UNIT I THEORY OF METAL CUTTING

Mechanics of chip formation, forces in machining, Types of chip, cutting tools – single point cutting tool nomenclature, orthogonal and oblique metal cutting, thermal aspects, cutting tool materials, tool wear, tool life, surface finish, cutting fluids and Machinability.

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MECHANICS OF CHIP FORMATION

- Metal cutting process is one of the most complex processes.
- The given figure shows the basic material removal operation schematically.
- The metal in front of the tool rake face gets immediately compressed first elastically and then plastically.
- This zone is traditionally called the shear zone, in view of the fact the material in the final form would be removed by shear from the parent metal.
- The actual separation of the metal starts from the cutting tool tip as yielding or fracture, depending upon the cutting conditions.



MECHANICS OF CHIP FORMATION

- Then the deformed metal (called chip) flows over the tool (rake) face.
- If the friction between the tool rake face and the underside of the chip (deformed material) is considerable, then chip gets further deformed, which is termed as secondary deformation.
- The chip after sliding over the tool rake face would be lifted away from the tool, and the resultant curvature of the chip is termed as chip curl.
- Plastic deformation can be caused by yielding, in which case strained layers of material would get displaced over other layers along the slipplanes which coincide with the direction of maximum shear stress.



MECHANICS OF CHIP FORMATION

Piispanen presented an interesting mechanism to account for the deformation process

taking place at the cutting edge.

> He considered the undeformed metal as a stack of cards which would slide over one

another as the wedge shaped tools moves under these cards as shown in Figure.

- Though this idea is an over simplified one, it would account for a number of features that are found in practice.
- > A practical example is when paraffin is cut; block wise slip is clearly evident.





Different types of chips are produced depending on the material being machined and the cutting conditions. These conditions include:

- i. Type of cutting tool used
- ii. Speed and rate of cutting
- iii. Tool geometry and cutting angles
- iv. Condition of machine
- v. Presence/Absence of cutting fluid, etc.,
- The study of chips produced are very important because the type of chips produced influence the surface finish of the work piece, tool life, chatter, force and power requirements, etc.,

- > The chip used in actual manufacturing practices is variable in both size and shape.
- Study of the chip is one of the most important things in metal cutting.
- The mechanics of metal cutting are greatly dependent on the shape and size of the chips produced.
- > The chip formation in metal cutting could be broadly categorized into three types:
 - i. Continuous chip
 - ii. Continuous chip with BUE
 - iii. Discontinuous chip
 - iv. Serrated chip

VELOCITIES IN METAL CUTTING PROCESS

- > Cutting Speed or Velocity (V): Velocity of the cutting tool relative to the work piece.
- Shear Velocity (Vs): It is the velocity of chip relative to the work piece. In other way, the velocity at which shearing takes place.
- Chip Velocity (Vc): It is the velocity of the chip up the tool face (rake face) during cutting.



Continuous chip:

- Continuous chips are normally produced when machining steel or ductile metals at high cutting speeds.
- The continuous chip, which is like a ribbon flows along the rake face as shown in Fig.
- Continuous chip is possible because of the ductility of metal (steel at high temperature generated due to cutting) flows along the shear plane instead of rupture.
- Thus on a continuous chip you do not see any notches.



- Continuous chips in the form of long coils having the same thickness ,throughout, usually are formed with ductile materials like mild steel, copper, aluminum which can have large plastic deformation that are machined at high cutting speeds and/or high rake angles.
- It can be assumed that each layer of metal flows along the slip plane till it is stopped by work hardening.
- Each of these layers gets welded to the previous ones because of the high temperature, thus forming a continuous chip.
- Some ideal conditions that promote continuous chips in metal cutting are: sharp cutting edge, small chip thickness (fine feed), large rake angle, high cutting speed, ductile work materials and less friction between chip tool interfaces through efficient lubrication.

- This is the most desirable form of chip since the surface finish obtained is good and cutting is smooth.
- > It also helps in achieving higher tool life and lower power consumption.
- > However, because of the large coils of chips, the chip disposal is a problem.
- To help in this direction various forms of chip breakers have been developed which are in the form of a step or groove in the tool rake face.
- The chip breakers allow the chips to be broken into small pieces so that they can be easily disposed of.



(a) Dry

(b) Wet

- When machining of a ductile material is done with minimum friction between material and tool and high speed then continuous chips are formed.
- Continuous chips are formed mainly due to plastic deformation.
- \succ The chip thickness is equal to the entire length.
- > Continuous chips provide excellent surface finishing.
- The major disadvantage of continuous chips is that they are difficult in handling as well as in disposing off.

TYPES OF CHIP

Various requirements for the production of continuous chips are:

- Material used should be ductile in nature such as copper, aluminum and mild steel.
- The speed of cutting in machining should be high.
- \succ The chips size should be small.
- Friction between the tool face and chip should be minimum.
- > Tool's rake angle may be high.
- Cutting lubricant used should be of efficient type.
- > Tool's coefficient friction should be low.

Advantages of Continuous Chips

- Better surface finish can be obtained by using ductile material because ductile materials have elasticity.
- Power consumption required in continuous chips is low.
- > Continuous chips have very less wear and tear therefore they provide larger lifespan.
- Due to less friction in between tool face and chip, they need lesser generation of heat.

Continuous chip with BUE:

- When the friction between tool and chip is high while machining ductile materials, some particles of chip adhere to the tool rake face near the tool tip.
- When such sizeable material piles up on the rake face, it acts as a cutting edge in place of the actual cutting edge as shown in Figure.
- This is termed as Built Up Edge (BUE).
- By virtue of work hardening, BUE is harder than the parent work material.



Continuous chip with BUE: TYPES OF CHIP

- > As the size of BUE grows, it becomes unstable and parts of it get removed while cutting.
- The removed portions of BUE partly adhere to the chip underside and partly to the machined surface as shown in Figure.
- \succ This causes the finished surface to be rough.
- However, since the cutting is carried by the BUE and not the actual tool tip, the life of the cutting tool increases while cutting with BUE.
- ➤ In this way BUE is not harmful during rough machining.



Continuous chip with BUE: TYPES OF CHIP

- The conditions that normally induce the formation of BUE are low cutting speed, high feed and low rake angle.
- One of the prerequisites for the formation of BUE is the work hardenability of the work piece material.
- > Higher the work hardenability, rougher is the machined surface produced .

Continuous chip with BUE:

Continuous chips with built-up edges occur:

- > Due to the use of materials which is ductile in nature at the time of machining.
- Due to tool's small rake angle.
- Due to the slow speed of cutting tool.
- Due to high feed rate of the tool.
- Due to high thickness of the chip.
- Due to the temperature between tool and work piece is high.
- Due to increase in friction between the tool and chip faces due to lack of coolant.

Advantages of Continuous Chips with built-up edges:

- Continuous chips with built-up edges increases life span of tool.
- > Tools are being protected from damage because of high friction.

Disadvantages of Continuous Chips with built-up edges:

The major disadvantage of continuous chips with built-up edges is that they produce rough surface finish.

Discontinuous chip:

- When brittle materials like cast iron are cut, the deformed material gets fractured very easily band thus the chip produced is in the form of discontinuous segments as shown in Figure.
- In this type the deformed material instead of flowing continuously gets ruptured periodically.
- Discontinuous chips are easier from the chip disposal view point.



Discontinuous chip:

- However, the cutting force becomes unstable with the variation coinciding with the fracturing cycle.
- Also they generally provide better surface finish.
- However, in case of ductile materials they cause poor surface finish and low tool life.
- Higher depths of cut (large chip thickness), low cutting speeds and small rake angles are likely to produce discontinuous chips.





Discontinuous chip:

- In the process of machining, when the chips produced are small and segmented and have breakage while cutting then the chips are as called segmented chips or discontinuous chips.
- Discontinuous or segmented chips are formed by the use of hard material or brittle material in machining process. Materials like bronze, brass and cast iron are used for discontinuous or segmented chips.
- Discontinuous or segmented chips are produced due to small rack angle and slow cutting speed. Discontinuous or segmented chips are generally produced when friction between the work piece and the tool is high. When a ductile material is used in discontinuous or segmented chips then the surface have poor finish. Discontinuous or segmented chips can be handled easily and can be disposed off easily.

Discontinuous chip:

Various requirements for the production of Discontinuous Chips:

- The speed of cutting in machining is low.
- \succ The friction between tool face and the chip is very high.
- They have small rake angle.

Advantages of Discontinuous or Segmented Chips:

- Discontinuous or segmented chips have less power consumption.
- Discontinuous or segmented chips provide long life span to tools.
- Discontinuous or segmented chips have excellent surface finish for materials which is brittle in nature.

Disadvantages of Discontinuous or Segmented Chips:

- The major disadvantage of discontinuous or segmented chips is that they provide poor surface finish to the ductile materials.
- \succ In this type of chips, the wear and tear occurs in the equipment is excess.

Serrated chip:

- Serrated chips (also called segmented or nonhomogeneous chips, are semi continuous chips with large zones of low shear strain and small zones of high shear strain, hence the latter zone is called shear localization.
- Metals with low thermal conductivity and strength that decreases sharply with temperature (thermal softening) exhibit this behavior, most notably titanium.
- \succ The chips have a saw tooth-like appearance.



TYPES OF CUTTING TOOLS

CUTTING TOOL NOMENCLATURE



SINGLE POINT CUTTING TOOL

Single Point Cutting Tool Examples :

Single Point Cutting tool consists of only one main cutting edge that can perform material removal action at a time in a single pass.

- 1.Turning tool
- 2.Shaping tool
- 3.Planing tool
- 4.Slotting tool
- 5.Boring tool
- 6.Fly Cutter

SINGLE POINT CUTTING TOOL

Material Used For single Point Cutting tools : (BOOK)

- Tool bits generally made of seven materials
- •High-speed steel
- •Cast alloys (such as stellite)
- •Cemented carbides
- •Ceramics
- •Cermets
- •Cubic Boron Nitride
- •Polycrystalline Diamond

SINGLE POINT CUTTING TOOL

Advantages of Single Point Cutting Tool :

- Single Point Cutting tool is simple in construction hence easy to Design and Manufacture.
- > As compare to multipoint cutting tool single point cutter are cheaper.'
- Resharpening of cutter is easy

Disadvantages of Single-point Cutting Tools :

- > These tools have low material removal rates (MRR) hence productivity is low.
- ➤ The tool wear rate is high.
- Tool life is short.
- High Cutting temperature.

Recommended Tool Angles in Degrees for High Speed Steel Cutting Tools

Work Material	Back Rake Angle	Side Rake Angle	Side Relief Angle	Front Relief Angle	Side Cutting Edge Angle	End Cutting Edge Angle
Steel	8-20	8-20	6	6	10	15
Cast steel	8	8	6	6	10	15
Cast iron	0	4	6	6	10	15
Bronze	4	4	6	6	10	10
Stainless steel	8-20	8-20	6	6	10	15

Recommended Tool Angles in Degrees for Cast Alloy Cutting Tools

Work Material	Back Rake Angle	Side Rake Angle	Side Relief Angle	Front Relief Angle	Side Cutting Edge Angle	End Cutting Edge Angle
Steel	8-20	8-20	6	6	10	= 15
Cast steel	8	8	6	6	10	15
Cast iron	0	4	6	6	10	15
Bronze	4	4	6	6	10	10
Stainless steel	8-20	8-20	6	6	10	15

Recommended Tool Angles in Degrees for Carbide Cutting Tool

Work Material	Back Rake Angle	Side Rake Angle	Side Relief Angle	End Relief Angle
Aluminium and magnesium alloys	0-10	10-20	6	6
Copper	0-4	15-20	6-8	6-8
Brass and bronze	0-5	- 5-8	6-8	6-8
Cast iron	- 7-0	- 7-6	5-8	5-8
Plain carbon steels	- 7-0	- 7-6	5-8	5-8
Alloy steels	- 7-0	- 7-6	5-8	5-8
Stainless steels	- 7-0	- 7-6	5-8	5-8
Titanium alloys	- 5-6	- 5-0	5-8	5-8

- A twist drill is basically a cylindrical piece of steel with special grooves.
- One end of the cylinder is pointed and the other end is so shaped that it can be attached to the drilling machine.
- The grooves are usually called flutes.
- The flutes formed by twisting a flat piece of steel into a cylindrical shape and such types of cylindrical shape drills are called twist drills.



https://www.youtube.com/watch?v=w2VJl6kMUI8&a b_channel=ShubhamKola



NOMENCLATURE OF THE DRILLING TOOL (DRILL)





Drill nomenclature comprises the various parts and important geometric parameters of cutting point. They are shown in Figure and defined below:

Body: The portion between the shank and the drill bit tip is called 'Body. The body is mostly fluted and relieved.

Shank: The part of the drill bit that holds into the holding is called the 'shank'.

Dead Centre: The sharp edge at the extreme tip end of the drill is formed by the intersection of the cone-shaped surfaces of the point. The dead center is always at the exact center of the axis of the drill.



Point: The entire cone-shaped surface at the cutting end of the tool.

Lips: The main cutting edges of the drill are formed by the intersection of the flank and the flute surfaces. For a good cutting, it should be straight, symmetrical with the axis of the shaft and equal in length.

Body clearance: To provide diameter clearance the body surface diameter is reduced.

Chisel edge: The chisel edge is the point. Here two cutting lips meet at extreme tip.

Chisel edge Angle: The chisel edge angle is the angle between the chisel edge and cutting lip measured plane normal to the axis.


Face: The flute surface portion adjacent to the lip, when it is cut from the work as the chip impinges.

Flank: Drill surface which extends behind the lip to flute.

Flutes: The Twist Drill body has grooves and it is known as flutes.

Heel: The Heel is the intersection of the flute surface and the body clearance.

Neck: Neck is the portion of the body with reduced diameter between body and shank.

Tang: The tang is flattened end of the taper shank.



Various Type of Twist Drill:

The various types of Twist Drill are follows:

- Taper-shank Drills
- Cobalt Highspeed Steel
- Straight shank drills, taper length
- Straight shank drills, jobber's length
- Heavy-duty drills
- Cotter pin drills
- Straight fluted drill
- Half-round drills
- Multi-cut drill
- Deep Hole Drill
- Shell-type core drill and
- Carbide Drills

Taper-shank Drill:

Taper shank drill is the general-purpose drill and has a morse taper shank. The taper-shank size varies with the drill body diameter.

Cobalt High-Speed Steel:

Cobalt high-speed steel is used in the case of heavy-duty work.

Straight-Shank Drill, taper length:

These drills have a straight shank for the same diameter as the bodies and the same overall length and the flute length as Per taper shank drills.

Carbide Drills:

Carbide Drills are used for drilling small holes. Solid carbide drills are used because they are very Rigid. It has high resistance to vibration and it produces clean and true holes in the work piece.

Twist Drill Advantages:

- The following advantages of twist drill is:
- •Twist Drill tool efficiency is higher.
- •It saves time also because of higher speed and feed can drill the workpiece fast.
- •It takes less power for performing an operation while other tools take high power for performing the operation.
- •Through the flute, the unwanted material cuts from the workpiece easily come out. Now moving to disadvantages,

Twist Drill Disadvantages:

The following disadvantages is:

- •If the tool has a smaller diameter there are chances of breaking.
- •The finish is not as good as compare to other tools like Single Point Cutting Tool and Multi-Point.
- •If the tool works continuously for a long duration, it may break because of heating. So there is coolant required as it may be water or other.

Twist Drill Application:

A twist drill is a tool that is used in the drilling machine for operations like making holes in the

workpiece. The hole in the workpiece depends on the diameter of the twist drill tool.

Twist Drill Material:

Many of the twist drills are made up of High- speed steel with or without a carbon steel shank joined to the body. Some Twist drills are made up of cobalt alloys and others have inserts of cement carbide.

Standard Angles Used in Drills

Material to be Drilled	Included Cutting Angle or Point Angle	Lip Clearance Angle	Helix Angle or Rake Angle	Chisel Edge Angle
Alluminium (pure)	80°-120°	8° -12°	24°-48°	120° - 135°
Cast iron (soft)	118°	8° -12°	24°-32°	120° - 135°
Cast iron (hard)	118°	8° -12°	24°-32°	120° - 135°
Brass	118°	8° -15°	$0^{\circ} - 18^{\circ}$	120° - 135°
Copper	120-140°	8° -15°	$28^{\circ} - 40^{\circ}$	120° - 135°
Steel	118°	8° -12°	$24^{\circ} - 32^{\circ}$	120° - 135°
Stainless steel	120-140°	$10^{\circ} - 12^{\circ}$	$24^{\circ} - 32^{\circ}$	120° - 135°
Al. Alloys	140°	8° -12°	$20^{\circ} - 40^{\circ}$	120° - 135°
Plastics and Hard rubber	80°	8° -12°	24°-32°	120° - 135°
Pure nickel	118°	10° –12°	24° - 32°	120° - 135°



https://www.johnstoncompanies.com/jc/anatomydrill-bit/

A milling cutter can be considered as the cluster of single point cutting tool. The various parts of milling cutter teeth are cutting edge, face, filling, and body. The teeth of milling cutter either straight (the cutting edge is parallel to the axis of rotation) or helical shaped.



Elements of a Plain Milling Cutter:

Body of cutter: It is the main frame of milling cutter, on which the teeth rest.

Periphery: It is defined as the locus of cutting edges of tooth of cutter.

Cutting edge: It is the portion that touches the workpiece during cutting action. It is the intersection of teeth face and tooth flank.

Fillet: portion where one teeth joins the face of another tooth. It is a reinforcement to cutting tooth.

Face of teeth: it is the surface upon the chip is formed while cutting. It may be curved or flat.

Back of tooth: it is the created by fillet and the secondary clearance angle.



Elements of a Plain Milling Cutter:

Land: it is the narrow surface on the back of cutting edge. Land is the result of providing the clearance angle.

Bottom Land: the blank space between the consecutive teeth.

Root diameter: diameter passing through centre of cutter and joining two ends of the periphery.

Root diameter: passing through centre of cutter and joining two bottom fillet.Gash: Gash or flute is the chip space between the back of one tooth and the face of the next tooth.



Elements of a Plain Milling Cutter: **Relief angle:** it is the angle between the tangent to the outside diameter of the cutter at cutting edge and the land of the tooth. The function relief angle is to avoid the interference between the land of the tooth and the work surface. The relief angle varies with the type of material to be machined.

Primary Clearance:

It is the angle between land surface (or a line passing through land) and a tangent to the periphery at the cutting edge. For the most of the cutters the clearance of 5deg is provided.

Secondary Clearance Angle:

To control the land width, a secondary clearance is ground on the tooth. It is the angle between back of teeth and a line passing through land. It is usually 3 deg greater than primary clearance angle.



Elements of a Plain Milling Cutter:

Radial Rake Angle: The angle between face of the cutter and a radial line passing through the tooth of cutting edge. It facilitates removal of chips. The radial rake angle usually ranges from 10deg to 20deg. Larger angles are adopted for milling soft materials and smaller angles for harder material. Carbide tipped cutters are provided with a negative rake angle which varies from 10deg to 15deg.

Axial Rake Angle: It is the angle between the face of the tooth and axis of the cutter.





PLAIN MILLING CUTTER - TYPES

Various Milling Cutters and Their Applications

Sl. No.	Type of Cutter	Features	Applications
1	Plain and face milling cutter (MILL)	Straight or helical teeth	For milling flat surface parallel to cutter axis
2	Side and face milling cutter	Similar to plain cutter, but has teeth on periphery as well as on one or both sides of the tool. Teeth may be straight, spiral or staggered.	Used for slotting, face milling and straddle milling
G ³ HE PI NIVI	End mill cutter EOPLE'S ERSITY	It has integral shaft for driving purpose and teeth on both periphery and ends. Flutes on cutter may be straight or helical. Shank may either be straight or tapered.	Used for milling flat, horizontal, vertical, bevel, chamfer and slant surfaces; grooves cutting, slots and keyways
4	Fly cutter	It has a cylindrical body with a provision to mount one or more tool bits.	Suitable for high speed operation and for quick machining of intricate shapes
5	Slitting or saw cutter	Thin plain milling cutter with straight or staggered teeth	Used for milling shallow slots
6	Hobs	Have cylindrical body with cutting teeth	Commonly used for cutting, spur, helical, horringbone and worm gears; splines, sprockets and ratchets

NOMENCLATURE OF SINGLE POINT CUTTING TOOL





1. Shank:

- \succ The main body of the tool is known as the shank.
- It is the backward part of the tool which is held by tool post.

