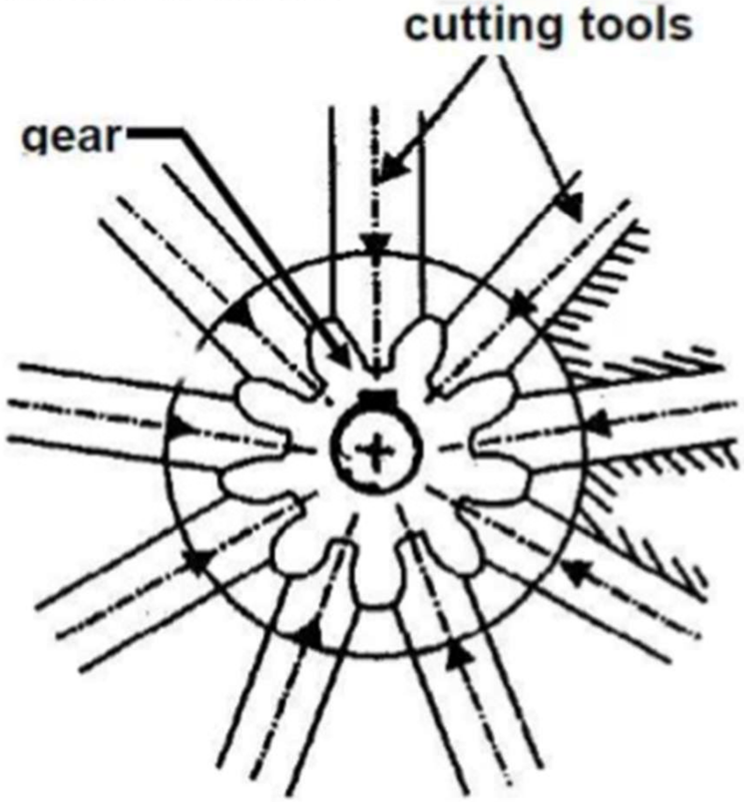
Fig. below schematically shows how teeth of straight toothed spur gear can be produced in shaping machine, if necessary. Both productivity and product quality are very low in this process which therefore, is used, if at all, for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose. In principle planning and slotting machines work on the same principle. Planing machine is used, if required at all, for making teeth of large gears whereas slotting, generally, for



3. Fast production of teeth of spur gears

- Parallel multiple teeth shaping

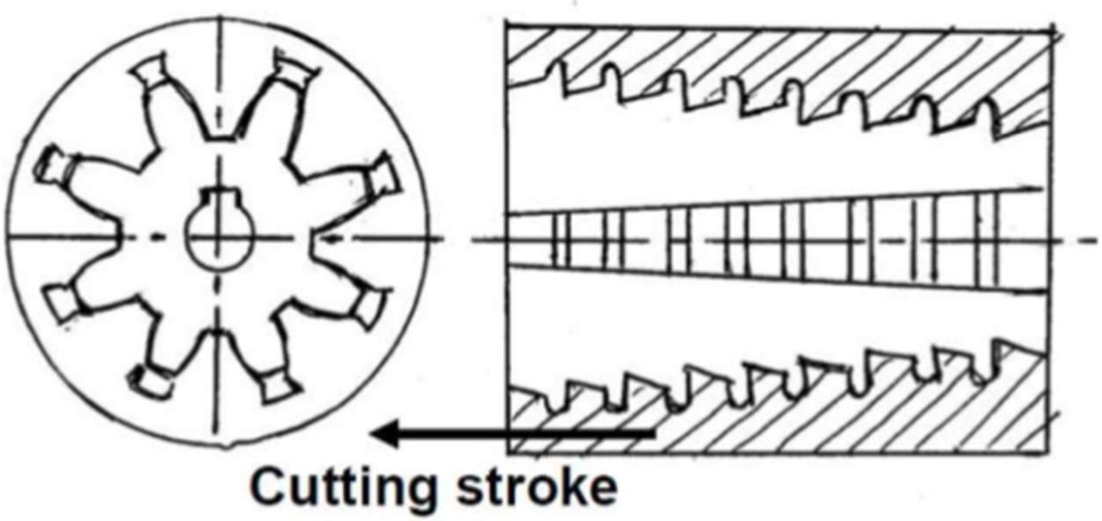
it is similar to ordinary shaping but all the tooth gaps are made simultaneously, without requiring indexing, by a set of radially infeeding single point form tools

