# Chapter 4

# Machining and Machine Tool Operations

## CHAPTER HIGHLIGHTS

- *Mechanics of Machining*
- *Geometry of Single Point Cutting Tool*
- *Tool Signature or Tool Designation*
- *Chip Thickness Ratio*
- *Forces on the Chips*
- *Merchant Theory*
- *Lee and Shaffer Theory*
- *Heat Generation During Metal Cutting*
- *Tool Wear*
- *Tool Life*
- *Principal Elements in Metal Machining*
- *Material Removal Rate (MRR) in Turning*
- *Grinding*
- *Non-traditional Machining Processes*
- *Electrochemical Machining Process*
- *Electric Discharge Machining (EDM)*

## Mechanics of Machining

Metal cutting or machining is the process of removing unwanted material from a block metal in the production of a dimensional work piece.

In metal cutting, a wedge shaped tool is made to move relative to the work piece. The tool exerts pressure on the metal resulting in a compression near the tool tip. Material ahead of the tool is sheared continuously along a plane called 'shear plane'. Cutting edge of the tool is formed by two intersecting surfaces called rake surface and flank. Rake surface is the top surface along which the metal chips formed by cutting moves upwards. The other surface, flank is relieved from rubbing with the machined surface.

### Tool Geometry

Cutting tools are classified into two groups

1. Single point tools
2. Multipoint tools

Single point tools have one cutting edge. The cutting edge is also called point. These may be further classified as follows.

1. According to the method of manufacturing
   - (i) Solid tool
   - (ii) Forged tool
   - (iii) Tipped type tool
   - (iv) Bit type tool
2. According to the method of cutting
   - (i) Right hand tools
   - (ii) Left hand tools
3. According to the use of the tool
   - (i) Turning tool
   - (ii) Facing tool
   - (iii) Parting tool
   - (iv) Thread cutting tool
   - (v) Boring tool etc.

Solid tool is formed by grinding a tool steel stock.

Forged tool is made by forging of high carbon steel or high speed steel and then hardened and ground.

In tipped type tool a tip of high grade material is fixed to the shank of a low grade material by brazing.

In bit type tool the high grade tool tip of square or rectangular shape is held mechanically in a tool holder by clamping.

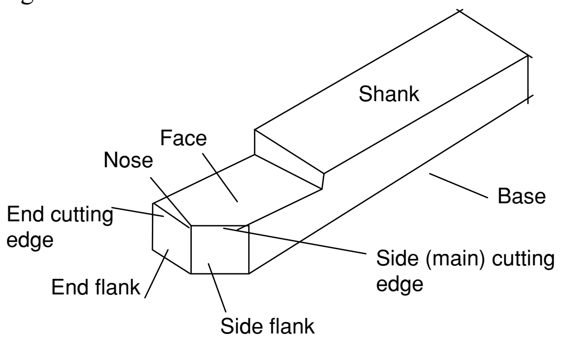
A right hand cutting tool or right cut tool will cut the material when the tool is fed from right to left. The cutting edge will be on the thump side of right hand with palm kept down ward and the fingers pointed towards the tool nose. For left hand or left cut tool the cutting edge is the other side which can be identified by using left hand.

### Multipoint Cutting Tools

Multipoint cutting tools have more than one effective cutting edge to remove the excess material. These can have rotary travel as in the case of drilling or milling cutters or a linear travel as in the case of broaching tools.

## Elements of Single Point Tool

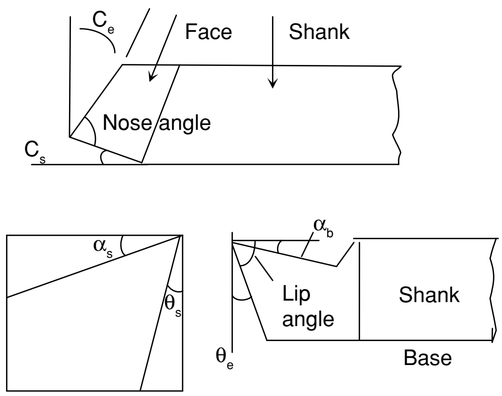
The elements of the single point tool is given in the following figure.




**Face:** It is the surface over which the chips flow.
**Shank:** It is the surface below the cutting edge.
**Nose:** It is the junction of side and end cutting edges.
**Side cutting edge:** It is the intersection of face and side flank. Main cutting work is done by this cutting edge.
**End or auxiliary cutting edge:** It is the intersection of face and end flank

## Geometry of Single Point Cutting Tool

In a single point tool there are various angles. Each angle has definite purpose.




$\alpha_b$ – Back rake angle
$\alpha_s$ – Side rake angle
$\theta_e$ – End relief angle
$\theta_s$ – Side relief angle
$C_e$ – End cutting edge angle
$C_s$ – Side cutting edge angle

**Back rake angle** or top rake angle is the angle between the face of the tool and a line parallel to the base of the tool and measured in a plane (perpendicular) through the side cutting edge. Its purpose is to guide the direction of chip flow. The size of the angle depends upon the material to be machined. Negative rake angle is used for high tensile strength materials.

**Side rake angle:** It is the angle between the tool face and a line parallel to the base of the tool and measured in a plane perpendicular to the base at the side cutting edge. Side rake is negative, if the slope is towards the cutting edge. It also guides the direction chip away from the job. Amount of bending of a chip depends upon the angle.

**End relief angle:** It is the angle between a plane perpendicular to the base and end flank. This angle prevents cutting tool from rubbing against the job.

**Side relief angle:** It is the angle, made the side flank of the tool and a plane perpendicular to the base just under the cutting edge. This angle permits the tool to be fed sideways into the job, so that it can cut without rubbing.

**End cutting edge angle:** It is the angle between the end cutting edge and a line normal to the tool shank side. It acts as a relief angle that allows only a small section of the end cutting edge to contact the machine surface.

**Side cutting edge angle:** It is also known as the lead angle. It is the angle between side cutting edge and side of the tool shank. It avoids the formation of built up edges, controls the direction of chip flow and distributes the cutting force and heat produced over large cutting edge.

**Nose angle:** It is angle between the two cutting edges. Nose radius is provided to increase the finish and strength of the cutting tip of the tool. It increases tool life and provides good surface finish. As nose radius is increased from zero values there is improvement in surface finish and permissible cutting speed. But too large a nose radius leads to chatter of the tool.

**Tool angle specification system** or tool nomenclature system.

1. ASA system
2. Orthogonal rake system (ORS)
3. British system or Maximum normal rake system (MRS)
4. German (DIN) system

In ASA system the geometry of the rake face is expressed in terms of the side rake angle and back rake angle. The back rake angle is the angle between the rake face and the base of the tool measured in a plane perpendicular to the base of and parallel to the longitudinal axis of the tool. Side rake angle is measured in a plane normal to the plane in which side rake angle is measured.

## Tool Signature or Tool Designation

A single point cutting tool may be specified by a sequence of numbers which represents various tool angles and nose radius. Tool angles have been standardized by American Standards Associations (ASA). Under ASA system, tool signature comprises seven elements. These are in the order given below.

Back rake angle ($\alpha_b$)
Side rake angle ($\alpha_s$)
End relief angle ($\theta_e$)
Side relief angle ($\theta_s$)

End cutting edge angle ($C_e$)
Side cutting edge angle ($C_s$)
And nose radius ($R$)
If a tool signature is
10, 10, 6, 6, 8, 8, 2
it means that
$\alpha_b$ - 10°
$\alpha_s$ - 10°
$\theta_e$ - 6°
$\theta_s$ - 6°
$C_e$ - 8°
$C_s$ - 8°
And nose radius = 2 mm

In ASA system angles are specified with out considering the position of cutting edge. So it does not give the true behaviour of cutting tool.

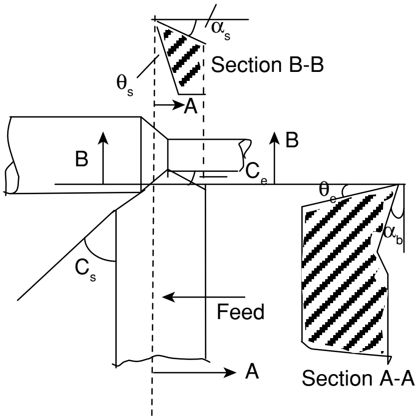
**In orthogonal rake system (ORS)** this problem is rectified.

Orthogonal rake system is also known as International system (ISO). The end rake angle is the angle between the base plane and the rake face, measured in a plane normal to the end cutting edge. The side rake angle is the angle between the base plane and the rake face, measured in a plane normal to the side cutting edge. This plane is known as orthogonal plane, or the chief plane. The angles in this plane are side relief angle ($r$).

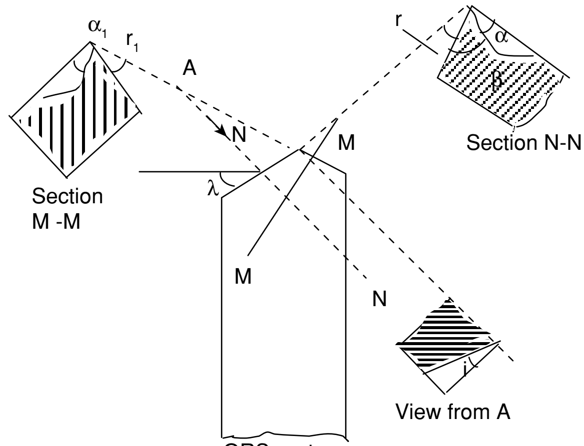
Side rake angle ($\alpha$)
Wedge (lip angle) ($\beta$)
And the cutting angle ($\delta$)

In ORS, back rake angle is measured through the side (principal) cutting edge. It is the inclination angle (i) between the principal cutting edge. And a line passing through the point of tool parallel to the principal plane, measured in a plane perpendicular to basic plane passing through the cutting edge.

Tool designation for ORS is
$i - \alpha - r - r_{1 - C_e} - \lambda - R$
where $\lambda$ is the plan approach angle.
$\beta + r = \delta =$ cutting angle.




ASA system




ORS system

According to British system rake angle is specified as the steepest slope of the rake face.

## Types of Metal Cutting Processes

Depending up on the movement of cutting edge with respect to the direction of relative work tool motion, metal cutting process is classified into two

1. Orthogonal cutting process or two dimensional cutting
2. Oblique cutting process or three dimensional cutting

In orthogonal cutting edge of tool is arranged perpendicular to the velocity vector $V$, where as in oblique cutting it is set at some angle.

## Types of Chips

The type of chip formed is a function of the work material and cutting conditions. Chips can be classified into 3 types

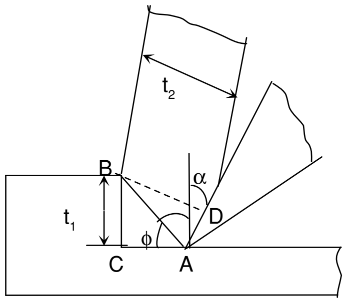
1. Continuous chips
2. Discontinuous chips
3. Continuous chip with cutting edge

Continuous chips are obtained from ductile materials such as mildsteel. As very lengthy chip in coil form is unsafe and hazardous it become necessary to break the chip for which chip breakers are used.

Dicontinuous chips are obtained while machining brittle materials like cast iron. Chips are small individual segments which may adhere to each other, loosely. Low cutting speed, small rake angle etc. contributes to the formation of discontinuous chips.

High pressure and temperature during the cutting causes alloying and welding actions of chip material to tool face near the nose. This is called built up edge. The accumulated built up of chip material break away. But some part adhere to the chip and some to the work piece. Low cutting speeds and larger depth of cut promote the formation of built up edges.

## Chip Thickness Ratio




$t_1$ = thickness of chip before cutting

$t_2$ = thickness of chip after cutting

$r$ = chip thickness ratio = $\frac{t_1}{t_2}$

As there is no change in the volume of metal cut

$$t_1\, b_1\, L_1 = t_2\, b_2\, L_2$$

Where $b_1$ and $b_2$ are width of cut before and after the cut and $L_1$ and $L_2$ are length of chip before and after cutting.

