6.1 Introduction
An examination of number of machined components will show that a large percentage of the machined surfaces are either flat or cylindrical in shape and much of the total machining time is devoted to producing such shapes. These surfaces are produced by suitable movements of the work and cutting tools in machine tools specially designed for this purpose.

The elements of the cutting are:
1-The tool must penetrate the work to the depth of cut.
2-The rake face must be inclined at such an angle that the cutting action causes the separating chip to come away with the least resistance.

This will result in the choice of different rake angles for materials with different properties. In particular two different chip forms result, Fig. 6.1

![Fig. 6.1 Continuous and discontinuous chips](image)

a) A continuous chip will occur where the material will withstand the sharp bending of the chip which occurs in separating it from the work.
b) A discontinuous chip will occur where the material is fragmented in the cutting process
From this it follows that chips of ductile materials are of the continuous type and those of brittle materials are discontinuous. This is, of course, only a simple description of the fundamentals of the mechanics of metal cutting.

### 6.2 Machining tools
There are three types of metal cutting tools, they are follows:

1. Single point cutting edge tool, as in turning (lathe) and shaping (shaper and planer) operations.
2. Two cutting edge tools, as in twist drill (drilling).
3. Multi-cutting edges tool, as in milling and grinding operations.

These tools type are illustrated in Figs 6.2, 6.3, 6.4, 6.5 and 6.6

**Fig. 6.2 Typical single point tool**

**Fig. 6.3 Twist drill**
Fig. 6.4 Horizontal milling cutter

Fig. 6.5 Vertical milling cutter
Generating motions of machine tools.
The principle used in all machine tools is one of generating the surface required by providing suitable relative motions between the cutting tools and the workpiece. The cutting edge on the cutting tool remove a layer of work material. The removed material is called chip. The simplest surfaces to generate are flat surfaces and internal or external cylindrical surfaces. For example, if a tool is reciprocated backwards and forwards in a straight line and a work is incrementally fed beneath the tool in a direction at right angles to the motion of the tool, a flat surface will be generated on the workpiece. Thus, two kinds of relative motion must be provided by a metal cutting machine tool. These motions are called primary motion and feed motion and are defined as follows:
The primary motion is the main motion provided by a machine tool to cause relative motion between the tool and workpiece so that the face of the tool approaches the workpiece material. Usually, the primary motion absorbs most of the total power required to perform a machining operation.
The feed motion is the motion that may be provided to the tool or workpiece by a machine tool which, when added to the primary motion, leads to a repeated or continuous chip removal and the creation of a machined surface with the desired geometric
characteristics. This motion may proceed by steps or continuously, in either case it usually absorbs a small proportion of total power required to perform a machining operation. The nature of these motion varies according to the machining operation, see Fig. 6.7 the next table includes the primary and secondary motions for different machining operations.

Table: main cutting motions for machining operations.

<table>
<thead>
<tr>
<th>MACHINING OPERATION</th>
<th>PRIMARY CUTTING MOTION</th>
<th>APPLIED BY</th>
<th>FEED MOTION</th>
<th>APPLIED BY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turning</strong></td>
<td>Continuous rotation round the axis</td>
<td>Workpiece</td>
<td>Linear and continuous</td>
<td>Cutting tool</td>
</tr>
<tr>
<td><strong>Planer</strong></td>
<td>Linear and reciprocate</td>
<td>Workpiece</td>
<td>Linear and intermittent</td>
<td>Tool</td>
</tr>
<tr>
<td><strong>Shaper</strong></td>
<td>Linear and reciprocate</td>
<td>Tool</td>
<td>Linear and intermittent</td>
<td>Workpiece</td>
</tr>
<tr>
<td><strong>Drilling</strong></td>
<td>Continuous rotation round the axis</td>
<td>Twist drill</td>
<td>Linear and axial</td>
<td>Twist drill</td>
</tr>
<tr>
<td><strong>Horizontal milling</strong></td>
<td>Continuous rotation round the axis</td>
<td>Milling cutter</td>
<td>Linear and continuous</td>
<td>Workpiece</td>
</tr>
<tr>
<td><strong>Cylindrical grinding</strong></td>
<td>Continuous rotation</td>
<td>Grinding Wheel</td>
<td>Linear and reciprocate</td>
<td>Workpiece or grinding wheel</td>
</tr>
<tr>
<td><strong>Surface grinding</strong></td>
<td>Continuous rotation</td>
<td>Grinding Wheel</td>
<td>Linear and reciprocate</td>
<td>Workpiece or grinding wheel</td>
</tr>
</tbody>
</table>
Fig. 6.7 Cutting motions in different machining operations
6.3 Cutting tools
The cutting tools are generally manufactured from hard metals. The hardness of tool material is higher than that of the workpiece material. The resistance of tool material to heat and wear is high. The cutting tool material are as follows:
- Carbon tool steel.
- Alloy tool steel.
- High speed steel.
- Cutting carbides.
- Ceramics.
- Diamond.