2. Face:

- The top surface tool on which chips passes after cutting is known as a face.
- It is the horizontal surface adjacent of cutting edges.

3 (a). Flank:

- Sometime flank is also known as cutting face.
- It is the vertical surface adjacent to the cutting edge. According to cutting edge, there are two flank side flank and end flank.

3 (b). Nose or Cutting Point:

The point where both cutting edge meets known as cutting point or nose. It is in front of the tool.





4. Base:

- The bottom surface of the tool is known as the base.
- It is just the opposite surface of the face.

5. Heel:

It is an intersecting line of face and base.

6. End Cutting Edge Angle:

- The angle between the end cutting edge or flank to the plane perpendicular to the side of the shank is known as the end cutting angle.
- \succ This angle usually varies from 5 to 15 degree.





7. Side Cutting Edge Angle:

The angle between the side cutting edge or flank to the plane parallel to the side of the shank known as side cutting edge angle.

8. Back Rake Angle:

- The angle form to smooth flowing of chips from the face, known as rack angle.
- It allows to smooth flow of chips.
- The back rack angle is the angle between the face and the plane perpendicular to the end cutting edge.
- Softer the material, greater should be the positive rake angle.
- The back rake angle may be positive negative or neutral.





9. Side Rack Angle:

- The angle between the face and plane perpendicular to the side cutting edge is known as the side rack angle.
- It allows chips to flow smoothly when material cut by side cutting edge.
- The amount by which a chip is bent depends upon this angle.
- When the side rack angle increases, the magnitude of chip bending decreases.
- Smoother surface furnish is produced by a larger side rake angle.

10. End Relief Angle:

- It is also known as a clearance angle. It is the angle that avoids tool wear.
- It avoid the rubbing of flank with a workpiece.
- End cutting angle made by end flank to the plane perpendicular to the base.
- This angle may vary from 6 to 10 degrees.





11. Side Relief Angle:

- It is the angle made by the side flank to the plane perpendicular to the base.
- It avoid rubbing of side flank with a workpiece.
- This angle allows the tool to fed sideways into the job in order to cut the work material without rubbing.
- When the side relief angle is very small, the tool will rub against the job and therefore it will get overheated and become blunt and the surface finish obtained will be poor.

12. Nose Radius:

The intersecting area of both cutting edges is known as the nose of the tool.





Factors influencing rake angle of the single point cutting tool:

Type of material being cut: a harder material like cast iron may be machined with a smaller rake angle than that required by a soft metal like mild steel or aluminum.

Type of tool material being used: tool material like cemented carbide permits turning at a very high speed. It has been observed that in machining at a very high cutting speed rake angle has a little influence of cutting pressure.

Depth of cut: in rough turning, a high depth of cut is given to withstand severe cutting pressure. so the rake angle should be decreased to increase the lip angle that provides strength to the cutting edge.

The rigidity of the tool holder and condition of the machine: an improperly supported tool on an old and worn out machine can't take up severe cutting pressure. so machining under such conditions the tool used should have a larger rake angle than that at the normal condition to reduce the cutting pressure.

Tool Signature:

The tool signature or tool designation is used to denote a standardized system of specifying the principal tool angles of a single-point cutting tool. Some common systems used for tool designation or tool nomenclature are the following-

1. American or (ASA) System.

It defines the principle angles like side rake, back rack, nose, etc. without any reference to their location concerning cutting edge. As such, this system of nomenclature does not give any indication of the tool behavior with regard to the flow of chip during the cutting operation the three reference planes adopted for designating different tool angles are similar to those used in conventional machine drawing i.e, x-x,y-y, and z-z the last one containing the base of the tool and the two plane being normal to this plane as well as mutually perpendicular. Thus, this system is a coordinate system of tool nomenclature.

2. British system:

This system, according to B-S1886-1952, defines the maximum rake. The various tool parameters in this system are indicated if the order of Back rake, Side rake, End relief angle, Side relief angle, End cutting angle, Side cutting edge angle, and Nose radius.

Tool Signature:

3. Continental systems:

This category of tool nomenclature systems includes the German or DIN System (DIN-6581), Russian Systems (OCT-BKC 6897and 6898), and Czechoslovakian System (CSN-1226). The various tool parameters in these systems are specified with reference to the tool reference to the tool reference planes.

4. International system:

It is an internationally adopted system, developed recently. It incorporates the salient

features of tool nomenclature of different systems in it.

Example: A tool with 8, 10, 6, 6, 6, 10, 0.2, signature in **the A.S.A system** is having the following specification. Back rake $(\alpha y) = 8^{\circ}$ Side rake $(\alpha x)=100$ End relief angle $(\beta y) = 60$ Side relief angle $(\beta x) = 60$ End cutting edge angle $(\varphi e) = 60$ Side cutting edge angle $(\varphi s) = 100$ Nose radius = 0.2mm

ORTHOGONAL CUTTING AND OBLIQUE CUTTING

METHODS OF CUTTING

ORTHOGONAL CUTTING:

- Orthogonal Cutting Is a Type of Cuttings in Which the Cutting Tool Is Perpendicular to the Direction of Motion.
- ➤ The Chip Flow in This Cutting Is State-Of-The-Art.
- This Type of Cutting Has a Lower Life Cutting Capacity in the Tool.
 OBLIQUE CUTTING:
- Oblique cutting is a type of cuttings in which the cutting tool is at an oblique angle in the direction of the tool's motion.
- The chip flow in this cutting is not cutting edge.
- The tool has a longer cutting life than orthogonal cutting.



ORTHOGONAL CUTTING vs OBLIQUE CUTTING

S.No	Orthogonal Cutting	Oblique Cutting
1	The cutting angle of the tool makes a right angle to the direction of motion	The cutting angle of the tool does not make the right angle to the direction of motion
2	The flow of the chip is perpendicular to the cutting edge.	The flow of the chip is not perpendicular to the cutting edge.
3	The tool has lesser cuttings life	The tool has a higher cuttings life.
4	The shear forces per unit area is high, which increases the heat per unit area.	The shear force per unit area is low, which decreases heat per unit area.
5	In orthogonal cutting, the surface finish is poor.	In oblique cutting surface finish is good.
6	Cutting edge is longer than the edge of the cut	Cuttings may or may not be longer than the edge of the cut.
7	In orthogonal cuttings, only two components of force are considered cutting force and thrust force, which can be represented by a 2D coordinate system.	In oblique cutting, three components of force are considered, cutting force, thrust force, and radial force, which cannot represent by 2D coordinate. It used a 3D coordinate to represent the forces acting during cutting, so it is known as 3D cutting.
8	Two mutually perpendicular cutting forces act on the workpiece	Three mutually perpendicular forces are involved.



- Benjamin Thomson (1798) conducted the first experiment on machine tools when he measured the thermal energy involved during the boring of brass cannon.
- > He observed that all the mechanical energy is converted into thermal energy.
- > He used the **calorimetric method**.
- Temperature of cutting is a very important parameter, which is of great consequence with reference to the life of a tool.
- The surface of the tool, if proper precautions are not taken, may be overheated at isolated points and localized phase transformations can occur.
- This may result in the softening of the surface of the tool and frequently very small cracks will be formed as a result of the intense residual stress system that accompanies surface transformation.
- Because of the very large amount of plastic strain involved in metal cutting, it is unlikely that more than 1% of the work done is stored as elastic energy (which can be neglected), the remaining 99% goes to heat the chip, the tool and the work.

The typical zones in metal cutting where the heat is generated are shown in figure and are categorized below:

- i. in the shear plane where the heat is generated because of internal friction, and this accounts for 65 to 75% of the total heat generated,
- ii. the friction at the chip tool interface which causes heat of the order of 15 to 25%
- iii. the friction at the tool work interface which causes heat of the order of 10%.



- The metal in the area ahead of the cutting edge of the tool is severely compressed, resulting in temperatures high enough to allow plastic flow.
- As the atoms in the metal ahead of the tool are disturbed, the friction involved in their sliding over one another is probably responsible for the shear plane heat.
- As the tool continues to push through the work piece, a chip eventually slides up the rake face of the tool.
- > This sliding is responsible for frictional heat.

There are a number of methods for measuring the chip tool interface temperature.

- a) Radiation pyrometers
- b) Embedded thermocouples
- c) Temperature sensitive paints
- d) Temper colours
- e) Indirect calorimetric technique
- f) Tool work thermocouple





Of all these methods, the tool work thermocouple technique is the most widely used technique for the measurement of the average chip tool interface temperature. The other methods suffer from various disadvantages such as slow response, indirectness, and complications in measurement.

Tool Work Thermocouple method:

Reference: Sushil D. Ghodam, "TEMPERATURE MEASUREMENT OF A CUTTING TOOL IN TURNING PROCESS BY USING TOOL WORK THERMOCOUPLE", International Journal of Research in Engineering and Technology, pp. 831 – 835.

- Tool and work materials are dissimilar and the temperature in the cutting zone is higher than the rest of the tool or work.
- Hence the tool work contact area serves as the hot junction in a thermoelectric circuit and the emf generated is proportional to temperature.
- The Tool-Work thermocouple is used to measure the temperature at the cutting point of the tool.
- The tool-work thermocouple is work on the principle of Seebeck effect which states that if there is a temperature difference between any two junctions then there will be a development of EMF in between the two junctions.

Tool Work Thermocouple method:

- > A typical setup is shown in Figure.
- The end of the tool is ground to a very small diameter such as 3 mm and a long chip generated by machining with very light feed is made as the tool work thermocouple.
- A mercury slip ring connection at the end of the work piece through the spindle bore is a convenient way for completing the EMF circuit.



Setup for measuring interface temperature

Tool Work Thermocouple method:

- Sources of errors in tool work thermocouple:
 - Not an ideal thermocouple, which means EMF, is low and the calibration need not always be a straight line.
 - Source the calibration procedure because it is done in the stationary situation.
- It is possible only to find the average chip-tool interface temperature from the above experiment.
- However, it is possible to use analytical techniques for predicting the average temperatures as well as temperature distributions.

Analytical Determination of Temperature in Metal Cutting:

> To get a generic idea, Cook developed a formula to estimate the tool tip temperature

using dimensional analysis as follows:

$$T = 0.4T_a \left[\frac{Vd}{K}\right]^{1/3}$$

Where K = thermal diffusivity of the work material, mm2/s

Specific heat = c;

Density = ρ Specific cutting energy, u_{s} , $u_{s} = \frac{F_{H}V}{MRR} = \frac{\tau \cos(\beta - \alpha)}{\sin(\phi) \cos(\phi + \beta - \alpha)}$ Adiabatic temperature, $T_{a} = \frac{u_{s}}{\rho c}$
- > Various cutting tool materials have been used in the industry for different applications.
- A number of developments have occurred in the 20th century, thanks to the aerospace and nuclear programmes.
- A large variety of cutting tool materials have been developed to cater to the variety of materials used in these programmes.

Before we proceed to know these materials, let us look at the important characteristics expected of a cutting tool material:

- 1. Higher hardness than that of the work piece material being machined, so that it can penetrate the work material.
- 2. Hot hardness, which is the ability of the material to retain its hardness at elevated temperatures, in view of the high temperatures existing in the cutting zone. This requirement becomes more and more stringent with the increasing emphasis on higher cutting speeds to bolster productivity.
- 3. Wear resistance The chip-tool and chip-work interfaces are exposed to such severe conditions that adhesive and abrasion wear is very common. The cutting tool material should therefore have high abrasion resistance to improve the effective life of the tool.

- 4. Toughness Even though the tool is hard, it should have enough toughness to withstand the impact loads at the beginning of the cut or to force fluctuations due to imperfections in the work material. This requirement is more useful for interrupted cutting, e.g. milling.
- 5. Low friction The coefficient of friction between chip and tool should be low which would allow for lower wear rates and better chip flow.
- 6. Better thermal characteristics Since a lot of heat is generated at the cutting zone, it is necessary that the tool material should have higher thermal conductivity to dissipate this heat in the shortest time, otherwise the tool temperature will become too high thus reducing its life.

- \succ All these properties may not be found in a single tool material.
- A comparison of the various properties of the cutting tool materials are presented in Table.
- Improvements in tool materials having been taking place over the past century to give us better cutting performance.
- Some of these tool materials have been discussed next.

Comparative properties of cutting tool materials

Cutting Tool		Transverse Rupture		
Material	Room Temperature	540°C	760°C	Strength × 10 ³ MPa
High-speed steel	85 to 87	77 to 82	Very low	3.8 to 4.5
Cast cobalt	82 to 85	75 to 82	70 to 75	1.4 to 2.8
Carbides	89 to 94	80 to 87	70 to 82	to 2.4
Ceramics	94	90	87	0.5 to 0.4
Diamond	7000 Knoop	7000 Knoop	7000 Knoop	—





High Speed Steel

Carbide Tools

Cast Cobalt



Ceramic Tools



Carbon Tool Steels:

- > These are the earliest tool materials used.
- These are essentially plain carbon steels with carbon percentages between 0.6 to 1.5% and some very small alloy additions such as manganese, silicon, tungsten, molybdenum, chromium and vanadium.
- The major disadvantage with this range of cutting tool materials is their inability to withstand high temperatures.
- Beyond 200°C they lose their hardness and cease to cut.
- Thus these are useful only for very low cutting speeds (about 0.15 m/s) and can be used with low temperature generating operations such as machining wood, magnesium, brass and aluminium.
- They are easy to prepare and ground, as a result they are used for form tool making to be used for low quantity production.

- They were able to significantly improve the cutting speeds by 3 to 5 times (about 0.5 m/s) than the speed prevalent at that time, using carbon tool steels.
- Because of this high cutting speed capability they were termed as high speed steels or more popularly called HSS.
- This class of tool materials have significant quantities of tungsten, molybdenum, chromium and vanadium.
- The complex carbides of tungsten, molybdenum and chromium distributed throughout the metal matrix provide very good hot hardness and abrasion resistance.
- The major alloying elements, which contribute to the hardness is tungsten and molybdenum.
- > Tungsten is expensive, while molybdenum is cheap but has higher toughness.

- For the same hardness, less amount of molybdenum needs to be added, however more care need to be exercised in hardening as decarburizing takes place in molybdenum steels.
- > Also they have narrow temperature range for heat treatment.
- Molybdenum tool steels are more popular.
- The main advantages of high speed steels are their high hardness, hot hardness, good wear resistance, high toughness and reasonable cost.
- > Toughness of high speed steels is highest among all the cutting tool materials.
- Thus they are quite extensively used in interrupted cutting such as milling. The hardness of HSS falls rapidly beyond 650°C and thus they are limited to lower cutting speeds of the order of 0.5 to 0.75 m/s.

- Tool steels have been classified by AISI as T-type and M-type depending on whether tungsten or molybdenum is the major alloying element present in the steel. Some typical compositions have been given in Table.
- Recently the HSS tool steels are also being produced through the powder metallurgy route.
- > In this method fine powder of alloy tool steel is compressed under hot isostatic pressure.
- With suitable hardening and tempering, this method provides for uniform dispersion of carbides in the matrix. These have been found to grind more easily, exhibit uniform properties and perform more consistently in cutting.

High Speed Steels:

Typical compositions of high speed steel materials

AISI Steel	% Chemical Composition						
Туре	С	Cr	V	W	Mo	Со	W _{eq}
T1	0.70	4.0	1.0	18.0			18.0
T6	0.80	4.25	1.5	2.0	0.90	12.0	21.8
M1	0.80	4.0	1.0	1.5	8.0		17.5
M6	0.80	4.0	1.50	4.0	5.0	12.0	14.0
M30	0.85	4.0	1.25	2.0	8.0	5.0	18.0
M42	1.10	3.75	1.15	1.50	9.50	8.25	20.5

High Speed Steels:

- These, termed as stellites, are normally produced by the powder metallurgy method, though casting is also used by some manufacturers.
- Fine powders of a number of non-ferrous metals (having compositions as shown in Table) are thoroughly mixed and compacted to the final shape under hot isostatic pressure.
- They are then ground to their final geometry.

Nominal % Composition					Grade			
Cr	W	Mo	С	Mn	Si	Ni	Co	
30	4.5	1.5	1.1	1.0	1.5	3.0	rest	Roughing
31	10.5	—	1.7	1.0	1.0	3.0	rest	General purpose
32	17.0		2.5	1.0	1.0	2.5	rest	Finishing

Typical compositions and uses of cast non-ferrous alloys

- They retain their hardness even at elevated temperatures better than HSS and consequently are used at cutting speeds higher (25% higher) than HSS. Because of their formability these are used for making form tools.
- They have higher toughness and higher stiffness.
- Currently these are being phased out since carbides are now available which have a larger range of properties.

Cemented Carbides:

- The best thing for the metal cutting industry is the invention of cemented carbides, which happened around 1926 in Germany.
- > By far this is the largest percentage of cutting tools used in metal cutting production.
- Cemented carbides are produced by the cold compaction of the tungsten carbide powder in a binder such as cobalt, followed by liquid-phase sintering.
- These have a very large number of advantages compared to the other cutting tool materials.
- (i) High hot hardness: These can retain their hardness to much higher temperatures and as a result the cutting speeds used are 3 to 6 times (about 5 to 6 m/s) than that of HSS.
- (ii) Higher Young's modulus: This results in stiffer cutting tools with less tendency towards chatter.

Cemented Carbides:

The following guidelines would be useful for selecting a carbide grade:

- i. Choose a grade with the lowest cobalt content and the finest grain size consistent with adequate strength to eliminate chipping.
- ii. Use straight WC grades if cratering, seizure or galling is not experienced in case of work materials other than steels.
- iii. To reduce cratering and abrasive wear when machining steel, use grades containing TiC.
- iv. For heavy cuts in steel where high temperature and high pressure deform the cutting edge plastically, use a multi-carbide grade containing W-Ti-Ta and/or lower binder content.

Cemented Carbides:

- As the cobalt content increases, toughness and impact strength of cemented carbide increase while hardness, Young's modulus and thermal conductivity decrease.
- Fine grain carbides are harder compared to coarse grain carbides. Multi-carbide grades increase chemical stability, hardness and hot hardness.
- Since tungsten and cobalt are expensive, some special cemented carbides having predominantly tantalum carbides with Ni and Mo as binder have been developed, for auto industry applications for finish machining of steels and malleable cast irons.
- > These are sometimes called 'cermets'.
- These are relatively brittle and easy to chip. These are relatively cheap and should find widespread use in future.

Coated Carbides:

- With the increase in material characteristics to cater to the increasing service requirements, the need for developing better cutting materials has been felt since the World War II.
- Since the range of work materials is large, there is a need for hard and refractive coatings on conventional tool materials, so that the same could be used in diverse situations.
- > Thus several coatings and coating methods have been developed for cutting tools.
- Since late 60's thin (about 5 mm) coating of TiN has been used on cemented carbide tools.

Coated Carbides:

- Ceramic coatings used are hard materials and therefore provide a good abrasion resistance.
- ➤ They also have excellent high temperature properties such as high resistance to diffusion wear, superior oxidation wear resistance, and high hot hardness.
- Further the good lubricating properties of the coatings minimise friction at the tool-chip and tool-work piece interfaces, thereby lowering the cutting temperature.
- All these translate into lower forces generated during machining compared to uncoated tools.

Coated Carbides:

- The substrate is a normal cemented carbide tool that has the necessary strength and toughness.
- The coating on the top, as shown in Figure, provides the required hardness and refractoriness that prolongs the life of the tool.
- The life of the coated tools is often two to three times of the uncoated, while these can be used at higher cutting speeds, thus increasing productivity.
- The coatings need to be metallurgically bonded to the substrate.
- These coatings such as titanium carbide, titanium nitride, aluminium oxide, hafnium nitride and hafnium carbide or multiple coatings of the above, are deposited on the carbide tool bits by the chemical vapour deposition (CVD) process.

Coated Carbides:

- The chemical reaction necessary to deposit the required coating takes place close to the substrate.
- The coating is deposited literally atom by atom onto the surface thereby providing a very strong adhesion between the coating and the substrate.