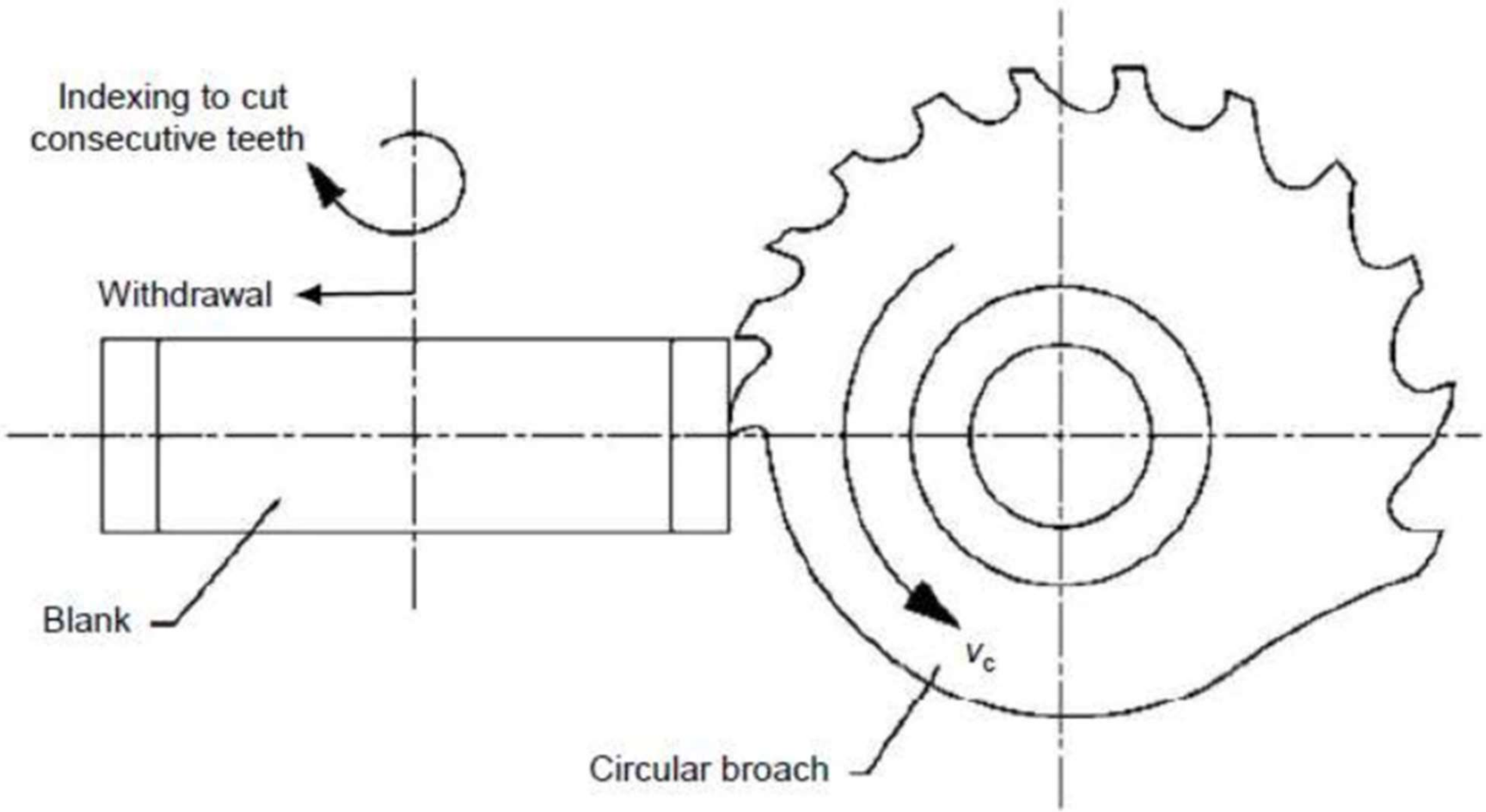


- Broaching

Teeth of small internal and external spur gears; straight or single helical, of relatively softer materials are produced in large quantity by this process. This method leads to very high productivity and quality but cost of machine and broach are very high.

- The form of the space between gear teeth corresponds to the form of the broach teeth. The diameter of the broach increases progressively to major diameter that completes the tooth form on the WP.




Indexing to cut consecutive teeth
Withdrawal
Blank
v_c
Circular broach

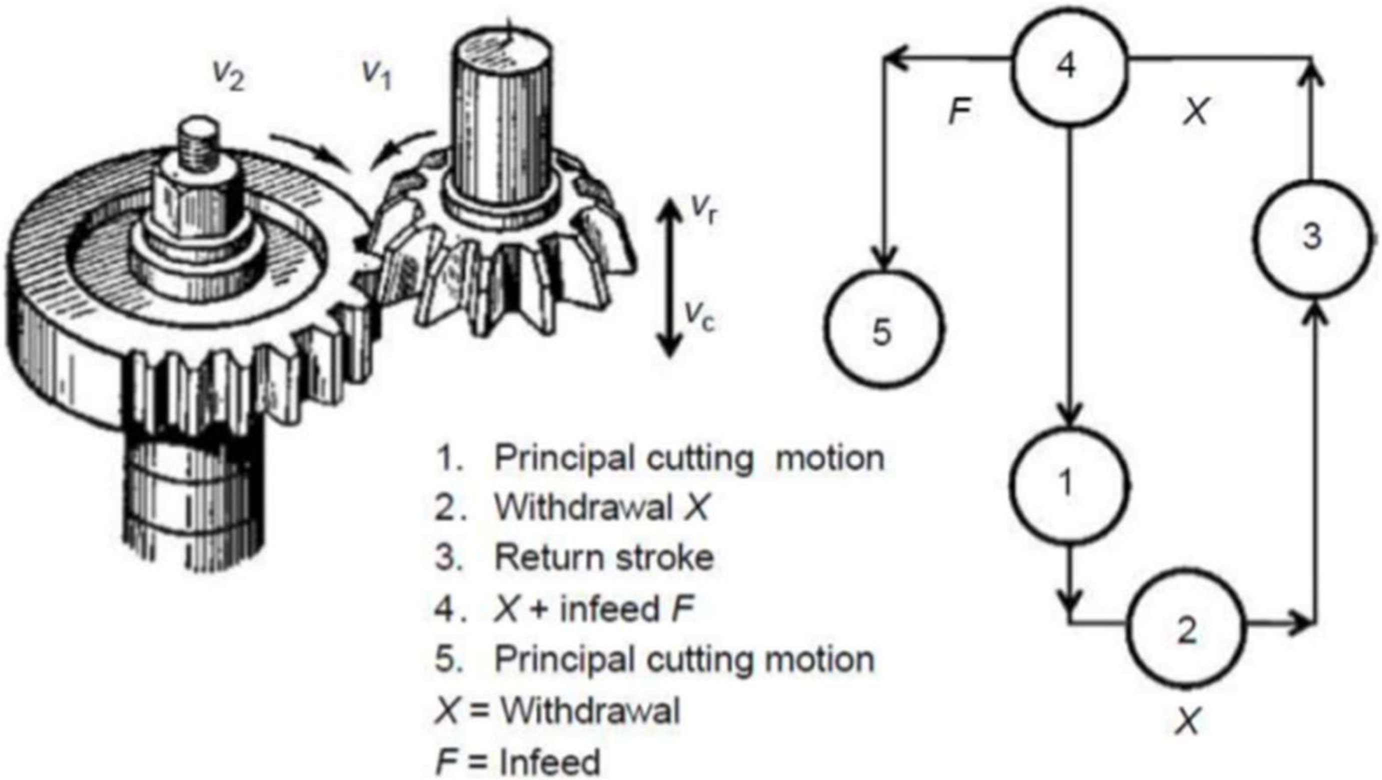
This technique is based on the fact that two involute gears of the same module and pitch mesh together—the WP blank and the cutter. So this method makes it possible to use one cutting gear for machining gears of the same module with a varying number of teeth.

Gear generation methods are characterized by their higher accuracy and machining productivity than gear forming.