As shown in Fig. 6.8 there are three main cutting tool angle:

1- Clearance angle ($\alpha$):
   It is the angle between the major flank and the cutting plane. This angle plays an important role in reducing the friction between the major flank of the cutting tool and workpiece. So that, the heating and wear of the tools reduce. Increasing the clearance angle, weakens the tool. Generally the clearance angle lies in between 6-12° according to the workpiece material and cutting conditions.

2- Tool angle ($\beta$):
   The angle between tool face and the main front plane. Increasing tool angle increase the tool rigidity and the rate of heat dissipation.

3- Rake angle ($\phi$):
   The angle between tool face and the plane perpendicular to the cutting plane. Increasing the rake angle gives the following properties.
   - Facilitates the tool penetration in the workpiece.
   - Reducing the cutting force and power consumed in cutting.
   - Increases the quality of the surface finish.
The rake angle is about 10° for hard metals, and about 30° for soft one.

![Diagram of cutting tool angles](image)

**Fig. 6.8 Main cutting tool angles**

**Turning operation**
Turning is the process of generation axis-symmetrical surfaces by cutting.

The main motions of the cutting tool and the workpiece are shown in Fig. 6.9

**Motion 1 (cutting motion)**
The workpiece rotates about its axis against the cutting edges of the tool.

**Motion 2 (feed motion)**
The tool moves slowly at a constant speed in a plane including the axis of the workpiece.

- For turning and cylinder, the feed motion must be parallel to the axis of the workpiece.
- For turning a cone, the feed motion must be inclined to the axis of the workpiece. With half of the apex angle of the cone.
- For turning profiles, the feed motion must be parallel to the profile of the workpiece.

**Motion 3 (depth of cut)**
Before starting with the feed motion, the tool must be moved radially to the desired depth of cut.
6.4 Machines using single cutting edge tools.

6.4.1 Engine lathe (Center lathe)

An engine lathe is shown diagrammatically in Fig. 6.10. It consists of horizontal bed supporting the headstock, the tailstock, and the carriage. All machine tools must have a means of supporting or holding the workpiece. The workpiece is gripped at one end by a chuck mounted on the end of the main spindle of the machine and is supported at the other end by a center mounted in the tailstock. The tailstock can be clamped at various positions along the bed to accommodate workpieces of various lengths. Short workpieces need only be gripped by the chuck.

Tool holding

The simplest form of tool holder is illustrated in Fig. 6.11 and is suitable for holding one single-point tool. In figure, the tool post is shown mounted on a compound rest, the rest is a small slideway that can be clamped in any angular position in the horizontal plane and is mounted on the cross slide of the lathe. Another common form of the tool post is shown in Fig. 6.12. It also would be mounted on the compound rest. This four-way post can accommodate as many as four cutting tools. Any cutting tool can be quickly brought into position by unlocking the tool post with the lever provided, rotating the tool post, and finally reclamping with the lever.
Workpiece holding
To hold work between centers, it must be drilled at each end or be supported with a drive fit on a mandrel so drilled. A carrier is fixed to the work, Fig. 6.13, and is driven by a catch plate on the spindle. It will be evident that the center in the spindle is a running center, while that in the tailstock is dead.

Fig. 6.10 a- An engine lathe, b- Cylindrical turning on an engine lathe
Chucks
A chuck is a device for gripping the workpiece as it is rotated. The chuck will be naturally fit on, or into the spindle end. Chuck are usually classified into two types.

a- Three jaws concentric  
Three jaws concentric chucks are operated by which rotates a scroll causes all the jaws to move equally, so that if they set at equal distance from the center initially or bored in position, they will maintain their relationship.

b- Four jaws independent Fig. 6.14  
Four jaws independent chucks usually have hard jaws with serrated teeth. The jaws are driven by individual square-thread screws, and will hold irregular work internally or externally.
6.4.2 Operations on center lathe
Figure 6.15 illustrates five typical lathe operations: Cylindrical turning, facing boring, external threading and parting. In each case the primary motion and the feed motion, together will certain other terms and dimensions are indicated. In any machining operation the workpiece has three important surfaces:

1- The work surface: the surface on the workpiece to be removed by machining.

1- The machined surface: the desired surface produced by the action of the cutting tool.