When there is no side flow of metal, $b_1 = b_2$

$$\therefore t_1 L_1 = t_2 L_2$$

$$\frac{t_1}{t_2} = \frac{L_2}{L_1} = r < 1$$

If side flow is to be considered, thickness ratio is to be multiplied by $\lambda = \frac{b_1}{b_2}$

From the right angle triangle ABC,

$$\sin\phi = \frac{BC}{AB}$$

$$\therefore AB = \frac{BC}{\sin\phi} = \frac{t_1}{\sin\phi}\cdots \quad (1)$$

From right angle triangle ABD

$$\sin(90 - f + \alpha) = \frac{BD}{AB}$$

$$AB = \frac{t_2}{\sin(90 - \phi + \alpha)}$$

$$= \frac{t_2}{\cos(\varphi - \alpha)} \quad (2)$$

From (1) and (2)

$$\frac{t_1}{\sin\phi} = \frac{t_2}{\cos(\phi - \alpha)}$$

$$\frac{t_1}{t_2} = \frac{\sin\phi}{\cos(\phi - \alpha)}$$

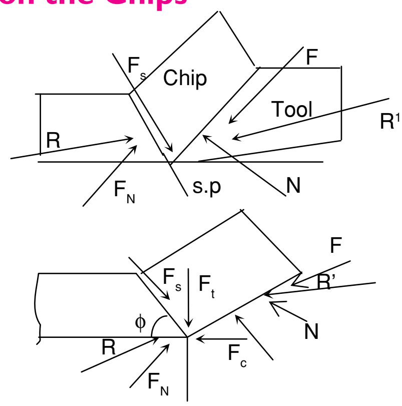
$$\text{i.e. } r = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$$

$$\frac{r\cos\alpha}{\tan\phi} + \sin\alpha = 1$$

$$r\frac{\cos\alpha}{\tan\alpha} = (1 - r\sin\alpha)$$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

## Forces on the Chips




Force components on the chip

### *Merchant Theory*

Merchant has worked out the relation ships amongst various forces. The following are the assumptions made

1. The tool is very sharp and there is no contact between clearance face and work piece
2. The chip does not flow to either side, i.e. there is no side spread
3. A continuous chip with out built up edge is produced.
4. The cutting velocity remains constant
5. The chip behaves as a free body in stable equilibrium under the action of two equal, opposite and almost collinear resultant forces

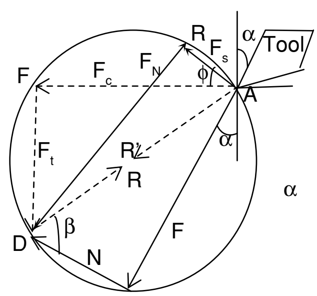
Forces $F_s$ and $F_n$ acts on the chip, $F$ along the shear plane and $F_n$ normal to the shear plane. $F_n$ is the backing up force provided by the work piece on the chip. $R$ is the resultant of $F_s$ and $F_n$.

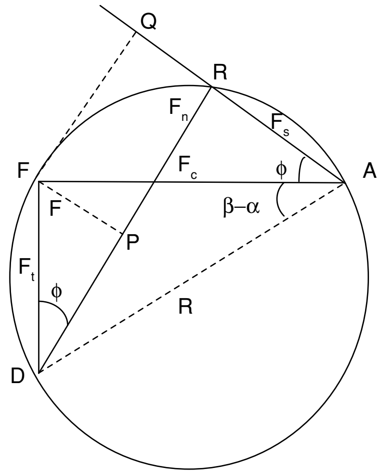
Force $F$ is the frictional resistance of the tool against the motion of the chip and $N$ is the force normal to the tool face. $R'$ is the resultant of these forces.

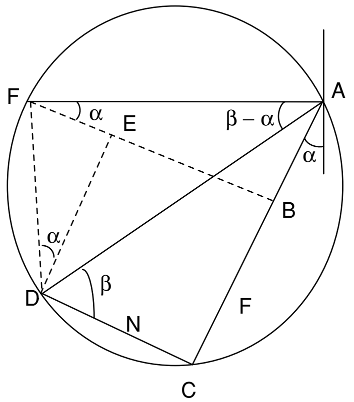
i.e. $\vec{R}^1 = \vec{F} + \vec{N}$

$R = \vec{F}_s + \vec{F}_n = \vec{F}_c + \vec{F}_t$

Merchant represented various forces inside a circle, with diameter $R$ or $R'$ passing through the tool point.






In this diagram the horizontal component is the cutting tone $F_c$ and the vertical component is the thrust force $F_t$. These two are measured by using a dynamometer. $t_1$, $t_2$ and $\phi$ are found by calculations. Other components are expressed in terms of known parameters.

As chip slides over the tool face under pressure the kinetic coefficient of friction ($\mu$) may be expressed as.

$$\mu = \frac{F}{N} = \tan\beta$$

Other force relationships are

1. $F = F_t \cos\alpha + F_c \sin\alpha$
   $N = F_c \cos\alpha - F_t \sin\alpha$

As $F = AB + BC$
$= AB + DE$
$= F_c \sin\alpha + F_t \cos\alpha$
$N = F_B - F_E$
$= F_c \cos\alpha - F_t \sin\alpha$

2. $F_s = F_c \cos\phi - F_t \sin\phi$
   $F_N = F_t \cos\phi + F_c \sin\phi$

as $F_s = AQ - QR$
$AQ - FP = F_c \cos\phi - F_t \sin\phi$
$F_N = DR = DP + PR = DP + FQ$
$= F_t \cos\phi + F_c \sin\phi$

3. $F_c = AD \cos(\beta - \alpha)$
   $= R\cos(\beta - \alpha)$
   $F_s = R\cos(\phi + \beta - \alpha)$

$$\frac{F_c}{F_s} = \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

$$F_c = \frac{F_s\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

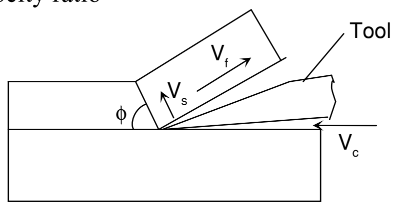
4. $$\frac{F}{N} = \frac{F_c \sin\alpha + F_t \cos\alpha}{F_c \cos\alpha - F_t \sin\alpha}$$

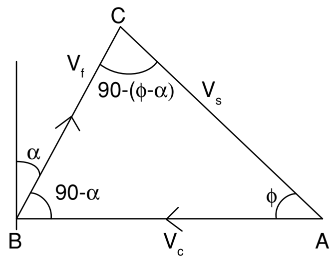
$$= \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha}$$

also $\dfrac{F}{N} = \tan\beta = \mu$

and $\dfrac{F_t}{F_c} = \tan(\beta - \alpha)$

Velocity ratio




Let $V_c$ be the cutting velocity,

i.e., velocity of the tool relative to the work piece

$V_f$ = flow velocity

i.e, velocity of chip relative to tool

$V_s$ = velocity of shear

i.e. velocity of displacement or formation of the newly cut chip elements relative to the work piece.

From the triangle ABC,

$$\frac{V_c}{\sin 90-(\phi-\alpha)} = \frac{V_f}{\sin\phi} = \frac{V_s}{\sin(90-\alpha)}$$

$$\frac{V_c}{\cos(\phi-\alpha)} = \frac{V_f}{\sin\phi} = \frac{V_s}{\cos\alpha}$$

$$\therefore V_s = \frac{V_c\cos\alpha}{\cos(\phi-\alpha)}$$

$$V_f = \frac{V_c\sin\phi}{\cos(\phi-\alpha)}$$

## *Condition for Minimum Cutting Force*

To find the value of shear angle $\phi$ which makes cutting force $F_c$ a minimum, the following expression is used.

$$2\phi+\beta-\alpha=\frac{\pi}{2}$$

In the above expression $(2\phi+\beta-\alpha)$ is known as **machining constant**

## *Lee and Shaffer Theory*

Lee and Shaffer theory is based on theory of plasticity. In this theory, the following assumptions are made.

1. Material ahead of tool in work piece behaves as an ideal plastic
2. Chip hardening does not take place
3. Between chip and work piece, there is a slip plane

Based on the above, Lee and Shaffer's shear angle relationship is.

$$\phi+\beta-\alpha=\frac{\pi}{4}$$

For built up nose formation the above relationship was further modified by introducing a factor $\theta$, as

$$\phi+\beta-\alpha-\theta=\frac{\pi}{4}$$

## *Heat Generation During Metal Cutting*

During metal cutting, heat is generated due to the rubbing of tool with work piece and chip moving with high velocity Factors that cause excessive heat generation are

1. Very high cutting speed
2. Cutting tool of poor surface finish
3. Incorrectly ground or worn cutting tool
4. Built up edge formation on cutting tool
5. High friction between tool and work piece

# Tool Wear

During a machining process, the tool is subjected to forces, temperature and sliding action due to relative motion between tool and work piece. Cutting edge of the tool gradually wears out and needs regrinding as the wear increases. This leads to down time loss of production etc. Tool wear can occur due to diffusion, adhesion, fatigue, oxidation, abrasion, chemical decomposition etc.

## *Flank Wear and Crater Wear*

Flank wear produces wear areas on side and end flanks of the tool.

Flank wear occur more at the corner and nose due to the sudden entry and sudden exit of the corner and nose portions. It is also due to the work hardening of the material in the width direction.

Crater wear is due to diffusion and abrasion between chip and face of the tool, near the cutting edge.

# Tool Life

Tool life is defined as the time clasped between two successive grinding of the tool. It is expressed in minutes. It is the total cutting time accumulated before total failure occurs. Two most commonly used criteria for measuring tool life are

1. Total destruction of the tool when it ceases to cut
2. A fixed size of wear land on tool flank

## *Tool Life Equation*

FW Taylor gave the following relationship between cutting speed and tool life.

$VT^n = C$

Where $V$ = cutting speed in m/minute

$T$ = tool life in minutes

$n$ = tool life index

= 0.1 to 0.15 for HSS tools

= 0.2 to 0.4 for tungsten carbide tools

= 0.4 to 0.6 for ceramic tools

$C$ = constant

Tool life also depends to a great extend on the depth of cut $d$ and feed rate per revolution, $f$. Assuming a logarithmic variation of $C$ with $d$ the equation can be written as $VT^n \cdot d^m = C$

Considering feed rate also the general equation can be

$$VT^n \cdot d^m \cdot f^x = C$$

Constants $n$ and $c$ for different work material and tool material.

| Work material | Tool material | *n* | *C* |
|---|---|---|---|
| Steel | HSS | 0.1–0.16 | 160–190 |
| | Carbide | 0.18–0.2 | 220–290 |
| CI | HSS | 0.08–0.1 | 100–180 |
| | Carbide | 0.2–0.28 | 250–325 |

### Solved Example

**Example 1:** While machining cast iron using a HSS tool, tool life of 50 min was observed with a cutting speed of 100 m/min. Tool life for a cutting speed of 80 m/min will be (Assume $n = 0.09$ in Taylor's equation).

**Solution:** $V = 100$ m/min

$T = 50$ min

$n = 0.09$

Tool life equation

$VT^n = C$

$\log V + n \log T = \log C$

$\log 100 + 0.09 \log 50 = \log C$

$C = 142.20$

$\therefore VT^{0.09} = 142.2$

$$T^{0.09}=\frac{142.2}{80}$$

$T = 596.57$ min

**Example 2:** In an machining operation cutting speed is reduced by 25%

Assuming $n = 0.5$ and $C = 300$ in Taylor's equation, calculate the increase in tool life.

**Solution:** $N = 0.5$,

$$V_1 T_1^{0.5} = 300 \quad (1)$$

$$V_2 = 0.75\ V_1$$

$$V_2 T_2^{0.5} = 300$$

$$0.75\ V, T_2^{0.5} = 300 \quad (2)$$

From (1) and (2)

$$\left(\frac{T_2}{T_1}\right)^{0.5} \times 0.75 = 1$$

$$\frac{T_2}{T_2} = \left(\frac{1}{0.75}\right)^2 = 1.78$$

$$\frac{T_2 - T_1}{T_1} = \frac{T_2}{T_1} - 1$$

$$= 1.78 - 1$$

$$= 0.78$$

i.e. increase in tool life = 78%

**Example 3:** A carbide cutting tool was used for machining a m.s. work piece at a cutting speed of 50 m/min. A tool life of 100 min was obtained. Life of the tool when cutting speed is increased by 25% is

**Solution:** $V_1 = 50$ m/min

$$T_1 = 100 \text{ min}$$

$$N = 0.26$$

$$V_2 = 1.25\ V_1$$

$$V_1 T_1^n = V_2 \mathrm{T}_2^n$$

$$\left(\frac{T_1}{T_2}\right)^{0.26} = 1.25$$

$$\left(\frac{T_1}{T_2}\right) = 2.36$$

$$T_2 = \frac{T_1}{2.36} = \frac{100}{2.36} = 42.37 \text{ min}$$

## Machinability

Machinability may be defined as the earness or difficulty with which a material can be machined under a given set of conditions.