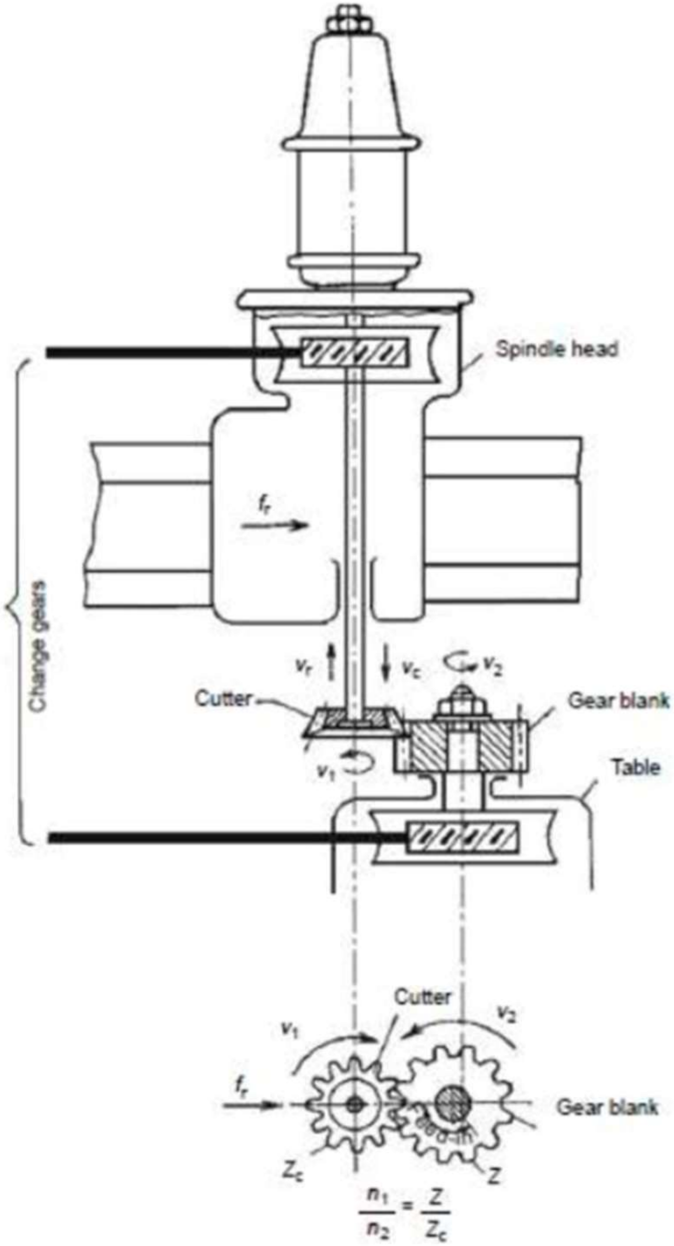
1. Gear shaper process
2. Rack planing process
3. Hobbing process

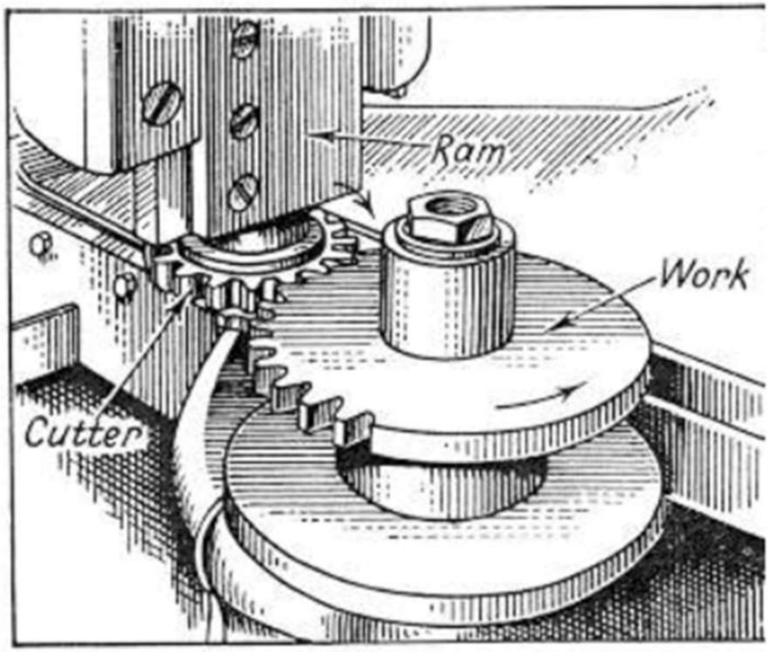
1. Gear Shaper Process

In this process, a pinion shaped cutter is used, which is mounted with its axis vertical and is reciprocate up and down. This process is the most versatile of all gear cutting processes. Also, the cutter and the gear blank both are rotated slowly about their own axis.



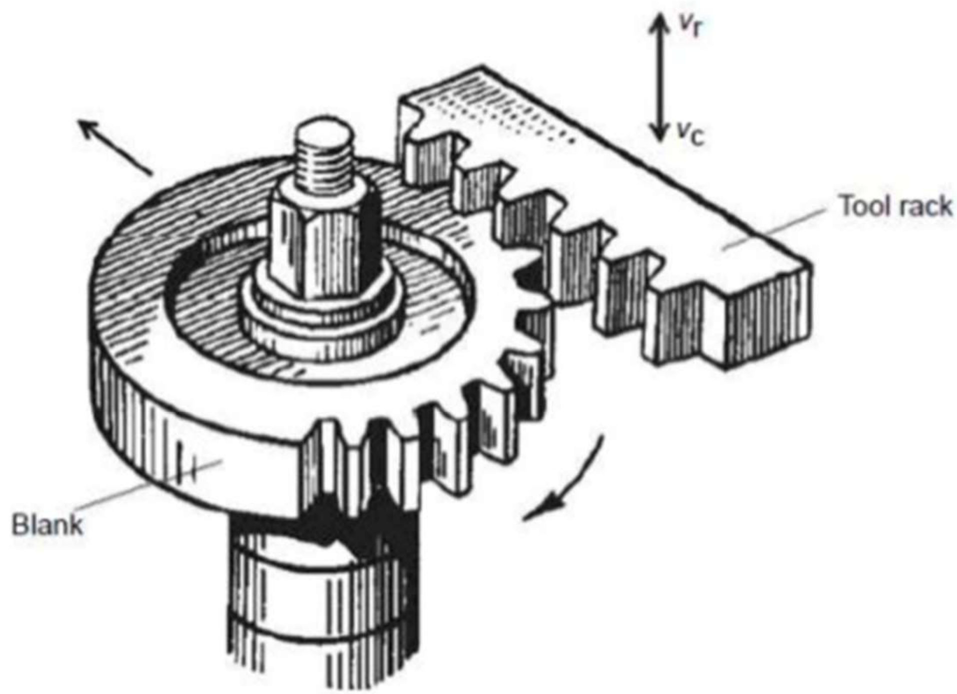
Principles of gear shaping.