2- The transient surface: the part of the surface formed on the workpiece by the cutting edge and removed during the following cutting stroke, during the revolution of the tool or workpiece.
Fig. 6.14 Lathe work holding using chucks. (a)- Three jaws chuck, (b) Independent four-jaws chuck

Fig. 6.15 Lathe operations
6.4.2.1 Types of lathes
There are many types of lathes, Fig. 16-18 which vary in size function and degrees of precision. Bench lathes are small enough to be placed on a work bench if required the bed length normally is less than 90 cm.

Fig. 6.16 Bench lathe

The engine lathe is the general purpose machine shop type. The bed length varies from 90 cm to 6 meters or more.

Fig. 6.17: Engine lathe
Gap lathe
Is a lathe with provision for turning larger diameter workpiece than it is possible on a standard lathe of comparable size. The bed of this lathe slides to permit about twice the normal swing, see the figure below.

Fig. 6.18 Gap lathe

6.4.2.2 Lathe tools
Fig. 6.19 shows a typical array of tools for right-hand or left-hand operations, with their names. The illustration also shows parting-off, screw – cutting and various boring tools.

Machining time
a- cylindrical surface turning:
to turn a cylindrical surface of length $I_w$ the number of revolution of the workpiece is $I_w/f$, and the machining time $t_m$ is given by

$$t_m = I_w / f.n_w$$

where $n_w$ is rotational frequency of the workpiece, and $f$ is the longitudinal feed. It should be emphasized at this point that $t_m$ is the time for one pass of the tool (one cut) along the workpiece. The cutting speed ($v$) varies according to the material type, where
\[ v = \frac{\pi d_w n_w}{1000} \text{ (m/min.)} \]

where \( \pi \) is constant, \( d_w \) = workpiece diameter

**b- parting – off:**

To calculate the part off time replace the feed \( f \) by the cross feed of the cutting tool.

**Example:**

Calculate the machining time required for cylindrical turning of 10 shafts, each with 30 mm diameter and 400 mm long. Knowing that the cutting speed for the material = 20 m/min, and the feed rate 0.1 mm/rev.

**Solution**

\[ V = \frac{\pi d_w n_w}{1000} \text{ (m/min)} \]

\[ 20 = \frac{\pi \times 30 \times n_w}{1000} \]

\[ i.e \ n_w = \frac{20000}{30\pi} \]

\[ t_m = \frac{400}{(0.1 \times n_w)} = \frac{30\pi \times 400}{(20000 \times 0.1)} \]

\[ = 19 \text{ min} = \text{The time for one shaft} \]

For ten shafts, the total machining time = \( 19 \times 10 \)

\[ = 190 \text{ min.} \]

---

**Fig. 6.19 lathe tools**
6.4.3 Shaping machine (shaper)
The shaper is a small machine on which the primary motion is linear, Fig. 6.20 the single point tool is gripped in toolhead mounted on the end of a ram. The ram is made to move backward and forward either by a mechanical derive system or a hydraulic piston and cylinder. The cutting stroke is the forward stroke. The forward ram speed is lower than the speed on the return stroke, causing the production time to be reduced as much as possible.
A quick return mechanism often used in mechanical shapers is shown in Fig. 6.21. The feed is applied to the workpiece in increments at end of the return stroke of the ram.
Shapers are most commonly used to machine flat surface on small components, Fig. 6.20 typical tool and work holding methods are illustrated in Fig. 6.22. The geometry when shaping horizontal, vertical and inclined flat surface are shown in Fig. 6.23 for a surface of width $b_w$.
The machining time $t_m$ will be given by

$$t_m = \frac{b_w}{f.n_r}$$

Where $n_r$ is the frequency of reciprocation or cutting strokes, and $f$ is the feed.

Fig. 6.20 Production of a flat surface on a shaper
Fig. 6.21 Quick return mechanism for a mechanical shaper

Fig. 6.22 Tool, and workholding in a shaper
Example
A planer is operated at two cutting strokes per second and is used to machine a workpiece 150 mm in length at a cutting speed of 0.5 m/s using feed of 0.4 mm and depth of cut = 6 mm. Calculate:

- The total machining time to produce 800 components each 100 mm in width.
- The percentage of this time when the tool is not contacting the workpiece.

**solution**

Machining time \( t_m = \frac{b_w}{f.n_r} \)

\[ \frac{100}{(0.4 \times 2)} = 125 \text{ seconds} \]

i.e. the total machining time = 800\times125 = 100000 \text{ s} = 27.77 \text{ hrs} \]

Time for one stroke = 0.5 S

Cutting time for one stroke = Workpiece length / cutting speed

\[ \frac{150}{0.5} = 0.3 \text{ seconds} \]

i.e. return time = 0.5-0.3 = 0.2 S
i.e. the percentage of return time to cutting time
\[ = \frac{0.2}{0.3} = 0.66 \]

6.4.4 Planning machine (planer)
The shaper is unsuitable for generating flat surface on very large parts because of limitations on the stroke and overhanging of the ram. This problem is solved in the planer, Fig. 6.24 by applying the linear primary motion to the workpiece and feeding the tool at right angles to this motion.

