

# Module

# 1

## Classification of Metal Removal Processes and Machine tools

# Lesson 2

Basic working  
principle,  
configuration,  
specification and  
classification of  
machine tools

## Instructional Objectives

At the end of this lesson, the students should be able to :

- (a) Describe the basic functional principles of machine tools
  - (i) Illustrate the concept of Generatrix and Directrix
  - (ii) Demonstrate Tool – work motions
  - (iii) Give idea about machine tool drives
- (b) Show configuration of basic machine tools and state their uses
- (c) Give examples of machine tools - specification
- (d) Classify machine tools broadly.

## Basic functional principles of machine tool operations

Machine Tools produce desired geometrical surfaces on solid bodies (preformed blanks) and for that they are basically comprised of;

- Devices for firmly holding the tool and work
- Drives for providing power and motions to the tool and work
- Kinematic system to transmit motion and power from the sources to the tool-work
- Automation and control systems
- Structural body to support and accommodate those systems with sufficient strength and rigidity.

For material removal by machining, the work and the tool need relative movements and those motions and required power are derived from the power source(s) and transmitted through the kinematic system(s) comprised of a number and type of mechanisms.

### (i) Concept of Generatrix and Directrix

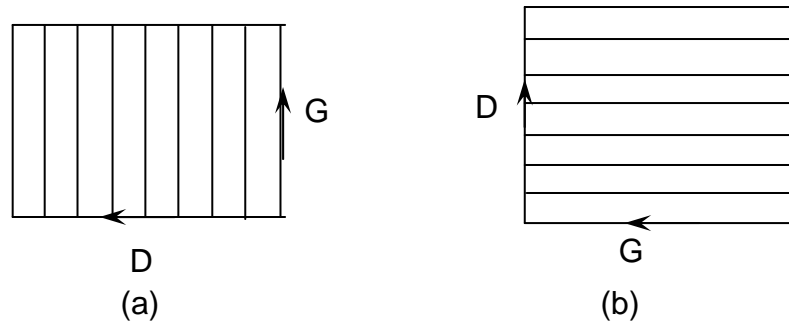
- Generation of flat surface

The principle is shown in Fig. 2.1 where on a flat plain a straight line called Generatrix (G) is traversed in a perpendicular direction called Directrix (D) resulting a flat surface.

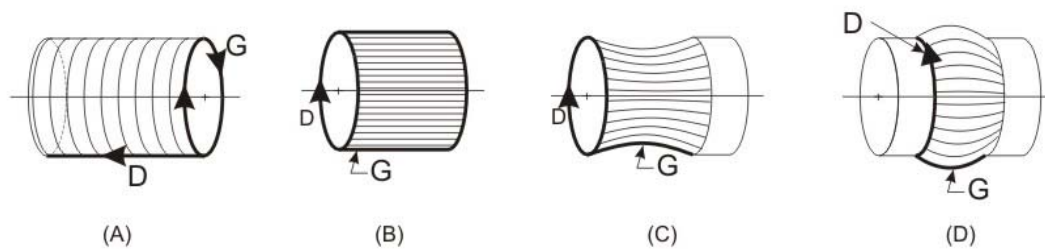
- Generation of cylindrical surfaces

The principles of production of various cylindrical surfaces (of revolution) are shown in Fig. 2.2, where,

- A long straight cylindrical surface is obtained by a circle (G) being traversed in the direction (D) parallel to the axis as shown in Fig. 2.2(a)
- A cylindrical surface of short length is obtained by traversing a straight line (G) along a circular path (D) as indicated in Fig. 2.2(b)
- Form cylindrical surfaces by rotating a curved line (G) in a circular path (D) as indicated in Fig. 2.2 (c and d).



**Fig. 2.1** Generation of flat surfaces by Generatrix and Directrix.



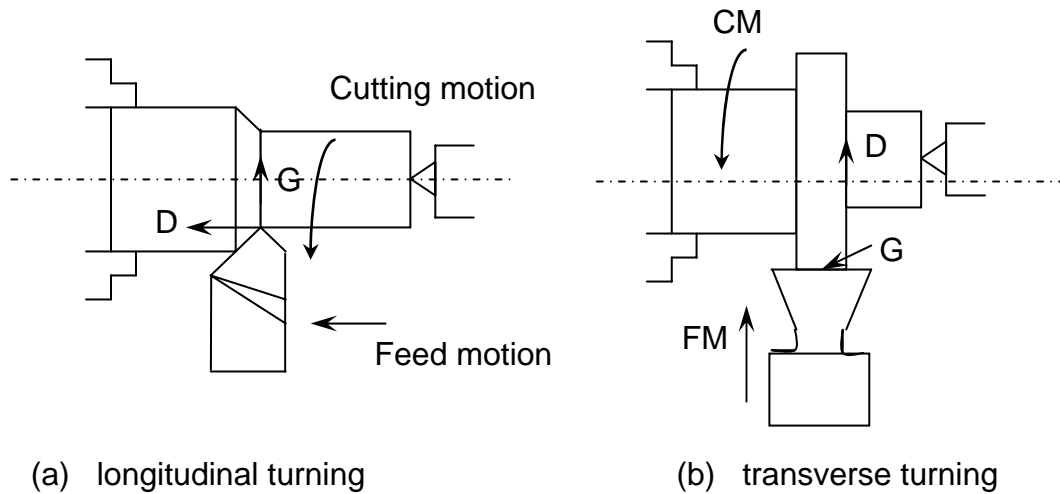
**Fig. 2.2** Generation of cylindrical surfaces (of revolution)