Spindle head
f_r
Change gears
v_r
v_c
v_2
Cutter
Gear blank
v_1
Table
Cutter
v_1
v_2
f_r
Gear blank
Z_c
Z
$\frac{n_1}{n_2} = \frac{Z}{Z_c}$


Ram
Work
Cutter

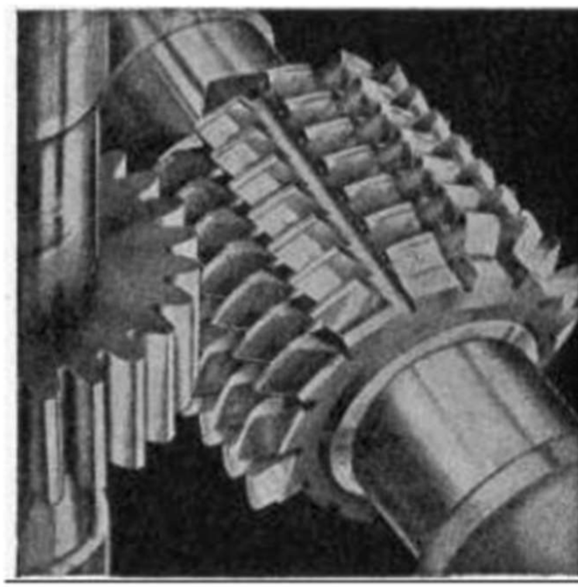
2. Gear Cutting Using Rack-type Cutter

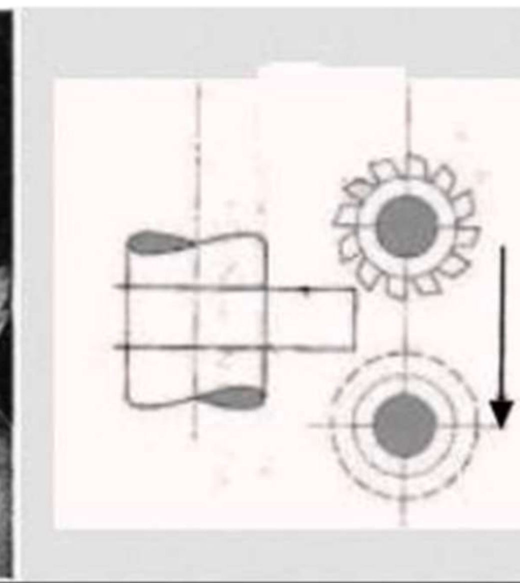
Gear shaping is performed by a rack cutter with 3–6 straight teeth. The cutters reciprocate parallel to the work axis when cutting spur gears, and parallel to the helix angle when cutting helical gears. In addition to the reciprocating action of the cutter, there is synchronized rotation of the gear blank with each stroke of the cutter, with a corresponding advance of the cutter in a feed movement.



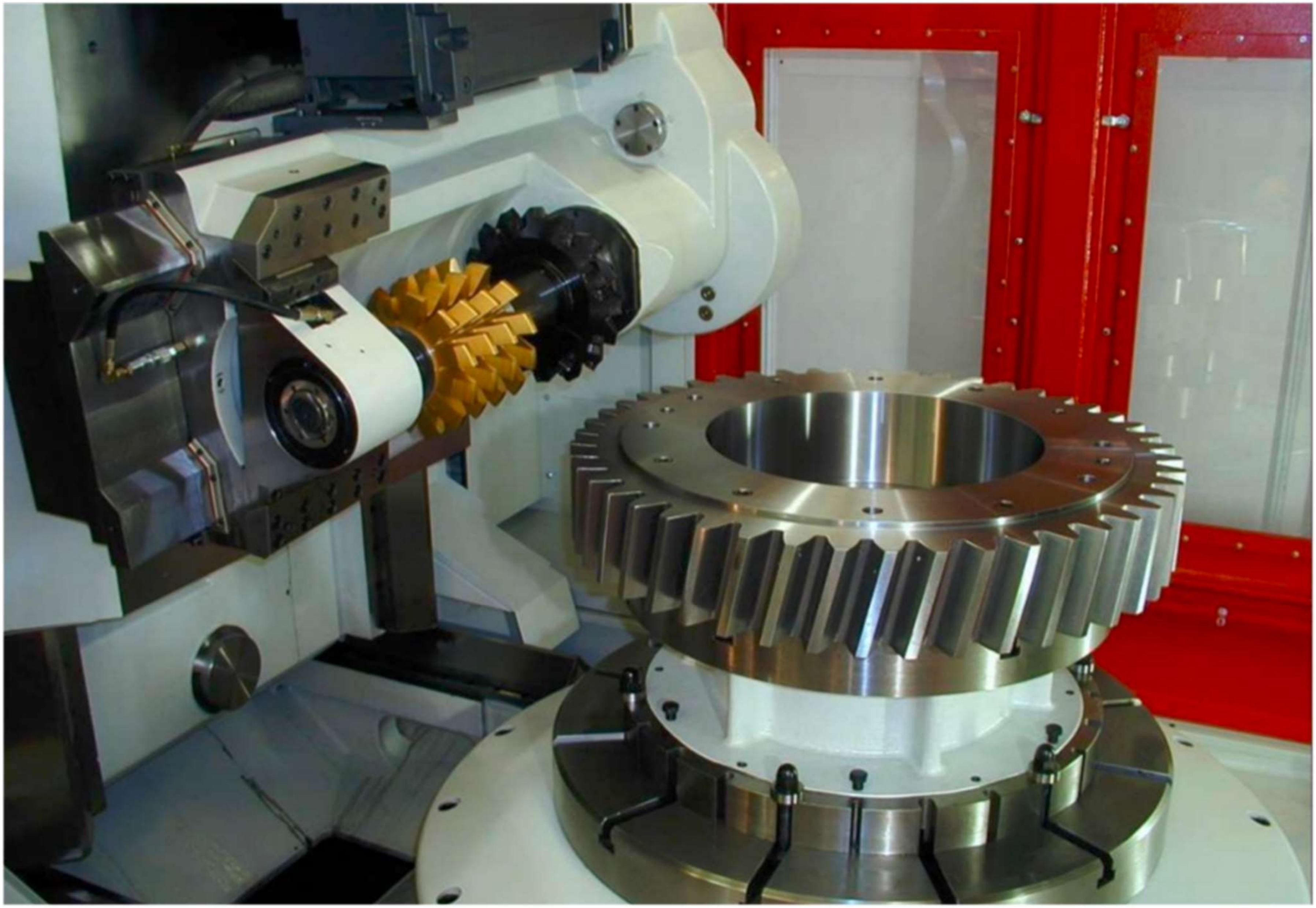
3. Gear Hobbing

Hobbing is a gear generation method most widely used for cutting teeth in spur gears, helical gears, worms, worm wheels, and many special forms. In this process, the gear blank is rolled with a rotating cutter called hob. A gear hob looks like a worm.