Coating	Room Temperature Hardness (HV)	Oxidation Resistance, °C	Coefficient of Friction
TiN	1930-2200	600	0.4-0.5
TiCN	2730-3000	400	0.3
TiAlN	3000-3500	800	0.7
TiN/AlN	4000	950	—
TiAlCN	3200	600	—

Properties of some coating materials

Ceramics:

- Ceramics are essentially alumina (AI2O3) based high refractory materials introduced specifically for high speed machining of difficult to machine materials and cast iron.
- These can withstand very high temperatures, are chemically more stable and have higher wear resistance than the other cutting tool materials.
- In view of their ability to withstand high temperatures, they can be used for machining at very high speeds of the order of 10 m/s.
- \succ It is possible to get mirror finish on cast iron using ceramic turning.
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Ceramics:

- In view of their ability to withstand high temperatures, they can be used for machining at very high speeds of the order of 10 m/s.
- \succ It is possible to get mirror finish on cast iron using ceramic turning.
- The machine tools used for ceramic machining have to be extremely rigid to provide smooth machining conditions for machining with ceramics and should be able to provide high cutting speeds.
- > They are not suitable for intermittent cutting or for low cutting speeds.
- Apart from the pure alumina based ceramics, sometimes other materials such as Titanium carbide (TiC), Titanium Nitride (TiN), and Titanium diboride (TiB2) are added to enhance the transverse rupture strength, hardness and thermal shock resistance.
- Some yittria (Y2O3 obtained as a heavy white powder and used especially formerly in incandescent gas mantles) may also be added as a sintering agent.

Ceramics:

- Ceramic tools should be used with very high cutting speeds on steels.
- > They are not suitable for low cutting speeds or for intermittent cutting.
- Cutting fluid if applied should be in flooding with copious quantity of fluid to thoroughly wet the entire machining zone, since ceramics have very poor thermal shock resistance. Else it can be machined with no coolant.
- > Ceramic tools are used for machining work pieces, which have high hardness such as

hard castings, case hardened and hardened steels.

Base System Density		Hard	Transverse Rupture	
	g/cm³	25°C (HRA)	1000°C (HV)	Strength, MPa
Al ₂ O ₃	3.98	93.9	710	50
$Al_2O_3 + TiC$	4.24	94.3	770	80
Si ₃ N ₄	3.27	92.6	1100	100

Properties of ceramic materials

Ceramics:

- Typical products that can be machined are brake discs, brake drums, cylinder liners, and flywheels.
- Correct cutting speed produces good surface finish, optimum productivity and better tool life.
- Ceramic tools cannot machine some materials such as aluminium, titanium, since they have strong affinity towards them, as a result of which chemical reactions are likely to take place.

Ceramics:

are:

Among other things, some of the vital requirements when machining with ceramics

- i. Use the highest cutting speed recommended and preferably select square or round inserts with large nose radius.
- ii. Use rigid machine with high spindle speeds and safe clamping angle.
- iii. Machine rigid work pieces.
- iv. Ensure adequate and uninterrupted power supply.
- v. Use negative rake angles so that less force is applied directly to the ceramic tip.
- vi. The overhang of the tool holder should be kept to a minimum; not more than 1.5 times the shank thickness.

Ceramics:

- vii. Large nose radius and side cutting edge angle on the ceramic insert to reduce the tendency of chipping.
- viii. Always take a deeper cut with a light feed rather than a light cut with heavy feed; ceramic tips are capable of cuts as deep as one-half the width of the cutting surface on the insert.
- ix. Avoid coolants with aluminium oxide based ceramics.
- x. Review machining sequence while converting to ceramics and if possible introduce chamfer or reduce feed rate at entry.

Diamond:

- Diamond is the hardest known (Knoop hardness ~ 8000 kg/mm2) material that can be used as a cutting tool material.
- It has most of the desirable properties of a cutting tool material such as high hardness, good thermal conductivity, low friction, non-adherence to most materials, and good wear resistance.
- However, the factors that weigh against its use are the high cost, possibility of oxidation in air, allotropic transformation to graphite above temperatures of 700°C, very high brittleness and difficulties associated in shaping it to suitable cutting tool form.
- Natural diamond tools could be used for relatively light cuts where these provide extremely high tool life, which can easily justify the high cost of diamond.
- However, natural diamond is unreliable in performance because of the impurities present and easy cleavage.

Diamond:

- Artificial diamonds are basically polycrystalline (PCD) in nature.
- These are extensively used in industrial application because they can be formed for any given shape with a substrate of cemented carbide.
- Polycrystalline diamond tools are metallurgically bonded to a tungsten carbide substrate and cut into small bits.
- > The tungsten carbide provides the necessary elastic support for the hard diamond tool.
- This is then placed in the carbide inserts that have precision pockets to receive the diamond bit and then brazed as shown in Figure.



Diamond:

They are used with a negative rake angle (–5°) for machining hard materials while positive rake angles (15°) can be used for soft materials such as copper. They cannot be used for machining low carbon steels, titanium, nickel, cobalt or zirconium because of the possible reaction with the work material. Typical materials that are machined with diamond tools and the suggested process parameters are given in Table.

Material Cutting Speed, m/min Depth of Cut, mm Feed Rate, mm/rev Aluminium alloys > 11% Si 300-3000 Up to 4 0.10-0.50 MMC SiC-particles (15-30%) 200-800 Up to 3 0.10-0.50 Copper, Brass and Bronze Up to 3 0.10-0.50 600-1200 Carbon and graphite 100 - 400Up to 3 0.10-0.50 Sintered carbide Up to 3 10 - 400.10-0.50 Green carbide 80-200 Up to 0.5 0.10-0.50 Green ceramic 100-600 Up to 2 0.05-0.20 Plastic composites 100 - 1000Up to 3 0.10-0.50

Cutting data for Polycrystalline Diamond (PCD) tool bits (From Seco catalogue)

Summary of applications for various cutting tool materials [Komanduri]

Tool Material	Work Materials	Remarks
Carbon steels	Low strength, softer materials, nonferrous alloys, plastics	Low cutting speeds, low strength materials
Low/medium alloy steels	Low strength, softer materials, nonferrous alloys, plastics	Low cutting speeds, low strength materials
HSS	All materials of low and medium strength and hardness	Low to medium cutting speeds, low to medium strength materials
Cemented carbides	All materials up to medium strength and hardness	Not suitable for low speed application
Coated carbides	Cast iron, alloy steels, stainless steels, super alloys	Not for Titanium alloys, not for non- ferrous alloys as the coated grades do not offer additional benefits over uncoated.
Ceramics	Cast iron, Ni-base super alloys, nonferrous alloys, plastics	Not for low speed operation or inter- rupted cutting. Not for machining Al, Ti alloys.
CBN	Hardened alloy steels, HSS, Ni-base super alloys, hardened chill cast iron, commercially pure nickel	High strength, hard materials
Diamond	Pure copper, pure aluminium, Al-Si alloys, cold pressed cemented carbides, rock, cement, plastics, glass-epoxy composites, non-ferrous alloys, hardened high carbon alloy steels (for burnishing only), fibrous composites	Not for machining low carbon steels, Co, Ni, Ti, Zr.

TOOL WEAR:

- With the usage of tools over a long time, they are subjected to wear.
- The type of wear found in cutting tools is shown in Figure.
- There are two major types of wear \succ found in tools.
- \succ They are:
 - i. Flank wear
 - ii. Nose wear
 - **Crater wear** iii.

Crater wear occurs as result of chips sliding along chip-tool interface, result of built-up edge on cutting tool • Nose wear occurs as result of friction between nose and metal being machined

When flank wear is .015 to .030 in. need to be reground

Occurs on side of cutting edge as result of friction between side of cutting-tool edge and metal being machined

TOOL WEAR:

1. Flank wear:

Flank wear is due to abrasive action of discontinuities like debris from built up edge etc. It wears out side and end flank of the tool. It is occur at tool work-piece interface. This wear predominates at low speed.

2. Crater wear:

Crater wear generally occur in machining ductile material due to abrasion and diffusion of metal at face of tool. It is occur at face at a short distance from cutting edge. This wear predominates at high speed.

3. Nose wear:

Nose wear are consider as separate part of wear. It wears out the tool corner. It is the matting part of flank and face which is combination effect of crater wear and flank wear. It is considered as separate wear because the tool corners are very important for proper cutting of work-piece.

Precautions to prevent tool wear:

Tool wear can be reduce by proper cooling and lubricate because the major cause of tool wear is friction and temperature rise due to tool and work contact. Lubricates reduce friction between chips and tool which reduce tool wear. It can also be reduced by using high hardness and abrasion resistance tool and high resistance to adhesion and diffusion.

TOOL WEAR: When sharp edge tool rubs over the work piece, shear off some material and give desire shape of work piece. Due to this rubbing and many other mechanism tool also worn out, which is known as tool wear. A number of wear mechanisms as follows have been proposed to explain the observed tool wear phenomenon.

Adhesion:

This wear is depends upon work hardening of work piece. When the tool cuts the work piece, some small chips form which acts as hard particle. These hard particle acts as small cutting edge like in grinding wheel, which cause tool wear.

Abrasion:

This tool wear is due to sliding of chips over the tool. The chips forms by metal cutting are hard and have high temperature. This is wear is due to rubbing of these chips over the tool. This wear cause due to high friction and high temperature of chips flowing over tool face.

Diffusion:

Diffusion means diffuse of hard metal into soft metal due to high temperature of contact surface between hard material and soft material. In tool wear chips act as hard material and tool act as soft material.

Oxidation:

Oxidation mean diffuse of oxygen particle tool face. It is also depend surface temperature of tool and tool material.

Chemical decomposing:

Due to high temperature and pressure there is change in chemical composition of tool which reduces its life.

TOOL WEAR:

Other than the types discussed above the following points are also taken into account when it comes to tool wear:

- i. Breakage of tool due to excessive shock and force.
- ii. Tool wears due to plastic deformation or change in chemical of physical condition of tool.

These wear breakage wear and wear due to plastic deformation are very harmful for both machine and work piece. So it should be totally eliminated by using favorable condition and taking high factor of safety.

TOOL WEAR, TOOL LIFE AND SURFACE FINISH

TOOL LIFE:

- Tool life represents the useful life of the tool, generally expressed in time units from the start of a cut to an end point defined by a failure criterion.
- A tool that no longer performs the desired function is said to have failed and hence reached the end of its useful life.
- At such an end point the tool is not necessarily unable to cut the work piece but is merely unsatisfactory for the purpose.
- The tool may be re-sharpened and used again.
- > The tool life can be specified by any of the following measurable quantities:
 - Actual cutting time to failure
 - Length of work cut to failure
 - Volume of metal removed to failure
 - Number of components produced
 - Cutting speed for a given time to failure
TOOL WEAR and TOOL LIFE

TOOL LIFE EQUATION:

- > Taylor thought that there is an optimum cutting speed for maximum productivity.
- He reasoned this from the fact that at low cutting speeds, the tools have higher life but productivity is low, and at higher speeds the reverse is true.
- > This inspired him to check the relationship between tool life and cutting speed.
- Based on his experimental work he proposed the formula for tool life:

 $V T^n = C$

T is the tool life in minutes V is the cutting speed, m/min C and n are constants

$$\begin{split} \theta &= \frac{c_o u_s V^{0.44} A^{0.22}}{k^{0.44} \tau^{0.56}} \\ \textbf{k} &= \textbf{thermal conductivity of work} \\ \textbf{t} &= \textbf{specific heat of work} \end{split}$$

$$T \theta^{B} = C VT^{\frac{0.5-2x}{1-2x}} = \left[\frac{T_{C}H^{0.5}}{C'u_{c}A^{x}}\right]^{\frac{1}{1-2x}}$$

H = specific heat ¥ thermal conductivity tetta= tool temperature A = area of cut us = specific cutting energy/unit cutting force

C and x are constants

TOOL WEAR and TOOL LIFE

TOOL LIFE EQUATION:

- > This is the most commonly employed tool life equation by a number of researchers.
- The constants for the above equation for some common work materials are given in Table.
- Apart from the cutting process parameters the tool life depends on the work material as well as tool material.
- > The constants therefore are given for each combination of work and tool material.

 $VT^n f^{n1} d^{n2} = C$

Constants for extended tool life equation

Tool Material	Work Material	Exponent for			Constant C
ISO Grade	AISI	Tool Life, n	Feed, n ₁	Depth of Cut, n ₂	
P01, P10	1020	-0.38	-0.06	-0.10	1150
P20, P30	1020	-0.38	-0.17	-0.11	780
P01, P10	1045	-0.22	-0.21	-0.11	350
P20, P30	1045	-0.22	-0.34	-0.12	226

SURFACE FINISH

SURFACE FINISH:

- Machining operations are performed in order to achieve better surface finish as compared to other manufacturing operations.
- Thus it is important to know the effective surface finish that can be achieved in a machining operation.
- > The surface finish in a given machining operation is a result of two factors:
- i. The ideal surface finish, which is a result of the geometry of the manufacturing process, can be determined by considering the geometry of the machining operation.
- ii. The natural component, which is a result of a number of the uncontrollable factors in machining, is difficult to predict.



Cutting Fluids: Definition & Purpose

DEFINITION: A cutting fluid is any liquid or gas that is applied directly to the machining operation to improve cutting performance.

PURPOSE:

- Act as lubricant: Reduce friction and wear by acting as a film and hence also reduce welding tendency.
- Act as coolant: Cooling of cutting zone and hence increasing tool life & improving dimensional stability, Reducing the temperature of the workpart for easier handling
- ✤ Reduce forces and energy consumption.
- Flush away the chips from the cutting zone to avoid interference in cutting
- Protect the machined surface from environmental corrosion (weakening and depletion of surface by deposition of other matter like rust) & contamination by the gases like SO₂, O₂, H₂S, and N_xO_y present in the atmosphere

Essential Properties of Cutting Fluids

* For cooling:

- High specific heat (high heat absorbing capacity), thermal conductivity and film coefficient for heat transfer
- spreading and wetting ability

* For lubrication:

- High lubricity without gumming (accumulation & sticking of dirt & dust) and foaming
- ✤ Wetting and spreading
- ✤ High film boiling point
- Friction reduction at extreme pressure and temperature
- Chemical stability, non-corrosive to the materials of the system
- Iess volatile (tendency of evaporation) and high flash point (temperature at which fluid vapor ignite by some source)
- ✤ high resistance to bacterial growth
- $\boldsymbol{\diamondsuit}$ odorless and also preferably colorless
- $\boldsymbol{\diamondsuit}$ nontoxic in both liquid and gaseous stage
- Easily available and low cost.
- ✤ It should permit clear view of the work operation.

***** Air blast or compressed air only

- Grey cast iron use no cutting fluid in liquid form as graphite flakes in the cast iron acts as a lubricant in itself by sliding over each other and producing short discontinuous chips.
- ✤ In such cases only air blast is recommended for cooling and cleaning

Water

For its good wetting and spreading properties and very high specific heat, water is considered as the best coolant and hence employed where cooling is most urgent.

* Cutting oils or Straight oils

- Compounds of mineral oil with vegetable, animal or marine oils added for improving spreading, wetting and lubricating properties.
- As and when required some EPA additive including Sulphur, chlorine, and phosphorus are also mixed to reduce friction, adhesion and BUE formation in heavy cuts.
- Additives react chemically with the chip and tool surfaces to form solid films (extreme pressure lubrication) that help to avoid metal-to-metal contact between the two.
- Advantages:: excellent lubrication, good corrosion protection, easy maintenance
- Limitation & Disadvantages: poor heat removal, toxic mist, high viscosity, flammable, expensive, not suitable for high speed machining

Emulsified oils or soluble oils

- ✤ Oil droplets suspended in water
- Water acts as the best coolant but does not lubricate and also induce rusting.
- So oil containing some emulsifying agent to improve blending and stability (An emulsion is a mixture of two or more liquids that are normally immiscible (unmixable or unblendable)) and extreme pressure additive (EPA) like Sulphur, chlorine, and phosphorus are mixed with water in a suitable ratio (1:30). It look likes white milk, used widely, have less lubrication qualities but have good cooling ability.
- Advantages: good lubrication, good cooling capability, some corrosion protection, low cost, nonflammable.
- Disadvantages: anti-bacteria additives and maintenance are needed, toxic mist, susceptible to hard water (may form insoluble precipitates).

Chemical fluids or synthetic fluids

- Blended chemicals with additives, diluted in water, and containing no oil.
- Synthetic fluids are water based solutions (or emulsions) of synthetic lubricants (soaps and other wetting agents), corrosion inhibitors, water softeners, Extreme pressure additives (EPA), anti-bacteria additives (biocides), glycols and other additives.
- Synthetic fluids are supplied in form of concentrates, which are mixed with water before use.
- Synthetic fluids are used in a wide variety of metalworking operations including poorly machinable alloys, heavy duty grinding, high speed cutting.
- Advantages of synthetic fluids: very good cooling capability, good lubrication properties, good stability in hard water, quick wetting ability, low surface tension so good spreading, good corrosion protection, easy handling, cleaning and maintenance.
- Disadvantages/Limitations of synthetic fluids: some toxicity, easily contaminated by foreign oils, relatively high cost.

Semi-Synthetic or Semi-Chemical Fluids

- These will contain small amounts of oil and other additives to enhance lubrication while providing maximum cooling.
- Semi-synthetic fluids are water based mixture (solution and emulsion) of synthetic lubricants, additives, emulsifiers and some amount (2%-30%) of mineral oil.
- Semi-synthetic fluids combine advantages (and disadvantages at some extent) of mineral emulsions and synthetic fluids
- Advantages: They possess better corrosion protection than synthetic fluids and better cooling and wetting capabilities, easier handling and maintenance than mineral emulsions.
- Disadvantages/Limitations: misting, relatively poor stability in hard water, contaminated by foreign oils, some toxicity, lower lubrication ability, possible skin irritants, and less corrosion protection.

Solid or Semi-Solid Lubricant

Paste, waxes, soaps, graphite, Moly-disulphide (MoS₂) may also often be used, either applied directly to the workpiece or as an impregnant in the tool to reduce friction and thus cutting forces, temperature and tool wear.

Cryogenic cutting fluid

Extremely cold (cryogenic) fluids (often in the form of gases) like liquid CO₂ or N₂ are used in some special cases for effective cooling without creating much environmental pollution and health hazards.

Selection of Cutting Fluids

- For high speed machining of not-difficult-to-machine materials greater cooling type fluids are preferred
- For low speed machining of both conventional and difficult-to-machine materials greater lubricating type fluid is preferred.

Grey cast iron:

- Generally dry for its self-lubricating property
- Air blast for cooling and flushing chips

Steels:

- Soluble oil for cooling and flushing chips in high speed machining and grinding
- If machined by HSS tools, sol. Oil (1: 20 ~30) for low carbon and alloy steels and neat oil with EPA for heavy cuts
- ✤ If machined by carbide tools thinner sol. Oil for low strength steel, thicker sol. Oil (1:10 ~ 20) for stronger steels and straight sulphurised oil for heavy and low speed cuts and EP cutting oil for high alloy steel.
- Often steels are machined dry by carbide tools for preventing thermal shocks.

Aluminum and its alloys:

- Preferably machined dry
- Light but oily soluble oil
- ✤ Straight neat oil or kerosene oil for stringent cuts.

Copper and its alloys:

- Water based fluids are generally used
- ✤ Oil with or without inactive EPA for tougher grades of Cu-alloy.

Stainless steels and Heat resistant alloys:

- High performance soluble oil or neat oil with
- ✤ High concentration with chlorinated EP additive.

The brittle ceramics and cermets should be used either under dry condition or light neat oil in case of fine finishing. Grinding at high speed needs cooling (1: $50 \sim 100$) soluble oil. For finish grinding of metals and alloys low viscosity neat oil is also used.

Application Methods of Cutting Fluids

- Drop-by-drop under gravity
- In the form of liquid jet(s)
- Flooding or Flood Cooling (under gravity)
 - Most common method also called flood as used with coolant-type cutting fluids.
 - ✤ A flood of cutting fluid is applied at the tool—work or tool—chip interface

Mist (atomized oil) with compressed air

- Supplies fluid to inaccessible areas in the form of a high-speed mist using pressurized air stream.
- Provides better visibility of the workpiece being machined
- ✤ It is effective with water-based fluids at air pressures ranging from 70 to 600 kPa.
- Limited cooling capacity.
- ✤ Requires venting to prevent the inhalation of airborne fluid particles by operator

Manual Operation:

- Manual application by means of a paint brush
- Used in tapping and other operations in which cutting speeds are low and friction is a problem.
- Not preferred by most production machine shops because of its variability in application.

