UNIT 1 INTRODUCTION TO TOOL ENGINEERING AND MANAGEMENT

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1.1 INTRODUCTION

Tool engineering is a vital area of production engineering. It includes metal cutting, pressing, and various work holding devices. Metal cutting is the operation in which thin layer of metal is removed by wedge shaped tool. Metal cutting is commonly associated with industries like automotive, aerospace, home appliance, etc. The machining of metal and alloys play a crucial role in the range of manufacturing activities including ultra precision machining of extremely delicate components.

Objectives

After studying this unit, you should be able to

- understand the basics of tool engineering,
- classify the tooling and machine tools, and
- recognise various types of operations performed on different machines.

1.2 BASICS OF TOOL ENGINEERING

Machine tools are very important for any industrialised country because they hold a key position in the technology chain. Machine tools are needed to build the machines and parts with which capital goods and consumer goods of all kinds are manufactured, from cars to airplanes, from glasses to ball point pen. If the creative tool engineers and qualified skilled workers are constantly producing faster, better and more intelligent machine tools for the market, they are helping many industries. This means innovation in machine tool industry have a far-reaching and multiplicative impact.

Tool engineer is a professional whose job is to assist the production engineer in design and refinement of production, in design and purchasing of machinery, tools, fixtures, dies and gauges to be used in producing the parts and in their assembly to the final production.

The most common classification of types of tooling is as follows:

Cutting Tools
   Drills, reamers, milling cutter, broaches, tap etc.

Jigs and Fixture
   For guiding the tool and holding the workpiece.
Sheet Metal Press Working Dies

Figure 1.1 shows various types of tool bit grinds. It should be noted that edges involved in cutting operation must be the only edges permitted to touch workpiece. All other faces should be ground so that they will not interfere with the cutting action.

![Figure 1.1: Various Types of Tool Bit Grinds](image)

Work holding devices such as jigs and fixtures are used for holding the workpiece. Jig is workpiece holding and locating device that positions and guides or controls a cutting tool. Drill jig makes it possible to drill, ream and tap hole at faster speed and with great accuracy as compared to that of conventional hand methods. Fixture is workpiece locating and holding device used with machine tools, inspection, welding and assembly. Fixture takes care of accuracy of workpiece to be machined and operators fatigue is also taken care by fixture itself. Fixture is always fixed to machine or bench. Table 1.1 shows the historical development of materials and manufacturing processes.

Table 1.1: Historical Development of Machine Tools and Related Devices

<table>
<thead>
<tr>
<th>Period</th>
<th>Tools, Tool Materials and Machining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 4000 BC</td>
<td>Tools of stone, flint, wood, bone, ivory</td>
</tr>
<tr>
<td>4000 - 3000</td>
<td>Corundum</td>
</tr>
<tr>
<td>3000 - 2000</td>
<td>Hole making, hammered axes, tools for iron making and carpentry</td>
</tr>
<tr>
<td>2000 - 1000</td>
<td>No significant development</td>
</tr>
<tr>
<td>1000 - 1BC</td>
<td>Improved chisel, saws, files, wood working lathes</td>
</tr>
<tr>
<td>AD 1-1000</td>
<td>Etching of armor</td>
</tr>
<tr>
<td>1000 - 1500</td>
<td>Sand paper, wind mill driven saw</td>
</tr>
<tr>
<td>1500 – 1600</td>
<td>Boring, turning, screw cutting lathe, drill press</td>
</tr>
<tr>
<td>1600 – 1700</td>
<td>Hand lathe (wood)</td>
</tr>
<tr>
<td>1700 – 1800</td>
<td>Shaping, milling, copying, lathe for gunstocks, turret lathe, universal milling machine, vitrified grinding wheel</td>
</tr>
<tr>
<td>1800 – 1900</td>
<td>Geared lathe, automatic screw machine, hobbing, HSS tools, Al$_2$O$_3$ and silicon carbide (synthetic)</td>
</tr>
<tr>
<td>1900 – 1920</td>
<td>Tungsten carbide, mass production, transfer machine</td>
</tr>
<tr>
<td>1920 – 1940</td>
<td>No significant development</td>
</tr>
<tr>
<td>1940 – 1950</td>
<td>No significant development</td>
</tr>
<tr>
<td>1950 – 1960</td>
<td>Electrical and chemical machining, automatic control</td>
</tr>
<tr>
<td>1960 – 1970</td>
<td>Titanium carbide, synthetic diamond, numeric control</td>
</tr>
<tr>
<td>1970 – 1980</td>
<td>CBN, coated tools, CIM, adaptive control, industrial robots, FMS, unmanned factory</td>
</tr>
</tbody>
</table>
1.3 ELEMENTS IN TOOL ENGINEERING