It is common to express machinability in terms of cutting speed for a given tool in minutes. Cutting speed for producing a predetermined value of tool life, termed as the specific cutting speed, could be made as the basis of comparison of machinability of materials. Machinability or machinability index of test material can be expressed as

$$\text{Machinability} = \frac{V_t}{V_s} \times 100\%$$

**Example 4:** In assessing machinability for different materials the following data was obtained.

| Material | Tool life (min) | Cutting speed (m/min) |
|---|---|---|
| A | 25 | 100 |
| | 10 | 150 |
| B | 40 | 200 |
| | 20 | 250 |

Relative machinability, taking cutting speed for a tool life of 50 min as criteria and material A as standard material is

**Solution:** Material A (standard material)

$$V_1 = 100 \text{ m/min}$$

$$T_1 = 25 \text{ min}$$

$$V_2 = 150 \text{ m/min}$$

$$T_2 = 10 \text{ min}$$

$$\log V + n \log T = \log C$$

$$\log 100 + n \log 25 = \log C$$

$$\log 150 + n \log 10 = \log C$$

$$n (\log 25 - \log 10) = \log 150 - \log 100$$

$$n \times 0.398 = 0.176$$

$$n = 0.44$$

$$C = 415.5$$

Taylor's equation is

$$VT^{0.44} = 415.5$$

Speed at $T = 50$ m/m

$$V_{50} = \frac{415.5}{50^{0.44}}$$

$$= 74 \text{ m/min}$$

Material B (test material)

$$\log 200 + n \log 40 = \log C$$

$$\log 250 + n \log 20 = \log C$$

$$N (\log 40 - \log 20) = \log 250 - \log 200$$

$$N = 0.32$$

$$C = 651$$

$$V_{50} = 186 \text{ m/min}$$

Relative machinability or machinability index

$$= \frac{V_{50} \text{ for } B}{V_{50} \text{ for } A} \times 100$$

$$= \frac{186}{74} \times 100$$

$$= 251.4\%$$

Machinability rating or index of different material is taken relative to the index which is standardized sometimes index of free cutting steel is arbitrarily taken as 100%. Then,

$$\text{Machinability index } \% = \frac{[\text{Cutting speed of test material for 20 min tool life}]}{[\text{Cutting speed of free cutting steel for romin. tool life}]}$$

## Principal Elements in Metal Machining

Principal elements in metal machining are

1. Cutting speed
2. Feed
3. Depth of cut

Cutting speed is the distance travelled by the work surface in a unit time with reference to the cutting edge of the tool. It is a relative term, since either the tool or the job or both may be moving during cutting. Cutting speed $V = \frac{\pi DN}{1000}$ m/s where $N$ = rpm and $D$ = diameter in mm.

Feed is the distance advanced by the tool relative to the job for each revolution of the work. It is generally expressed in mm/rev. Some times it is expressed in mm/min or mm/s and is called as feed rate. In machine tools such as shaper or planer it is expressed as mm/stroke.

**Depth of cut** is the measured perpendicular distance between the machined surface and the un machined surface of the job. Or it is the thickness of the layer of metal removed in one cut, measured in a direction perpendicular to the machined surface. It is expressed in mm.

### *Machining Time*

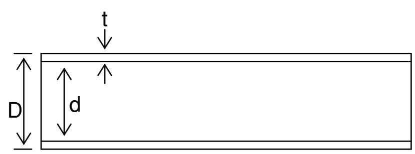
$$T = \frac{L}{fN}$$

Where $L$ = length of cut

$f$ = feed, $N$ = rpm

### *Material Removal Rate (MRR) in Turning*

Material removal rate is the volume of metal removed in unit time. It is expressed in mm$^3$/min




$f$ = feed/revolution

$N$ = number of revolutions per minute (rpm)

Material removal rate

$$\text{MRR} = \frac{\pi}{4}\left(D^2 - d^2\right) fN$$

$$= \pi \frac{(D+d)}{2}\frac{(D-d)}{2} fN$$

$$= \pi D_{av} t f N \text{ mm}^3/\text{min}$$

Where $t$ = chip thickness in mm

$D_{av}$ = average diameter of work piece in mm.

**Example 5:** Find the time required, for one complete cut on a work piece 350 mm long and 50 mm in diameter. Cutting speed is 35 m/min and feed is 0.5 mm/rev.

**Solution:** No. of revolution $= \frac{350}{0.5} = 700$

$V = \pi$ DN $= \pi \times 50 \times N = 35$ m/min

$$\text{Rpm} = N = \frac{35 \times 1000}{\pi \times 50}$$

$$\text{Time required (L/fN)} = \frac{700 \times \pi \times 50}{35 \times 1000} = 3.14 \text{ min}$$

**Example 6:** In orthogonal cutting of a work piece

Feed force = 350 kgf

Cuting force = 150 kgf

Chip thickness ratio = 0.44

Rake angle = 10°

Calculate the shear angle, force $F_s$ and $F_t$

**Solution:** Let shear angle = $\phi$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

$$= \frac{0.44 \cos 10}{1 - 0.44 \sin 10}$$

$$= 0.4691$$

$$= 25.13°$$

$F_s = F_c \cos\phi - F_t \sin\phi$

$= 150 \times 0.906 - 50 \times 0.4225$

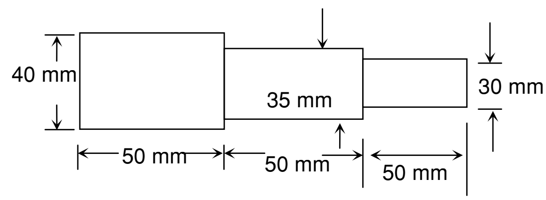
$= 114.8$ kgf

$F_n = F_t \cos\phi + F_c \sin\phi$

$= 50 \times 0.906 + 150 \times 0.4225$

$= 108.7$ kgf

**Example 7:** A 40 mm diameter and 150 mm long shaft is to be converted to a stepped shaft of dimensions as shown in the figure by turning.




The depth of cut should not exceed 2.5 mm. Cutting speed is to be 20 m/min and feed to be 0.3 mm/rev for each cut. Estimate the machining time.

**Solution:** Reduce 40 mm to 35 mm dia for a length of 100 mm. This can be done in a single cut.

Machining time

$$T_1 = \frac{L}{fN}$$

$$= \frac{100}{0.3 N_1} \text{ min}$$

$$\text{but } N_1 = \frac{20 \times 1000}{\pi \times 40} = 159.15 \text{ rpm}$$

$$\therefore T_1 = \frac{100}{0.3 \times 159.15} = 2.09 \text{ min}$$

$$N_2 = \frac{20 \times 1000}{\pi \times 35}$$

$$= 181.89$$

$$T_2 = \frac{50}{0.3 \times 181.89}$$
$$= 0.92 \text{ min}$$

Total machining time $= T_1 + T_2$
$= 2.09 + 0.92$
$= 3.01$ min

## Operating Conditions in a Shaping Machine

$$\text{Cutting speed } V_C = \frac{\text{Length of stroke}}{\text{Time required for cutting stroke}}$$

$$\text{Return speed } V_R = \frac{\text{Length of stroke}}{\text{Time required for return stroke}}$$

$$\therefore \text{Time per cycle} = \frac{L}{V_C} + \frac{L}{V_R} = \frac{L(V_C + V_R)}{V_C \cdot V_R}$$

## Feed

Feed is the relative distance moved by the work piece in a direction perpendicular to the line of tool travel, per cycle.

$$\text{Machining time } T_m = \frac{w}{f} L \frac{(V_C + V_R)}{V_C \cdot V_R}$$

where $w$ = width of the job
$L$ = length of stroke
$f$ = feed per cycle

$$\left(\text{Total number of cycles or double strokes required} = \frac{w}{f}\right).$$

$$\text{But time/cycle} = \frac{1}{N} \text{ min}$$

Where $N$ = number of cycles per minute
∴ Machining time can also be obtained from the relation

$$T_m = \frac{w}{fN}$$

$$\text{Material removal rate (MRR)} = \frac{\text{Volume of metal removed}}{\text{Machining time}}$$
$$= \frac{wdL}{\frac{w}{fN}}$$
$$= fdLN \text{ mm}^3/\text{min}$$

where $d$ = depth of cut
Cutting speed

$$V_C = \frac{LN(1+m)}{1000} \text{ m/min}$$

Where $m$ = ratio of return time to cutting time.

$$= \frac{V_C}{V_R}$$

$N$ = number of double strokes

From the above,

$$T_m = \frac{w}{f} \frac{L(1+m)}{1000 V_C}$$

## Drilling

**Cutting speed** ($V$) is the peripheral speed of the cutter (drill bit)

$$V = \frac{\pi DN}{1000} \text{ m/min}$$

where $D$ = drill diameter in mm
$N$ = rotational speed in rpm

**Feed** is the distance that the drill enters the work piece for each revolution of the drill bit. It is expressed in mm/revolution.

## Machining Time

$$T_m = \frac{L}{fN} = \frac{\ell + x + y}{fN}$$

Where $\ell$ = hole length or depth
$x$ = tool approach
$= 0.3\,D$
$y$ = tool over travel (1 to 2 mm)
$f$ = feed

Material removal rate

$$\text{MRR} = \frac{\pi D^2}{4} fN \text{ mm}^3/\text{min}$$

## Grinding

Grinding is the process of material removal in the form of small chips from the surface of a work piece, by the abrasive action of a revolving wheel called grinding wheel. It is a finishing process for the production of high quality surface with close tolerance. It is also used for removal of excess material from a work piece and machining of hard materials.

**Grinding wheel** is made of two main elements-abrasives and bonding agents. Abrasives are hard substances suitable for cutting action. Bonding agents hold the abrasive grains during grinding operation. So they should have good binding properties.

There are two types of abrasives – natural and synthetic or manufactured. Sand abrasives, emery, corundum and diamond are examples of natural abrasives. Silicon carbide and aluminium oxide are examples of manufactured abrasives.

## Properties of Abrasive Grains

A good abrasive should have uniform physical properties of hardness, toughness and friability.

Hardness of abrasive grain is required to scratch or penetrate the work piece during operation.

Toughness is required to absorb shock loads.

The ability to fracture under pressure is called friability. When cutting edges of grains become smooth, they break off under pressure exposing new cutting edges.

### Characteristics of a Grinding Wheel

Knowledge of characteristics of grinding wheels and abrasive particles are essential to understand accuracy, surface finish and material removal rate etc. that can be obtained using different grinding wheels. The characteristics are grit, grade and structure.

### Grit or Grain Size

It is the number of the finest sieve through which the grain pass. Smaller the grain size, larger is the number. For example grain size 10 is very coarse and grain size 100 is fine.

### Grade

The term grade refers to the hardness with which the bond holds the abrasive grains. It is indicated by English alphabets A to Z, A denoting weakest and Z the strongest.

### Structure

The relative spacing of the abrasive grains in the bond is called structure. Dense structure is denoted by numbers 1 to 8 and open structure is denoted by 9 to 15 or higher. Open structure is used for soft and ductile materials and dense structure is used for brittle materials and finishing cuts.

### Grinding Wheel Wear

During use, a grinding wheel slowly wears out. The wear can be due to grain fracture, bond fracture or attrious wear. Due to attrious wear the cutting edges become dull.

### Loading and Glazing

Chips formed during operation get entrapped in the inner granular space of abrasive particles. This is called loading.

When the bond of the abrasive wheel is very hard, abrasive particles are not dislodged and become blunt leading to a shining appearance. This is called glazing.

By loading and glazing the grinding wheel operation become ineffective.

### Dressing and Truing

Dressing and truing are operations done on grinding wheel to remove the ineffectiveness due to loading, glazing and wear.

Dressing is the process of sharpening abrasive elements using various dressing tools like star dressing tool, diamond dressing tool and round abrasive dressing sticks.

Truing is the process of changing the shape of the periphery of the grinding wheel when it becomes worn due to breaking away of abrasive grains and bond. The wheel periphery is made concentric with its axis of rotation. In conventional grinding wheels truing and dressing are done simultaneously.

## Non–Traditional Machining Processes

Conventional manufacturing process include casting, forming, joining etc. Non conventional resources such as laser, plasma, chemicals etc. can be made use of in shaping materials. When these are applied for manufacturing processes they are called unconventional manufacturing process, which include machining process also. These processes are also called non-traditional machining processes or non-traditional manufacturing methods (NTMM) or new technology.