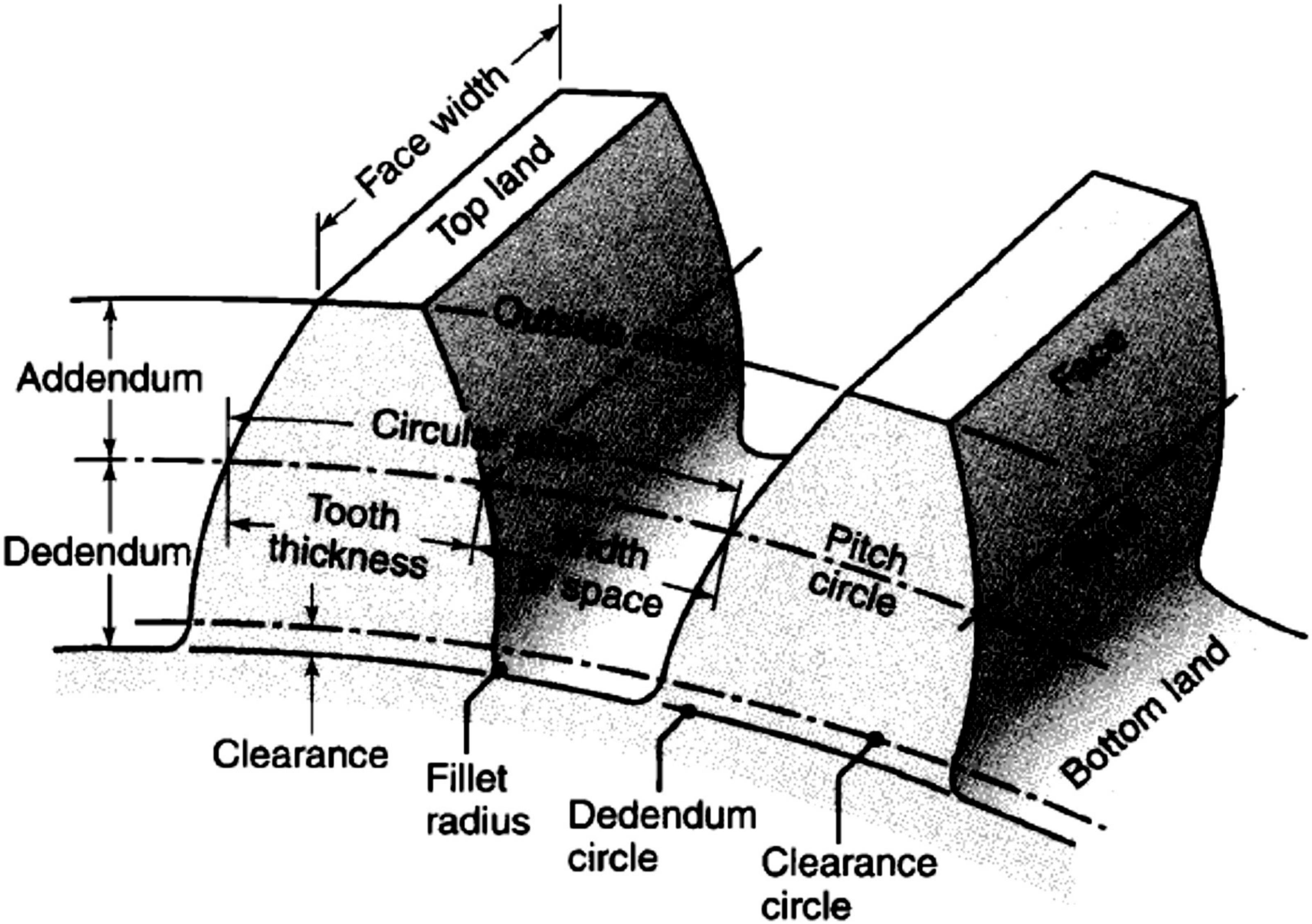




3. Gear Hobbing



The standard nomenclature for an involute **spur gear**



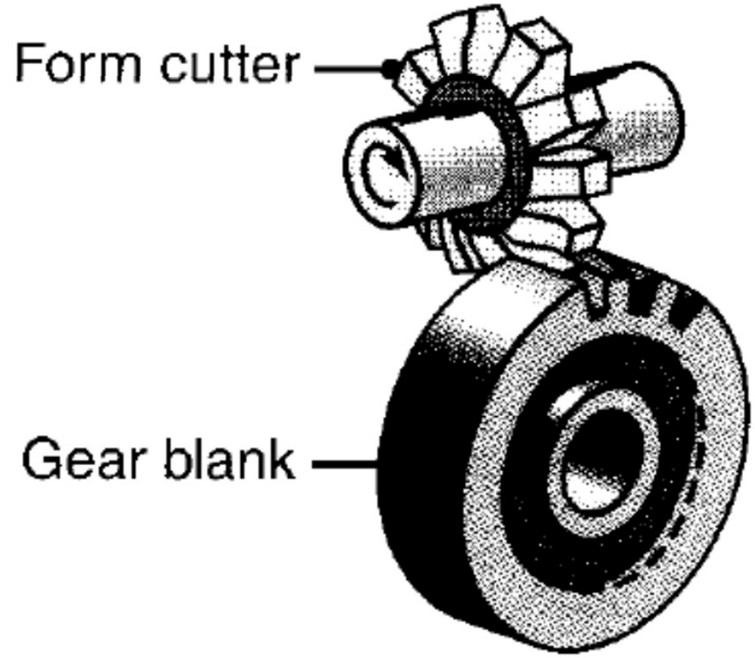
Gear Manufacturing by Machining

Starting with a wrought or cast gear blank, there are two basic methods of making such gear teeth:

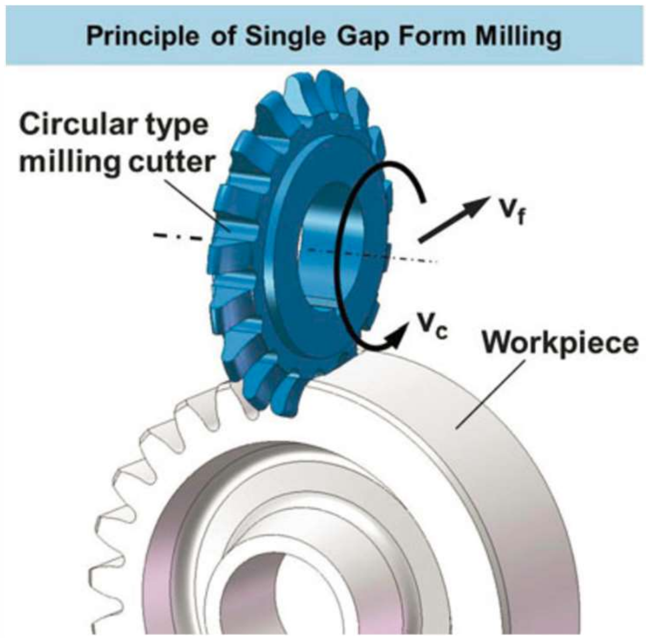
a. form cutting (Same profile cutters are used)
b. Template process (Cutting by single point cutting tool)
c. Generating (Combination of straight movement of tool and rotation of work piece by spindle)