The basic elements of tool engineering are single point cutting tool and multiple point cutting tool.

1.3.1 Single Point Cutting Tool

The cutting tool, which has only one cutting edge, is termed as single point cutting tool. Single point cutting tools are generally used while performing turning, boring, shaping and planing operation. The important elements in single point cutting tools are rake angle, principle cutting edge, nose etc.

Types of single point tools are as follows:

(a) Solid type tool bit
(b) Brazed tip tool
(c) Long indexable insert tool
(d) Throwaway indexable insert tool

Solid Type Tool Bit

It is made up of same material as that of the tool. Solid tools are ground to the required geometry by machine operator. They are also used for special ground form tools since material is easier to grind the special shapes. They may be mounted on the machine tool directly in the tool post. Smaller size solid bit are usually held in tool holder. This type of tool is tipped up to an angle from 15° to 20°. High speed steel and cast alloy tools are commonly categorized into solid type. The material used in solid bit is relatively cheaper than others.

Brazed Tip Tool

These have the cutting insert held in tool shank by silver brazing, i.e. soldering. Tungsten carbide is generally used as a material for brazed tip tools. Torch or gas burners, and induction heating are used for brazing carbide tips of tool. In all these three methods, a pocket is machined in the shank material to fit the shape of carbide insert. Induction heating is used by large industries to produce it in large quantity. Torch method is used by small industries or limited production. The main advantage of induction heating is the localized heat generated with tool shank and carbide tool. Also it is faster than torch and gas burner method. Brazed tool is having lower cost. Also, it doesn’t occupy much space.

Long Indexable Insert Tool

It consists of mechanical tool holder and an indexable insert with top and bottom that can be regrounded to correct geometry. Regrinding is done by grinding the ends of inserts normal to the side only enough to clean up the cutting edge. Inserts are available in square, rectangular, diamond, round, triangular shapes.

Throwaway or Disposable Insert Tool

It refers to the cutting tool insert, which is mechanically held in the tool holder. The inserts are used depending upon the shape and insert geometry. Inserts have number of cutting edges that can be indexed into position. When all the cutting edges are used, the insert is discarded and not resharpened. This process eliminates the tool grinding requirement. Inserts are available in triangular, square, round, diamond, parallelogram and button shapes.

1.3.2 Multi Point Cutting Tool

A cutting tool which has more than one cutting edge is multi point cutting tool. Multi point cutting tools are generally used while performing drilling, milling, broaching, grinding etc. Important elements are cutting edge, helix angle, the number of teeth. The cutting edge is the only element that comes in direct contact with the work. The axial
angle corresponds to side rake angle in single point tool and similar angle with respect to the cutting axis, i.e. the radial angle is same as the back rake angle.

In case of straight tooth milling cutter, a sudden change in tooth load occurs when the chip drops off as the tooth leaves the work. This type of force formation is responsible for chatter formation. Much smoother operation is obtained when more than one tooth cut at the same time. This happens particularly when the cutting edge length is gradually changing as in helical cutters.

SAQ 1
(a) What are the different types of single point cutting tool?
(b) Differentiate between brazed tip tool and long indexable insert tool.
(c) What are the different operations that can be performed by multi point cutting tool?
(d) Discuss about the functions of jig and fixture.

1.4 TYPES OF MACHINE TOOLS

Machine tools are classified as follows:

General Purpose Machine Tool

The machine tool that is able to perform all the metal cutting operations within their range of operation is called as general purpose machine tool. These are also called basic machine tool.

Examples of general purpose machine tools are engine lathe, drilling machine, milling machine, boring machine, grinding machine, shaping and planing machine etc.