NTMM generally are non-mechanical. They do not produce chips or a lay pattern on the work. There is no direct physical contact between tool and work piece. So tool need not be harder than the job as in the case of conventional machining.

### Classification

NTMM can be classified in to various groups according to the type of energy used. They are

1. Mechanical
2. Chemical
3. Electro chemical
4. Thermoelectric

In mechanical energy methods, material is removed by mechanical erosion of the work piece material. Energy source is pneumatic or hydraulic pressure cutting tool. The processes include

1. Waterjet machining (WTM)
2. Ultra sonic machining (USM)
3. Abrasive jet machining

Chemical energy methods involve controlled etching of the work piece material in contact with a chemical solution. Energy source is a chemical corrosive agent. An example is chemical machining method (CHM).

Electro chemical energy methods involve electrolytic (anodic) dissolution of the work piece material in contact with a chemical solution. Energy source is high current and electrolyte solution. Energy source is high current and electrolyte solution. These methods include

1. Electro chemical machining (ECM)
2. Electro chemical grinding (ECG)
3. Electro chemical debarring (ECD)

In thermoelectric machining, thermal energy is employed to melt and vapourise tiny particles of work material by concentrating the heat energy as a small area of the work piece. The processes are

1. Ion beam machining (IBM)
2. Plasma arc machining (PAM)
3. Electrical discharge machining (EDM)
4. Electron beam machining (EBM)
5. Laser beam machining (LBM)

## Water Jet Machining Process

In this process a very high velocity water jet of small cross -sectional area is directed to the area to be cut. The very high kinetic energy of the jet is converted to pressure energy, which erodes the material at the small area of impingement. On movement of the jet crack is developed thus forming the cut. Water in the pressure range of 1500 to 4000 MPa is used.

## Chemical Machining Process

In this method acids react with the metal to be cut are used. Acids form compounds which are soluble in water. The chemical reagent used is known as 'etchant' and the process is also called etching. The areas from where the material is not to be removed are protected by a chemically resistant material known as 'maskant'.

## Electrochemical Machining Process

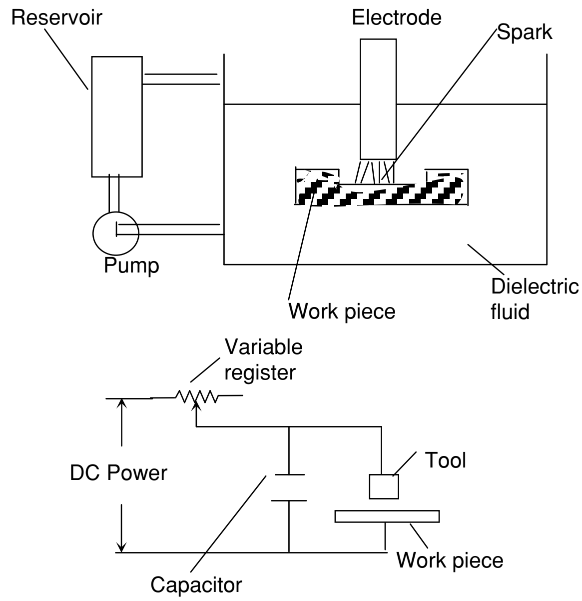
In the electro chemical machining (ECM) a direct current with high amperage and low voltage is passed between the work piece (anode) and a pre-shaped tool (cathode) through electrolyte. At the work piece metal is dissolved in electrolyte as metallic ions. Areas where metal is not to be removed as masked by suitable maskants. The process is similar to electroplating. In ECM, the electrotype is so chosen such that no electroplating takes place and the tool shape is maintained. If a close gap of 0.1 to 0.2 mm is maintained between the tool and work, the machined surface takes the replica of the tool shape. The electrolyte is forced to flow through the gap. The positive metallic ions from the work reacts with the negative ions in solution, forming metallic hydroxides and other compounds known as 'sludge' and precipitate.

## Electric Discharge Machining (EDM)

It is observed that a powerful spark, such as the terminals of an automobile battery causes pitting or erosion of metal at both anode and cathode. This principle is used in EDM which is also called spark erosion. If anode and cathode are of same material, it is observed that more erosion takes place at anode. So in EDM work is connected as anode.

In EDM the work piece and electrode (cathode) are generally immersed in a moving insulating fluid called 'dielectric fluid'. A suitable gap known as spark gap is maintained between the electrode and work piece. The control of erosion a metal is achieved by controlling the rapidly recurring spark impinging against the work piece surface.

As soon as the spark occurs high pressure is developed in the gap and temperature of the order of 10000°C is reached at the spot hit by the spark. Here metal gets melted and eroded.




EDM process can be used for machining hard and tough materials for manufacturing of dies for forging and extrusion, intricate mould cavities, carbide tools etc.

The disadvantage of EDM process are that the metallurgical properties of the material will change at very high temperatures, machining of complicated profiles, are not possible, and specific power consumption is very high.

# Economics of Machining

The main aim of a machining operation is to produce quality parts at minimum cost and maximum production rate.

Production costs and production rates depend upon the cutting parameters namely

1. Cutting speed
2. Feed
3. Depth of cut

Experience gained over years has led to certain empirical rules or guiding principles for choosing the optimum cutting condition.

Production time is defined as the average time taken to produce one component and production cost is defined as the average cost of performing the machining operation.

When cutting speed and feed are increased while other conditions held constant the machining time will be reduced, the tool wear rate increases. It can be seen that at very slow speeds and feeds the production time is increased due to the long machining time.

Very high speeds and feeds also will result in a high production time due to the frequent need to change the cutting tools. Therefore there will be an optimum condition at which production time will be minimum. Similarly there will be an optimum condition for minimum production cost also. A manufacturing engineer should aim at reducing both production time and production cost. In general, these objectives cannot be reached simultaneously so a compromise is sought.

Choice of feed depends upon type of operations whether a roughing operation or finishing operation.

It is seen that equal changes in speed or feed affect the tool temperature by the same amount an increase in feed will not affect the relative speed of sliding at the wearing surface of the tool, whereas the speed of sliding increases with increase in cutting speed. Tool wear is a function of both temperature and relative speed of sliding. There fore an increase in cutting speed will result in a greater reduction of tool life than similar increases in feed. Therefore in a rough machining for increased production rate feed is increased rather than the cutting speed. But there is a limitation in increasing the feed. Because tool forces increase with the increase in feed. The guiding principle in choosing optimum conditions in a roughing operations is that the feed should always be set maximum possible.

### *Economic Cutting Speed*

An increase in cutting speed has two main effects upon the economics of cutting

1. The metal removal rate is increased
2. Tool life is decreased

Due to the first the direct cost of metal removal is decreased. Reduction in tool life increases the cost of servicing and replacement of worn out tools.

As cutting speed '$v$' increases cost of cutting falls. Therefore cost of cutting $\alpha \frac{1}{v}$

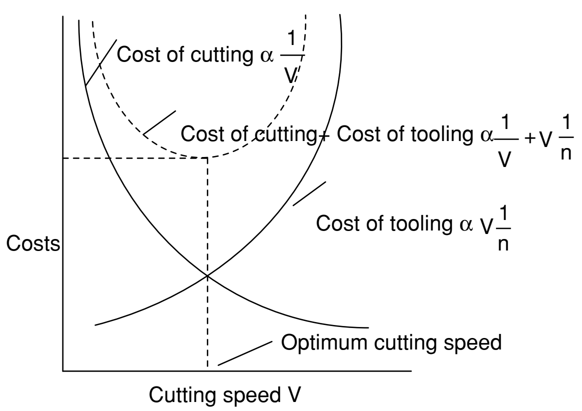
As $v$ increases the tool life $T$ falls. Cost of tooling increases. Therefore cost of tooling $\alpha \frac{1}{T}$

From Taylor's equation,

$$\frac{1}{T} = \left(\frac{V}{C}\right)^{\frac{1}{n}}$$

Therefore cost of tooling $\alpha V^{\frac{1}{n}}$

The above costs and total costs can be plotted against cutting speed as shown. The ideal cutting speed is where the total cost is minimum.




## Jigs and Fixtures

In mass production when articles are to be produced with high degree of accuracy some specially designed tooling is required. Jigs and fixtures come under such category of tools. Jigs and fixtures are work holding devices designed and built to hold, support and locate every component to ensure that each is drilled or machined within the specified limits. They are accurately made and the material used must be able to with stand wear and operational forces experienced during metal cutting.

Jig is a frame or body which holds and positions the work and guides the cutting tool during, the machining operation such as drilling reaming, lapping etc.

Fixture is a production tool that locates, holds and support the work securely in a fixed orientation with respect to the tool such that the required machining operation can be performed.

Jigs are connected with operation while fixtures are most commonly related to specific machine tools. Most common jigs are drilling jigs, reaming jigs assembly jigs etc. They are not fastened to a machine tool or tables, but are free to be moved so as to permit proper resisting of work and the tool. But fixtures are attached to some machine tool or table. Examples are milling fixtures broaching fixtures, grinding fixtures, assembly fixtures etc. Fixtures are heavier in construction and are bolted rigidly on machine table.

### Principles of Design of Jigs and Fixtures

Jigs and fixtures have the following components.

***Location*** This ensure that the work piece is given the desired constraint and determine the position of the work piece with respect to the cutting tool.

***Clamping*** The clamps should be positioned to give best resistance to the cutting force. The clamp should be such that they should not cause reformation of work piece.

***Clearance*** Enough clearance should be allowed for variation of work piece size, for operator's hand etc.

### Stability and Rigidity

Uneven seating should be avoided (provide four feets). The equipment should be made sufficiently rigid to make it suitable for the operation.

### Handling

The equipment should be as light as possible and easy to handle. Sharp corners should be avoided and lifting points should be provided for heavy equipment.

### General

The design should be simple to minimize the cost. Standard parts should be utilized as much as possible.

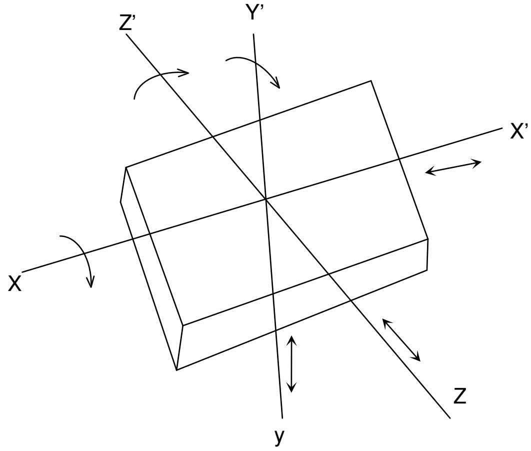
## Types of Jigs and Fixtures

1. Used with machine tools, drilling fixtures, milling fixtures, broaching fixtures etc.
2. Devices for locating and clamping, arbors, holders etc.
3. Assembly fixtures
4. Inspection fixtures
5. Special jigs and fixtures

## Degrees of Freedom

An unrestricted object in space is free to move in any of the twelve possible directions and is said to have twelve degrees of freedom. An object is free to revolve around or move parallel to any axis in either direction.

Degree of freedom can be taken as six if we consider three freedom of translation and three freedoms of rotation about the three axes irrespective of the directions.




In order to locate the block correctly, with in a jig all these six movements must be restrained by arranging suitable locating points and then clamping the block in position.

## Exercises

## Practice Problems I

**1.** While machining steel using HSS steel a tool life of 40 min was observed with cutting speed of 100 m/min. Tool life for a cutting speed of 75 m/min, assuming value $n = 0.12$ in Taylor's equation will be
(A) 420 min (B) 440 min
(C) 430 min (D) 450 min

**2.** In a cutting operation the cutting speed was reduced by 20%. Assuming $n = 0.5$ and $C = 350$, increase in tool life is
(A) 56% (B) 48%
(C) 59% (D) 46%

***Direction for questions 3 and 4:***

A cutting tool when used for machining a work piece material at a cutting speed of 45 m/min, lasted for 120 min. Value of $n = 0.26$ in Taylor's equation.