## (ii) Tool – work motions

The lines representing the Generatrix and Directrix are usually produced by the locus of a point moving in two different directions and are actually obtained by the motions of the tool-tip (point) relative to the work surface. Hence, for machining flat or curved surfaces the machine tools need relative tool work motions, which are categorized in following two groups:

- Formative motions namely
  - Cutting motion (CM)
  - Feed motion (FM)
- Auxiliary motions such as
  - Indexing motion
  - Additional feed motion
  - Relieving motion

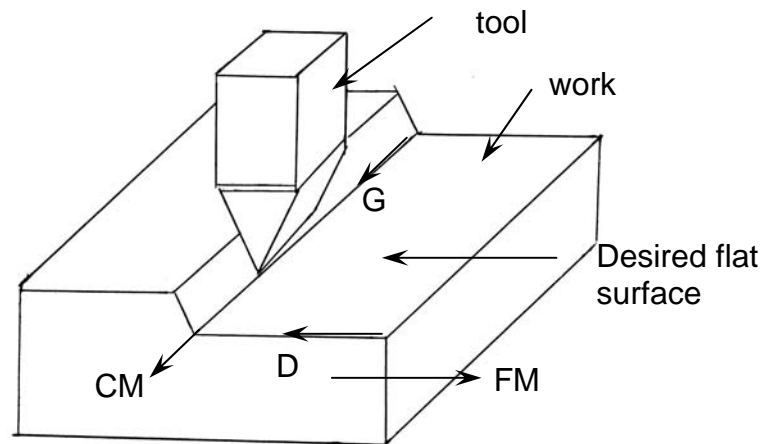
The Generatrix and Directrix, tool and the work and their motions generally remain interconnected and in different way for different machining work. Such interconnections are typically shown in Fig. 2.3 for straight turning and in Fig. 2.4 for shaping.



**Fig. 2.3** Principle of turning (cylindrical surface)

The connections in case of straight longitudinal turning shown in Fig. 2.3 (a) are:

Generatrix (G) – Cutting motion (CM) – Work (W)  
 Directrix (D) – Feed motion (FM) – Tool (T)



**Fig. 2.4** Principle of producing flat surface in shaping machine

In case of making flat surface in a shaping machine as shown in Fig. 2.4 the connections are:

G – CM – T  
 D – FM – W

which indicates that in shaping flat surfaces the Generatrix is provided by the cutting motion imparted to the cutting tool and the Directrix is provided by the feed motion of the work.

Flat surfaces are also produced by planing machines, mainly for large jobs, where the cutting motion is imparted to the work and feed motion to the tool and the connections will be:

G – CM – Work  
D – FM – Tool

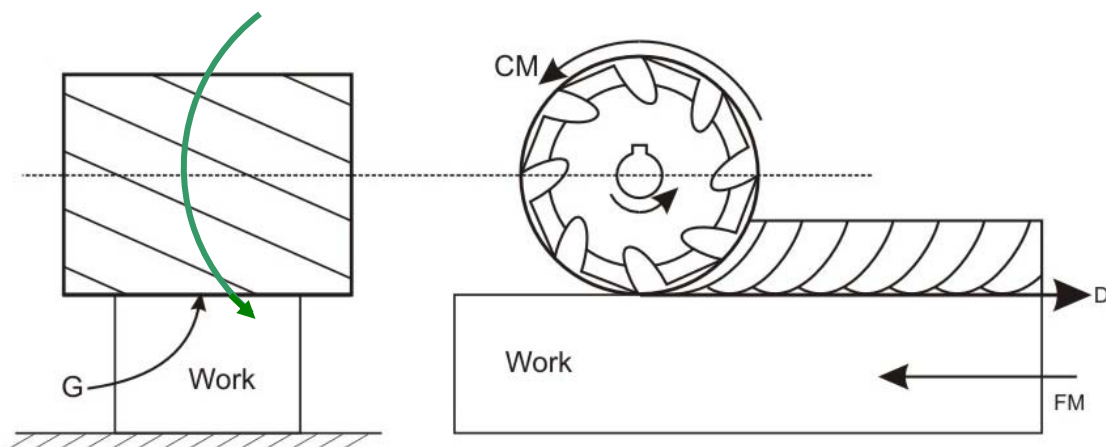
The Genatrix and Directrix can be obtained in four ways:

- Tracing (Tr) – where the continuous line is attained as a trace of path of a moving point as shown in Fig. 2.3 and Fig. 2.4.
- Forming (F) – where the Generatrix is simply the profile of the cutting edge as indicated in Fig. 2.2 (c and d)
- Tangent Tracing (TTr) – where the Directrix is taken as the tangent to the series of paths traced by the cutting edges as indicated in Fig. 2.5.
- Generation (G): Here the G or D is obtained as an envelope being tangent to the instantaneous positions of a line or surface which is rolling on another surface. Gear teeth generation by hobbing or gear shaping is the example as can be seen in Fig. 2.6.