General purpose machine tools are further classified in accordance with surface produced and are as follows:

For Cylindrical Work

Centre lathe, bar turret lathe, capstan lathe, boring machine, cylindrical grinder etc.

For Surface Work

By Reciprocating Motion: Planing, shaping, slotting and broaching machines etc.

By Rotary and Translatory Motion: Milling machine, surface grinding machine, lathe etc.

For Producing or Enlarging Hole

Lathes, drilling machine, boring machine, honing machine, broaching machine etc.

For Gear Cutting

Milling machine, Rack cutter and pinion cutter machine, hobbing machine etc.

For Thread Cutting

Lathe screw cutting machine, tapping, thread milling, thread grinding, thread rolling machine etc.

Production Machine Tools
Production machine tools are capable of enhancing the rate of production and reducing the manufacturing cost as well.

Examples of production machine tools are multiple tool lathe, multiple head drilling machine, capstan and turret lathe, automatic screw machine, semi-automatic lathe, production milling machine etc.

**Special Purpose Machine Tool**

The machine tools that are able to perform machining of large quantity of same products are classified as special purpose machine tools. These types of machines are quite important in reducing manufacturing cost when relative jobs are performed continuously. Examples of special purpose machine tools are piston turning lathe, camshaft grinder, gear generator, form tool etc.

**SAQ 2**

(a) What are the different types of machine tool?
(b) Discuss about special purpose machine tool.
(c) Define general purpose machine tool.

### 1.5 OPERATIONAL ISSUES IN TOOL ENGINEERING

The different kinds of operations performed by a cutting tool are given as follows:

**Facing**

Facing is carried out on lathe machine. Facing generates flat surface, normal to the axis of rotation by feeding the tool from the surface towards the centre or outward from the centre. In facing, the depth of cut is measured in direction parallel to the axis and feed in a radial direction. The cutting speed in this operation varies continuously, i.e. approaching zero towards the centre of the bar.

**Turning**

Turning is also carried out on lathe. The tool is held rigidly in a tool post and moved at a constant rate along the axis of the bar, cutting away the layer of material to form a cylinder or a surface of more complex profile. Figure 1.2 shows principle of turning operation.

![Figure 1.2: Lathe Turning](image)

**Drilling**
It is carried out on drilling machine as well as on the lathe. Twist drill is commonly used for drilling operations. Drilling is the operation through which holes are produced. Essential feature of drilling is the variation in cutting speed along the cutting edge. The speed is maximum at the periphery that generates cylindrical surface and approaches zero near centerline of drill. There are only even numbers of tooth on twist drill for balancing purpose. Figure 1.3 depicts the nomenclature of twist drills.

![Figure 1.3: Twist Drill](image)

**Drilling Time Estimation**

The cutting speed in the drilling operation is given by following equation

\[ V = \frac{\pi DN}{1000} \]  

where,  
\( V \) = cutting speed, m/min  
\( D \) = diameter of the twist drill, mm  
\( N \) = rotational speed of the drill, rev/min

The drill will have to approach the start of the hole from a distance say, \( A_i \), and also traverse beyond the actual hole by a distance termed as the total approach allowance \( A \). Generally, \( A_i \) is taken as 2 to 3 mm. Total approach distance is given by

\[ A = \frac{D}{2} \tan \gamma \]  

where,  \( \gamma = 59^\circ \) in common case

So,  
\[ A = \frac{D}{3.3286} \]

Total length of tool travel

\[ L = (I + A + 2) \text{ mm} \]  

where, \( I \) = length of hole

Thus, time for drilling the hole  
\[ t = \frac{L}{(f \times N)} \]

where, \( f \) = feed rate in mm/rev.

**Example 1.1**

A hole of 20 mm diameter and 50 mm depth is to be drilled in a mild steel component. The cutting speed can be taken as 60 m/min and the feed rate as 0.25 mm/rev. Calculate the machining time.