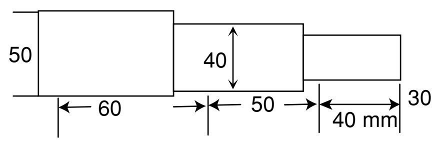
**3.** Life of the tool when cutting speed is increased by 25% will be
(A) 60.5 min (B) 50.9 min
(C) 46.2 min (D) 48.7 min

**4.** Cutting speed of the tool to get a tool life of 180 min will be
(A) 45.2 m/min (B) 38.6 m/min
(C) 40.5 m/min (D) 43.7 m/min

**5.** In an orthogonal cutting, the following observations were made.
Cutting force = 150 kgf
Feed force = 50 kgf
Chip thickness ratio, $r = 0.44$
Rake angle, $\alpha = 10°$
Cutting speed = 100 m/min
Coefficient of friction in the cutting is
(A) 0.54 (B) 0.67
(C) 0.48 (D) 0.59

**6.** A work piece 400 mm long and 50 mm diameter was reduced in diameter by turning. Cutting speed was 30 m/min and feed was 0.5 mm/revolution. The time required for a cut of length 300 mm is
(A) 6.28 min (B) 3.54 min
(C) 3.14 min (D) 3.98 min

**7.**




A stepped shaft of the dimensions as per the sketch shown is to be made from a shaft of 50 mm diameter and 150 mm long by turning. The depth of cut should not exceed 2.5 mm. The cutting speed is to be 25 m/ min and feed to be 0.3 mm per revolution. The required machining time is
(A) 4.97 min (B) 4.83 min
(C) 3.86 min (D) 3.54 min

***Direction for questions 8 and 9:***

A 150 mm long 12 mm dia SS rod is to be reduced to 10 mm dia in a single cut by turning. The spindle rotates at 500 rpm and tool speed is 200 mm/ min

**8.** Cutting speed of the lathe in the operation is
(A) 19.54 m/min (B) 16.76 m/min
(C) 17.92 m/min (D) 18.85 m/min

**9.** The material removal rate in $mm^3$/min is
(A) 7540 (B) 8630 (B) 9960 (D) 8190

**10.** A 170 mm long 60 mm diameter shaft is to be connected to 166 mm long and 50 mm dia shaft by turning and facing operations. The work piece rotates at 450 rpm, feed is 0.3 mm per revolution and maximum depth of cut is 2 mm. Turning operation is performed first. Assuming total approach and over travel distance of 5 mm for turning operation, the total machining time will be
(A) 3.92 min (B) 4.26 min
(C) 3.76 min (D) 4.33 min

**11.** 1000 Nos 8 mm diameter and 100 mm length pieces are to be produced from 10 mm diameter and 100 mm length pieces.

Cutting speed is 31.42 m/min and feed rate is 0.7 mm/rev. Assuming $n$ = 1.2 and $C$ = 180 in Taylors's expression, the number of times sharpening required for the cutting tool is
(A) 44 (B) 22 (C) 33 (D) 55

**12.** A batch of ten cutting tools could produce 500 components while working at 50 rpm with a tool feed of 0.25 mm/rev and depth of cut of 1 mm. A similar batch of 10 tools of the same specifications could produce 122 components while working at 80 rpm with a feed of 0.25 mm/rev and 1 mm depth of cut. How many components can be produced with one cutting tool at 60 rpm?
(A) 29 (B) 31 (C) 37 (D) 42

**13.** During life testing of tool on a lathe under dry cutting condition gave $n$ and $C$ of Taylor's equations as 0.12 and 130 m/min respectively. When a coolant was used $C$ increased by 8%. Find the percentage increase in tool life with the use of coolant at a cutting speed of 90 m/min
(A) 85% (B) 90%
(C) 88% (D) 97%

**14.** Match correct pairs

| Machining process | Metal removal method |
|---|---|
| (P) ECM | (1) Plastic shear |
| (Q) EDM | (2) Erosion/britt fracture |
| (R) USM | (3) corrosive reactions |
| (S) LBM | (4) \|melting and vaporization |
| | (5) Ion displacement |
| | (6) Plastic shear and ion displacement |

(A) A-3, B-5, C-1, D-6
(B) A-1, B-3, C-4, D-2
(C) A-5, B-1, C-2, D-4
(D) A-2, B-4, C-6, D-5

**15.** In electro discharge machining, the tool is made of
(A) Plain carbon steel (B) Copper
(C) Cast iron (D) High speed steel

**16.** In ECM, the material removal is due to
(A) Erosion (B) Corrosion
(C) Ion displacement (D) Fusion

**17.** In EDM process, the work piece is connected to
(A) Anode (B) Cathode
(C) Earth (D) Any of these

**18.** A 500 mm × 42 mm flat surface of a plate is to be machined on a shaper, fixing the longer side in the direction of tool travel. If the tool over travel is 20 mm at each end, average cutting sped is 8m/min, feed rate is 0.3 mm/stroke and ratio of return to cutting time is 1:2, the time required for machining will be
(A) 12.3 min (B) 15.8 min
(C) 14.2 min (D) 13.6 min

**19.** 10 mm diameter through holes are to be drilled in a MS plate of 25 mm thickness. Drill point angle is 120°, feed is 0.2 mm/revolution, and spindle speed is 300 rpm. Assuming a drill over travel of 2 mm, the time for producing one hole will be
(A) 25 sec (B) 28 sec
(C) 32 sec (D) 30 sec

**20.** The tool signature of a cutting tool in ASA system is
5 – 5 – 7 – 7 – 8 – 15 – 0
In a cutting operation if the feed rate is $f$, the peak value height of surface produced is
(A) 0.135 f mm (B) 0.95 f mm
(C) 0.236 f mm (D) 0.156 f mm

## Practice Problem 2

**1.** In a machining operation when cutting speed was reduced to half tool life reached 8 times of the original value. The exponent in Taylor's tool life equation is

(A) $\frac{1}{2}$ (B) $\frac{1}{4}$

(C) $\frac{1}{3}$ (D) $\frac{1}{5}$

***Direction for questions 2 and 3:***

In a machining experiment tool life varied with cutting speed as follows.

| Cutting speed (m/min) | Tool life (minutes) |
|---|---|
| 60 | 80 |
| 90 | 35 |

**2.** Exponent $n$ and constant $C$ of the Taylor's equation are
(A) 0.35, 540.2 (B) 0.38, 520.8
(C) 0.42, 515.9 (D) 0.49, 513.6

**3.** Percentage increase in tool life when cutting speed is halved.
(A) 306.4 (B) 311.5
(C) 313.7 (D) 315.6

**4.** In an orthogonal cutting test on steel the following conditions were obtained.
Cutting speed = 45 m/min
Depth of cut = 0.3 mm
Tool rake angle = +6°
Chip thickness = 1.5 mm
Cutting force= 900 N
Thrust force = 450 N
Using Merchant's analysis, the friction angle during the machining will be
(A) 32.6° (B) 35.4°
(C) 30.8° (D) 28.9°

**5.** In orthogonal turning of a mild steel bar of diameter 150 mm with a carbide tool the cutting velocity was 80 m/min. Feed was 0.25 mm/rev. Chip thickness obtained was 0.5 mm. If the orthogonal rake angle is zero and principal cutting edge angle is 90°, the shear angle in degrees is
(A) 28.32 (B) 26.56
(C) 24.81 (D) 22.78

**6.** In a single point turning tool, side rake angle and orthogonal rake angle are equal. The principal cutting edge angle is between zero and 90°. The chip flows in the orthogonal plane. The value of $f$ is approximately equal to
(A) 0° (B) 45°
(C) 60° (D) 90°

***Direction for questions 7, 8 and 9:***

In an orthogonal machining operation, the following data were obtained.
Uncut thickness = 0.5 mm
Cutting speed = 18 m/min
Rake angle = 15°
Width of cut = 5 mm
Chip thickness = 0.7 mm
Thrust force = 200 N
Cutting force = 1200 N
Assume Merchant's theory

**7.** Values of shear angle and shear strain respectively are
(A) 38.4°, 1.187 (B) 42.3°, 1.198
(C) 40.2°, 1.1645 (D) 45.7°, 1.147

**8.** Coefficient of friction at the tool chip interface
(A) 0.455 (B) 0.536
(C) 0.392 (D) 0.477

**9.** The percentage of total energy dissipated due to friction at the tool chip interface is
(A) 32% (B) 25% (C) 34% (D) 30%

***Direction for questions 10 and 12:***

Orthogonal turning is performed on a cylindrical work piece with shear strength of 260 N/mm$^2$. The following data were observed.
Cutting velocity: 170 m/min
Feed: 0.2 mm/rev
Depth of cut: 3 mm
Chip thickness of ratio: 0.5
Orthogonal rake angle: 6°
Use Mechant's theory:

**10.** Shear plane angle and shear force are
(A) 28°, 336 N (B) 26°, 332 N
(C) 30°, 340 N (D) 24°, 328 N

**11.** Cutting and frictional forces respectively are
(A) 598 N, 475 N (B) 595 N, 471 N
(C) 578 N, 465 N (D) 582 N, 467 N

**12.** In an orthogonal turning of carbon steel specific machining energy is 2.5 J/mm$^3$. Cutting velocity, fed and depth of cut are 125 m/min; 0.2 mm per revolution and 2 mm respectively. The main cutting force in Newton is
(A) 1000 N (B) 800 N
(C) 900 N (D) 1100 N

**13.** Taylor's tool life exponent for tool A is 0.4 and for tool B is 0.3. Constants of Taylor's equation for A and B are 90 and 60 respectively. Cutting speed in m/min above which tool A will have a higher tool life than tool B is
(A) 15.6 m/min (B) 17.8 m/min
(C) 18.2 m/min (D) 14.4 m/ min

**14.** Match the lists and select correct answer.

| Machining process | Associated medium |
|---|---|
| P USM | 1. Kerosene |
| Q EDM | 2. Abrasive slurry |
| R ECM | 3. Vacuum |
| S EBM | 4. Salt solution |

(A) P-2, Q-3, R-4, S-1
(B) P-4, Q-1, R-2, S-3
(C) P-2, Q-1, R-4, S-1
(D) P-4, Q-3, R-2, S-1

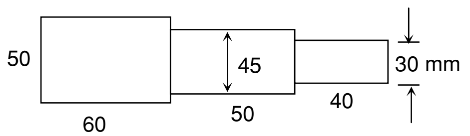
**15.** Holes in nylon button are made by
(A) EDM (B) CHM
(C) USM (D) LBM

**16.** In ECM, the material removal is due to
(A) Corosion (B) Erosion
(C) Fusion (D) Ion displacement

**17.** Two tools P and Q have tool signature
5- 5- 6- 6- 7- 20- 0 and
5- 5-7- 7- 8- 30- 0 respectively as per ASA system. They are used under same machining conditions. Ratio of peak to valley heights of the tools will be
(A) 0.7 (B) 0.8
(C) 0.9 (D) 1.1

**18.** In a single pass drilling operation a through hole of 16 mm diameter is to be drilled in a 45 mm thick steel plate. Details of the drill used are
Spindle speed = 500 rpm
Feed = 0.2 mm/rev
Drill point angle = 118°
Clearance at approach and exit = 3 mm
Time required to drill a hole will be
(A) 33.5 sec (B) 35.1 sec
(C) 30.2 sec (D) 31.3 sec

**19.** 3 numbers 600 mm × 30 mm flat pieces have to be finish machined as a shaper, fixing 600 mm side along tool travel direction. Tool travel at each end of the plate is 20 mm. Average cutting speed is 8 m/min.
Feed ratio is 0.3 mm/stroke. Cutting to return time ratio is 2:1. Set up time required per piece is 3 min. Total time required for the 3 pieces will be
(A) 50 min (B) 45 min
(C) 48 min (D) 40 min

**20.**



A stepped shaft as per dimensions given is to be made by turning. A 150 mm long 50 mm diameter shaft is available. Estimate the time required to make the shaft. The depth of cut should not exceed 2.5 mm. Cutting speed is to be 25 m/min and feed to be 0.3 mm per revolution.
(A) 3.89 min (B) 4.26 min
(C) 3.38 min (D) 4.73 min

**21.** A 200 mm long, 20 mm diameter ms. rod is to be reduced to 18 mm diameter, in a single cut by turning. Cutting speed is 20 m/min feed rate is 200 mm/min rpm and material removal rate in $mm^3$/min are
(A) 302 rpm, 12322 $mm^3$/min,
(B) 328 rpm, 12722 $mm^3$/min
(C) 326 rpm, 12820 $mm^3$/min
(D) 318 rpm, 12566 $mm^3$/min