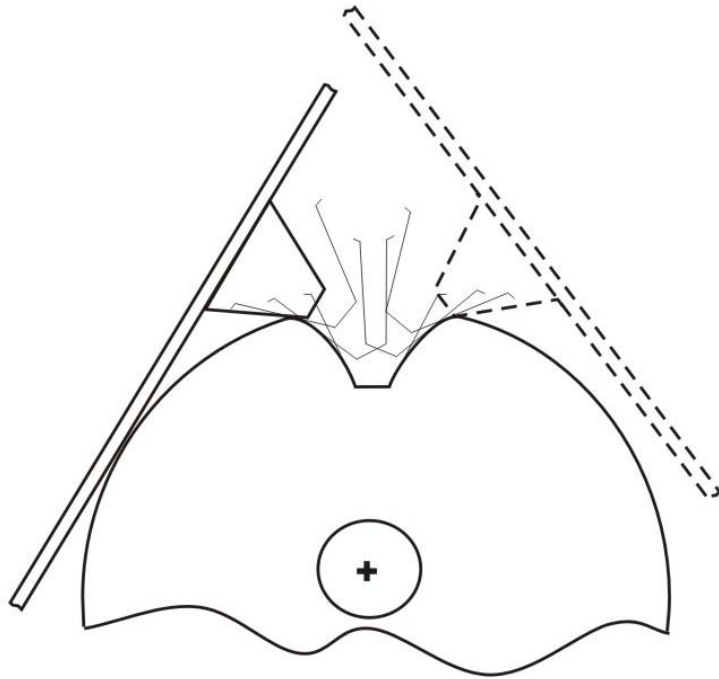
Fig. 2.5 typically shows the tool-work motions and the corresponding Generatrix (G) and Directrix (D) while producing flat surface by a plain or slab milling cutter in a conventional horizontal arbour type milling machine. The G and D are connected here with the tool work motions as

G – x – T – F  
D – FM – W – T.Tr  
CM – T

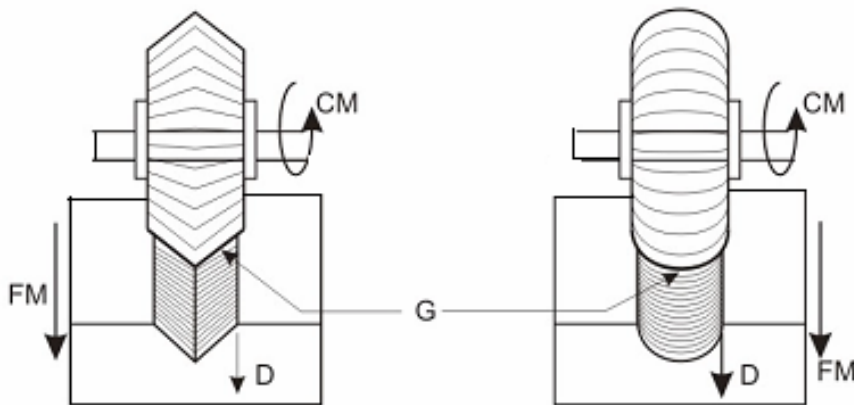
Here G and D are independent of the cutting motion and the G is the line of contact between the milling cutter and the flat work surface. The present cutter being of roller shape, G has been a straight line and the surface produced has also been flat. Form milling cutters will produce similar formed surfaces as shown in Fig. 2.7 where the 'G' is the tool-form.



**Fig. 2.5** Directrix formed by tangent tracing in plain milling



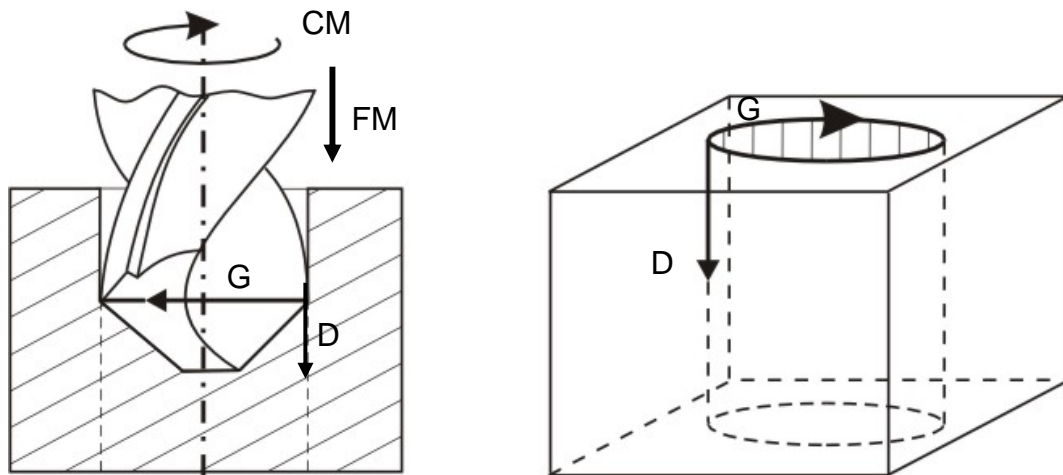
**Fig. 2.6** Generatrix (or Directrix) in gear teeth cutting by generation.