**Solution**
Given \( V = 60 \, \text{m/min} \)
\( f = 0.25 \, \text{mm/rev} \)
\( D = 20 \, \text{mm} \)
\( L = 50 \, \text{mm} \)

Spindle speed, \( N = \frac{1000 \times 60}{\pi \times 20} \)
\[ = 955 \, \text{rev/min} \]

Total approach distance, \( A = \frac{20}{2} \tan 59 \)
\[ = 6 \, \text{mm} \]

Total length of drill travel = \( 50 + 6 + 3 = 59 \, \text{mm} \)

Time for the drilling the hole = \( \frac{59}{0.25 \times 955} \)
\[ = 0.247 \, \text{minutes} \]

**Reaming**

It is similar to drilling operation. It is basically used for finishing of holes and enlarging of small holes. Reaming is carried out by the reamer, which has large number of flutes.

**Boring**

Boring is used to enlarge already produced hole or bore hole. It is carried out on boring machine.

**Trippaning**

Trippaning is the operation carried out to produce large hole without drilling. It is carried out by tripanning tool. Trippaning tool is hollow drill bit. It has only disadvantage that it only produces through hole and not used for blind hole. The trippaning tool is portrayed in Figure 1.4. The function of tripanning tool is same as that of drill but only difference is that it produces the hole thoroughly.

![Figure 1.4: Tripanning Tool](image)

**Broaching**

Broaching is the operation performed to enlarge hole especially, non-circular hole. It is carried out by broach tool. As a pre requirement, there must be an initial hole. Broach tool has multiple traverse cutting edges. Each successive cutting edge removes a layer of material giving steady approach to required final shape. The shape produced may be flat surfaces but more often, they are holes of various forms of grooved components such as the teeth of gear. Cutting speed and feed are kept low in this operation. Also adequate lubrication is required during operation.

**Milling**
The removing of metal by advancing a workpiece against a rotating multiple point tool is known as Milling. Milling operation is generally divided into 2 types:

(a) Slab Milling  
(b) Face Milling

**Slab Milling**

Producing the slot on the surface of workpiece is called slab milling operation. The geometry of the chip generated by slab milling depends upon the path followed by the cutting edge. The milling cutter rotates at uniform velocity and the workpiece feed linearly under the cutting edge. As a result the tip of the cutting tool traces a trochoid.

![Figure 1.5 : Slab Milling](image)

In the up milling operation the chip starts with zero thickness at A and reaches the maximum thickness at B'. The length of the chip AB' in case of up milling is given by

\[
AB' = \frac{D\phi_c}{2} + f \sqrt{d (D - d)} \frac{\pi}{D} 
\]  

... (1.5)

In case of down milling, the chip length is given by

\[
AB' = \frac{D\phi_c}{2} + f \sqrt{d (D - d)} \frac{\pi}{D} 
\]  

... (1.6)

The difference in the chip length is relatively small and depends upon the increase in feed rate.

**Example 1.2**

A 100 mm diameter cutter having 8 teeth cuts steel at 20 m/min. the depth of cut is taken as 4 mm and the table feed rate is 150 mm/min. Find the length of the chip in up milling operation.

**Solution**

Spindle speed \(= \frac{(1000 \times 20)}{(\pi \times 100)}\)  
\(= 63.66 \text{ rev/min}\)

Feed rate of the cutter \(= \frac{150}{63.66}\)  
\(= 2.35 \text{ mm/rev.}\)

Tooth contact angle \(\phi = \cos^{-1} \left[ \frac{(50 - 4)}{50} \right] \)
= 23.074 degree = 0.406 radians.

In up milling, the chip length is

\[ AB' = \frac{100 \times 0.403}{2} + \frac{1.57 \sqrt{4(100 \times 4)}}{\pi \times 100} \]

= 20.2479 mm.

**Face Milling**

Removal of thin layer of material from flat workpiece is called **face milling** operation. In order to arrive at chip thickness, we have considered Figure 1.6 where the top view of face milling is shown. It is again assumed here that the face mill is located symmetrically above the workpiece to simplify the analysis.

![Figure 1.6: Cross-section for the Chip Produced by Milling using a Face Milling Cutter with Symmetrical Cut](image)

The tooth angle, \( \phi_c \), in case of face milling is given by

\[
\sin \phi_c = \frac{W}{D} = \frac{W}{D} \quad \ldots (1.7)
\]

The chip thickness at any section is given by

\[ t_x = f_t \sin \phi \quad \ldots (1.8) \]

where, \( f_t \) = feed per tooth.