**22.** A work piece 170 mm long and 60 mm diameter is to be machined to 166 mm lonf and 50 mm diameter by facing and turning. The work piece rotates at 450 rpm, feed is 0.3 mm/rev and maximum depth of cut is 2 mm. Facing operation is performed first. Assuming total approach and over travel distance of 5 mm for turning, the total machining time will be
(A) 4.26 min (B) 4.24 min
(C) 3.88 min (D) 3.92 min

**23.** A hole is to be drilled in a metal block with a 10 mm drill at a feed of 0.2 mm/rev. Spindle speed is 800 rpm. The material removal rate in $mm^3$/min will be
(A) 12932 (B) 12356
(C) 12566 (D) 12289

**24.** 20 mm diameter through holes are to be drilled in work pieces of 100 mm length and 50 mm diameter. Approach and over travel instance is 20 mm. Feed is 0.5 mm/rev and rpm is 200. Assuming a set up time of 25% of the processing time the number of pieces that can be drilled in a shift of 8 hrs is
(A) 320 (B) 240
(C) 360 (D) 280

**25.** A 600 × 800 mm steel pieces is to surface machined on a shaping machine. Cutting speed is 8m/min. Return to cutting time ratio is 1:4, feed is 2 mm/double strokes. Clearance at each end is 75 mm, 600 mm is in tool travel direction. The machining time will be
(A) 36.2 min (B) 38.5 min
(C) 42.7 min (D) 46.9 min

**26.** A slot of 300 × 25 mm is to be milled in a work piece of 300 mm length with a side and face milling cutter of 100 mm diameter, 25 mm wide and having 18 teeth. The depth of cut is 5 mm. feed per tooth is 0.1 mm and cutting speed is 30 m/min. Assuming an approach and over travel distance of 50 mm the required time to mill the slot will be
(A) 1.8 min (B) 2.2 min
(C) 2.4 min (D) 1.9 min

**27.** If under a given condition of plain turning, the life of cutting tool decreases by 50%, due to an increase of velocity by 25%. The index of Taylor equation will be
(A) 0.252 (B) 0.244
(C) 0.264 (D) 0.268

**28.** The tool life of a single point cutting tool has been found to be 1500 sec at a cutting speed of 0.5 m/s. How many pieces can be produced with in one tool life, if each piece is 50 mm in diameter and 80 mm long, using a feed of 0.1 mm/rev and a cutting speed od 0.5 m/s (approach and overshoot can be neglected)
(A) 5 (B) 7
(C) 4 (D) 3

**29.** Choose the best set of operation–process combinations

| Operation | Process |
|---|---|
| P Deburring (internal surface) | 1. Plasma arc machining |
| Q Die sinking | 2. Abrasive flow machining |
| R Fine hole drilling in thin sheets | 3. Electric discharge machining |

| Operation | Process |
|---|---|
| S Tool sharpening | 4. Ultra sonic machining |
| | 5. Laser beam machining |
| | 6. Electrochemical grinding |

(A) P-1, Q-5, R-3, S-4
(B) P-1, Q-4, R-1, S-2
(C) R-5, Q-1, R-2, S-6sf
(D) P-2, Q-3, R-5, S-6

**30.** In abrasive jet machining, as the distance between the nozzle tip and work surface increases the material removal rate
(A) Increases continuously
(B) Decrease continuously
(C) Decreases, becomes stable and then increases
(D) Increases, becomes stable and then decreases

## Previous Years' Questions

**1.** The mechanism of material removal in EDM process is **[2004]**
(A) Melting and evaporation
(B) Melting and corrosion
(C) Erosion and cavitation
(D) Cavitation and evaporation

**2.** A standard machine tool and an automatic machine tool are being compared for the production of a component. Following data refers to the two machines. **[2004]**

| | Standard machine tools | Automatic machine tool |
|---|---|---|
| Setup time | 30 min | 2 hours |
| Machining time per piece | 22 min | 5 min |
| Machine rate | ₹ 200 per hour | ₹ 800 per hour |

The breakeven production batch size above which the automatic machine tool will be economical to use will be
(A) 4 (B) 5
(C) 24 (D) 225

**3.** Through holes of 10 mm diameter are to be drilled in a steel plate of 20 mm thickness. Drill spindle speed is 300 rpm, feed 0.2 mm/rev and drill point angle is 120°. Assuming drill over travel of 2 mm, the time for producing a hole will be **[2004]**
(A) 4 sec (B) 25 sec
(C) 100 sec (D) 110 sec

**4.** In an orthogonal cutting test on mild steel, the following data were obtained: **[2004]**
Cutting speed: 40 m/min
Depth of cut: 0.3 mm
Tool rake angle: + 5°
Chip thickness: 1.5 mm
Cutting force: 900 N
Thrust force : 450 N
Using Merchant's analysis, the friction angle during the machining will be
(A) 26.6° (B) 31.5°
(C) 45° (D) 63.4°

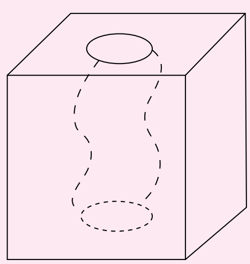
**5.** In a machining operation, doubling the cutting speed reduces the tool life to $\frac{1}{8}^{\text{th}}$ of the original value. The exponent $n$ in Taylor's tool life equation $VT^n = C$ is **[2004]**
(A) $\frac{1}{8}$ (B) $\frac{1}{4}$
(C) $\frac{1}{3}$ (D) $\frac{1}{2}$

**6.** Typical machining operations are to be performed on hand-to-machine materials by using the processes listed below. Choose the best set of operation–process combinations **[2004]**

| Operation | Process |
|---|---|
| P. Deburring (internal surface) | 1. Plasma arc machining |
| Q. Die sinking | 2. Abrasive flow machining |
| R. Fine hole drilling in thin sheets | 3. Electric discharge machining |
| S. Tool sharpening | 4. Ultrasonic machining |
| | 5. Laser beam machining |
| | 6. Electrochemical grinding |

(A) P-1, Q-5, R-3, S-4
(B) P-1, Q-4, R-1, S-2
(C) P-5, Q-1, R-2, S-6
(D) P-2, Q-3, R-5, S-6

**7.** A zigzag cavity in a block of high strength alloy is to be finish machined. This can be carried out by using **[2005]**

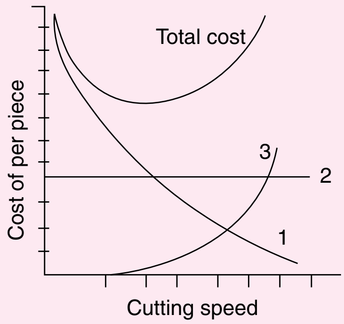


(A) Electric discharge machining
(B) Electro-chemical machining
(C) Laser beam machining
(D) Abrasive flow machining

**8.** When 3-2-1 principle in used to support and locate a three dimensional work-piece during machining, the number of degrees of freedom that are restricted is **[2005]**

(A) 7 (B) 8
(C) 9 (D) 10

**9.** The figure below show a graph which qualitatively relates cutting speed and cost per piece produced. **[2005]**




The three curves 1, 2 and 3 respectively represent

(A) Machining cost, non-productive cost, tool changing cost
(B) Non-productive cost, machining cost, tool changing cost
(C) Tool changing cost, machining cost, non-productive cost
(D) Tool changing cost, non-productive cost, machining cost

**10.** A 600 mm × 30 mm flat surface of a plate is to be finish machined on a shaper. The plate has been fixed with the 600 mm side along the tool travel direction. If the tool over-travel each end of the plate is 20 mm, average cutting speed is 8 m/min, feed rate is 0.3 mm/stroke and the ratio of return time to cutting time of the tool is 1:2, the time required for machining will be **[2005]**

(A) 8 min (B) 12 min
(C) 16 min (D) 20 min

**11.** Two tools $P$ and $Q$ have signatures 5°–5°–6°–6°–8°–30°–0 and 5°–5°–7°–7°–8°–15°–0 (both ASA) respectively. They are used to turn components under the same machining conditions. If $h_P$ and $h_Q$ denote the peak-to-valley heights of surfaces produced by the tools $P$ and $Q$, the ratio $\frac{h_P}{h_Q}$ will be **[2005]**

(A) $\dfrac{\tan 8° + \cot 15°}{\tan 8° + \cot 30°}$ (B) $\dfrac{\tan 15° + \cot 8°}{\tan 30° + \cot 8°}$

(C) $\dfrac{\tan 15° + \cot 7°}{\tan 30° + \cot 7°}$ (D) $\dfrac{\tan 7° + \cot 15°}{\tan 7° + \cot 30°}$

**12.** If each abrasive grain is viewed as a cutting tool, then which of the following represents the cutting parameters in common grinding operations? **[2006]**

(A) Large negative rake angle, low shear angle and high cutting speed
(B) Large positive rake angle, low shear angle and high cutting speed
(C) Large negative rake angle, high shear angle and low cutting speed
(D) Zero rake angle, high shear angle and high cutting speed

**13.** Arrange the processes in the increasing order of their maximum material removal rate.
Electrochemical machining (ECM)
Ultrasonic machining (USM)
Electron beam machining (EBM)
Laser beam machining (LBM) and
Electric discharge machining (EDM) **[2006]**

(A) USM, LBM, EBM, EDM, ECM
(B) EBM, LBM, USM, ECM, EDM
(C) LBM, EBM, USM, ECM, EDM
(D) LBM, EBM, USM, EDM, ECM

***Direction for questions 14 to 16:***

In an orthogonal machining operation:
Uncut thickness = 0.5 mm
Width of cut = 5 mm
Thrust force = 200 N
Rake angle = 15°
Cutting speed = 20 m/min
Chip thickness = 0.7 m
Cutting force = 1200 N
Assume Merchant's theory

**14.** The values of shear angle and shear strain, respectively, are **[2006]**

(A) 30.3° and 1.98 (B) 30.3° and 4.23
(C) 40.2° and 2.97 (D) 40.2° and 1.65

**15.** The coefficient of friction at the tool-chip interface is **[2006]**

(A) 0.23 (B) 0.46
(C) 0.85 (D) 0.95

**16.** The percentage of total energy dissipated due to friction at the tool-chip interface is: **[2006]**

(A) 30% (B) 42%
(C) 58% (D) 70%

**17.** In orthogonal turning of a low carbon steel bar of diameter 150 mm with uncoated carbide tool, the cutting velocity is 90 m/min. The feed is 0.24 mm/rev and the depth of cut is 2 mm. The chip thickness obtained is 0.48 mm. If the orthogonal rake angle is zero and the principal cutting edge angle is 90°, the shear angle in degree is **[2007]**

(A) 20.56 (B) 26.56
(C) 30.56 (D) 36.56

**18.** In electrodischarge machining (EDM), if the thermal conductivity of tool is high and the specific heat of work piece is low, then the tool wear rate and material removal rate are expected to be respectively. **[2007]**

(A) High and high (B) Low and low
(C) High and low (D) Low and high

**19.** In orthogonal turning of medium carbon steel, the specific machining energy is 2.0 J/mm$^3$. The cutting velocity, feed and depth of cut are 120 m/min, 0.2 mm/rev and 2 mm respectively. The main cutting force in N is **[2007]**

(A) 40 (B) 80
(C) 400 (D) 800

**20.** In orthogonal turning of low carbon steel pipe with principal cutting edge angle of 90°, the main cutting force is 1000 N and the feed force is 800 N. The shear angle is 25° and orthogonal rake angle is zero. Employing Merchant's theory, the ratio of friction force to normal force acting on the cutting tool is **[2007]**

(A) 1.56 (B) 1.25
(C) 0.80 (D) 0.64

**21.** Match the most suitable manufacturing processes for the following parts. **[2007]**

| | Parts | | Manufacturing processes |
|---|---|---|---|
| **(P)** | Computer chip | **(1)** | Electrochemical machining |
| **(Q)** | Metal forming dies and molds | **(2)** | Ultrasonic machining |
| **(R)** | Turbine blade | **(3)** | Electrodischarge machining |
| **(S)** | Glass | **(4)** | Photochemical machining |

(A) P-4, Q-3, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-2, R-4, S-3

***Direction for questions 22 and 23:***

A low carbon steel bar of 147 mm diameter with a length of 630 mm is being turned with uncoated carbide insert. The observed tool lives are 24 min and 12 min for cutting velocities of 90 m/min and 120 m/min respectively. The feed and depth of cut are 0.2 mm/rev and 2 mm respectively. Use the unmachined diameter to calculate the cutting velocity.