**Fig. 2.7** Tool-work motions and G & D in form milling

For making holes in drilling machines both the cutting motion and the feed motion are imparted to the cutting tool i.e., the drill bit whereas the workpiece remains stationary. This is shown in Fig. 2.8. The G and D are linked with the tool-work in the way:

$$\begin{aligned}
 G & - CM - T - Tr \\
 D & - FM - W - Tr
 \end{aligned}$$



**Fig. 2.8** Tool-work motions and  $G$  &  $D$  in drilling.

Boring machines are mostly used for enlargement and finishing of existing cylindrical holes. Boring machines are of two types:

- Vertical boring machine – low or medium duty and high precision, e.g., Jig boring machine
- Horizontal axis boring machine – medium or heavy duty.

In respect of tool-work motions and  $G$  and  $D$ , vertical boring and drilling are same. In horizontal boring machine the feed motion is imparted to the work to provide the Directrix by Tracing.

### (iii) Machine tool drives

For the desired tool-work motions with power, machine tools are driven by electric motors and use of some mechanisms like belt-pulley, gears etc. In some machine tools, the tool-work motions are provided by hydraulic drive also.

Machine tools essentially need wide ranges of cutting speed and feed rate to enable

- Machining different jobs (material and size)
- Using different cutting tools (material, geometry and size)
- Various machining operations like high speed turning to low speed thread cutting in lathes
- Degree of surface finish desired.

Machine tool drives may be

- Stepped drive
- Stepless drive



Stepped drives are very common in conventional machine tools where a discrete number of speeds and feeds are available and preferably in G.P. (Geometric Progression) series. Whereas the modern CNC machine tools are provided with stepless drives enabling optimum selection and flexibly automatic control of the speeds and feeds.

Stepped drive is attained by using gear boxes or cone pulley (old method) along with the power source. Stepless drive is accomplished usually by

- Variable speed AC or DC motors
- Stepper or servomotors
- Hydraulic power pack

## Configuration of Basic Machine Tools and their use

- **Centre lathes**

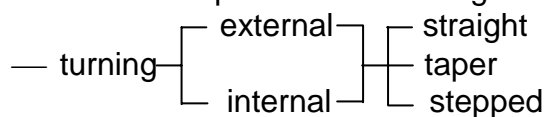
- configuration

Fig. 2.9 shows the general configuration of center lathe. Its major parts are:

- o Head stock: it holds the blank and through that power and rotation are transmitted to the job at different speeds
- o tailstock: supports longer blanks and often accommodates tools like drills, reamers etc for hole making.
- o carriage: accommodates the tool holder which in turn holds the moving tools
- o bed:  $\Delta$  headstock is fixed and tailstock is clamped on it. Tailstock has a provision to slide and facilitate operations at different locations
  - $\Delta$  carriage travels on the bed
- o columns: on which the bed is fixed
- o work-tool holding devices

— uses of center lathes

Centre lathes are quite versatile being used for various operations:



— facing, centering, drilling, recessing and parting

— thread cutting; external and internal

— knurling.

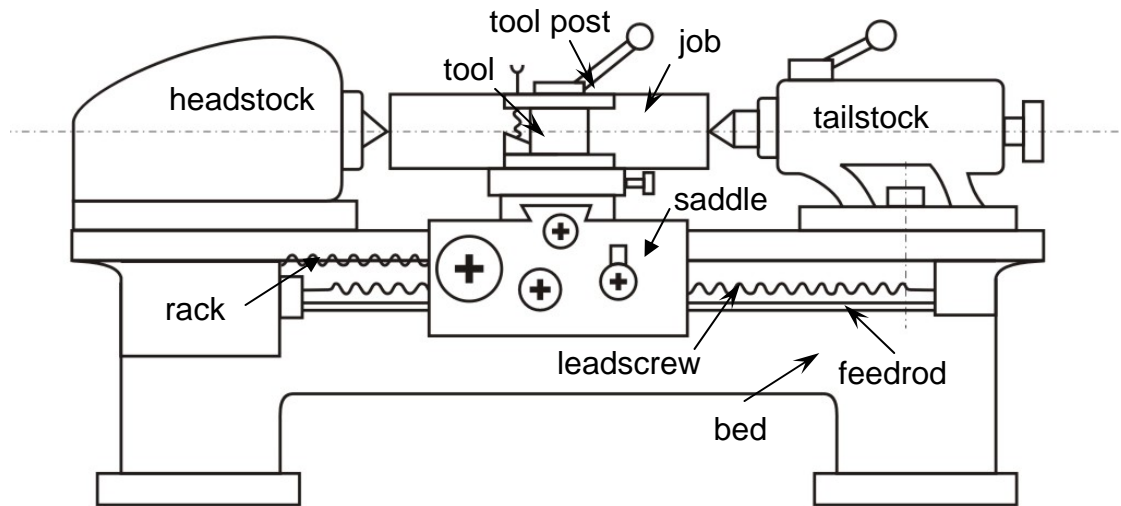
Some of those common operations are shown in Fig. 2.10. Several other operations can also be done in center lathes using suitable attachments.