The smallest chip thickness is at the edge of the workpiece while the maximum is at the centre of the workpiece. The angle at the minimum chip thickness is

\[ \phi = \frac{\pi}{2} - \frac{\phi_c}{2} \quad \ldots (1.9) \]

Hence,

\[ t_{min} = f_t \cos \phi_c \]

Similarly,

\[ t_{max} = f_t \]

**Example 1.3**
A 100 mm diameter cutter having 8 teeth cuts steel bar with a width 80 mm and feed rate 160 mm/min. The depth of cut is taken as 4 mm. Find the minimum and maximum chip thickness in face milling operation.

**Solution**

The tooth angle \( \phi_c \) in case of face milling is given by

\[
\sin \phi_c = \frac{W}{D} = \frac{80}{100} = 0.8
\]

\( \phi_c = 53.13 \) degrees = 0.927 radians

Feed rate per tooth, \( f_t = \frac{160}{8} = 20 \) mm/min

\( t_{min} = f_t \cos \phi_c = 20 - 0.6 = 12 \) mm

\( t_{max} = f_t \) = 20 mm.

**Shaping Operation**

Shaping is the machining operation used to produce flat surfaces. It is carried out by shaper. In shaping operation, workpiece is kept stationary while the cutting tool is given a reciprocating motion. The cutting action takes place during forward stroke only while the return stroke is made idle to avoid damage to tool and workpiece. To reduce machining time, the return stroke has higher velocity than forward stroke. This is achieved by Whitworth Quick Return motion mechanism. In shaping operation, velocity is maximum at the middle of the return stroke and is minimum at the beginning of forward stroke. Figure 1.7 shows principle of shaping operation.

![Figure 1.7: Shaping Operation](image)

Planing is similar to shaping operation. Only difference being that the tool is stationary and workpiece is reciprocating to achieve the cutting. It is used for producing flat surfaces on workpiece that are too large.

**Slotting**

Slotting is also similar to shaping. It is carried out by slotting machine. Slotting machine is generally vertical shaper. Slotting machine has vertical ram to slot holes, keyways and grooves.

**Grinding**

It is a machining operation in which a multi-edged rotating abrasive tool called grinding wheel removes excess material from translatory workpiece (i.e. Surface Grinding) or a rotating workpiece (i.e. Cylindrical Grinding). Nature of relative motion of various cutting operations is explained in Table 1.2.

**Table 1.2: Nature of Relative Motion of Various Cutting Operations**
Hobbing
Hobbing is a process to produce gear. It is a machining operation, which is carried out by hob. Hob is used to produce tooth and other profiles such as helical gear, worm gear, spline shaft, spur gear (external) etc.

Forming and Parting Off
Forming operation involves the formation of complex profile on the workpiece by using tool with the cutting edge of required profile. It is carried out by form tool. Form tool is fed into the peripheral surface of the bar in a radial direction and categorized as a special purpose tool.

Honing
Honing is a fine finishing operation. In honing operation, rotating and reciprocating bonded abrasive sticks, and slowly abrades the workpiece to the desired finish and accuracy.

Lapping
Lapping is also fine finishing operation. In this, laps are made of metal that is softer than the workpiece and it lightly rubs the abrasive particles against the workpiece. Figure 1.8 shows the principle of lapping.

Superfinishing
Superfinishing is also the fine finishing operation in which, a fairly large, boned abrasive stone, is kept pressing lightly against rotating workpiece. The workpiece is given a reciprocating motion in axial direction. Generally, flat surfaces are finished by superfinishing operation.