6.5 Machines using multi point cutting tools
Mulitpoint tools
A multipoint tools can be regarded as a series of two or more cutting parts secured to a common body (drills, reamers and milling cutter)
6.5.1 Drilling machine
Drilling is the process of producing a hole in the workpiece by cutting the volume to be removed into chip. The main motions are provided through the drilling tool (twist drill), Fig. 6.25 Cutting motion is along the axis of the twist drill. Feed motion is along the axis of the twist drill.

A drill press (Fig. 6.26) can perform only those operations where the tool is rotated and fed along its axis of rotation. The
workpiece always remains stationary during the machining process. On many drill presses, the tool is fed by the manual operation of a lever to the right of the head. Both the worktable and the head can be raised and lowered to accommodate workpiece of different heights.

Fig. 6.26 Drilling on a drill press

Large twist drills are usually provided with a taper shank as shown in Fig. 6.27 this shank is designated to be inserted in a corresponding taper hole in the end of the machine spindle.
Small twist drills have a parallel shank and are held in a three jaws chuck of the familiar type used in hand drills. These chucks are provided with a taper shank for location in the drill press spindle or in the tailstock of a lathe Fig. 6.28.

Fig. 6.27 a) Drill with taper shank, 1- Taper, 2- Flat tang
b) Complete taper sleeve joint

Fig. 6.28 Three jaws chuck.
1- collet, 2- jaws, 3- compression spring
Several other machining operations can be performed on a drill press, and some of the more common ones are illustrated in Fig. 6.29.

For large workpiece a radial-arm drilling machine is used, Fig. 6.30. In the machine the drilling head and motor can be positioned along an arm that is free to swing in a horizontal plane about the column, allowing large areas to be covered. The radial-arm drilling machine is particularly suitable for drilling large numbers of holes in heavy workpieces.

![Fig 6.29 Some drill-press operations](image)

(a) Center drilling  
(b) Reaming  
(c) Spot facing

### 6.5.2 Milling machines

#### 1- Horizontal milling machine

In horizontal milling machine shown in Fig. 6.31, the milling cutter is mounted on a horizontal arbor driven by the main spindle. The tools are therefore rotated and the work fed continuously. The simplest operation, slab milling, is used to generate a horizontal surface on the workpiece. The geometry of the slab milling cutter is shown in Fig. 6.24. Some milling operations are illustrated in Fig. 6.32.
Fig. 6.30 Radial-arm drill
Fig. 6.31 Slab milling on a knee-type horizontal milling machine.
A wide variety of operations involving the machining of horizontal, vertical and inclined surfaces can be performed on a vertical milling machine. Fig. 6.33 illustrates this type of milling and face milling operation. A variety of vertical milling machine operations are shown in Fig. 6.34.
Fig. 6.33: Face milling machine

Fig. 6.34 Some vertical milling machine operations.
a- Horizontal surface, b- Slot, c- Dovetail, d- T-Slot.

6.5.3 Grindning machine.
Grinding wheels are generally cylindrical, disc-shaped, or cup-shaped Fig. 6.35 The machines on which they are used are called grinders machines, or grinders, they all have a spindle which can be rotated at high speed and on which the grinding wheel is mounted.
Abrasive wheels are sometimes used in rough grinding where material removal is the important factor, more commonly abrasive wheels are used in finishing operations where the resulting surface finish is the criterion.

Horizontal-spindle surface grinding machine.
As shown in Fig. 6.36 a horizontal spindle provides primary motion to the wheel. The principle feed motion is the reciprocation of the worktable on which the work is mounted. This motion is known as the traverse and is hydraulically operated.

![Diagram](image)

Fig. 6.35: Principal shapes of grinding wheels
b- disc b- straight c- cup d- dish
Cylindrical grinding machine
In the cylindrical grinding machine Fig. 6.37, the workpiece is supported and rotated between centers. The head stock provides the low-speed rotational drive to the workpiece and is mounted together with the tailstock on a worktable that is reciprocated horizontally using a hydraulic drive.

Internal grinding machine
The last machine to be described here is the internal grinder Fig. 6.38 which is designed to produce an internal cylindrical surface. The wheel head supports a horizontal spindle and can be reciprocated in a direction parallel to the spindle axis. A small cylindrical grinding wheel is used and is rotated at very high speed. The workpiece is mounted in a chuck or on a magnetic faceplate and rotated. Horizontal feed is applied to the wheel head in a direction normal to wheel spindle, this motion is known as infeed.
Fig. 6.37 Cylindrical grinding
Fig. 6.38 Internal grinding