Application Methods of Cutting Fluids

High-pressure systems

- These systems use high-pressure refrigerated coolant systems to increase the rate of heat removal from the cutting zone.
- ✤High pressures also are used in delivering the cutting fluid via specially designed nozzles that aim a powerful jet of fluid to the zone, particularly into the clearance or relief face of the tool.
- The pressures employed, which are usually in the range from 5.5 to 35 MPa, act as a chip breaker in situations where the chips produced would otherwise be long and continuous, interfering with the cutting operation.
- ✤In order to avoid damage to the workpiece surface by impact from any particles present in the high-pressure jet, contaminant size in the coolant should not exceed 20 um.
- ✤ Proper and continuous filtering of the fluid also is essential to maintain quality.

Application Methods of Cutting Fluids

Through the cutting tool system

- Narrow passages can be produced in cutting tools, as well as in tool holders, through which cutting fluids can be applied under high pressure.
- $\boldsymbol{\bigstar}$ Two applications of this method are
- $\checkmark\,$ Gun drilling, with a long, small hole through the body of the drill itself
- ✓ Boring bars, where there is a long hole through the shank (tool holder), to which an insert is clamped.
- Delivering cutting fluids through the spindle of the machine tool is also developed.
- Z-Z method centrifugal through the grinding wheels (pores)





Figure 2.13 Application of cutting fluid by hole in the tool

Figure 2.14: Z-Z Method ingrinding

Cutting Fluid Filtration

- Cutting fluids become contaminated over time by various substances like tramp oil (machine oil, hydraulic fluid, etc.), garbage (cigarette butts, food, etc.), small chips, molds, fungi, and bacteria.
- ✤ In addition to causing odors and health hazards, contaminated cutting fluids do not perform their lubricating function as well.
- Alternative ways of dealing with this problem are to:
 replace the cutting fluid at regular and frequent intervals
 use a filtration system to periodically clean the fluid
 Dry machining; that is, machine without cutting fluids.
- Because of growing concern about environmental pollution and associated legislation, disposing old fluids is a major concern.
- Filtration systems are being installed which have advantages of prolonged cutting fluid life between changes, reduced fluid disposal cost, cleaner cutting fluid for better working environment and reduced health hazards, lower machine tool maintenance & longer tool life. Several techniques of filtration are settling, skimming, centrifuging, and filtering.
- Recycling involves treatment of the fluids with various additives, agents, biocides, and deodorizers, as well as water treatment (for water-based fluids).

Dry Machining

- ✤ No cutting fluid is used.
- It has advantages of addressing pollution concern, cost reduction & improving surface quality. Associated problems are overheating the tool, operating at lower cutting speeds and production rates to prolong tool life, and absence of chip removal benefits in grinding and milling.
- ✤ Application of a fine mist of an air-fluid mixture having very small amount of cutting fluid.
- ✤ The mixture is delivered to the cutting zone through the spindle of the machine tool, typically through a 1-mm-diameter nozzle and under a pressure of 600 kPa.
- It is used at rates on the order of 1 to 100 cc/hr, which is estimated to be (at most) one ten-thousandth of that used in flood cooling. Consequently, the process is also known as minimum-quantity lubrication (MQL).
- Viable alternative in various machining operations (especially turning, milling, and gear cutting) on steels, steel alloys, and cast irons, but generally not for aluminum alloys.
- Flushing of chips is achieved by pressurized air, often through the tool shank which doesn't serve a lubrication purpose and provides only limited cooling

Cutting Fluid Maintenance

- Maintenance and monitoring includes concentration checks using the appropriate test, including:
 - Refractometers which are used to determine the total amount of soluble in a solution.
 - Titration Kits which are used to analyze fluid concentration in metal cutting fluids contaminated with tramp oils.
 - Tests for PH levels and alkalinity (acid splits) are also useful.
- The fluid manufacturer's product data sheets should always be consulted and rigidly followed.



Machinability is the ease with which a given material may be worked with a cutting tool. The machinability of a material is usually defined in terms of four factors:

- Surface finish
- Tool life.
- Force and power required.
- The level of difficulty in chip control.

Thus, good machinability indicates good surface finish and surface integrity, a long tool life, low force and power requirements and desired chip control in the cutting zone.

MACHINABILITY

Machinability Index/Rating

Because of the complex nature of cutting operations, it is difficult to establish relationships that quantitatively define the machinability of a particular material. The machinability rating of a material attempts to quantify the machinability of various materials.

$$K_{M} = V_{60} / V_{60R}$$

where V_{60} is the cutting speed for the target material that ensures tool life of 60 min, V_{60R} is the same for the reference material.

- Reference materials are selected for each group of work materials (ferrous and non-ferrous) among the most popular and widely used brands.
- ✓ If KM > 1, the machinability of the target material is better that this of the reference material, and vice versa.
- ✓ Note that this system can be misleading because the index is different for different machining processes.

Machinability Rating Example

The reference material for steels, AISI 1112 steel has an index of 1. Machining of this steel at cutting speed of 0.5 m/s gives tool life of 60 min.

Therefore, $V_{60R} = 0.5$ m/s.

For the austenitic 302 SS steel (tool life of 60 min is reached at 0.23m/s) The machinability index is $K_M = 0.23/0.5 = 0.46$

For AISI 1045 steel (tool life of 60 min is reached at 0.36 m/s). The machinability index is $K_M = 0.36/0.5 = 0.72$.

So, we can rate these steels in a descending order of machinability:

AISI 1112>AISI 1045>302 SS

Note: Tool life cannot be considered as the only criteria for judging machinability as it is dependent on many factors other than cutting velocity. Keeping all such factors and limitations in view, Machinability can be tentatively defined as "ability of being machined" and more reasonably as "ease of machining".

Machinability Factors

The machinability is affected by following variables Aspects

- (a) Work material Aspects
- (b) Cutting tool Aspects
- (c) Process parameters Aspects
- (d) Machining environments Aspects

Work Material Aspects

Following work material properties govern machinability.

- Nature Brittle/Ductile
- Microstructure-Coarse/Fine
- Mechanical strength fracture or yield
- Hardness, hot strength and hot hardness
- Work hardenability
- Thermal conductivity
- Chemical reactivity
- Stickiness / self lubricity.

Work Material Aspects

Nature-Brittle/Ductile

Brittle materials are easy to machine as the chip separation is due to brittle fracture requiring lesser energy of chip formation and further shorter chips causing lesser frictional force and heating at the rake surface Ductile materials like mild steel produce better surface finish but BUE, if formed, may worsen the surface finish. Also cutting forces increase with the increase in yield shear strength, tof the work material

Microstructure – Coarse / Fine

The value of shear strength and hence shear force of a given material depends on its microstructure. Coarse microstructure leads to lesser value of Ts Therefore, Ts can be desirably reduced by either proper heat treatment like annealing of steels or controlled addition of materials like Sulphur (S), lead (Pb), Tellurium etc. leading to free cutting of soft ductile metals and alloys.

Work Material Aspects

Hardness, hot strength and hot hardness and work hardening

Harder materials are obviously more difficult to machine for increased cutting forces and tool damage.

Usually, with the increase in cutting velocity the cutting forces decrease to some extent making machining easier through reduction in s and also chip thickness. s decreases due to softening of the work material at the shear zone due to elevated temperature. Such benefits of increased temperature and cutting velocity are not attained when the work materials are hot strong and hard like Ti and Ni based superalloys and work hardenable like high manganese steel, Ni- hard, Hadfield steel etc.

Stickiness/Self Lubricity

Sticking of the materials (like pure copper, aluminium and their alloys) and formation of BUE at the tool rake surface also hamper machinability by increasing friction, cutting forces, temperature and surface roughness.

Thermal Conductivity

Lower thermal conductivity of the work material affects their machinability by raising the cutting zone temperature and thus reducing tool life.

Cutting Tool Aspects

Tool Materials:

- In machining a given material, the tool life is governed mainly by the tool material which also influences cutting forces and temperature as well as accuracy and finish of the machined surface.
- The composition, microstructure, strength, hardness, toughness, wear resistance, chemical stability and thermal conductivity of the tool material play significant roles on the machinability characteristics though in different degree depending upon the properties of the work material.
- High wear resistance and chemical stability of the cutting tools like coated carbides, ceramics, cubic Boron nitride (cBN) etc. also help in providing better surface integrity of the product by reducing friction, cutting temperature and BUE formation in high speed machining of steels.
- Very soft, sticky and chemically reactive material like pure aluminium attains highest machinability when machined by diamond tools.



Figure : Role of cutting tool material on machinability /Tool life

Process Parameter Aspects

- ✓ Proper selection of the cutting velocity, feed and depth of cut provide better machinability characteristics of a given work – tool pair even without sacrificing productivity or MRR.
- ✓ Amongst the process parameters, depth of cut plays least significant role and is almost invariable.
- ✓ Now increase in cutting velocity in general, reduces tool life but it also reduces cutting forces or specific energy requirement and improves surface finish through favorable chip-tool interaction.
- ✓ Some cutting tools especially ceramic tools perform better and last longer at higher V within limits.
- ✓ Increase in feed raises cutting forces proportionally but reduces specific energy requirement to some extent.
- ✓ Cutting temperature is also less affected by increase in feed than V. But increase in feed unlike V raises surface roughness. Therefore, proper increase in V, even at the expense of feed often can improve machinability quite significantly.

Work Environment Aspects

The basic purpose of employing cutting fluid is to improve machinability characteristics of any work – tool pair through :

- improving tool life by cooling and lubrication
- reducing cutting forces and specific energy consumption
- improving surface integrity by cooling, lubricating and cleaning at the cutting zone

The favorable roles of cutting fluid application depend not only on its proper selection based on the work and tool materials and the type of the machining process but also on its rate of flow, direction and location of application.

Possible ways of Improving Machinability

- ✓ The machinability of the work materials can be more or less improved, without sacrificing productivity, by the following ways:
- ✓ Favorable change in composition, microstructure and mechanical properties by mixing suitable type and amount of additive(s) in the work material and appropriate heat treatment
- ✓ Proper selection and use of cutting tool material and geometry depending upon the work material and the significant machinability criteria under consideration
- ✓ Optimum selection of cutting velocity, feed and depth of cut based on the tool work materials and the primary objectives.
- ✓ Proper selection and appropriate method of application of cutting fluid depending upon the tool – work materials, desired levels of productivity i.e., VC and f and also on the primary objectives of the machining work undertaken.
 - ✓ Proper selection and application of special techniques like dynamic machining, hot machining, cryogenic machining etc, if feasible, economically viable and eco-friendly.



Assumptions :-1. No contact at the blank (sharp) 2. Width of w/p and chip remains contant 3. Uniform cutting velocity, Vc= constant 4. Chip produced = Continuous chip. 5. Volumetric changes of material during machining is zero. Before cut = After cut. tibli = tabla tibVe= tabVf. $Y = \frac{L_1}{L_1} = \frac{L_2}{V_1} = \frac{V_4}{V_2}$

ti= uncut chip thickness tg = chip thickness r = chip cutting ratio $Y = \frac{b_1}{b_2} < 1 \cdot [:: t_1 < t_2]$ k= chip reduction = 1/r coefficient 8 = rake angle. Vc = cutting velocity Vs = shear velocity V1 = velocity of chip \$ = Shear angk.

$$S_{r}^{P} = \frac{t_{2}}{t_{1}} \int_{A} \frac{t_{2}}{q_{0} q_{0}} \int_{A} \frac{t_{2}}{dt} \int_{A} \frac{t_{2$$

$$t_{1} = AB \sin \phi$$

$$t_{2} = AB \cos(\phi - \psi)$$

$$r = \frac{t_{1}}{t_{2}} = \frac{AB \sin \phi}{AB \cos(\phi - \psi)}$$

$$r = \frac{\sin \phi}{\cos(\phi - \psi)}$$

$$r = \frac{\sin \phi}{\cos\phi \cdot \cos\psi + \sin\phi \cdot \sin\psi}$$

$$r = \frac{(\sin \phi) (\cos \phi)}{(\cos \phi \cos\psi + \sin\phi \cdot \sin\psi)} + \frac{Mr}{Dr} by \cos\phi$$

$$r = \frac{ban \phi}{(\cos \phi \cos\psi + \sin\phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(\cos \psi + \sin\phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(\cos \psi + ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(\cos \psi + ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(\cos \psi + ban \phi \cdot \sin\psi)}$$

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$$r = \frac{ban \phi}{(\cos \psi + ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(\cos \psi + ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(ban \phi - r \cdot ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(ban \phi - r \cdot ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(ban \phi - r \cdot ban \phi \cdot \sin\psi)}$$

$$r = \frac{ban \phi}{(ban \phi - r \cdot ban \phi \cdot \sin\psi)}$$

S



For example:
Griven:
$$y = 10$$

 $p = 30$
 V_{6} = 30
 V_{6} = V_{5}
 V_{c}
 V_{c}

T

By sine law, w.k.t, the length of the side of the triangle is proportional to sine of the angle opposite to it.

 $\frac{V_c}{\sin\left[q_0^\circ - (\phi - v)\right]} = \frac{V_s}{\sin\left(q_0^\circ - v\right)} = \frac{V_b}{(\sin\phi)}$ $\frac{V_c}{(\cos\phi - v)} = \frac{V_s}{\cos v} = \frac{V_b}{\sin\phi}$

From Fig (1)+(4.) Forces involved in Metal Cutting Operation. 8= rake angle According to Phythogans Merchant Circle [M.C] Fo= Frictional force = MI theorem. Fc $R = \int F_c^2 + F_E^2$ From big(a)N = Normal component Ray (1)Ft= N.N $tanc = \frac{opp}{adj} = \frac{F_{L}}{F_{c}}$ 554 M= coefficient of N Fy briction. Ft Again from drg. () B= angle of brichion. Fig(4) Fs = Force acting on From Fig (4) Fig() shear plane. Fs ∞ + 90 - B+Y= 90° FSN= Force acting In $\infty = 90^\circ - 90^\circ + B + V$ to shear plane En x x $x + y = P(\overline{y})$ \$ = Angle made by (or) 1-Formulasi R Fig(2)Fig. (3) Shear angle. 1. Cutting = Fc. Vc. energy = Fc. Vc. From Fig (3) + (1) Fc = cutting force (or) Vertical force. 2. Energy for = Ft. Vt. braction Using Pythogaras theorem. Ft = thrust force (or) horizantal 3. 7. Power lost Fb.Vt In Unichion Fr.Ve Fr.Ve $R = \int F_{s}^{2} + F_{sN}^{2}$ borce. R = resultant force [dia of M.C] $\tan(\sec\phi) = \frac{F_{SN}}{F_{S}}$ Merchant . 4. Machining Const:x= angle made by R' Cm= 28+ B-8. w.r.t $F_c \neq F_t$



Shear borce acting parallel to shear plane can be given by. $T = \frac{F_s}{A_{s,i}}$, $A_s = Shear area$ Shear strain;- $= \cot \phi + \tan(\phi - y) \rightarrow 0$ shear strain Ratio. = Vs Vs = velocity of shear mbs ts = primary shear thickness Minimum value of shear Strain when rake angle 2=0 For 2=0. Shear = cot \$ + lan\$ For minimum value of shear strain we need to differentiate w.r. E \$. and equate to zero.

$$\frac{d}{d\phi} = \frac{(cot\phi + bond) = 0}{cosec^{\phi} + sec^{\phi} = 0}$$

$$-\frac{1}{sin^{2}\phi} + \frac{1}{cos^{2}\phi} = 0$$

$$\frac{1+cos2\phi}{2} - \frac{(1-(os2\phi))}{2} = 0$$

$$\frac{2\phi}{2} = 0$$

$$\frac{2\phi}{b} = 90^{0}$$

Important Formulas: For orthogonal cutting: Depth of cut = Uncut chip't' = Feed x sin r r = 90°-Cs Width of cut = <u>D.O.C</u> sin r 3 Fb = Fc sin Pt Fc cosr

- (N= Fccost Ftsing
- 6 Fs= Fccos &- Fising
- 6 FSN = Fcsind + Fzcosp

In an orthogonal cutting test, the following observations were made (7) Cutting Force = 1200N; Thrust Force = 500N, Tool Rake Angle = 0, Cutting Speed = Im/s Depth of cut = 0-8mm, Chip thickness = 1.5 mm. Friction angle during m/c (a) 22.6 (b) 32.6 (c) 57.1 (d) 67.4 Chip speed along tool rake face will be (a) 0.83m/s (b) 0.58m/s (c) 1.2m/s d) 1.83m/s



w-k.t, $\tan \Theta = \frac{F_T}{F_c} = \frac{F_{\ell}}{N}$ $\tan \Theta = \frac{500}{1200}$ $\Theta = 22.6).$

Volume remains const $t_1 = V_c = t_2 = V_f$ $0 - 8 \times 1 = 1.5 \times V_f$ $V_f = 1.88 \text{ m/s}$
The following are date related to orthogonal turning process:
Back rake angle: 15°, Width of cut:
$$amm$$
, Chip thickness: 0.4 mm,
Feed rate : 0.2 mm/rv.
If the cutting Force is 900N to Thrust force is 810N, what will be the
the mean shear strength in MPa, and what will be shear angle.
 $y=15^{\circ}$
 $b: 2 mm$
 $t_{1}: b= 0.5$
 $t_{2}: TC = 900^{N}$, $F_{7}: 810N$
 $R = \sqrt{F_{2}^{2} + F_{1}^{2}}$
 $R = \sqrt{F_{2}^{2} + F_{1}^{2}}$
 $R = \sqrt{F_{2}^{2} + F_{1}^{2}}$
 $R = \sqrt{900^{2} + 810^{2}}$
 $R = \sqrt{900^{2} + 810^{2}}$

In orthogonal cutting test, the cutting force: 900N, The thrust force = 600 N and chip shear angle is 30°. Calulate the chip force.

9

Fz= 900 F7=600 $R = \int 900^{2} + 600^{2}$ R= 1081-6N $\tan \Theta = \frac{F_T}{F_c} = \frac{600}{900}$ 0-33.69°

0

F34 0-33.60 0+ = 30°+33.69 = 63.69. $\cos(63.69) = \frac{F_s}{R}$ $\cos 63.69^\circ = \frac{F_s}{F_s}$ 1081.6 FS = 479.4 N

The merchant: constant for aluminium for the following orthog. M/c
Rake angle of tool: 35°, cutting force = 200N, Thrust force: 90N,
Uncut chip thickness: 0.15mm, chip thickness: 0.3mm, width d ut:
2.5mm, cutting speed = 30m/min. Calulate Merchant constant

$$V: 35°$$

 $F_c = 300N$
 $F_T = 900N$
 $F_T = 900N$
 $F_T = 900N$
 $F_T = 0.15mm$
 $V: 30m/min$
Soln.
 $Y = \frac{F_1}{F_2} = 0.5$
 $T_{F_2} = \frac{1}{2} \frac{1}{$

UNIT II TURNING MACHINES

Centre lathe, constructional features, specification, operations – taper turning methods, thread cutting methods, special attachments, machining time and power estimation. Capstan and turret lathes- tool layout – automatic lathes: semi-automatic – single spindle: Swiss type, automatic screw type – multi spindle.

CENTRE LATHE

- > The Centre Lathe is used to manufacture cylindrical shapes from a range of materials including; steels and plastics.
- > Many of the components that go together to make an engine work have been manufactured using lathes.
- These may be lathes operated directly by people (manual lathes) or computer controlled lathes (CNC machines) that have been programmed to carry out a particular task.
- This type of lathe is controlled by a person turning the various handles on the top slide and cross slide in order to make a product / part.
- > The headstock of a centre lathe can be opened, revealing an arrangement of gears.
- > These gears are sometimes replaced to alter the speed of rotation of the chuck.
- The lathe must be switched off before opening, although the motor should automatically cut off if the door is opened while the machine is running (a safety feature).
- \succ The speed of rotation of the chuck is usually set by using the gear levers.
- \succ These are usually on top of the headstock or along the front and allow for a wide range of speeds.