- **Shaping machine**

Fig. 2.11 shows the general configuration of shaping machine. Its major parts are:

- o Ram: it holds and imparts cutting motion to the tool through reciprocation
- o Bed: it holds and imparts feed motions to the job (blank)
- o Housing with base: the basic structure and also accommodate the drive mechanisms

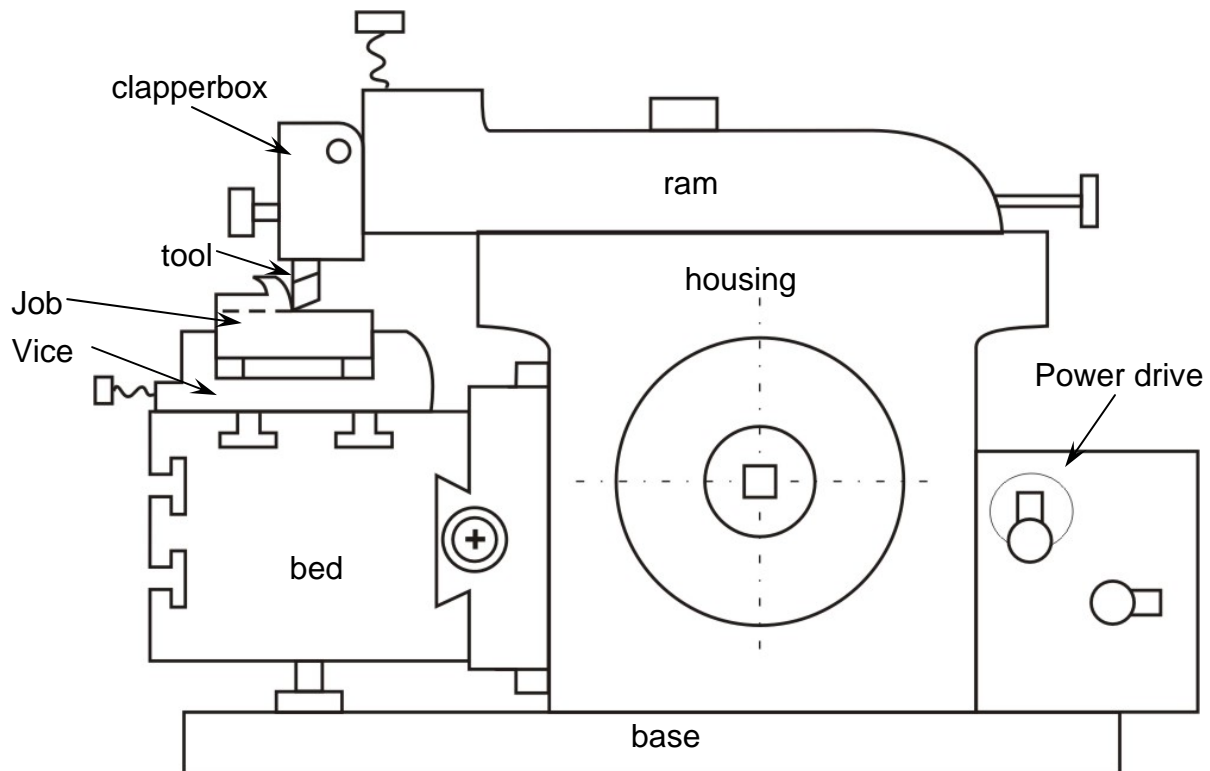
o Power drive with speed and feed change mechanisms. Shaping machines are generally used for producing flat surfaces, grooving, splitting etc. Because of poor productivity and process capability these machine tools are not widely used now-a-days for production.



**Fig. 2.9** Schematic view of a center lathe

	turning	facing	grooving	forming	threadin
External					
Internal					

**Fig. 2.10** Some common machining operations done in center lathes.



**Fig. 2.11** Schematic view of a shaping machine

- **Planing machine**

The general configuration is schematically shown in Fig. 2.12. This machine tool also does the same operations like shaping machine but the major differences are:

- o In planing the job reciprocates for cutting motion and the tool moves slowly for the feed motions unlike in shaping machine.
- o Planing machines are usually very large in size and used for large jobs and heavy duty work.

- **Drilling machine**

Fig. 2.13 shows general configuration of drilling machine, column drill in particular. The salient parts are