**22.** When tool life is 20 min, the cutting velocity in m/min is **[2007]**

(A) 87 (B) 97
(C) 107 (D) 114

**23.** Neglect over-travel or approach of the tool. When tool life is 20 min, the machining time in min for a single pass is **[2007]**

(A) 5 (B) 10
(C) 15 (D) 20

**24.** Internal gear cutting operation can be performed by **[2008]**

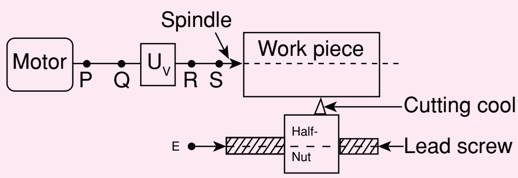
(A) Milling
(B) Shaping with rack cutter
(C) Shaping with pinion cutter
(D) Hobbing

**25.** In a single point turning tool, the side rake angle and orthogonal rake angle are equal. $\phi$ is the principal cutting edge angle and its range is $0° \leq \phi \leq 90°$. The chip flows in the orthogonal plane. The value of $\phi$ is closest to **[2008]**

(A) 0° (B) 45°
(C) 60° (D) 90°

**26.** A researcher conducts electrochemical machining (ECM) on a binary alloy (density 6000 kg/m$^3$) of iron (atomic weight 56, valency 2) and metal $P$ (atomic weight 24, valency 4). Faraday's constant = 96500 coulomb/mole. Volumetric material removal rate of the alloy is 50 mm$^3$/s at a current of 2000 A. The percentage of the metal P in the alloy is closest to **[2008]**

(A) 40 (B) 25
(C) 15 (D) 79

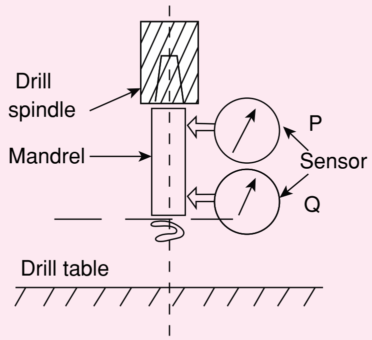



**27.** The figure shows an incomplete schematic of a conventional lathe to be used for cutting threads with, different pitches. The speed gear box $U_v$ is shown and the feed gear box $U_s$ is to be placed $P$, $Q$, $R$ and $S$ denote locations and have no other significance. Changes in $U_V$ should NOT affect the pitch of the thread being cut and changes in $U_v$ should NOT affect the cutting speed.

The correct connections and the correct placement of $U_s$ are given by **[2008]**

(A) $Q$ and $E$ are connected. $U_s$ is placed between $P$ and $Q$
(B) $S$ and $E$ are connected. $U_s$ is placed between $R$ and S
(C) $Q$ and $E$ are connected. $U_s$ is placed between $Q$ and E
(D) $S$ and $E$ are connected. $U_s$ is placed between $S$ and E

**28.** A displacement sensor (a dial indicator) measures the lateral displacement of a mandrel mounted on the taper hole inside a drill spindle. The mandrel axis is an extension of the drill spindle taper hole axis and the protruding portion of the mandrel surface is perfectly cylindrical. Measurements are taken with the sensor placed at two positions $P$ and $Q$ as shown in the figure. The readings are recorded as $R_X$ = maximum deflection minus minimum deflection, corresponding to senor position at $X$, over one rotation. **[2008]**




If $R_P = R_Q > 0$, which one of the following would be consistent with the observation?

(A) The drill spindle rotational axis is coincident with the drill spindle taper hole axis
(B) The drill spindle rotational axis intersects the drill spindle taper hole axis at point $P$
(C) The drill spindle rotational axis is parallel to the drill spindle taper hole axis
(D) The drill spindle rotational axis intersects the drill spindle taper hole axis at point $Q$

***Direction for questions 29 and 30:***
Orthogonal turning is performed on a cylindrical work piece with shear strength of 250 MPa. The following conditions are used: cutting velocity is 180 m/min, feed is 0.20 mm/rev, depth of cut is 3 mm, chip thickness ratio = 0.5. The orthogonal rake angle is 7°. Apply Merchant's theory for analysis.

**29.** The shear plane angle (in degrees) and the shear force respectively are **[2008]**
(A) 52; 320 N (B) 52; 400 N
(C) 28; 400 N (D) 28; 320 N

**30.** The cutting and frictional forces, respectively, are **[2008]**
(A) 568 N; 387 N (B) 565 N; 381 N
(C) 440 N; 342 N (D) 480 N; 356 N

**31.** Friction at the tool-chip interface can be reduced by **[2009]**
(A) Decreasing the rake angle
(B) Increasing the depth of cut
(C) Decreasing the cutting speed
(D) Increasing the cutting speed

**32.** Minimum shear strain in orthogonal turning with a cutting tool of zero rake angle is **[2009]**
(A) 0.0 (B) 0.5
(C) 1.0 (D) 2.0

**33.** Electrochemical machining is performed to remove material from an iron surface of 20 mm × 20 mm under the following conditions: **[2009]**
Inter electrode gap = 0.2 mm
Supply voltage (DC) = 12 $V$
Specific resistance of
electrolyte = 2 Ω cm
Atomic weight of iron = 55.85
Valency of iron = 2
Faraday's constant = 96540 Coulombs
The material removal rate (in g/s) is
(A) 0.3471 (B) 3.471
(C) 34.71 (D) 347.1

***Direction for questions 34 and 35:***
In a machining experiment, tool life was found to vary with the cutting speed in the following manner:

| Cutting speed (m/min) | Tool life (min) |
|---|---|
| 60 | 81 |
| 90 | 36 |

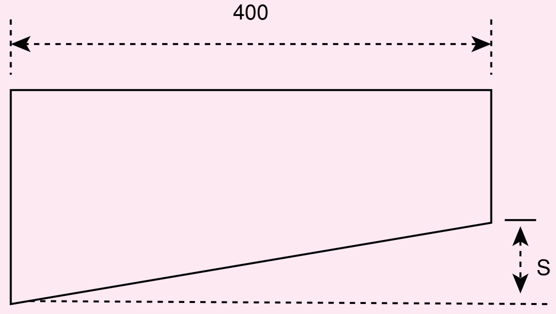
**34.** The exponent ($n$) and constant ($k$) of the Taylor's tool life equation are **[2009]**
(A) $n = 0.5$ and $k = 540$
(B) $n = 1$ and $k = 4860$
(C) $n = -1$ and $k = 0.74$
(D) $n = -0.5$ and $k = 1.155$

**35.** What is the percentage increase in tool life when the cutting speed is halved? **[2009]**
(A) 50%
(B) 200%
(C) 300%
(D) 400%

**36.** For tool $A$, Taylor's tool life exponent ($n$) is 0.45 and constant ($K$) is 90. Similarly for tool $B$, $n = 0.3$ and $K = 60$. The cutting speed (in m/min) above which tool $A$ will have a higher tool life than tool $B$ is **[2010]**
(A) 26.7
(B) 42.5
(C) 80.7
(D) 142.9

***Direction for questions 37 and 38:***
In a shear cutting operation, a sheet of 5 mm thickness is cut along a length of 200 mm. The cutting blade is 400 mm long and zero-shear ($S = 0$) is provided on the edge. The ultimate shear strength of the sheet is 100 MPa and penetration to thickness ratio is 0.2.

Neglect friction




**37.** Assuming force vs displacement curve to be rectangular, the work done (in J) is **[2010]**

(A) 100 (B) 200
(C) 250 (D) 300

**38.** A shear of 20 mm ($S$ = 20 mm) is now provided on the blade. Assuming force vs displacement curve to be trapezoidal, the maximum force (in kN) exerted is **[2010]**

(A) 5 (B) 10
(C) 20 (D) 40

**39.** A single-point cutting tool with 12° rake angle is used to machine a steel work-piece. The depth of cut, i.e., uncut thickness is 0.81 mm. The chip thickness under orthogonal machining condition is 1.8 mm. The shear angle is approximately. **[2011]**

(A) 22° (B) 26°
(C) 56° (D) 76°

**40.** Match the following non-traditional machining processes with the corresponding material removal mechanisms: **[2011]**

| | Machining process | | Mechanism of material removal |
|---|---|---|---|
| (P) | Chemical machining | (1) | Erosion |
| (Q) | Electro-chemical machining | (2) | Corrosive reaction |
| (R) | Electro-discharge machining | (3) | Ion displacement |
| (S) | Ultrasonic machining | (4) | Fusion and vaporization |

(A) P-2, Q-3, R-4, S-1
(B) P-2, Q-4, R-3, S-1
(C) P-3, Q-2, R-4, S-1
(D) P-2, Q-3, R-1, S-4

**41.** In abrasive jet machining, as the distance between the nozzle tip and the work surface increases, the material removal rate **[2012]**

(A) Increases continuously
(B) Decreases continuously
(C) Decreases, becomes stable and then increases
(D) Increases, becomes stable and then decreases

**42.** A CNC vertical milling machine has to cut a straight slot of 10 mm width and 2 mm depth by a cutter of 10 mm diameter between points (0, 0) and (100, 100) on the XY plane (dimension in mm). The feed rate used for milling is 50 mm/min. Milling time for the slot (in seconds) is **[2012]**

(A) 120 (B) 170
(C) 180 (D) 240

**43.** Details pertaining to an orthogonal metal cutting process are given below. **[2012]**

Chip thickness ratio = 0.4
Undeformed thickness = 0.6 mm
Rake angle = +10°
Cutting speed = 2.5 m/s
Mean thickness of primary shear zone = 25 $\mu$m

The shear strain rate in $s^{-1}$ during the process is

(A) $0.1781 \times 10^5$ (B) $0.7754 \times 10^5$
(C) $1.0104 \times 10^5$ (D) $4.397 \times 10^5$

**44.** In a single pass drilling operation, a through hole of 15 mm diameter is to be drilled in a steel plate of 50 mm thickness. Drill spindle speed is 500 rpm, feed is 0.2 mm/rev and drill point angle is 118°. Assuming 2 mm clearance at approach and exit, the total drill time (in seconds) is **[2012]**

(A) 35.1 (B) 32.4
(C) 31.2 (D) 30.1

**45.** A steel bar 200 mm in diameter is turned at a feed of 0.25 mm/rev with a depth of cut of 4 mm. The rotational speed of the work piece is 160 rpm. The material removal rate in $mm^3/s$ is **[2013]**

(A) 160 (B) 167.6
(C) 1600 (D) 1675.5

**46.** During the electrochemical machining (ECM) of iron (atomic weight = 56, valency = 2) at current of 1000 A with 90% current efficiency, the material removal rate was observed to be 0.26 gm/s. If titanium (atomic weight = 48, valency = 3) is machined by the ECM process at the current of 2000 A with 90% current efficiency the expected material removal rate in gm/s will be **[2013]**

(A) 0.11 (B) 0.23
(C) 0.30 (D) 0.52

**47.** Two cutting tools are being compared for a machining operation. The tool life equations are

Carbide tool: $VT^{1.6} = 3000$
HSS tool: $VT^{0.6} = 200$

where $V$ is the cutting speed in m/min and $T$ is the tool life in min. The carbide tool will provide higher tool life if the cutting speed in m/min exceeds **[2013]**

(A) 15.0 (B) 39.4
(C) 49.3 (D) 60.0

***Direction for questions 48 and 49:***
In orthogonal turning of a bar 100 mm diameter with a feed of 0.25 mm/rev, depth of cut of 4 mm and cutting velocity of 90 m/min, it is observed that the main (tangential) cutting force is perpendicular to the friction force acting at the chip-tool interface. The main (tangential) cutting force is 1500 N.