<u>https://www.youtube.com/watch?v=Ee7MSSPG4hk&ab_chann</u> <u>el=CNCprogrammer</u> – automation of lathe

BED:

- The bed supports all major components of the lathe.
- Beds have a large mass and are built rigidly, usually from gray or nodular cast iron.
- The top portion of the bed has two ways with various cross sections that are hardened and machined for wear resistance and dimensional accuracy during turning.
- In gap-hed lathes, a section of the bed in front of the headstock can be removed to accommodate larger diameter workpieces.





CARRIAGE:

- The carriage, or carriage assembly, slides along the ways and consists of an assembly of the crossslide, tool post, and apron.
- The cutting tool is mounted on the tool post, usually with a compound rest that swivels for tool positioning and adjustment.
- The cross-slide moves radially in and out, controlling the radial position of the cutting tool in operations such as facing.
- The apron is equipped with mechanisms for both manual and mechanized movement of the carriage and the cross-slide by means of the lead screw.



HEADSTOCK:

- The headstock is fixed to the bed and is equipped with motors, pulleys, and V-belts that supply power to a spindle at various rotational speeds.
- The speeds can be set through manually controlled selectors or by electrical controls.
- Most headstocks are equipped with a set of gears, and some have various drives to provide a continuously variable range of speed to the spindle.
- Headstocks have a hollow spindle to which work-holding devices are mounted and long bars or tubing can be fed through them for various turning operations.
- The accuracy of the spindle is important for precision in turning, particularly in high-speed machining; preloaded tapered or ball bearings typically are used to rigidly support the spindle.



TAILSTOCK:

- The tailstock, which can slide along the ways and be clamped at any position, supports the other end of the workpiece.
- It is equipped with a center that may be fixed (dead center), or it may be free to rotate with the workpiece (live center).
- Drills and reamers can be mounted on the tailstock quill
 (a hollow cylindrical part with a tapered hole) to drill
 axial holes in the workpiece.





FEED ROD AND LEAD SCREW:

- The feed rod is powered by a set of gears through the headstock.
- The rod rotates during the lathe operation and provides movement to the carriage and the crossslide by means of gears, a friction clutch, and a keyway along the length of the rod.
- Closing a split nut around the lead screw engages it with the carriage; the split nut is also used for cutting threads accurately.



LATHE SPECIFICATIONS

LATHE SPECIFICATIONS:

A lathe generally is specified by the following parameters:

° Its swing, the maximum diameter of the workpiece that can be machined.

° The maximum distance between the headstock and tailstock centers.

° The length of the bed.

Swing indicates the maximum diameter workpiece you can turn on a lathe. Measure from the top of the bed to the center of the spindle and then double that value. Similarly, the bed measurement is the maximum length of the workpiece that you can turn.

A lathe may have the following size: 360-mm swing by 760 mm between centers by 1830-mm length of bed. Lathes are available in a variety of styles and types of construction and power. Maximum workpiece diameters may be as much as 2 m.



- ➢ Work holding devices are important, particularly in machine tools and machining operations, as they must hold the workpiece securely.
- ➤ As shown in Figure one end of the workpiece is clamped to the spindle of the lathe by a chuck, collet, face plate or mandrel.



(a) and (b) Schematic illustrations of a draw-in type of collet. The workpiece is placed in the collet hole, and the conical surfaces of the collet are forced inward by pulling it with a draw bar into the sleeve.
 (c) A push-out type of collet.
 (d) Work holding of a workpiece on a face plate.

- > A **chuck** usually is equipped with three or four jaws.
- Three-jaw chucks generally have a geared-scroll design that makes the jaws self-centering.
- They are used for round workpieces (such as bar stock, pipes, and tubing), which can be centered to within 0.025 mm.
- Four-jaw (independent) chucks have jaws that can be moved and adjusted independently of each other.
- Thus, they can be used for square, rectangular, or oddshaped workpieces.
- Because they are constructed more ruggedly than three jaw chucks, four-jaw chucks are used for heavy workpieces or for work requiring multiple chuckings where concentricity is important.





- ➤ The jaws in some types of chucks can be reversed to permit clamping of hollow workpieces, such as pipes and tubing, either on the outside surfaces or on the inside surfaces.
- > Also available are jaws made of low-carbon steel (soft jaws) that can be machined into desired shapes.
- Because of their low strength and hardness, soft jaws conform to small irregularities on workpieces and therefore result in better clamping.
- > Chucks can be power or manually actuated with a chuck wrench.
- ➤ The manually actuated chucks consume more amount of time therefore they are only used for limited applications.

- Power chucks, actuated pneumatically or hydraulically, are used in automated equipment for high production rates, including the loading of parts using industrial robots.
- Also available are several types of power chucks with lever- or wedge-type mechanisms to actuate the jaws; these chucks have jaw movements (stroke) that usually are limited to about 13 mm.
- Chucks are available in various designs and sizes.
- Their selection depends on the type and speed of operation, workpiece size, production and dimensional accuracy requirements, and the jaw forces required.
- By controlling the magnitude of the jaw forces, an operator can ensure that the part does not slip in the chuck during machining.
- High spindle speeds can reduce jaw (clamping) forces significantly due to the effect of centrifugal forces; this effect is particularly important in precision tube turning. Modern jaw-actuating mechanisms permit a higher clamping force for roughing, and lower force for finishing, operations.

- > A collet is basically a longitudinally-split, tapered bushing.
- The workpiece (generally with a maximum diameter of 25 mm is placed inside the collet, and the collet is pulled or pushed mechanically into the spindle.
- The tapered surfaces shrink the segments of the collet radially, tightening onto the workpiece.
- Collets are used for round workpieces as well as for other shapes (e.g., square or hexagonal workpieces) and are available in a wide range of sizes.
- One advantage to using a collet (rather than a three- or four-jaw chuck) is that the collet grips nearly the entire circumference of the part, making the device well suited particularly for parts with small cross sections.
- Because the radial movement of the collet segments is small, workpieces generally should be within 0.125 mm of the nominal size of the collet.



- Face plates are used for clamping irregularly shaped workpieces.
- The plates are round and have several slots and holes through which the workpiece is bolted or clamped.
- Mandrels are placed inside hollow or tubular workpieces and are used to hold workpieces that require machining on both ends or on their cylindrical surfaces.
- Some mandrels are mounted between centers on the lathe.

https://www.youtube.com/watch?v=FT3lhnIffV4&ab_cha nnel=ChrisMaj – lathe mandrel











https://engineeringlearn.com

ACCESSORIES:

Several devices are available as accessories and attachments for lathes. Among these devices are the following:

- Carriage and cross-slide stops, with various designs to stop the carriage at a predetermined distance along the bed.
- > Devices for turning parts with various tapers.
- > Milling, sawing, gear-cutting, and grinding attachments.
- > Various attachments for boring, drilling, and thread cutting.

Taper Turning:

- Taper turning means to produce a conical surface by gradual reduction in diameter from a cylindrical workpiece.
- > The tapering of a part has wide applications in the construction of machines.
- Almost all machine spindles have taper holes which receive taper shanks of various tools and work holding devices.
- > Taper turning can be carried out on lathes by the following methods :
 - ✤ By setting over the tailstock centre.
 - ✤ By swiveling the compound rest.
 - ✤ By using a taper turning attachment.
 - ✤ By manipulating the transverse and longitudinal feeds of the slide tool simultaneously.
 - Sy using a broad nose form tool.

CUTTING OPERATIONS

- (a) Straight turning \downarrow Depth of cut feed, $f \leftarrow$ Tool
- (d) Turning and external grooving



(g) Cutting with a form tool



(j) Cutting off



(b) Taper turning



(e) Facing



(h) Boring and internal grooving



(k) Threading



(c) Profiling



(f) Face grooving



(i) Drilling



(l) Knurling



Figure 1 Various cutting operations that can be performed on a late. Not that all parts have circular symmetry.

OPERATIONS IN A LATHE

Turning: to produce straight, conical, curved, or grooved workpieces such as shafts, spindles, and pins as shown in (Figs. 23.la through d).

Facing: to produce a flat surface at the end of the part and perpendicular to its axis (Fig. 23.1e), useful for parts that are assembled with other components.

Face grooving produces grooves for applications such as O-ring seats (Fig. 23.1f). **Cutting with form tools**: (Fig. 23.1g) to produce various axisymmetric shapes for functional or aesthetic purposes.

Boring: to enlarge a hole or cylindrical cavity made by a previous process or to produce circular internal grooves (Fig. 23.1h).

Drilling: to produce a hole (Fig. 23.1i), which may be followed by boring to improve its dimensional accuracy and surface finish.

Parting: also called cutting off, to cut a piece from the end of a part, as is done in the production of slugs or blanks for additional processing into discrete products (Fig. 23.1j).

Threading: to produce external or internal threads (Fig. 23.1k).

Knurling: to produce a regularly shaped roughness on cylindrical surfaces, as in making knobs and handles (Fig. 23.11).

Table 1 General characteristics of machining processes and typicaldimensional tolerances

General Characteristics of Machining Processes and Typical Dimensional Tolerances

		Typical dimensional
Process	Characteristics	tolerances, $\pm mm$
Turning	Turning and facing operations on all types of materials, uses	Fine: 0.025–0.13
	single-point or form tools; engine lathes require skilled labor; low	Rough: 0.13
	production rate (but medium-to-high rate with turret lathes and	
	automatic machines) requiring less skilled labor	
Boring	Internal surfaces or profiles with characteristics similar to turning;	0.025
	stiffness of boring bar important to avoid chatter	
Drilling	Round holes of various sizes and depths; high production rate; labor	0.075
	skill required depends on hole location and accuracy specified; requires	
	boring and reaming for improved accuracy	
Milling	Wide variety of shapes involving contours, flat surfaces, and slots;	0.013-0.025
	versatile; low-to-medium production rate; requires skilled labor	
Planing	Large flat surfaces and straight contour profiles on long workpieces,	0.08-0.13
	low-quantity production, labor skill required depends on part shape	
Shaping	Flat surfaces and straight contour profiles on relatively small workpieces;	0.05-0.08
	low-quantity production; labor skill required depends on part shape	
Broaching	External and internal surfaces, slots, and contours; good surface finish;	0.025-0.15
	costly tooling; high production rate; labor skill required depends on	
	part shape	
Sawing	Straight and contour cuts on flat or structural shapes; not suitable for	0.8
	hard materials unless saw has carbide teeth or is coated with diamond;	
	low production rate; generally low labor skill	

Taper Turning - By setting over the tailstock

centre :

- This method is used for small tapers only (the amount of setover being limited).
- It is based upon the principle of shifting the axis of rotation of the workpiece, at an angle to the axis, and feeding the tool parallel to the lathe axis.
- The angle at which the axis of rotation of the workpiece is shifted is equal to half angle of taper.
- This is done when the body of the tailstock is made to slide on its base towards or away from the operator by a setover screw as shown in the given Figure.



Taper Turning - By setting over the tailstock centre :

- By setting tailstock centre to the back (away from the operator) the taper will have bigger diameter towards the tailstock.
- If the tailstock centre is taken in the front, bigger diameter will be on the headstock side.
- ➤ The reduction in diameter will be twice the offset of tailstock centre if entire length is turned.
- The major disadvantage of this method is that the live and dead centres are no equally stressed and the wear is non-uniform.
- Also, the lathe carrier being set at an angle, the angular velocity of the work is not constant.
- It is useful for turning very long tapers up to about 5°.
 This method should be avoided if possible.



Taper Turning - By swivelling the compound rest :

- ➢ It is the best method as it does not affect the centering of the job or centres.
- ➢ In this method of taper turning the workpiece is rotated on the lathe axis and the tool is fed at an angle to the axis of rotation of the workpiece.
- ➤ The tool mounted on the compound rest is attached to the circular base, graduated in degrees, which maybe swivelled and clamped at any desired angle as shown in Figure.
- After the compound rest is set at the desired half taper angle, rotation of the compound slide screw will cause the tool to be fed at that angle and generate a corresponding taper.



Taper Turning - By swiveling the compound rest :

- The setting of compound rest is done by swiveling the rest at the half taper angle, if this is already known.
- Owing to the limited movement of the cross-slide, this method is limited to turn a short taper ; a small taper may also be turned.
- Short lengths of tapers not exceeding 45° included angle are usually turned by this method.
- This method gives a low production capacity and poor surface finish because the movement of the tool is completely controlled by hand.
- > This method is tiring if the traverse is lengthy.



Taper Turning - By using a taper turning attachment:

- > This method provides a very wide range of taper.
- In this method of taper turning a tool is guided in a straight path set at an angle to the axis of rotation of the workpiece, while the work is being revolved between centres or by a chuck aligned to the lathe axis.
- As shown in Figure, a taper turning attachment essentially consists of a bracket or frame which is attached to the rear end of the lathe bed and supports a guide bar pivoted at the centre.
- The bar is provided with graduations and may be swivelled on either side of the zero graduation and is set at the desired angle with the lathe axis.



Taper Turning - By using a taper turning attachment:

The taper turning attachment is used as follows :

- The cross-slide is first made free of the lead screw by removing the binder screw.
- The rear end of the cross-slide is then tightened with the guide block by means of a bolt.
- On the engagement of the longitudinal feed, the tool mounted on the cross-slide will follow the angular path, as the guide block slides on the guide bar set at an angle to the both axes. The required depth of cut is given by the compound slide which is placed at right angles to the axis of the lathe.
- The guide bar must be set at half taper angle and the taper on the work must be converted in degrees.



THREAD CUTTING METHODS

Cutting screws is another of the most important tasks carried out in lathes. A typical thread form is shown in the figure. There are a large number of thread forms that can be machined in lathe such as Whitworth, ACME, ISO Metric, etc.



Figure Simple form a thread

Taper Turning - By manipulating the transverse and longitudinal feeds of the slide tool simultaneously :

- Taper turning by manipulation of both feeds is inaccurate and requires skill on the part of the operator.
- \succ It is used for *sharp tapers only*.

Taper Turning - By using a broad nose form tool:

- In this method of taper turning Figure a broad nose tool having straight cutting edge is set on to the work at half taper angle and is fed straight into the work to generate a tapered surface.
- > With this method, tapers of short length only can be turned.



- One of the most basic machining processes is turning, meaning that the part is rotated while it is being machined.
- The starting material is generally a workpiece that has been made by other processes, such as casting, forging, extrusion, drawing, or powder metallurgy.
- Turning processes, which typically are carried out on a lathe or by similar mac/vine tools, are outlined in Fig. 1 and Table 1.
- These machines are highly versatile and capable of a number of machining processes that produce a wide variety of shapes.



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THREAD CUTTING METHODS

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- > A typical thread form is shown in the given Figure.
- ➤ There are a large number of thread forms that can be machined in lathe such as Whitworth, ACME, ISO Metric, etc.



Nomenclature of a simple thread
- Thread cutting can be considered as another form of turning since the path to be travelled by the cutting tool is helical.
- > However, there are some major differences between turning and thread cutting.
- > Where as in turning the interest is in generating a smooth cylindrical surface, in thread cutting the interest is in cutting a helical thread of a given form and depth which can be calculated from the formulae for different forms of threads as given in Table mentioned in the following slides.
- \succ The shape of the cutting tool is of the same form as the thread to be generated.

Thread Form	Formulae for Calculating the Parameters	
British Standard Whitworth (BSW)	Depth = $0.6403 \times \text{Pitch}$ Angle = 55° in the plane of the axis Radius at the crest and root = $0.137329 \times \text{Pitch}$	
British Association (BA)	Depth = $0.6 \times \text{Pitch}$ Angle = 47.5° in the plane of the axis Radius at the crest and root = $\frac{2 \times \text{Pitch}}{11}$	
International Standards Organisation (ISO) metric thread	Max. Depth = $0.7035 \times Pitch$ Min. Depth = $0.6855 \times Pitch$ Angle = 60° in the plane of the axis Root radius Maximum = $0.0633 \times Pitch$ Minimum = $0.054 \times Pitch$	
American Standard ACME	Height of thread = $0.5 \times \text{Pitch} + 0.254 \text{ mm}$ Angle = 29° in the plane of the axis Width at tip = $0.3707 \times \text{Pitch}$ Width at root = $0.3707 \times \text{Pitch} - 0.132 \text{ mm}$	

- For the purpose of feeding the tool for generating the thread, the feed is given by the lead screw.
 Feed
 - same as the lead of the pitch to be generated. In normal turning the thickness of the uncut chip is
 - same as the feed rate chosen, whereas in the thread cutting case it is controlled by the depth of

cut, d, in view of the thread form being generated as shown in the given Figure.

> The uncut chip thickness, Tu, can be shown to be

 $Tu = 2 x d x tan\alpha$

> The depth of cut in the case of thread cutting can be given in two ways: plunge cutting as shown in

or compound cutting as in f





(b) Plunge cutting

- In the case of plunge cutting, the cutting of the thread takes place along both the flanks of the tool.
- This would mean that the cutting tool would have to be provided with a zero or negative rake angle. In addition the relief along the cutting edges cannot be provided in view of the form to be achieved. Cutting is also taking place along a longer length of the tool. This gives rise to difficulties in machining in terms of higher cutting forces and consequently chattering (violent vibrations).
- > This results in poor surface finish and lower tool life, thus this method is not generally preferred.

Compound cutting:

With the compound feeding, the tool needs to

be moved in both the directions (along the

bed as well as a direction perpendicular to it)

simultaneously to position the tool tip along

one flank of the thread.

This configuration helps in smoother flow of

chips as the cutting takes place only along one cutting edge.

This method therefore is much preferred compared to the earlier method.



Compound cutting:

- The compound slide is rotated by the half angle of the thread, and the cutting tool is adjusted to make it perpendicular to the work piece surface.
- For this purpose a thread setting gauge which contains the required form of the thread being cut is kept perpendicular to the surface of the work piece, and the tool tip is set as shown in Figure.



- The next important consideration for thread cutting is the feeding of the tool along the helical path.
- ➢ For this purpose, the lead screw is normally employed for feeding the tool along the length of the job.
- In turning the engaging of tool at any point would be of no consequence since the surface to be generated is cylindrical.
- However in thread cutting it is essential that the tool tip should always follow the same thread profile generated in the first cut, otherwise no thread would be generated.

- ➢ One of the methods that can be followed in this case is to reverse the spindle while retaining the engagement between the tool and the work piece.
- The spindle reversal would bring the cutting tool to the starting point of the thread following the same path in reverse.
- ➢ After giving a further depth of cut the spindle is again reversed and the thread cutting is continued in the normal way.
- This is easy to work and is somewhat more time consuming due to the idle times involved in the stopping and reversing of the spindle at the end of each stroke.

CHASING DIAL PRINCIPLE:

Another alternative method is to use a chasing

dial to help in following the thread.

As shown in Figure the chasing dial consists

of a worm gear located inside the carriage in mesh with the lead screw.

A vertical shaft connected with the worm gear has a dial with separate markings to indicate equal divisions of the circumference.



CHASING DIAL PRINCIPLE:

Since the worm gear is in continuous contact with the lead screw, which is in continuous engagement with the spindle, markings on its surface indicate the precise position of the thread being cut on the work piece.

Thus it is possible to engage with the work piece at any desired location.



THREAD CUTTING ON A TAPER:



Limitations of a Centre Lathe

- > The setting time for the job in terms of holding the job is large.
- Only one tool can be used in the normal course. Sometimes the conventional tool post can be replaced by a square tool post with four tools.
- > The idle times involved in the setting and movement of tools between the cuts is large.
- Precise movement of the tools to destined places is difficult to achieve, unless proper care is exercised by the operator.

All these difficulties mean that the centre lathe cannot be used for production work in view of the low production rate. Thus the centre lathe is modified to improve the production rate. The various modified lathes are:

- Turret and capstan lathes
- ➤ semi-automatics
- ➤ Automatics

Limitations of a Centre Lathe

The improvements are achieved basically in the following areas:

- work holding methods
- multiple tool availability
- ➤ automatic feeding of the tools
- > automatic stopping of tools at precise locations
- > automatic control of the proper sequence of operations

- The main characteristic feature of the capstan and turret lathes is the six sided (hexagonal) block mounted on one end of the bed replacing the normal tailstock as shown in Figure.
- This allows for mounting six tool blocks each of which can contain one or more tools depending upon the requirement. Further on the cross slide, two tool posts are mounted, one in the front and the other in the rear.
- Each one of them can hold up to four tools each.
- Thus the total carrying capacity is a maximum of 14 tools when only one tool is mounted in each of the locations.