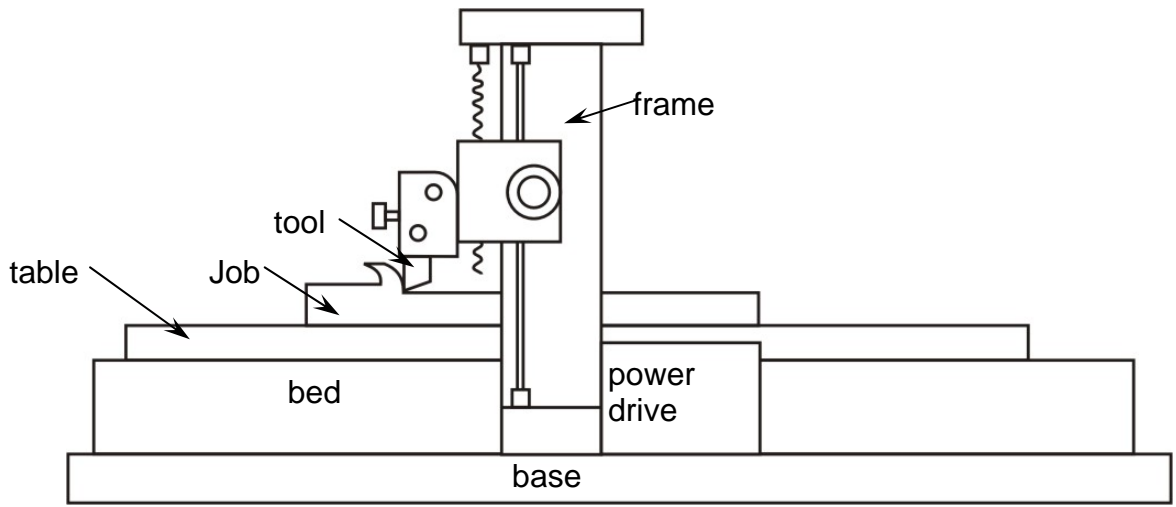
- o Column with base: it is the basic structure to hold the other parts
- o Drilling head: this box type structure accommodates the power drive and the speed and feed gear boxes.
- o Spindle: holds the drill and transmits rotation and axial translation to the tool for providing cutting motion and feed motion – both to the drill.

Drilling machines are available in varying size and configuration such as pillar drill, column drill, radial drill, micro-drill etc. but in working principle all are more or less the same.

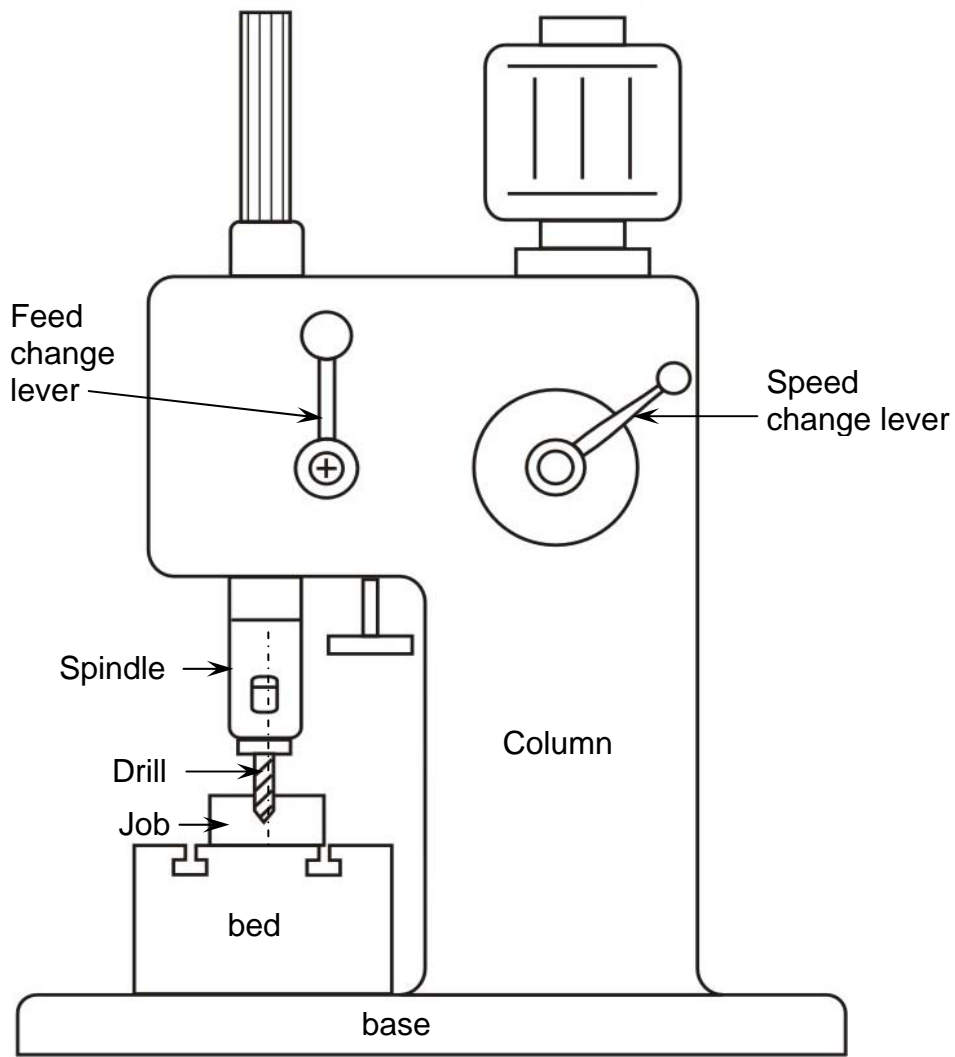
Drilling machines are used:

- o Mainly for drilling (originating or enlarging cylindrical holes)

- o Occasionally for boring, counter boring, counter sinking etc.
- o Also for cutting internal threads in parts like nuts using suitable attachment.