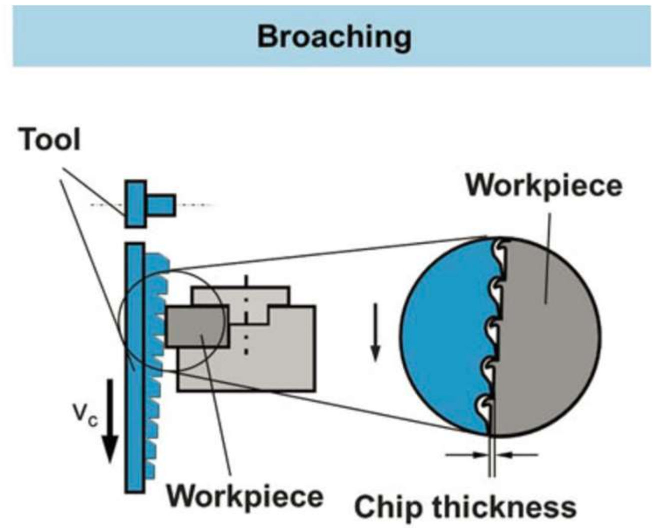
Form Cutting

1. the cutting tool is similar to a form-milling cutter made in the shape of the space between the gear teeth
2. The gear-tooth shape is reproduced by machining the gear blank around its periphery.
3. The cutter travels axially along the length of the gear tooth and at the appropriate depth to produce the gear tooth profile.
4. After each tooth is cut, the cutter is withdrawn, the gear blank is rotated (indexed), and the cutter proceeds to cut another tooth. This process continues until all of the teeth are machined.



Form Cutting





Form Cutting

1. The precision of the form-cut tooth profile depends on the accuracy of the cutter and on the machine and its stiffness.
2. Form cutting can be done on milling machines with the cutter mounted on an arbor and the gear blank mounted in a dividing head.
3. Because the cutter has a fixed geometry, form cutting can be used only to produce gear teeth that have a constant width-that is, on spur or helical gears but not on bevel gears.
4. Internal gears and gear teeth on straight surfaces (such as those in a rack and pinion) are form cut with a shaped cutter on a machine similar to a shaper.
5. Form cutting is a relatively simple process and can be used for cutting gear teeth with various profiles.

Form Cutting

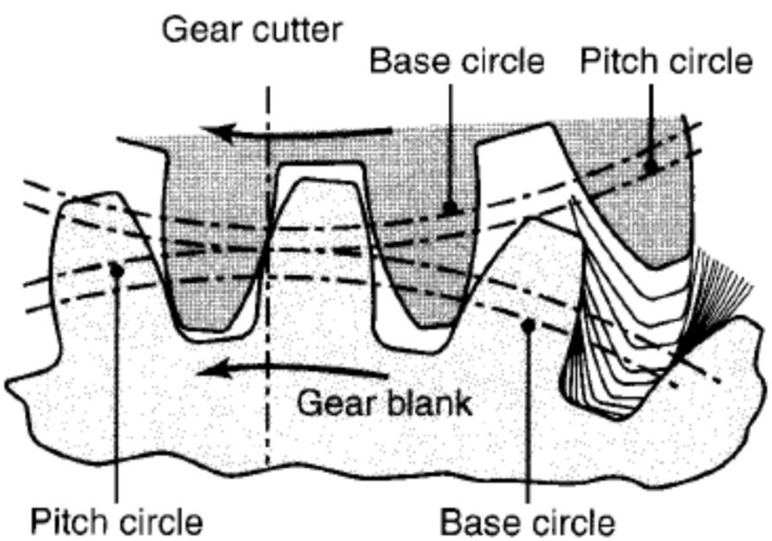
Limitations:

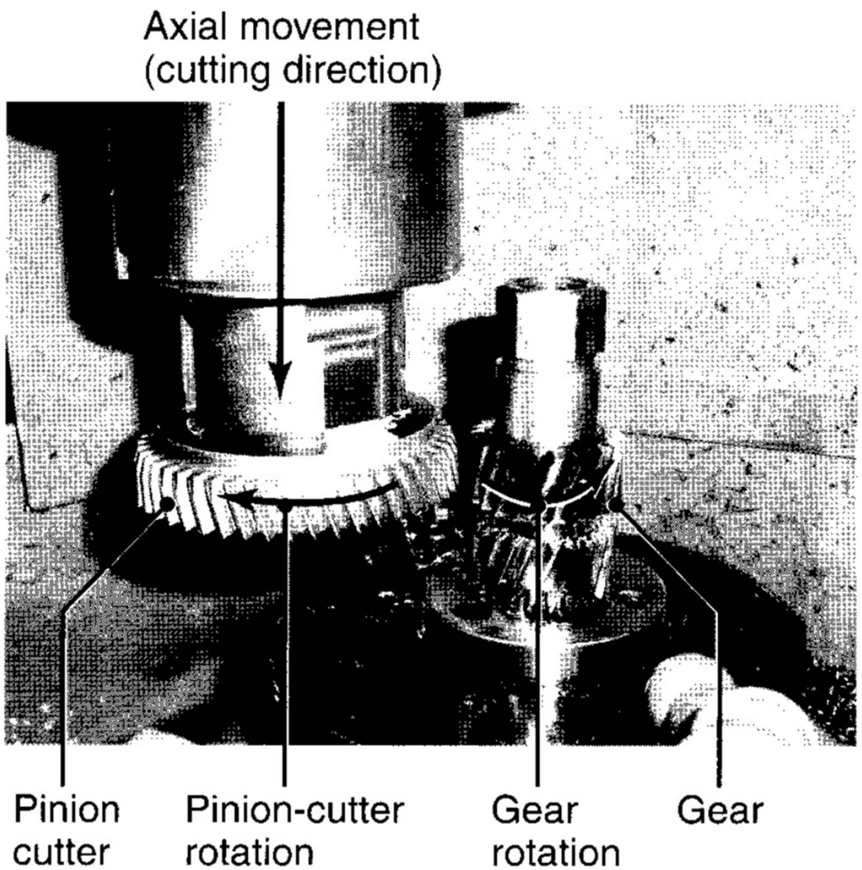
1. It is a slow operation
2. Some types of machines require skilled labor. Machines with semiautomatic features can be used economically for form cutting on a limited-production basis.
3. Generally, however, form cutting is suitable only for low-quantity production.

Gear Generating by pinion-shaped cutter

The cutting tool used in gear generating may be a pinion-shaped cutter, a rack-shaped straight cutter, or a hob.