Blanking
In blanking operation, a punch cuts through unprocessed workpiece and striped metal can be treated as scrap. Blanking operation results in a formation of a blank. Blanking is done by shearing and tearing operation. Principle of blanking operation is illustrated in Figure 1.9.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Motion of Job</th>
<th>Motion of Cutting Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turning</td>
<td>Rotary</td>
<td>Translation</td>
</tr>
<tr>
<td>Shaping</td>
<td>Intermittent Translation</td>
<td>Translation</td>
</tr>
<tr>
<td>Planing</td>
<td>Translatory</td>
<td>Intermittent Translation</td>
</tr>
<tr>
<td>Drilling</td>
<td>Fixed</td>
<td>Rotation, Translatory</td>
</tr>
<tr>
<td>Boring</td>
<td>Forward Translation</td>
<td>Rotation</td>
</tr>
<tr>
<td>Milling</td>
<td>Translatory</td>
<td>Rotation</td>
</tr>
<tr>
<td>Hobbing</td>
<td>Rotation</td>
<td>Rotation and translation</td>
</tr>
<tr>
<td>Surface Grinding</td>
<td>Translation</td>
<td>Rotation</td>
</tr>
</tbody>
</table>

Figure 1.8 : Principle of Lapping Operation
**Piercing**

Piercing is a machining operation in which, a punch cuts through unprocessed workpiece and the resulting slug (i.e. blank) is treated as scrap. Piercing results a hole in workpiece. Piercing is done by shearing and tearing operation. Principle of piercing operation is also illustrated in Figure 1.9.

![Figure 1.9 : Principle of Blanking and Piercing Operation](image)

**Lancing**

This is combined bending and cutting operation along the line in a work material. The punch is designed to cut two or three sides and bend along the fourth side. Figure 1.10 shows the principle of lancing operation.

![Figure 1.10 : Principle of Lancing Operation](image)

**Cutting Off and Parting**

A cut-off operation separates the work material along a straight line in a single line cut. It is used to separate the workpiece from the scrap strip and is also used to break the scrap strip skeleton as it leaves the die, enabling it easier to handle.

When the operation separates the work material along the straight line in double line cut, it is called parting operation. Parting is used to separate the workpiece from the scrap strip.

**Notching**

The operation which removes material from either or both edges of strip are called notching. Notching is used to shape the outer counter of workpiece in a progressive die. It also removes excess material before drawing or forming operation in a progressive die. Figure 1.11 depicts the principle of parting and notching operations.

![Figure 1.11 : Principle of Parting and Notching Operations](image)
Shaving

The operation in which the surface of previously cut edge is finished smoothly to accurate dimension is called shaving. Shaving is a secondary operation as it is usually done after punching. Figure 1.12 illustrates the principle of shaving operation.

Trimming

In trimming, the distorted excess material is removed from drawn shapes and it results in smoothing the edge obtained after blanking operation.

Nibbling

In nibbling, a machine called nibbler moves a straight punch up and down rapidly into a die. The sheet metal is fed through the gap and a number of overlapping holes are made. This operation is similar to making a large elongated hole by successfully punching holes with a taper punch. Sheet can be cut along any desired path by manual control. This process is economical for small production. This process is useful for making complex contour.

SAQ 3

(a) What are the various types of single point cutting tools? Discuss in detail.
(b) Explain the various types of machine tools.
(c) Differentiate between following:
   (i) Facing and Turning
   (ii) Drilling and Trippaning
   (iii) Broaching and Milling
   (iv) Blanking and Punching
   (v) Notching and Shaving
1.6 SUMMARY

Tool engineering includes metal cutting, pressing, and various work holding devices. Metal cutting is commonly associated with industries like automotive, aerospace, home appliance etc. Cutting tool involves single point cutting tool and multipoint cutting tool.

The various types of single point cutting tools such as solid type tool bit, brazed tip tool, long indexable insert, and throwaway indexable inserts are used as per requirement. Machine tools are classified as general purpose, production and special purpose machine tools. Various operations such as facing, turning, drilling, planing, shaping, milling, boring, grinding are discussed in this unit. Various fine finishing operations are also explained in this unit.

1.7 KEY WORDS

<table>
<thead>
<tr>
<th>Jigs</th>
<th>Jig is workpiece holding and locating device that positions and guides or controls a cutting tool.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixtures</td>
<td>Fixture is workpiece locating and holding device used with machine tools, inspection, welding and assembly.</td>
</tr>
<tr>
<td>Total Approach Allowance</td>
<td>Distance travelled by tool in drilling operation beyond the actual hole is termed as the total approach allowance.</td>
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