**48.** The orthogonal rake angle of the cutting tool in degree is **[2013]**
(A) zero (B) 3.58
(C) 5 (D) 7.16

**49.** The normal force acting at the chip-tool interface in *N* is **[2013]**
(A) 1000 (B) 1500
(C) 2000 (D) 2500

**50.** The main cutting force acting on a tool during the turning (orthogonal cutting) operation of a metal is 400 N. The turning was performed using 2 mm depth of cut and 0.1 mm/rev feed rate. The specific cutting pressure (in N/mm$^2$) is **[2014]**
(A) 1000 (B) 2000
(C) 3000 (D) 4000

**51.** During pure orthogonal turning operation of a hollow cylindrical pipe, it is found that the thickness of the chip produced is 0.5 mm. The feed given to the zero degree rake angle tool is 0.2 mm/rev. The shear strain produced during the operation is ____ **[2014]**

**52.** If the Taylor's tool life exponent $n$ is 0.2, and the tool changing time is 1.5 min, then the tool life (in min) for maximum production rate is ____ **[2014]**

**53.** Match the machine tools (Group A) with the probable operations (Group B): **[2014]**

| | Group A | | Group B |
|---|---|---|---|
| (P) | Centre Lathe | (1) | Slotting |
| (Q) | Milling | (2) | Counter-boring |
| (R) | Grinding | (3) | Knurling |
| (S) | Drilling | (4) | Dressing |

(A) P-1, Q-2, R-4, S-3
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-3, Q-4, R-2, S-1

**54.** The following four unconventional machining processes are available in a shop floor. The most appropriate one to drill a hole of square cross section of 6 mm × 6 mm and 25 mm deep is **[2014]**
(A) Abrasive jet machining
(B) Plasma arc machining
(C) Laser beam machining
(D) Electro discharge machining

**55.** A hole of 20 mm diameter is to be drilled in a steel block of 40 mm thickness. The drilling is performed at rotational speed of 400 rpm and feed rate of 0.1 mm/rev. The required approach and over run of the drill together is equal to the radius of drill. The drilling time (in minute) is **[2014]**
(A) 1.00 (B) 1.25
(C) 1.50 (D) 1.75

**56.** The process utilizing mainly thermal energy for removing material is **[2014]**
(A) Ultrasonic machining
(B) Electrochemical machining
(C) Abrasive jet machining
(D) Laser beam machining

**57.** A straight turning operation is carried out using a single point cutting tool on an AISI 1020 steel rod. The feed is 0.2 mm/rev and the depth of cut is 0.5 mm. The tool has a side cutting edge angle of 60°. The uncut chip thickness (in mm) is _______ **[2014]**

**58.** Cutting tool is much harder than the workpiece. Yet the tool wears out during the tool-work interaction, because **[2014]**
(A) Extra hardness is imparted to the workpiece due to coolant used
(B) Oxide layers on the workpiece surface impart extra hardness to it
(C) Extra hardness is imparted to the workpiece due to severe rate of strain
(D) Vibration is induced in the machine tool

**59.** Which pair of following statements is correct for orthogonal cutting using a single-point cutting tool? **[2014]**
P. Reduction in friction angle increases cutting force
Q. Reduction in friction angle decreases cutting force
R. Reduction in friction angle increases chip thickness
S. Reduction in friction angle decreases chip thickness
(A) P and R (B) P and S
(C) Q and R (D) Q and S

**60.** Two separate slab milling operations, 1 and 2, are performed with identical milling cutters. The depth of cut in operation 2 is twice that in operation 1. The other cutting parameters are identical. The ratio of maximum uncut chip thickness in operations 1 and 2 is ____ **[2014]**

**61.** The principle of material removal in electrochemical machining is **[2014]**
(A) Fick's law (B) Faraday's laws
(C) Kirchoff's laws (D) Ohm's law

**62.** Better surface finish is obtained with a large rake angle because **[2014]**
(A) The area of shear plane decreases resulting in the decrease in shear force and cutting force
(B) The tool becomes thinner and the cutting force is reduced
(C) Less heat is accumulated in the cutting zone
(D) The friction between the chip and the tool is less

**63.** A cast iron block of 200 mm length is being shaped in a shaping machine with a depth of cut of 4 mm, feed of 0.25 mm/stroke and the tool principle cutting edge angle of 30°. Number of cutting strokes per minute is 60. Using specific energy for cutting as 1.49 J/mm$^3$, the average power consumption (in watt) is ____ **[2014]**

**64.** Under certain cutting conditions, doubling the cutting speed reduces the tool life to $\left(\frac{1}{16}\right)^{th}$ of the original. Taylor's tool life index ($n$) for this tool-work piece combination will be ______. **[2015]**

**65.** In a linear arc welding process, the heat input per unit length is inversely proportional to: **[2015]**
(A) Welding current
(B) Welding voltage
(C) Welding speed
(D) Duty cycle of the power source

**66.** An orthogonal turning operation is carried out under the following conditions: rake angle = 5º, spindle rotational speed = 400 rpm; axial feed = 0.4 m/min and radial depth of cut = 5 mm. The chip thickness, $t_c$, is found to be 3 mm. The shear angle (in degrees) in this turning process is ____. **[2015]**

**67.** The primary mechanism of material removal in electro chemical machining (ECM) is: **[2015]**
(A) Chemical corrosion
(B) Etching
(C) Ionic dissolution
(D) Spark erosion

**68.** A single point cutting tool with 0° rake angle is used in an orthogonal machining process. At a cutting speed of 180 m/min, the thrust force is 490 N. If the coefficient of friction between the tool and the chip is 0.74, then the power consumption (in kW) for the machining operation is _______. **[2015]**

**69.** A resistance–capacitance relaxation circuit is used in an electrical discharge machining process. The discharge voltage is 100 V. At spark cycle time of 25 $\mu s$, the average power input required is 1 kW. The capacitance (in $\mu F$) in the circuit is: **[2015]**
(A) 2.5 (B) 5.0
(C) 7.5 (D) 10.0

**70.** In a machining operation, if the generatrix and directrix both are straight lines, the surface obtained is: **[2015]**
(A) cylindrical
(B) helical
(C) plane
(D) surface of revolution

**71.** Orthogonal turning of a mild steel tube with a tool of rake angle 10° is carried out at a feed of 0.1 mm/rev. If the thickness of the chip produced is 0.28 mm, the values of shear angle and shear strain will be respectively. **[2015]**
(A) 28° 20′ and 2.19 (B) 22° 20′ and 3.53
(C) 24° 30′ and 4.19 (D) 37° 20′ and 5.19

**72.** A shaft of length 90 mm has a tapered portion of length 55 mm. The diameter of the taper is 80 mm at one end and 65 mm at the other. If the taper is made by tailstock set over method, the taper angle and the set over respectively are: **[2015]**
(A) 15° 32′ and 12.16 mm
(B) 18° 32′ and 15.66 mm
(C) 11° 22′ and 10.26 mm
(D) 10° 32′ and 14.46 mm

**73.** The non-traditional machining process that essentially required vacuum is: **[2016]**
(A) electron beam machining
(B) electro chemical machining
(C) electro chemical discharge machining
(D) electro discharge machining

**74.** In an orthogonal cutting process the tool used has rake angle of zero degree. The measured cutting force and thrust force are 500 N and 250 N, respectively. The coefficient of friction between the tool and the chip is _______. **[2016]**

**75.** The tool life equation for HSS tool is $VT^{0.14}f^{0.7}d^{0.4}$ = constant. The tool life ($T$) of 30 min is obtained using the following cutting conditions:

$$V = 45 \text{ m/min}, f = 0.35 \text{ mm}, d = 2.0 \text{ mm}$$

If speed ($V$), feed ($f$) and depth of cut ($d$) are increased individually by 25%, the tool life (in min) is: **[2016]**
(A) 0.15 (B) 1.06
(C) 22.50 (D) 30.0

**76.** The following data is applicable for a turning operation. The length of job is 900 mm, diameter of job is 200 mm, feed rate is 0.25 mm/rev and optimum cutting speed is 300 m/min. The machining time (in min) is ______. **[2016]**

**77.** In an ultrasonic machining (USM) process, the material removal rate (MRR) is plotted as a function of the feed force of the USM tool. With increasing feed force, the MRR exhibits the following behavior: **[2016]**

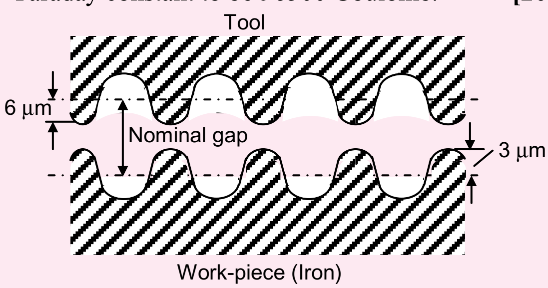
(A) Increases linearly
(B) Decreases linearly
(C) Does not change
(D) First increases and then decreases

**78.** For a certain job, the cost of metal cutting in ₹18*C*/*V* and the cost of tooling is ₹2701*C*/(*TV*), where *C* is a constant, *V* is the cutting speed in m/min and *T* is the tool life in minutes. The Taylor's tool life equation is $VT^{0.25} = 150$. The cutting speed (in m/min) for the minimum total cost is ________. **[2016]**

**79.** The surface irregularities of electrodes used in an electrochemical machining (ECM) process are 3 μm and 6 μm as shown in the figure. If the work-piece is of pure iron and 12 V DC is applied between the electrodes, the largest feed rate is ________ mm/min.

| | |
|---|---|
| Conductivity of the electrolyte | 0.02 ohm$^{-1}$ mm$^{-1}$ |
| Over-potential voltage | 1.5 V |
| Density of iron | 7860 kg/m$^3$ |
| Atomic weight of iron | 55.85 gm |

Assume the iron to be dissolved as $Fe^{+2}$ and the Faraday constant to be 96500 Coulomb. **[2016]**




**80.** In a wire–cut EDM process the necessary conditions that have to be met for making a successful cut are that: **[2016]**

(A) wire and sample are electrically non-conducting
(B) wire and sample are electrically conducting
(C) wire is electrically conducting and sample is electrically non-conducting
(D) sample is electrically conducting and wire is electrically non-conducting

**81.** Internal gears are manufactured by **[2016]**

(A) hobbing
(B) shaping with pinion cutter
(C) shaping with rack cutter
(D) milling

**82.** For an orthogonal cutting operation, tool material is HSS, rake angle is 22°, chip thickness is 0.8 mm, speed is 48 m/min and feed is 0.4 mm/rev. The shear plane angle (in degrees) is **[2016]**

(A) 19.24
(B) 29.70
(C) 56.00
(D) 68.75

**83.** In a single turning operation with cemented carbide tool and steel work piece, it is found that the Taylor's exponent is 0.25. If the cutting speed is reduced by 50% then the tool life changes by _______ times. **[2016]**

## Answer Keys

# Exercises

### Practice Problems 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** B | **2.** A | **3.** B | **4.** C | **5.** A | **6.** C | **7.** B | **8.** D | **9.** A | **10.** B |
| **11.** C | **12.** A | **13.** B | **14.** C | **15.** B | **16.** C | **17.** A | **18.** C | **19.** D | **20.** A |

### Practice Problems 2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** C | **2.** D | **3.** B | **4.** A | **5.** B | **6.** B | **7.** C | **8.** A | **9.** D | **10.** A |
| **11.** B | **12.** A | **13.** B | **14.** C | **15.** D | **16.** D | **17.** C | **18.** A | **19.** B | **20.** A |
| **21.** D | **22.** B | **23.** C | **24.** A | **25.** D | **26.** B | **27.** C | **28.** A | **29.** D | **30.** D |

### Previous Year's Questions

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** A | **2.** D | **3.** B | **4.** B | **5.** C | **6.** D | **7.** A | **8.** C | **9.** A | **10.** B |
| **11.** B | **12.** A | **13.** D | **14.** D | **15.** B | **16.** A | **17.** B | **18.** D | **19.** D | **20.** C |
| **21.** A | **22.** B | **23.** C | **24.** C | **25.** A | **26.** B | **27.** C | **28.** C | **29.** D | **30.** B |
| **31.** D | **32.** D | **33.** A | **34.** A | **35.** C | **36.** A | **37.** A | **38.** B | **39.** B | **40.** A |
| **41.** D | **42.** B | **43.** C | **44.** A | **45.** D | **46.** C | **47.** B | **48.** A | **49.** B | **50.** B |
| **51.** 2.8 to 3.0 | | **52.** 5.9 to 6.1 | | **53.** C | **54.** D | **55.** B | **56.** D | **57.** 0.08 to 0.12 | |
| **58.** C | **59.** D | **60.** 0.70 to 0.72 | | | **61.** B | **62.** A | **63.** 295 to 305 | | |
| **64.** 0.25 | **65.** C | **66.** 18.5 to 19 | | **67.** C | **68.** 2.0 to 2.2 | | **69.** B | **70.** C | **71.** A |
| **72.** A | **73.** A | **74.** 0.5 | **75.** B | **76.** 7.5 to 7.6 | | **77.** D | **78.** 57.8 to 58 | | |
| **79.** 51 to 52 | | **80.** B | **81.** B | **82.** B | **83.** 16 | | | | |