**Fig. 2.12** Schematic view of a planing machine

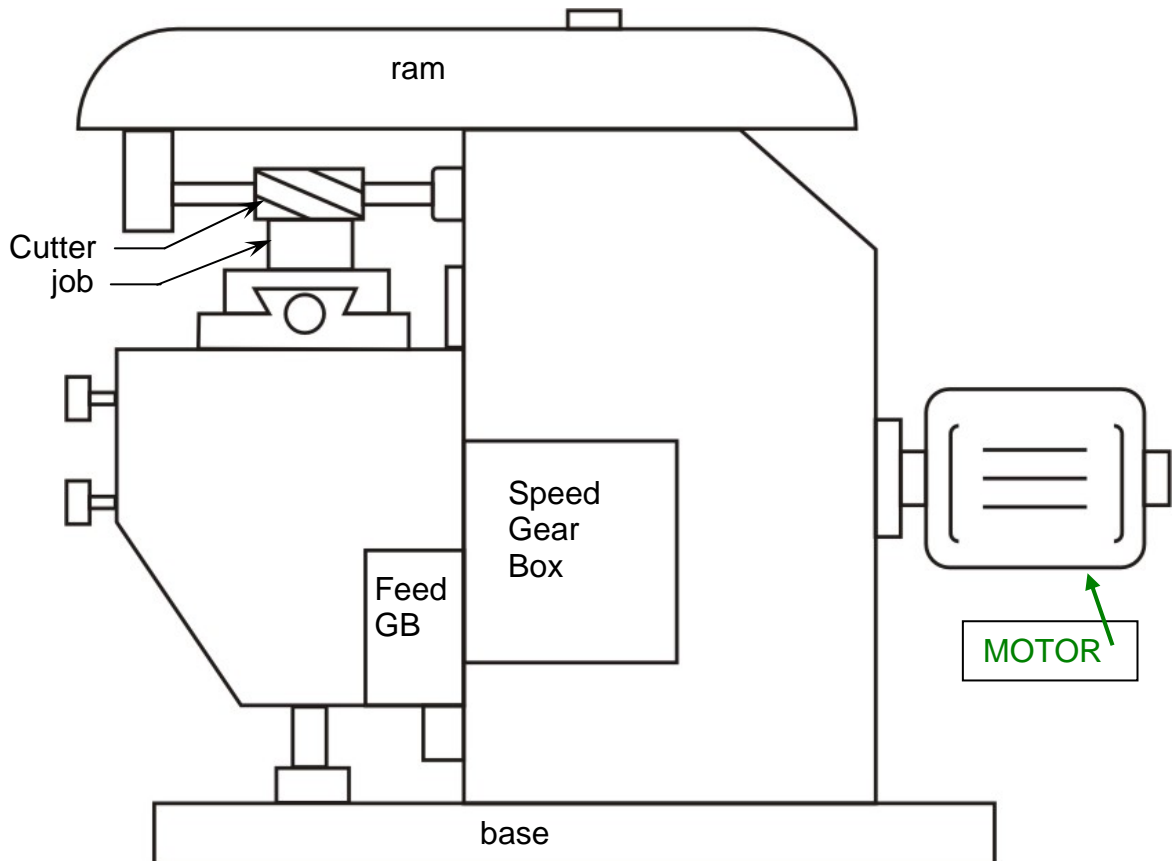


**Fig. 2.13** Schematic view of a drilling machine

- **Milling machine**

The general configuration of knee type conventional milling machine with horizontal arbour is shown in Fig. 2.14. Its major parts are

- o Milling arbour: to hold and rotate the cutter
- o Ram: to support the arbour
- o Machine table: on which job and job holding devices are mounted to provide the feed motions to the job.
- o Power drive with Speed and gear boxes: to provide power and motions to the tool-work
- o Bed: which moves vertically upward and downward and accommodates the various drive mechanisms
- o Column with base: main structural body to support other parts.



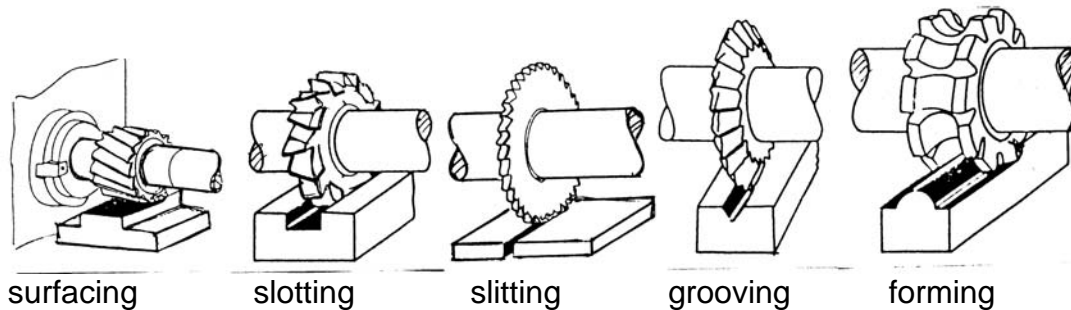
**Fig. 2.14** Schematic view of a milling machine

Milling machines are also quite versatile and can do several operations like

- o making flat surfaces
- o grooving, slitting and parting
- o helical grooving

- o forming 2-D and 3-D contoured surfaces

Fig. 2.15 shows some of the aforesaid milling operations.



**Fig. 2.15** Some common milling operation

## Specification of Machine Tools.

A machine tool may have a large number of various features and characteristics. But only some specific salient features are used for specifying a machine tool. All the manufacturers, traders and users must know how are machine tools specified.