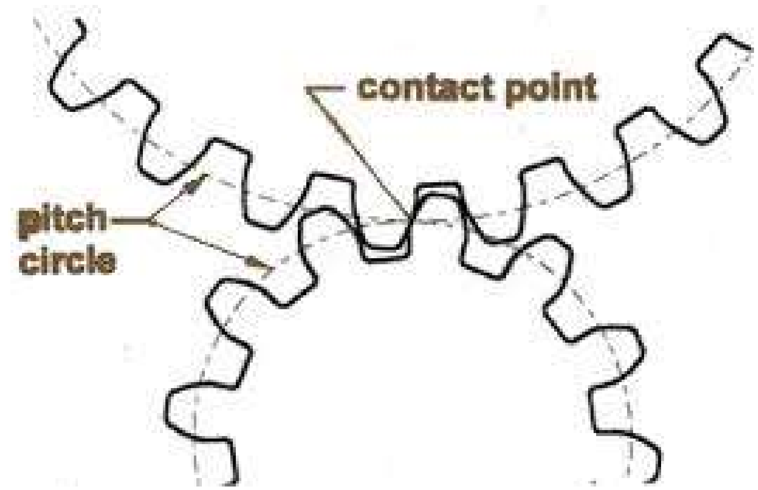
- A pinion-shaped cutter can be considered as one of the two gears in a conjugate pair, with the other being the gear blank.





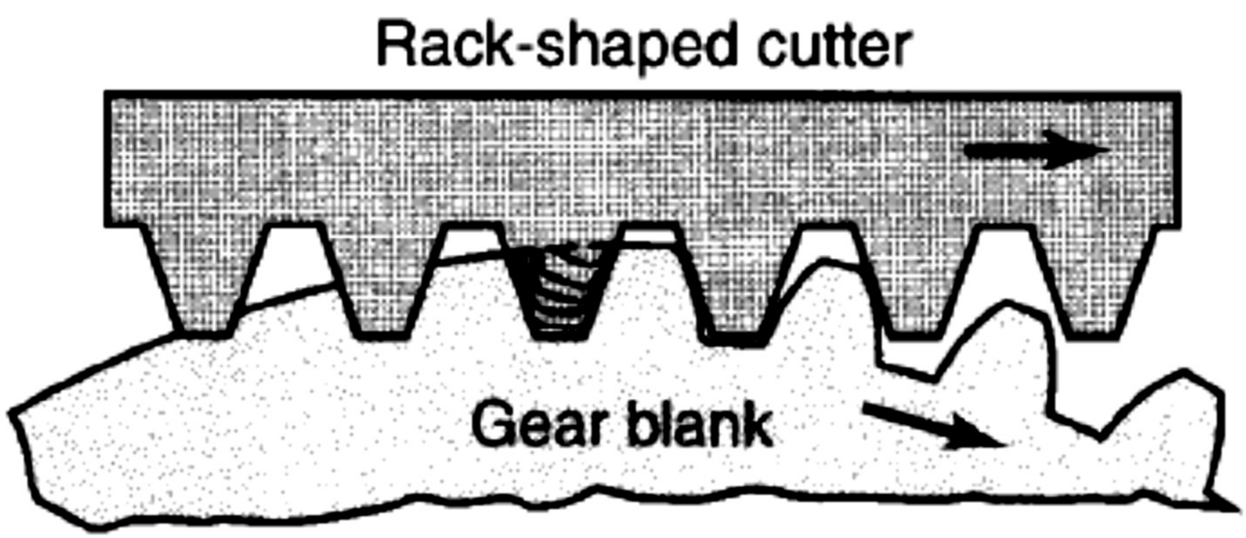
Gear Generating by pinion-shaped cutter

- The cutter has an axis parallel to that of the gear blank and rotates slowly with the blank at the same pitch-circle velocity and in an axial-reciprocating motion.
- A train of gears provides the required relative motion between the cutter shaft and the gear-blank shaft.
- Cutting may take place at either the down-stroke or the upstroke of the machine.
- The process can be used for low-quantity as well as high-quantity production.



Gear Generating by rack shaper

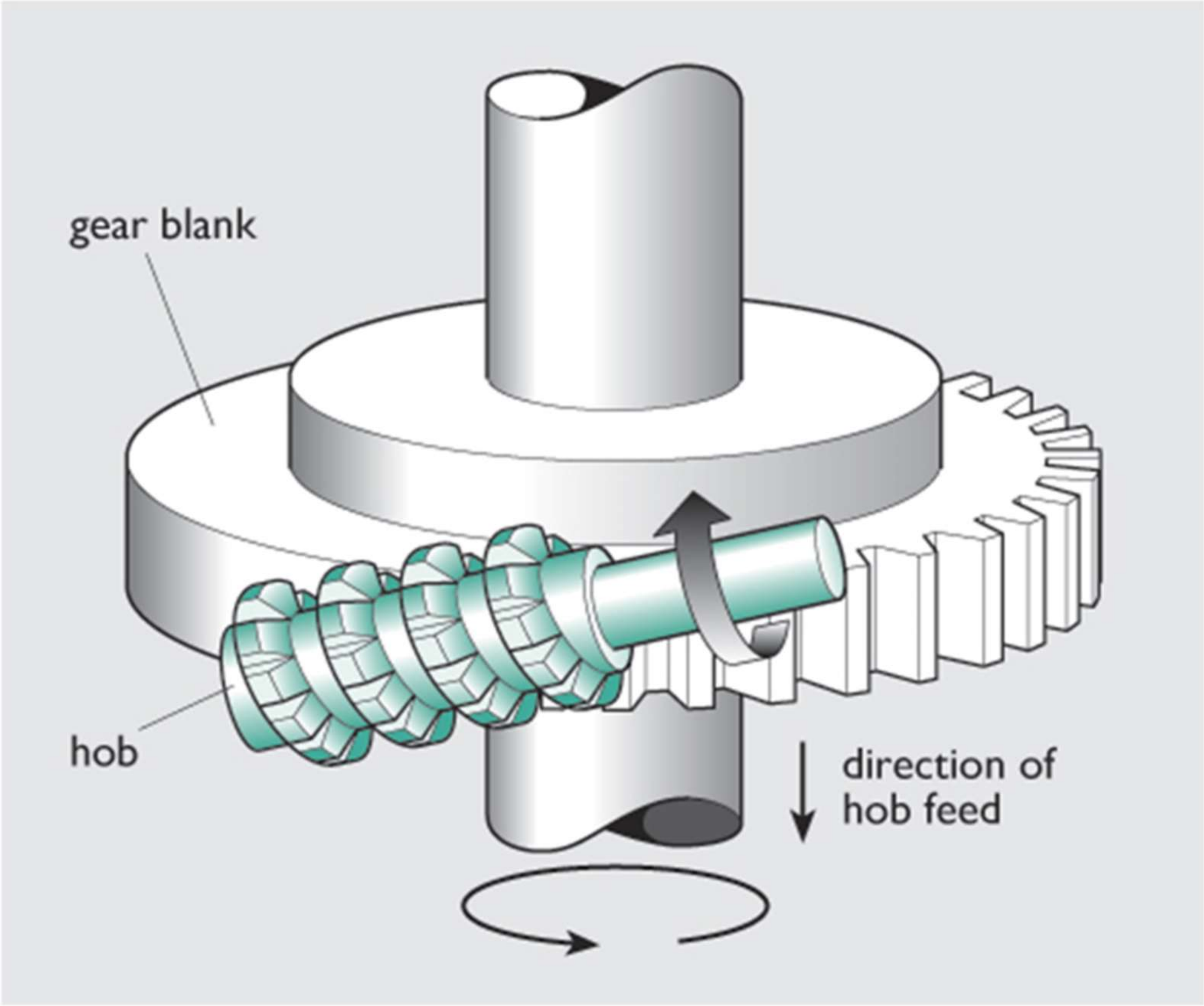
- On a **rack shaper**, the generating tool is a segment of a rack which reciprocates parallel to the axis of the gear blank.
- Because it is not practical to have more than 6 to 12 teeth on a rack cutter, the cutter must be disengaged at suitable intervals and returned to the starting point.
- The gear blank remains fixed during the operation.