- ➤ As shown in Figure the turret lathe consists of an all gear, heavy duty headstock with a greater range of spindle speeds.
- \succ The turret is mounted on a saddle, which in turn is sliding on the bed.
- When the saddle moves on the bed during the return stroke it would automatically be indexed to the next tool position, thus reducing the idle time of the machine.
- The tools in the turret lathe are provided with a system of stops and trips on the feed rod which can precisely control the actual distance moved by the tool.
- Thus it is possible to set and control the individual movements of the tools as required by the component.

- The type of work holding devices that can be used with turret lathes is similar to the conventional lathes, but in view of the higher productivity demanded and greater repeatability required, generally automatic fixtures such as collets, self centering chucks or pneumatic chucks are used.
- ➤ The collet chucks come in a variety of designs as shown in Figure. The actual clamping is done by the movement of the collet tube along the axis of the spindle by either pushing or pulling Fig. .
- Sometimes it is possible that the bar material will be either pushed or pulled back during the closing of the collet. This can be prevented by having an external tubular locking stop so that the axial movement is prevented.

Many turret lathes would be fitted with taper turning attachment very similar to that used in centre lathes, for machining tapers. Small tapers can be produced by form tools from the cross slide, while internal tapers are produced by taper reamers.

Thus the various differences between capstan and turret lathes, and a general purpose centre lathe are:

- 1. Headstock has more range of speeds and is heavier to allow for higher rate of production.
- 2. Tool post is indexable (four tools). Any one tool can be brought into cutting position.
- 3. Tail stock is replaced by a tool turret with six tool positions.
- 4. Feed of each tool can be regulated by means of feed stops.
- 5. Two or more tools mounted on a single tool face can cut simultaneously.
- 6. Semi-skilled operators are required.
- 7. Used for production operations involving better repeatability.

TO BE PLAYED IN CLASS

https://www.youtube.com/watch?v=KKIrh4Nmn4o&ab_channel=LiveFree_-

video link for reversilble jaw chucks

https://www.youtube.com/watch?v=4lagsONbeYc&ab_channel=AniMech -

Types of chucks

https://www.youtube.com/watch?v=6gLk62xIdNo&ab_channel=AutomateCNC Power chucks

https://www.youtube.com/watch?v=FT3IhnIffV4&ab_channel=ChrisMaj -

lathe mandrel

https://www.youtube.com/watch?v=VDwbQWCprTk&ab_channel=AniMech -

Taper turning methods

https://www.google.com/search?q=setover+in+lathe&rlz=1C1CHZN_enIN932IN9

32&source=lnms&sa=X&ved=2ahUKEwjW_eyqrrX2AhWUSmwGHXPHCpoQ_AUo

<u>AHoECAEQAg#kpvalbx= N7EmYoibArOZseMPqPyKoAM12</u> –

Tailstock setover method

https://www.youtube.com/watch?v=PItK-rbaKLI&ab_channel=MECH4mechs -

Taper turning attachment method

UNIT 4.0

ABRASIVE PROCESSES



Overview

- Abrasive processes: grinding wheel specifications and selection
- Types of grinding process: cylindrical grinding, surface grinding, centreless grinding, internal grinding
- Micro finishing methods
- Typical applications
- Concepts of surface integrity

Introduction to Grinding

- Most common form of abrasive machining.
- Process of removing material by abrasive action of a revolving wheel on the surface of a work-piece in order to bring it to required shape and size
- Cutting by abrasive tool whose cutting elements are grains of abrasive material known as grit.
- Grits have sharp cutting points, high hot hardness, and chemical stability and wear resistance.
- The grits are held together by a suitable bonding material to give shape of an abrasive tool.
- Abrasive machining is advanced version of conventional grinding with better performance



Cutting action of abrasive grains

Grinding Process



The types of workpieces and operations: typical grinding: (a) cylindrical surfaces, (b) conical surfaces. (c) fillets on a shaft, (d) helical profiles, (e) concave shape, (f) cutting off or slotting with thin wheels, and (g) internal grinding

Grinding Wheel

- Consists of abrasive particles and bonding material. The bonding material holds the particles in place and establishes the shape and structure of the wheel. These two ingredients and the way they are fabricated determine the five basic parameters of a grinding wheel:
 - Abrasive material
 - Grain size
 - Bonding material
 - Wheel structure
 - Wheel grade
- To achieve the desired performance in a given application, each of the parameters must be carefully selected.

Abrasive Material

- Abrasives are extreme hard, sharp edged, irregular shaped particles used to shape other materials by a grinding or abrading action in the form of tiny chips.
- Used as loose grains as in grinding wheels, or as coatings on cloth or paper or forming into ceramic cutting tools for machining.
- Because of their superior hardness and refractory properties, they have advantages in speed of operation, depth of cut, and smoothness of finish.
- Abrasives also are used to hone, lap, buff, and polish workpieces.
- By computer-controlled machines a wide variety of workpiece geometries with very fine dimensional accuracy and surface finishes can be achieved. Dimensional tolerances can be less than 1µm, and surface roughness can be as fine as 0.025 /µm.
- Used for cleaning and machining all types of metal, for grinding and polishing glass, for grinding logs to paper pulp, for cutting metals, glass, and cement, removing unwanted weld beads and spatter, cleaning surfaces with jets of air or water containing abrasive particles and for manufacturing many miscellaneous products such as brake linings and nonslip floor tile.

Abrasive Material

 General properties of an abrasive material used in grinding wheels include high hardness, wear resistance, toughness (common properties of any cutting tool) and friability.

Friability

- Refers to the capacity of the abrasive material to fracture when the cutting edge of the grain becomes dull, thereby exposing a new sharp edge.
- High friability indicates low strength or low fracture resistance of the abrasive. Aluminum oxide has lower friability than silicon carbide and, correspondingly, a lower tendency to fragment.
- Blocky grains (which are analogous to a negative rake angle in single-point cutting tools are less friable than less blocky or plate-like grains.
- Probability of defects diminishes as the grain size becomes smaller (due to the size effect), smaller grains are stronger and less friable than larger ones.

Abrasive Material

Ranges of Knoop Hardness for Various Materials and Abrasives			
Common glass	350-500	Titanium nitride	2000
Flint, quartz	800-1100	Titanium carbide	1800-3200
Zirconium oxide	1000	Silicon carbide	2100-3000
Hardened steels	700-1300	Boron carbide	2800
Tungsten carbide	1800-2400	Cubic boron nitride	4000-5000
Aluminum oxide	2000-3000	Diamond	7000-8000

The Knoop hardness test is an alternative to the Vickers hardness test in the micro hardness testing range, and it can be performed on the same universal or micro hardness testing machine. It is mainly used to overcome cracking in brittle materials, as well as to facilitate the hardness testing of thin layers.

As in the Vickers hardness test, the indenter used in the Knoop hardness test is a pyramidal diamond. However, instead of being symmetrical, the pyramid is elongated. Knoop Hardness (HK) is ascertained by measuring optically along the long diagonal of the indent.

Natural Abrasive

- The common natural abrasives are sand stone, emery (50-60% crystalline Al₂O₃ + iron oxide) corundum (75-90% crystalline aluminium oxide + iron oxide), and diamond.
- ✤ The sand stone is used only for sharpening some wood-working tool.
- Diamond is used for dressing the grinding wheel and acts as an abrasive material for hard material.
- Other natural abrasives are garnet, an aluminosilicate mineral; feldspar, used in household cleansers; calcined clay; lime; chalk; and silica, SiO₂, in its many forms — sandstone, sand (for grinding plate glass), flint, and diatomite.
- Generally contain impurities and possess non uniform properties, their performance is inconsistent and unreliable.

Artificial abrasive

• These are manufactured under controlled conditions in closed electric furnaces in order to avoid the introduction of impurities and to achieve the necessary temperature for chemical reactions to take place

Advantages and use of artificial Abrasive

- The controlled conditions in the electric furnace enable uniformly in the product
- The quality of production and supply can easily be varied according to the demands
- Fulfill growing demand of more abrasive material in the modern manufacturing process
- Aluminum oxide, silicon carbide, cubic boron nitride, and diamond are mostly used.

Aluminum oxide (Al₂O₃)

- Aluminum oxide was first made in 1893 and is produced by fusing bauxite, iron filings, and coke.
- Dark (less friable), white (very friable), and single crystal.
- Seeded gel (1987) is purest form of unfused aluminum oxide known as ceramic aluminum oxide. Very small grain size on the order of 0.2 µm. These grains are sintered to form larger sizes. Relatively high friability hence sharp, used for difficult-togrind materials.
- Used to grind steel and other ferrous, high-strength alloys

Silicon carbide (SiC)

- 1891, made with silica sand and petroleum coke.
- black (less friable) and green (more friable)
- higher friability than aluminum oxides. Hence, they have a greater tendency to fracture and remain sharp.
- Used on ductile metals such as aluminum, brass, and stainless steel, as well as brittle materials such as some cast irons and certain ceramics. Nonferrous metals, cast irons, carbides, ceramics, glass, and marble.
- Cannot be used effectively for grinding steel because of the strong chemical affinity between the carbon in SiC and the iron in steel
 11

Cubic boron nitride (cBN)

- Developed in 1970, second hardest material, cubic boron nitride is made by bonding a 0.5 to 1 mm layer of polycrystalline cubic boron nitride to a carbide substrate by sintering under high pressure and high temperature. While the carbide provides shock resistance, the cBN layer provides very high wear resistance and cutting-edge strength. Cubic-boronnitride tools also are made in small sizes without a substrate.
- At elevated temperatures, cBN is chemically inert to iron and nickel. (Hence, there is no wear due to diffusion.) Its resistance to oxidation is high; thus, it is particularly suitable for cutting hardened ferrous Braze and high-temperature alloys and for high-speed machining operations
- It also is used as an abrasive. Because cBN tools are brittle, stiffness of the machine tool and the fixturing is important to avoid vibration and chatter.
- Furthermore, in order to avoid chipping and cracking due to thermal shock, machining generally should be performed dry (i.e., cutting fluids should be avoided), particularly in interrupted cutting operations (such as milling), which repeatedly subject the tool to thermal cycling.
- Used for hard materials such as hardened tool steels and aerospace alloys
- Steels and cast irons above 50 HRC hardness and high temperature alloys.

Diamond:

- Diamond first used as an abrasive in 1955.
- Principal form of carbon with a covalently bonded structure.
- It is the hardest substance known (7000 to 8000 HK).
- However, it is brittle and begins to decompose in air at about 700°C, but it resists higher temperatures in nonoxidizing environments.
- Manufactured by putting graphite to a hydrostatic pressure of 14 GPa and a temperature of 3000°C.
- Synthetic diamond has superior properties because of its lack of impurities, available in various sizes and shapes; for abrasive machining, the most common grit size is 0.01 mm in diameter.
- Diamond-like carbon also has been developed and is used as a diamond film coating, Diamond particles also can be coated with nickel, copper, or titanium for improved performance in grinding operations.
- Used on hard, abrasive materials such as ceramics, cemented carbides, and glass and some hardened steels
- Because of its chemical affinity, diamond cannot be used for grinding steels, since diamond dissolves in iron at the high temperatures encountered in grinding.

Grain Size

- Important in determining surface finish and material removal rate.
- Large grit- big grinding capacity, rough workpiece surface
- Fine grit- small grinding capacity, smooth workpiece surface
- The selection of grit size also depends to some extent on the hardness of the work material. Harder work materials require smaller grain sizes to cut effectively, whereas softer materials require larger grit sizes.
- The grit size is measured using a screen mesh procedure. In this procedure, smaller grit sizes have larger numbers and vice versa. Grain sizes used in grinding wheels typically range between 8 and 250. Grit size 8 is very coarse and size 500 is very fine.

Bonding Material

- The bonding material holds the abrasive grains and establishes the shape and structural integrity of the grinding wheel.
- Desirable properties of the bond material include strength, toughness, hardness, and temperature resistance.
- The bonding material must be able to withstand the centrifugal forces and high temperatures experienced by the grinding wheel
- It should resist shattering in shock loading of the wheel, and hold the abrasive grains rigidly in place to accomplish the cutting action while allowing those grains that are worn to be dislodged so that new grains can be exposed.

Types of Bonding Material

- Vitrified bond (V)
- Silicate bond (S)
- Shellac bond (E)
- Resinoid bond (B)
- Rubber bond (R)
- Oxychloride bond (O)
- Metallic bond
- Electroplated bond
- Brazed bond
- Reinforced Wheels
- Thermoplastics

Vitrified Bond (V)

- In this process, the abrasive and clay are mixed with sufficient water and then poured in moulds, dried, and after cooling trimmed to more perfect size and shape and then baked at a temp **1260 degree**. When the burning proceeds, the clay vitrifies and forms a porcelain or glass like substance that surrounds and connects the abrasive grains.
- Also called ceramic bond and most widely used bond material
- Wheels with vitrified bonds are strong, stiff, porous, and resistant to oils, acids, water and high temperatures. Porosity combined with strength allow high stock removal, excellent coolant flow and chip clearance
- However, they are **brittle** and lack resistance to mechanical and thermal shock.
- Not recommended for very high speed grinding because of possible breakage of the bond under centrifugal force
- **Different wheel color** can be added so that wheels can be color coded for use with specific workpiece materials. 18
Silicate Bond (S)

- In this process, the abrasive and silica of soda or water glass are mixed then pressed in moulds, dried and later the shapes are baked at a temp 260 degree.
- The silicate bonded wheels are water proof.
- Consists of sodium silicate (Na₂SO₃)
- Limited to situations in which heat generation must be minimized, such as grinding cutting tools.

Shellac Bond (E)

- In this process, the abrasive and shellac are mixed in heated containers and then rolled or pressed in heated moulds and later the shapes are baked at a temp 150 degree.
- Shellac bond wheels are also known as elastic bonded wheels.
- Relatively greater elasticity, considerable strength but not rigid
- often used in applications requiring a good fine finish
- It is not used for heavy duty.
- Used for finishing chilled iron, cast iron and steel rolls

Resinoid Bond (B)

- In this process, the abrasive and thermosetting resins and additives are mixed and then pressed in shape of grinding wheel and later the shapes are cured at a temp 175 degree.
- Resin Phenol formaldehyde is generally used. Bond material is an organic compound.
- It has very high strength, tougher and more resistant to higher temperatures and is used for rough or heavy duty grinding because of their ability to withstand shock load.
- More flexible bond than vitrified (low E), also more resistant to higher temperatures.
- Vibration absorbing characteristics finds its use with diamond and cBN in grinding of cemented carbide and steel respectively.
- Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening.
- Fiberglass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation

Rubber Bond (R)

- In this process, the abrasive and pure rubber and Sulphur are mixed and rolled into sheets then wheels are punched out of these sheets on a punch press followed by heating under pressure for vulcanization
- These are less heat resistant and more dense then the Resinoid wheels
- Flexible bond type, inexpensive, used in bonding of cutoff wheels or cutoff blades like saw.
- Its principal use is in thin wheels for wet cut-off operation.
- Rubber bond was once popular for finish grinding on bearings and cutting tools

Oxychloride Bond (O)

- This process consists of mixing abrasive grains with oxide and chloride of magnesium.
- The mixing of bond and abrasive is performed in the same way as for vitrified bond wheel.
- These wheels are used in making wheels and wheel segments for disc grinding operation.
- Denoted by "O"

Metallic Bond (M)

- The abrasive grains (usually diamond or cubic boron nitride) are bonded to the periphery of a metal wheel to depths of 6 mm or less using powder metallurgy under high pressure and temperature.
- The wheel itself (the core) may be made of aluminum, bronze, steel, ceramics, or composite materials depending on requirements such as strength, stiffness, and dimensional stability.
- Most inexpensive bond type
- Metal, usually bronze, is the common bond material for diamond and cBN grinding wheels
- Used with super abrasive wheels.
- Extremely high toughness provides form accuracy and high stock removal if desired.

Electroplated Bond

- This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing.
- This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels.
- Presently it is the only bond for making wheels for abrasive milling and ultrahigh speed grinding

Brazed Bond

- Recent development, allows crystal exposure as high 60-80%.
- Grit spacing can be precisely controlled.
- This bond is particularly suitable for very high material removal either with diamond or cBN wheel.
- The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

Reinforced Wheels

- These wheels typically consist of one or more layers of fiberglass mats of various mesh sizes.
- The fiberglass in this laminate structure provides reinforcement in resinoid wheels by slowing the disintegration of the wheel if it breaks during use, rather than improving its strength.
- Large-diameter resinoid wheels can be supported additionally with one or more internal rings made of round steel bars inserted during the molding of the wheel.

Thermoplastic

 In addition to thermosetting resins, thermoplastic bonds are used in grinding wheels. Wheels are available with sol-gel abrasives bonded with thermoplastics.



- Refers to the relative spacing of the abrasive grains in the wheel.
- Abrasive grains, bond material and air gaps or pores complete the structure. The volumetric proportions of grains, bond material, and pores can be expressed as-

$$\mathbf{P}_{g} + \mathbf{P}_{b} + \mathbf{P}_{p} = \mathbf{1}$$

Where

P_g=proportion of abrasive grains in the total wheel volume

P_b=proportion of bond material

P_p =proportion of pores (air gaps)

Open: Pp is relatively large, and Pg is relatively small. Recommended in situations in which clearance for chips must be provided. The space between the grits also serves as pocket for holding grinding fluid and cooling.

Dense: Pp is relatively small, and Pg is larger. Used to obtain better surface finish and dimensional control

Wheel Grade

- Wheel grade indicates the grinding wheel's bond strength in retaining the abrasive grits during cutting.
- This is largely dependent on the amount of bonding material present in the wheel structure P_b.

Minimum and maximum range of scale:

- Soft: lose grains readily, used for applications requiring low material removal rates and grinding of hard work materials. The worn out grit must pull out from the bond and make room for fresh sharp grit in order to avoid excessive rise of grinding force and temperature. Therefore, a soft grade should be chosen for grinding hard material.
- Hard: retain their abrasive grains, used to achieve high stock removal rates and for grinding of relative soft work materials. On the other hand, during grinding of low strength soft material grit does not wear out so quickly. Therefore, the grit can be held with strong bond so that premature grit dislodgement can be avoided.

A grinding wheel requires two types of specification

- Geometrical specification
- Compositional specification

Geometrical specification

- Refers to geometry & includes wheel diameter, width and depth of rim and the bore diameter.
- Depends on operation and material
- Wide ranges : diameter (400 mm in high efficiency grinding to 1 mm in internal grinding),Width (less than an mm in dicing and slicing)



Compositional specifications

- Refers to composition of grinding wheel, Specification of a grinding wheel ordinarily means compositional specification.
- Conventional abrasive grinding wheels are specified by the following parameters.
 - The type of grit material (Abrasive Type)
 - The grit size (Abrasive Grain Type)
 - The bond strength of the wheel, commonly known as wheel hardness (Grade)
 - The structure of the wheel denoting the porosity i.e. the amount of inter grit spacing
 - The type of bond material
 - Manufacturer identification code prefixing or suffixing (or both)
- The preceding parameters can be concisely designated in a standard grinding wheel marking system defined by the American National Standards Institute (ANSI)/BIS
- This marking system uses numbers and letters to specify abrasive type, grit size, grade, structure, and bond material.

Prefix	Abrasive type	Abrasive grain size		Grade	Structure		Bety	ond /pe	Manufacturer's record
Manufacturer's symbol (indicating exact type of abrasive) (use optional) <u>A</u> Aluminium oxide <u>C</u> Silicon carbide	Coarse 8 10 12 14 16 20 24	Medium 30 <u>36</u> 46 54 60	Fine 70 80 90 100 120 150 180	Very fine 220 240 280 320 400 500 600	Dense	1 2 3 4 <u>5</u> 6 7 8 9			Manufacturer's private marking (to identify wheel) (use optional)
Soft ABCDEFGH	Medium IJKLMNOI	PQRS	тиv	Hard WXYZ	Open	11 12 13 14 15 16 etc.	B BF E O R RF S	Resil Resil Shell Oxyo Rubt Silica	noid noid reinforced lac shloride per per reinforced ate





Wheel Wear

Grain fracture: some portion of grain breaks off; produce new cutting edges and rest remains bonded in the wheel. The tendency of the grain to fracture is called friability. High friability means that the grains fracture more readily because of the cutting forces on the grains Fc'

Attritious wear: Attritious wear involves dulling of the individual grains, resulting in flat spots and rounded edges. Attritious wear is analogous to tool wear in a conventional cutting tool. It is caused by similar physical mechanisms including friction and diffusion, as well as chemical reactions between the abrasive material and the work material in the presence of very high temperatures.