The methods of specification of some basic machine tools are as follows:

- o **Centre lathe**
  - Maximum diameter and length of the jobs that can be accommodated
  - Power of the main drive (motor)
  - Range of spindle speeds
  - Range of feeds
  - Space occupied by the machine.
- o **Shaping machine**
  - Length, breadth and depth of the bed
  - Maximum axial travel of the bed and vertical travel of the bed / tool
  - Maximum length of the stroke (of the ram / tool)
  - Range of number of strokes per minute
  - Range of table feed
  - Power of the main drive
  - Space occupied by the machine
- o **Drilling machine (column type)**
  - Maximum drill size (diameter) that can be used
  - Size and taper of the hole in the spindle
  - Range of spindle speeds

- Range of feeds
  - Power of the main drive
  - Range of the axial travel of the spindle / bed
  - Floor space occupied by the machine
- **Milling machine** (knee type and with arbour)
    - Type; ordinary or swiveling bed type
    - Size of the work table
    - Range of travels of the table in X-Y-Z directions
    - Arbour size (diameter)
    - Power of the main drive
    - Range of spindle speed
    - Range of table feeds in X-Y-Z directions
    - Floor space occupied.

## Broad classification of Machine Tools

Number of types of machine tools gradually increased till mid 20<sup>th</sup> century and after that started decreasing based on Group Technology. However, machine tools are broadly classified as follows:

- According to direction of major axis :
  - horizontal center lathe, horizontal boring machine etc.
  - vertical – vertical lathe, vertical axis milling machine etc.
  - inclined – special ( e.g. for transfer machines).
- According to purpose of use :
  - general purpose – e.g. center lathes, milling machines, drilling machines etc.
  - single purpose – e.g. facing lathe, roll turning lathe etc.
  - special purpose – for mass production.
- According to degree of automation
  - non-automatic – e.g. center lathes, drilling machines etc.
  - semi-automatic – capstan lathe, turret lathe, hobbinh machine etc.
  - automatic – e.g., single spindle automatic lathe, swiss type automatic lathe, CNC milling machine etc.
- According to size :
  - heavy duty – e.g., heavy duty lathes (e.g.  $\geq 55$  kW), boring mills, planning machine, horizontal boring machine etc.
  - medium duty – e.g., lathes – 3.7 ~ 11 kW, column drilling machines, milling machines etc.
  - small duty – e.g., table top lathes, drilling machines, milling machines.
  - micro duty – e.g., micro-drilling machine etc.
- According to precision :

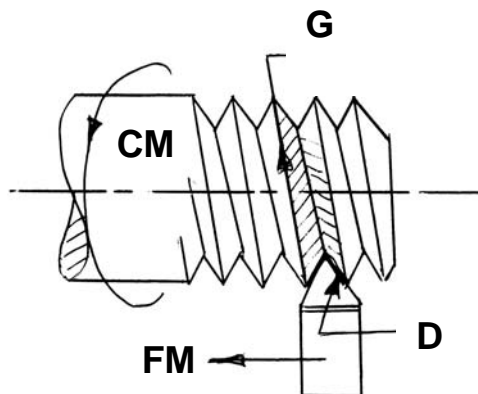
- o ordinary – e.g., automatic lathes
- o high precision – e.g., Swiss type automatic lathes
- According to number of spindles :
  - o single spindle – center lathes, capstan lathes, milling machines etc.
  - o multi-spindle – multispindle (2 to 8) lathes, gang drilling machines etc.
- According to blank type :
  - o bar type (lathes)
  - o chucking type (lathes)
  - o housing type
- According to type of automation :
  - o fixed automation – e.g., single spindle and multispindle lathes
  - o flexible automation – e.g., CNC milling machine
- According to configuration :
  - o stand alone type – most of the conventional machine tools.
  - o machining system (more versatile) – e.g., transfer machine, machining center, FMS etc.

## Exercise – 2

1. Show the tool-work motions and the Generatrix and Directrix in external thread cutting in centre lathe. Also state how those 'G' & 'D' are obtained.
2. In which conventional machine tools flat surface can be produced ?
3. State the major differences between shaping machine and planing machine.
4. In which machine tools both the cutting motion & the feed motion are imparted to the tool ?
5. How is feed expressed in turning, shaping, drilling and milling ?

## Answers

Ans. Q 1





$$G - x - T - F$$

$$D - (CM+FM) - (T+W) - T$$

Ans. Q. 2

Flat surfaces can be produced in

- centre lathes – e.g., facing
- shaping, slotting and planing machines
- milling machines

Ans. Q. 3

Shaping machine	Planing machine
o for small and medium size jobs	o for medium and large size jobs
o tool reciprocates and provide CM	o job on table reciprocates and provide CM
o feed motion is given to the job	o feed motion is given to the tool
o $G - CM - T - Tr$ $D - FM - W - Tr$	o $G - CM - W - Tr$ $D - FM - T - Tr$

Ans. Q. 4

Both CM and FM are imparted to the tool in

- drilling machine
- vertical boring machine

Ans. Q. 5

- turning – mm/rev
- shaping – mm/stroke
- drilling machine – mm/rev
- milling machine – mm/min