Gear Generating by a hob

- Hob is basically a gear-cutting worm, or screw, made into a gear generating tool by a series of longitudinal slots or gashes machined into it to form the cutting teeth.
- When bobbing a spur gear, the angle between the hob and gear-blank axes is 90° minus the lead angle at the hob threads.
- All motions in hobbing are rotary, and the hob and gear blank rotate continuously-much as two gears in mesh-until all of the teeth are cut.

Gear Generating by a hob



Gear Generating by a hob

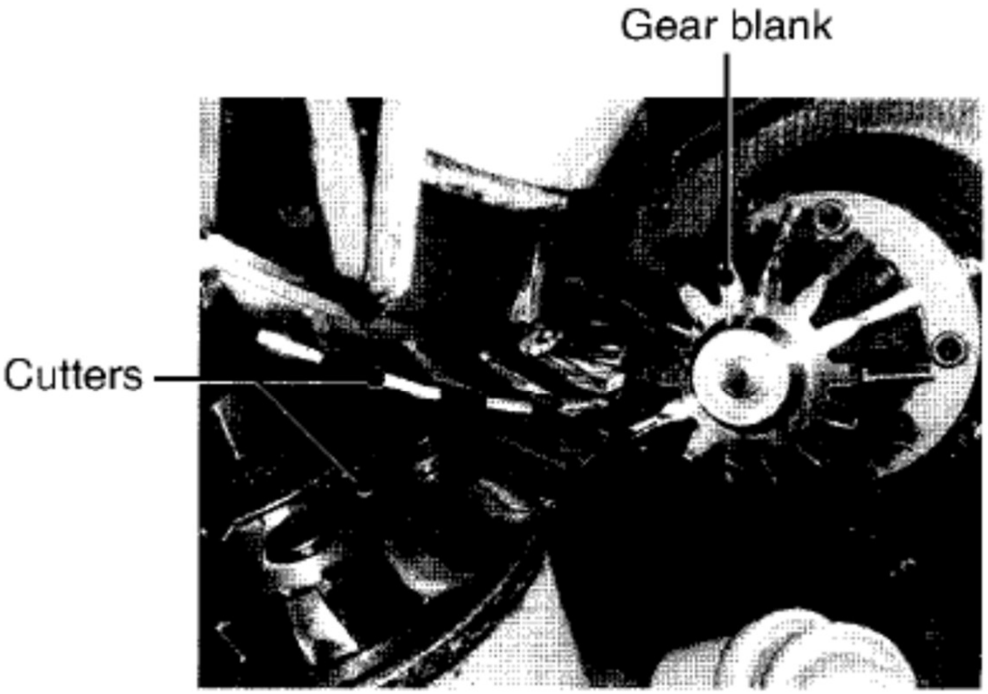
1. Hobs are available with one, two, or three threads.
2. For example, if the hob has a single thread and the gear is to have 40 teeth,
   - the hob and the gear spindle must be geared together such that the hob makes 40 revolutions while the gear blank makes 1 revolution.
3. Similarly, if a double-threaded hob is used,
   - the hob would make 20 revolutions to the gear blank's 1 revolution.
4. In addition, the hob must be fed parallel to the gear axis for a distance greater than the face width of the gear tooth in order to produce straight teeth on spur gears.
5. The same hobs and machines can be used to cut helical gears by tilting the axis of the hob spindle.

Gear Generating by a hob

- Because it produces a variety of gears at high rates and with good dimensional accuracy, gear hobbing is used extensively in industry.
- Although the process also is suitable for low-quantity production, it is most economical for medium- to high quantity production.
- Gear-generating machines also can produce spiral-bevel and hypoid gears.
- Like most other machine tools, modern gear-generating machines are computer controlled.
- Multi-axis computer-controlled machines are capable of generating many types and sizes of gears using indexable milling cutters.

Cutting Bevel Gears

1. Straight bevel gears generally are roughed out in one cut with a form cutter on machines that index automatically.
2. The gear is then finished to the proper shape on a gear generator.
3. The generating method is analogous to the rack-generating method described previously.
4. The cutters reciprocate across the face of the bevel gear as does the tool on a shaper.
5. The machines for spiral bevel gears operate essentially on the same principle, and the spiral cutter is basically a face-milling cutter with a number of straight-sided cutting blades protruding from its periphery



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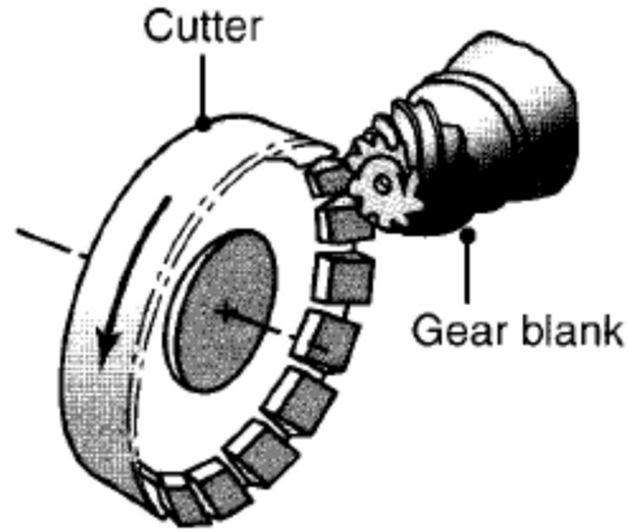

(b)

Thank You