Bond fracture: Bond fracture occurs when the individual grains are pulled out of the bonding material.

The tendency toward this mechanism depends on wheel grade, among other factors. Bond fracture usually occurs because the grain has become dull because of attritious wear, and the resulting cutting force is excessive. Sharp grain cut more efficiently with lower cutting forces; hence, they remain attached in the bond structure.

Typical Wheel Wear Curve



First region:

- Grains are initially sharp, and wear is accelerated because of grain fracture.
- This corresponds to the "break-in" period in conventional tool wear.

Second region:

- Wear rate is fairly constant, resulting in a linear relationship between wheel wear and volume of metal removed.
- This region is characterized by attritious wear, with some grain and bond fracture.

Third region:

- Grains become dull, and the amount of plowing and rubbing increases relative to cutting.
- In addition, some of the chips become clogged in the pores of the wheel. This
 is called wheel loading, and it impairs the cutting action and leads to higher
 heat and work surface temperatures.
- As a consequence, grinding efficiency decreases, and the volume of wheel removed increases relative to the volume of metal removed.

Grinding Ratio

The grinding ratio is a term used to indicate the slope of the wheel wear curve. Specifically

 $GR = \frac{V_w}{V_g}$

Where GR =the grinding ratio Vw = the volume of work material removed Vg = the corresponding volume of the grinding wheel that is worn in the process.



Grinding ratio and surface finish as a function of wheel speed

Grinding Machines

Classification

Surface grinding machine

- horizontal spindle with reciprocating worktable
- vertical spindle with reciprocating worktable
- horizontal spindle with rotating worktable
- vertical spindle with rotating worktable
- Creep feed grinding machine

Cylindrical grinding machine (External Cylindrical grinder)

- Plain centre type cylindrical grinder
- Universal cylindrical surface grinder
- Centreless cylindrical surface grinder
- Special application of cylindrical grinder
- Tool post grinder

Classification

Internal grinding machine

- Chucking type internal grinder
- Planetary internal grinder
- Centreless internal grinder
- Tool and cutter grinding machine

Other Grinding Operations

- Tool grinding
- Jig grinding
- Disk grinding
- Snag grinding
- Abrasive belt grinding

Surface Grinding Machine

- Surface grinding is normally used to grind plain flat surfaces.
- It is performed using either the periphery of the grinding wheel or the flat face of the wheel. Because the work is normally held in a horizontal orientation, peripheral grinding is performed by rotating the wheel about a horizontal axis, and face grinding is performed by rotating the wheel about a vertical axis.
- In either case, the relative motion of the workpart is achieved by reciprocating the work past the wheel or by rotating it.
- These possible combinations of wheel orientations and workpart motions provide the four types of surface grinding machines.

Surface Grinding Machine



Four types of surface grinding: (a) horizontal spindle with reciprocating worktable, (b) horizontal spindle with rotating worktable, (c) vertical spindle with reciprocating worktable, and (d) vertical spindle with rotating worktable.

Horizontal spindle reciprocating table grinder



- Working motions as in figure for grinding action
- A disc type grinding wheel performs the grinding action with its peripheral surface.
- Both traverse and plunge grinding can be carried out



Surface grinding (a) traverse grinding (b) plunge grinding

Vertical spindle reciprocating table grinder



- Working motions as in figure for grinding action
- similar to face milling on a vertical milling machine.
- a cup shaped wheel grinds the workpiece over its full width using end face of the wheel.
- more grits in action hence a higher material removal rate

Horizontal spindle rotary table grinder



A: rotation of grinding wheel B: table rotation C: table reciprocation

D: down feed of grinding wheel

- Working motions as in figure for grinding action
- In principle the operation is same as that for facing on the lathe.
- limitation in accommodation of workpiece hence less used.
- However, by swiveling the worktable, concave or convex or tapered surface can be produced on individual part
- A: rotation of grinding wheel B: table rotation C: table reciprocation D: down feed of grinding wheel O: swivel angle
- Grinding of a tapered surface in horizontal spindle rotary table surface grinder 54

Vertical spindle rotary table grinder





- A: rotation of grinding wheel
- B: work table rotation
- C: down feed of grinding wheel

- Working motions as in figure for grinding action
- suitable for small workpieces in large quantities.
- often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table.



Horizontal spindle reciprocating table



Horizontal spindle rotary table



Vertical spindle reciprocating table



Vertical spindle rotary table

Typical Surface Grinder



Creep Feed Grinding



Comparison of (a) conventional surface grinding and (b) creep feed grinding.

Creep feed grinding is performed at very high depths of cut and very low feed rates; hence, the name creep feed. Single pass operation 58

Creep Feed Grinding

- A number of operations can be performed on the workpiece.
- Can be automated by CNC in the view of their size and complexity
- Depths of cut are 1000 to 10,000 times greater than conventional surface grinding, and the feed rates are reduced by about the same proportion.
- Material removal rate and productivity are increased because the wheel is continuously cutting not like In conventional surface grinding in which the reciprocating motion of the work results in significant lost time during each stroke.
- Creep feed grinding can be applied in both surface grinding and external cylindrical grinding.
- Surface grinding applications include grinding of slots and profiles. The cylindrical applications include threads, formed gear shapes, and other cylindrical components.
- Typical advantages of creep feed grinding include: (1) high material removal rates, (2) improved accuracy for formed surfaces, and (3) reduced temperatures at the work surface.

Cylindrical Grinding (External Cylindrical Grinder)

- This machine is used to produce external cylindrical surface.
- The surfaces may be straight, tapered, steps or profiled.
- Broadly there are three different types of cylindrical grinding machine as follows:
 - ✓ Plain centre type cylindrical grinder
 - ✓ Universal cylindrical surface grinder
 - ✓ Centreless cylindrical surface grinder

Plain centre type cylindrical grinder



A: rotation of grinding wheel B: work table rotation C: reciprocation of worktable D: infeed

- The machine is similar to a centre lathe in many respects.
- The workpiece is held between head stock and tailstock centers.
- A disc type grinding wheel performs the grinding action with its peripheral surface.
- Both traverse and plunge grinding can be carried out in this machine.
- A: rotation of grinding wheel B: workpiece rotation
- C: reciprocation of worktable
- D: infeed





Universal Cylindrical Surface Grinder



- Universal cylindrical grinder is similar to a plain cylindrical one except that it is more versatile.
- In addition to small worktable swivel, this machine provides large swivel of head stock, wheel head slide and wheel head mount on the wheel head slide.

Special Application of Cylindrical Grinder



- A: rotation of grinding wheel
- B: rotation of workpiece
- C: Downfeed
- D: Longitudinal feed of wheel

- Principle of cylindrical grinding is being used for thread grinding with specially formed wheel that matches the thread profile. A single ribbed wheel or a multi ribbed wheel can be used
- Roll grinding is a specific case of cylindrical grinding wherein large workpieces such as shafts, spindles and rolls are ground.
- Crankshaft or crank pin grinders also resemble cylindrical grinder but are engaged to grind crank pins which are eccentric from the centre line of the shaft. The eccentricity is obtained by the use of special chuck.



A: rotation of wheel B: rotation of crank pin
External Centreless Grinder

- A production machine in which outside diameter of the workpiece is ground.
- The workpiece is not held between centres but by a work support blade. This results in work handling time reduction; hence, used for high-production work.
- It is rotated by means of a regulating wheel and ground by the grinding wheel. Both wheels rotate in same directions
- The work parts which may be many individual short pieces or long rods (e.G., 3 to 4m long) are supported by a rest blade and fed through between the two wheels. The grinding wheel does the cutting, rotating at surface speeds of 1200 to 1800 m/min

Centreless through feed grinding

In through-feed centreless grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the workpiece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel and the workpiece is fed longitudinally



Centreless Infeed & End feed grinding

- Parts with variable diameter can be ground by Centreless in feed grinding. • The operation is similar to plunge grinding with cylindrical grinder.
- End feed grinding is used for workpiece with tapered surface. The grinding ٠ wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the workpiece.



Tool Post Grinder

A self powered grinding wheel is mounted on the tool post or compound rest to provide the grinding action in a lathe. Rotation to the workpiece is provided by the lathe spindle. The lathe carriage is used to reciprocate the wheel head.



Internal Grinding Machine

- Used to produce internal cylindrical surface.
- The surface may be straight, tapered, grooved or profiled.
- three different types
 - 1. Chucking type internal grinder
 - 2. Planetary internal grinder
 - 3. Centreless internal grinder

Chucking type internal grinder



- various motions required for grinding action as per figure
- The workpiece is usually mounted in a chuck. A magnetic face plate can also be used.
- A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out

Chucking type internal grinder



Planetary Internal grinder



A: rotation of grinding wheel B: orbiting motion of grinding



- Various motions required for grinding action as per figure
- Used where the workpiece is of irregular shape and cannot be rotated conveniently.
- Workpiece does not rotate. Instead, the grinding wheel orbits the axis of the hole in the workpiece.



- Various motions required for grinding action as per figure
- Used for grinding cylindrical and tapered holes in cylindrical parts (e.g. Cylindrical liners, various bushings etc.).
- The workpiece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel
- In place of the rest blade, two support rolls are used to maintain the position of the work.
- The regulating wheel is tilted at a small inclination angle to control the feed of the work past the grinding wheel.
- Because of the need to support the grinding wheel, throughfeed of the work as in external centerless grinding is not possible. Therefore this grinding operation cannot achieve the same high-production rates as in the external centerless process.
- Its advantage is that it is capable of providing very close concentricity between internal and external diameters on a tubular part such as a roller bearing race

Tool & Cutter Grinder Machine



Tool holding 3-D vice

- Tool grinding may be divided into two subgroups: tool manufacturing and tool resharpening.
- There are many types of tool and cutter grinding machine to meet these requirements.
- Simple single point tools are occasionally sharpened by hand on bench or pedestal grinder.
- However, tools and cutters with complex geometry like milling cutter, drills, reamers and hobs require sophisticated grinding machine commonly known as universal tool and cutter grinder.
- Present trend is to use tool and cutter grinder equipped with CNC to grind tool angles, concentricity, cutting edges and dimensional size with high precision.

Other Grinding Operations & Machine

- Tool grinding
- Jig grinding
- Disk grinding
- Snag grinding
- Abrasive belt grinding

Tool Grinding

- Cutting tools are made of hardened tool steel and other hard materials.
- Tool grinders are special grinding machines of various designs to sharpen and recondition cutting tools.
- They have devices for positioning and orienting the tools to grind the desired surfaces at specified angles and radii.
- Some tool grinders are general purpose while others cut the unique geometries of specific tool types.
- General-purpose tool and cutter grinders use special attachments and adjustments to accommodate a variety of tool geometries.
- Single-purpose tool grinders include gear cutter sharpeners, milling cutter grinders of various types, broach sharpeners, and drill point grinders.

Jig Grinders

- traditionally used to grind holes in hardened steel parts to high accuracies.
- The original applications included press working dies and tools.
- today used where high accuracy and good finish are required on hardened components.
- Numerical control is available on modern jig grinders to achieve automated operation.







- Grinding machines with large abrasive disks mounted on either end of a horizontal spindle.
- **Single disk:** the work is held (usually manually) against the flat surface of the wheel to accomplish the grinding operation.
- **Double disk:** have double opposing spindles. By setting the disks at the desired separation, the workpart can be fed automatically between the two disks and ground simultaneously on opposite sides.
- Advantages good flatness and parallelism at high production rates.



Snag Grinders





- Similar in configuration to a disk grinder. Both single disc & double disc available
- Grinding is done on the outside periphery of the wheel rather than on the side flat surface.
- Different in design than those in disk grinding.
- Generally a manual operation, used for rough grinding operations such as removing the flash from castings and forgings, and smoothing weld joints.

Abrasive Belt Grinders

Idler pulley

= belt speed

Abrasive belt

Drive spindle

Platen

- Uses abrasive particles bonded to a flexible (cloth) belt.
- Support of the belt is required when the work is pressed against it, and this support is provided by a roll or platen located behind the belt. A flat platen is used for work that will have a flat surface. A soft platen can be used if it is desirable for the abrasive belt to conform to the general contour of the part during grinding.
- Belt speed depends on the material being ground; a range of 750 to 1700 m/min is typical.
- Owing to improvements in abrasives and bonding materials, abrasive belt grinding is being used increasingly for heavy stock removal rates, rather than light grinding, which was its traditional application.
- The term belt sanding refers to the light grinding applications in which the workpart is pressed against the belt to remove burrs and high spots, and produce an improved finish quickly by hand.



Related Abrasive Processes & Surface Finishing Processes in Grinding

Related Abrasive Surface Finishing Processes

- Honing
- Lapping
- Superfinishing
- Polishing
- Buffing

Introduction

- To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with *high dimensional and geometrical accuracy* but also with *high surface finish.*
- The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction.
- Unfortunately, normal machining methods like turning, milling or even classical grinding cannot meet this stringent requirement.
- Therefore, super finishing processes like lapping, honing, polishing, burnishing are being employed to achieve and improve the abovementioned functional properties in the machine component

Introduction

Process	Diagram of resulting surface	Height of micro irregularity (µm)
Precision Turning	Roughness	1.25-12.50
Grinding	mining	0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super Finishing		0.01-0.25

gradual improvement of surface roughness produced by various processes ranging from precision turning to super finishing including lapping and honing

Finishing Operations Short Overview

COATED ABRASIVESBELT GRINDINGWIRE BRUSHINGhave a more pointed high rate of material produces a fine orand open structure than removal with good controlled texturegrinding wheelssurface finish







SUPERFINISHINGLAPPINGCHEMICAL-very light pressure in a abrasive or slurryMECHANICAdifferent path to the wears the piece'sPOLISHINGpieceridges down softlyslurry

MECHANICAL POLISHING slurry of abrasive particles and a controlled chemical corrosive

HONING improves surface after boring, drilling, or internal grinding



ELECTROPLATING an unidirectional pattern by re removing metal a from the surface

- finishing process for internal cylindrical surfaces in which a tool called hone carries out a combined rotary and reciprocating motion while workpiece is stationary.
- Main purpose to remove scratches after grinding
- Hone uses a cylindrical mandrel dressed with bonded abrasive sticks of aluminium oxide, silicon carbide, diamond etc.



- The number of sticks depends on size of hole. Two to four sticks for small holes (e.g., gun barrels), and a dozen or more for larger diameter holes.
- The honing stones are held against the workpiece with controlled light pressure. The honing head is guided by the work surface.
- Honing stones should not leave the work surface & Stroke length must cover the entire work length.





- During the process, the sticks are pressed outward against the hole surface to produce the desired abrasive cutting action.
- The honing tool is supported in the hole by two universal joints, thus causing the tool to follow the previously defined hole axis. Honing enlarges and finishes the hole but cannot change its location.
- Combined rotary and reciprocating motion is complex and produce crosshatched pattern beneficial for retaining lubrication
- Surface finish of around 0.12 mm or slightly better are typically achieved
- Honing speeds are 15 to 150 m/min. The amount of material removed from the work surface during a honing operation may be as much as 0.5 mm, but is usually much less than this.
- A cutting fluid must be used in honing to cool and lubricate the tool and to help remove the chips.

- Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. Other applications include bearings, hydraulic cylinders, and gun barrels.
- The critical process parameters are:
 - ✓ Rotation speed
 - ✓Oscillation speed
 - ✓ Length and position of the stroke
 - ✓ Honing stick pressure
- Diamond and carbon boron nitrite grits are used for complete the operation in just one stroke rather than several strokes needed in conventional honing stick.

- Parameters affecting MRR (Q) and surface roughness (R)
- The important parameters that affect material removal rate (MRR) and surface roughness (R) are:
 - ✓ Unit pressure, p
 - ✓ Peripheral honing speed, V_p
 - ✓ Honing time, T



Effect of honing pressure on MRR and surface finish

unit pressure should be selected so as to get minimum surface roughness with highest possible MRR.



an increase of peripheral honing speed leads to enhancement of material removal rate and decrease in surface roughness.



Effect of honing time on material removal rate and surface roughness

With honing time T, MRR decreases. On the other surface hand, roughness decreases and after attaining a value again minimum rises. The selection of honing time depends much on the very permissible surface roughness.

Lapping

- The oldest method of obtaining a fine finish.
- An abrasive process in which loose abrasives function as cutting points finding momentary support from the laps.
- A process where two surfaces are rubbed against each other with abrasive particles in between them
- Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1 mm in certain cases.



Scheme of lapping Process

Lapping

- Characteristics of lapping process:
- Use of loose abrasive between lap and the workpiece
- Usually lap and workpiece are not positively driven but are guided in contact with each other
- Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the workpiece.
- Materials used:
- Cast iron is the mostly used lap material.
- However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

Vehicle materials for lapping

- Machine oil
- Rape oil
- Grease

Abrasives of lapping:

- Al_2O_3 and SiC, grain size 5~100 μm
- Cr_2O_3 , grain size 1~2 μ m
- B_4C_3 , grain size 5-60 μm
- Diamond, grain size 0.5~5 V

Technical parameters affecting lapping processes are:

- Unit pressure
- The grain size of abrasive
- •Concentration of abrasive in the vehicle
- lapping speed

Lapping

Types:

Hand Lapping: Hand lapping is done manually with abrasive powder as lapping medium

Machine Lapping: Machine lapping is done either with abrasive powder or with bonded abrasive wheel.

Flat Lapping by hand

- by rubbing the component over accurately finished flat surface of master lap usually made of a thick soft close-grained cast iron block.
- Lapping compound is spread on CI plate and moved manually on a path like emglish letter 8.
- abrading action is accomplished by very fine abrasive powder held in a vehicle.
- Manual lapping requires high personal skill because the lapping pressure and speed have to be controlled manually.





Ring Lapping

- Laps in the form of ring made of closed grain cast iron are used for manual lapping of external cylindrical surface.
- Workpiece held in lathe chuck and rotated. Ring lap is reciprocated over workpiece. Lap should be short than workpiece and should have adjustable slots
- Bore of ring lap and work size are very close and can be adjusted by screws.
- Ring lapping is recommended for finishing plug gauges and machine spindles requiring great roundness accuracy.
- For External threads lapping, Special laps having interchangeable threaded bush corresponding to the external thread to be lapped, with provision for precise adjustment are used.



Lapping external cylindrical surface

External threads lapping

Machine Lapping

- In this method a rotating table is used in place of the plate.
- Again the work piece to be lapped is given rotary by a cage and rotated on the surface of the table. Rotating lap is used above & below the work piece to produce parallel surfaces
- Used for economic lapping with high accuracy of batch qualities.
- Metal laps and abrasive powder held in suitable vehicles are used.
- Bonded abrasives in the form wheel are chosen for commercial lapping.
- Machine lapping can also employ abrasive paper or abrasive cloth as the lapping medium.



Production lapping of flat surfaces



Production lapping of cylindrical surfaces

Machine Lapping

- Conditioning Rings or Retaining Rings
- to prevent the components from being thrown off the plate from the action of centrifugal force.
- to evenly spread and maintain a thin film layer of slurry that contributes to process consistency by maximizing the transfer of cutting energy.
- to continuously machine (condition) the surface of the lap plate to eliminate wear caused by the abrasive action of the components and to maintain the flatness of the components by adjusting the concave or convex curvature movement of the lap plate.





Lapping Advantages

- Reduction of peaks and valleys results in maximum bearing area
- between mating surfaces This ensures tight seating of seals
- Improves service life of the moving parts which are subject to wear
- Improves geometrical & dimensional accuracies
- Absolutely **no distortion** in the component after lapping since no clamping devices are used
- The lapping process **generates minimal heat** so hardened parts will not have to be hardened again
- Accessible flat surfaces of parts of any shape & size and any type of material can be lapped

Typical Applications & Industries that Make Use of Lapping



Valve Manufacturers



Automotive industries





Air Compressor Industries



Electronic Industries

What can be lapped?


Superfinishing

- Similar to honing, but uses a single abrasive stick.
- The reciprocating motion of the stick is performed at higher frequency and smaller amplitudes.
- Also, the grit size and pressures applied on the abrasive stick are smaller.
- A cutting fluid is used to cool the work surface and wash away chips.
- Cutting action terminates by itself when a lubricant film is built up between the tool and work surface. Thus, superfinishing is capable only of improving the surface finish but not dimensional accuracy.
- Mirror like finishes with surface roughness values around 0.01
 µm.
- Superfinishing can be used to finish flat and external cylindrical surfaces.



Superfinishing



Schematic illustration of the superfinishing process for a cylindrical part. (a) Cylindrical microhoning (b) Centerless microhoning

Radial & Plunge Mode in Superfinishing





In **Radial Mode** both feeding and oscillation of the superfinishing stone is given in the radial direction.

In **Plunge Mode** the abrasive stone covers the section of the workpiece requiring super finish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction

Burnishing

 In this process, also called surface rolling, the surface of the component is cold worked by a hard and highly polished roller or set of rollers. The process is used on various flat, cylindrical, or conical surfaces



(a) (b) (c) Burnishing tools and roller burnishing of (a) the fillet of a stepped shaft to induce compressive surface residual stresses for improved fatigue life; (b) a conical surface; and (c) a flat surface.

Burnishing

- **Roller burnishing** improves surface finish by removing scratches, tool marks, and pits and induces beneficial compressive surface residual stresses. Consequently, corrosion resistance is improved, since corrosive products and residues cannot be entrapped.
- Low-plasticity burnishing: the roller travels only once over the surface, inducing residual stresses and minimal plastic deformation.
- Ball burnishing:
- Internal cylindrical surfaces are burnished by ballizing or ball burnishing.
- In this process, a smooth ball (slightly larger than the bore diameter) is pushed through the length of the hole.
- The burnishing process consists of pressing hardened steel rolls or balls into the surface of the workpiece and imparting a feed motion to the same.

Burnishing

Use & Advantages

- Considerable residual compressive stress is induced in the surface of the workpiece and thereby fatigue strength and wear resistance of the surface layer increase.
- to improve the mechanical properties of surfaces as well as their surface finish.
- It can be used either by itself or in combination with other finishing processes, such as grinding, honing, and lapping.
- The equipment can be mounted on various CNC machine tools for improved productivity and consistency of performance.
- All types of metals (soft or hard) can be roller burnished.
- Roller burnishing is typically used on hydraulic-system components, seals, valves, spindles, and fillets on shafts.

Magnetic Float Polishing



- Used for precision polishing of ceramic balls.
- A magnetic fluid is used for this purpose. The fluid is composed of water or kerosene carrying fine ferro-magnetic particles along with the abrasive grains.
- Ceramic balls are confined between a rotating shaft and a floating platform.
- Abrasive grains ceramic ball and the floating platform can remain in suspension under the action of magnetic force.
- The balls are pressed against the rotating shaft by the float and are polished by their abrasive action.
- Fine polishing action can be made possible through precise control of the force exerted by the abrasive particles on the ceramic ball.

Magnetic Float Polishing



- Magnetic field assisted polishing is particularly suitable for polishing of steel or ceramic roller.
- A ceramic or a steel roller is mounted on a rotating spindle.
 - Magnetic poles are subjected to oscillation, thereby, introducing a vibratory motion to the magnetic fluid containing these magnetic and abrasive particles.
- This action causes polishing of the cylindrical roller surface.
- In this technique, the material removal rate increases with the field strength, rotational speed of the shaft and mesh number of the abrasive.
- But the surface finish decreases with the increase of material removal rate.

Electropolishing

- Electropolishing is the reverse of electroplating.
- Here, the workpiece acts as anode and the material is removed from the workpiece by electrochemical dissolution.
- The process is particularly suitable for polishing irregular surface since there is no mechanical contact between workpiece and polishing medium.
- The electrolyte electrochemically etches projections on the workpiece surface at a faster rate than the rest, thus producing a smooth surface.
- This process is also suitable for deburring operation.



Schematics of the buffing operation.



- Buffing is a surface finishing process, which is performed after polishing for providing a high bright lusture finish to the polished surface of metal & composites.
- Buffing is a rotating cloth wheel that is impregnated with liquid rouge or a greaseless compound-based matrix of specialized fine abrasive called compound. Mostly buffing wheel is made by linen, cotton, broad cloth and canvass. This wheel made by multiple layers of these cloths overlapped on each other
- The compound is sprayed or pressured into the rotating buffing wheel. The buff wheel acts as the carrier of the compound, which ultimately does the surface finishing.

Difference between Buffing & Polishing

- Finishing processes that utilize abrasive belts are referred to as polishing, and processes that use cloth wheels with compound applied is buffing.
- Polishing generates a brushed or lined finish, where buffing removes the lines and creates a bright luster finish.

Requirements before buffing

- Surface refinement polishing prior to buffing.
- First Polishing by abrasive belts or discs is done by fine abrasives to level surfaces, remove scratches, pits, scale and polish the surface enough so the cut buff can remove the polishing lines.
- Each finer polishing step should be cross-polished 90 degrees from the previous polishing process. A 320 - 400 grit polishing line is generally the coarsest surface preparation that a cut buff process can efficiently remove.

Stages after polishing:

- **Cut Buff:** Cut buff is the course buff process. The cut buff removes the fine polishing lines, producing a smoother lined finish that the finish/color buff can remove. The cut buff is the more difficult buff process and requires more time, effort and pressure, causing increased operator fatigue.
- Finish Color buff: Finish/color buff is the finest buff process for surface finishing. The finish buff removes the fine lines created by the cut buff process, while creating a bright luster finish. The finish buff is an easier, quicker, less pressure process than the cut buff.

Finishing Compounds :

- Green Rouge Primarily used in final finish (coloring) buff operations on stainless steel, steel, brass, aluminum, nickel, and chrome. The green rouge is a chrome oxide, and is considered the best all around luster compound.
- White Rouge The white rouge is the softer, calcite alumina (unfused) type. Primarily used in the final finish (coloring) of steel, stainless steel, and zinc. This compound is also a favorite in coloring aluminum and brass.
- Red Rouge Primarily used in the final finish (coloring) of gold and silver, it is the finest of all rouges. The abrasive is Ferric Oxide, which is spherical in shape and gives an exceptionally high luster. It is produces an excellent finish on brass.

Wheel Conditioning

Overview

- Loading
- Glazing
- Chattering
- Wheel Conditioning-Truing
- Wheel Conditioning-Dressing

Glazing



1

- When the surface of a grinding wheel develops a smooth and shining appearance, it is said to be glazed.
- Abrasive grains due to wear become dull, flat, round and loose sharpness
- Hard bonds don't break and supply of fresh sharp grains is stopped.
- For proper cutting wheel is to be cleaned and sharpened (or dressed)
- Glazing takes place if the wheel is rotated at very high speeds and is made with harder bonds.
- Rotating the wheel at lesser speeds and using soft bonds are the remedies.
- The glazed wheels are dressed to have fresh, sharp cutting edges.

Loading

Fig. 2

PARTICLES OF

METAL BEING GROUND

CLOG SPACE BETWEEN

SURFACE

DOTTED AND STREAKED WITH

METALLIC PARTICLES

LOADED WHEEL

GRAINS

- When soft materials like aluminium, copper, lead, etc. are ground, the metal particles either adhere to the grits or get clogged between the void between abrasive particles. This condition is called loading.
- Loading can occur in grinding soft materials or from improper selection of wheels or process parameters.
- The loaded grinding wheel cuts inefficiently, dull very fast, raising grinding forces and temperature thus reducing its grinding ability which results in surface damage and loss of dimensional accuracy of the workpiece.
- It is caused by grinding a softer material or by using a very hard bonded wheels and SELECT A MORE OPEN STRUCTURE WHEEL (8). running it very slowly. It may also take place if very deep cuts are taken by not using the right type of coolant.

Chattering

- The wavy pattern of crisscross lines is visible on the ground surface some times. This condition is known as chattering.
- It takes place when the spindle bearings are not fitted correctly and because of the imbalance of the grinding wheel.

Wheel Conditioning-Truing

- A worn, loaded and glazed wheel ceases to cut and lose its original shape and geometry.
- Truing is the act of regenerating the required geometry on the grinding wheel. Geometry may be a special form or flat profile
- It make the wheel concentric with the bore, and its sides plane and parallel and change the face contour for form grinding.
- Produces the macro-geometry of the grinding wheel.
- Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system.
- Truing and dressing are done with the same tools, but not for the same purpose.
- The procedure uses a diamond-pointed tool that is fed slowly and precisely across the wheel as it rotates. A very light depth is taken (0.025 mm or less) against the wheel.

Truing Operation



Truing Tools

- Steel cutter: used to roughly true coarse grit conventional abrasive wheel to ensure freeness of cut.
- Vitrified abrasive stick and wheel: It is used for offhand truing of conventional abrasive wheel. These are used for truing resin bonded superabrasive wheel.
- Steel or carbide crash roll: It is used to crush-true the profile on vitrified bond grinding wheel.
- Diamond truing tool: Single Point/ Multipoint
- Impregnated diamond truing tools
- Rotary Powered truing wheels
- Diamond form truing blocks

Single Point Diamond Truing Tools

The single point diamond truing tools for straight face truing are made by setting a high quality single crystal into a usually cylindrical shank of a specific diameter and length by brazing or casting around the diamond. During solidification contraction of the bonding metal is more than diamond and latter is held mechanically as result of contraction of metal around it.





Multistone Diamond Truing Tools

- Consists of a number of small but whole diamonds which contact the abrasive wheel.
- The diamond particles are surface set with a metal binder
- Tool with one layer or multilayer configuration are possible
- Normal range about 0.02 carat to as large as of 0.5 carat.
- Suitable for heavy and rough truing



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Distribution of diamond	Diamond weight	Distribution of diamond`	Diamond weight
(i) 1 layer-3stone	10	(v) 5 layer-17 stone	50
(ii) 2 layer-3 stone	10	(vi) 5 layer-7 stone	10
(iii) 3 layer-5 stone	10	(vii) 5 layer-25 stone	250
(iv) 5 layer-13 stone	25	(viii) throughout	50



Diamond distribution pattern of diamond particles in multi-stone diamond

Impregnated diamond truing tools

- Crushed and graded diamond powder mixed with metal powder and sintered.
- Diamond particles randomly distributed in matrix
- The size of diamond particles may vary from 80-600 microns.
- By using considerably smaller diamond grit and smaller diamond section it is possible to true sharp edge and fine grit grinding wheel.
- The use of crushed diamond product ensures that there are always many sharp points in use at the same time and these tools are mainly used in fine grinding, profile grinding, thread grinding, cylindrical grinding and tool grinding.





Impregnated diamond truing tools

Rotary powered diamond truing tools

- Most widely recommended truing tool in long run mass production
- Not ideally suited for wheels with large diameters (greater than 200 mm).
- They can be pneumatic, hydraulic or electrically powered.
- Rotary powered truing device can be used in cross axis and parallel axis mode.
- Three types
- ✓ Surface set truing wheels
- ✓ Impregnated truing wheels
- ✓ Electroplated truing tool





Rotary power truing wheel being used in (a) cross-axis (b) parallel-axis

Rotary powered diamond truing tools

Surface set truing wheels

Here the diamond particles are set by hand in predetermined pattern.
 A sintered metal bond is used in this case. These truing wheels are designed for high production automated operations.

Impregnated truing wheels

In this case impregnated diamond particles are distributed in a random pattern to various depths in a metal matrix. This type of roll finds its best applications (i.e. groove grinding) where excess wheel surfaces must be dressed of.

Electroplated truing tool

In this truing wheel diamond particles are bonded to the wheel surface with galvanically deposited metal layer. Main advantage of this technique is that no mould is necessary to fabricate the diamond truing wheel unlike that of surface set or impregnated truing wheels.

Diamond form truing blocks

- can be either diamond impregnated metal bond or electroplated.
- Brazed type diamond truing block has also come as an alternative to electroplated one. They can be as simple as flat piece of metal plated with diamond to true a straight faced wheel or contain an intricate form to shape the grinding wheel to design profile.
- Truing block can eliminate the use of self propelled truing wheels and are used almost exclusively for horizontal spindle surface grinder to generate specific form.



Diamond form truing block to true (a) a straight faced wheel (b) a form wheel

Dressing

- Dressing is the conditioning of the wheel surface to remove dull grits and to expose fresh sharp grains and removing chips that have become clogged in the wheel.
- Done by a rotating disk, an abrasive stick, or another grinding wheel operating at high speed, held against the wheel being dressed as it rotates.
- Although dressing sharpens the wheel, it does not guarantee the shape of the wheel. Dressing therefore produces micro-geometry.
- Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for superabrasive wheel.



Dressing of Super abrasive wheel

- Done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the superabrasive grits.
- However, modern technique like electrochemical dressing has been successfully used in metal bonded superabrasive wheel. The wheel acts like an anode while a cathode plate is placed in front of the wheel working surface to allow electrochemical dissolution.
- Electro discharge dressing is another alternative route for dressing metal bonded superabrasive wheel. In this case a dielectric medium is used in place of an electrolyte.
- Touch-dressing, a new concept differs from conventional dressing in that bond material is not relieved. In contrast the dressing depth is precisely controlled in micron level to obtain better uniformity of grit height resulting in improvement



Surface Integrity

Surface finish influences not only the dimensional accuracy of machined parts but also their properties and their performance in service. The term surface finish describes the geometric features of a surface and surface integrity pertains to material properties, such as fatigue life and corrosion resistance, that are strongly influenced by the nature of the surface produced.

Factors influencing surface integrity are as follows:

• Temperatures generated during processing and possible metallurgical transformations.

• Surface residual stresses.

•Severe plastic deformation and strain hardening of the machined surfaces, tearing, and cracking.

Selection of Grinding Wheel

Selection of Grinding Wheel

- To achieve better result in grinding operation the following factors are to be considered. The factor are classified in to two groups
- Constant factor
 - a. Material to be ground
 - b. Amount of stock to be removed
 - c. Area of contact
 - d. Type of grinding (nature of work)
- Variable factor
 - a. Wheel speed
 - b. work speed
 - c. Condition of machine
 - d. personal factor

Constant Factors

- Material to be ground: Its affect the selection of grinding wheel which influence the selection of
 - Abrasive: aluminium oxide for high tensile strength material (steel and steel alloys)
 - Grain size: Medium grains are used for operation where the stock removal and finish both are required
 - Grade: Hard wheel for soft material & vice versa
- Amount of stock to be removed:
- Coarse grain are used for fast removal of material & fine grain for finishing
- Area of contact:
- For long contact area coarser grain and soft grades of grinding wheels are used and for small contact area finer and hard wheels are used.
- Type of grinding machine:
- Light machine is subjected to vibration. For harder grinding wheel the poor condition machine would be ok
- For soft grinding wheel the heavy rigidly constructed and well maintained machine

Variable Factors

- Wheel speed: It is influenced by Grade & Bond, High wheel speed for soft grinding wheel
- Work Speed: Harder wheel for high speed work in relation with wheel speed
- Condition of grinding machine: heavy rigid machine required softer wheel
- **Personal Factor**: Skilled operator can worked with softer wheel & achieve optimum production

Wheel Balancing

- Grinding wheels rotate at high speeds. The density and weight should be evenly distributed throughout the body of the wheel. If it is not so, the wheel will not rotate with correct balance and will produce poor surface quality.
- The grinding wheels are balanced by mounting them on test mandrels. The wheel along with the mandrel is rolled on knife edges to test the balance and corrected.
- New wheels are supplied with removable balance weights allowing for location adjustment. In static balancing, the wheel is rotated on an arbor and the balancing weights are adjusted until the wheel no longer stops its rotation at a specific position.





a. Counter balance b. Test mandrel



Wheel Mounting



Mounting of the grinding wheel. (a) Clamping flange, (b) circular groove, (c) counter balance, (d) carboard packing felt or leather.

 All wheels should be closely inspected just before mounting to make sure that they have not been damaged in transit, storage, or otherwise.

The wheel must first be subjected to the ringing test. For this purpose, the grinding wheel is put on an arbor while it is subjected to slight hammer blows. A clear, ringing, vibrating sound must be heard. If a grinding wheel contains fine cracks, discordant sound that fail to vibrate will be emitted. This test is applicable to vitrified and silicate wheels. Shellac, resinoid or rubber loaded wheels will not ring distinctly.
Wheel Mounting

- The abrasive wheels should have an easy fit on their spindles or locating spigots. They should not be forced on.
- The hole of grinding wheels mostly is lined with lead. The lead liner bushes should not project beyond the side of wheels.
- There must be a flange on each side of the wheel. The mounting flanges must be large enough to hold the wheel properly, at least the flange diameter must be equal to the half of the grinding wheel diameter. Both the flanges should be of the same diameter, other-wise the wheel is under a bending stress which is liable to cause fracture.
- The sides of the wheel and the flanges which clamp them should be flat and bear evenly all round
- All flanges must be relieved in the center so that the flanges contact the wheel only with the annular clamping area. If they are not properly relieved, the pressure of the flanges is concentrated on the sides of the wheel near the hole, a condition which should be avoided.

Wheel Mounting

- Washers of compressible materials such as card board, leather, rubber, etc. not over 1.5 mm thick should be fitted between the wheel and its flanges. In this way any unevenness of the wheel surface is balanced and a tight joint is obtained. The diameter of washers may be normally equal to the diameter of the flanges.
- The inner fixed flange should be keyed or otherwise fastened to the spindle, whereas the outer flange should have an easy sliding fit on the spindle so that it can adjust itself slightly to give a uniform bearing on the wheel and the compressible washers.
- The nut should be tightened to hold the wheel firmly. Undue tightness is unnecessary and undesirable as excessive clamping strain is liable to damage the wheel.
- The wheel guard should be placed and tightened before the machine is started for work.

Analysis of the Grinding Process



 $v = \pi DN$

Where

v = surface speed of wheel, m/min

N = spindle speed, rev/min

D = wheel diameter, m

d = depth of cut, called the infeed, is the penetration of the wheel below the original work surface.

w =Crossfeed or lateral feed which determines the width of the grinding path w figure (a). This width, multiplied by depth d determines the crosssectional area of the cut.

(a) The geometry of surface grinding, showing the cutting conditions; (b) assumed longitudinal shape and (c) cross section of a single chip

Analysis of the Grinding Process

In most grinding operations, the work moves past the wheel at a certain speed v_w , so that the material removal rate is

$$R_{MR} = v_w w d$$

Each grain in the grinding wheel cuts an individual chip whose longitudinal shape before cutting is shown in Figure (b) and whose assumed cross-sectional shape is triangular, as in Figure (c). At the exit point of the grit from the work, where the chip cross section is largest, this triangle has height t and width w'.

In a grinding operation, we are interested in how the cutting conditions combine with the grinding wheel parameters to affect

- surface finish
- forces and energy
- temperature of the work surface
- wheel wear

Surface Finish

- The surface finish of the workpart is affected by the size of the individual chips formed during grinding.
- One obvious factor in determining chip size is grit size—smaller grit sizes yield better finishes.
- Let us examine the dimensions of an individual chip. From the geometry of the grinding process, it can be shown that the average length of a chip is given by

$$l_c = \sqrt{Dd}$$

Where

 I_c = length of the chip, mm

D=wheel diameter, mm

d=depth of cut, infeed, mm



This assumes the chip is formed by a grit that acts throughout the entire sweep arc shown in the diagram. Figure (c) shows the assumed cross section of a chip in grinding. The cross sectional shape is triangular with width w' being greater than the thickness t by a factor called the grain aspect ratio r_g

Typical values of grain aspect ratio are between 10 and 20.

Surface Finish

- The number of active grits (cutting teeth) per square inch on the outside periphery of the grinding wheel is denoted by C.
- In general, smaller grain sizes give larger C values. C is also related to the wheel structure. A denser structure means more grits per area.
- Based on the value of C, the number of chips formed per time n_c is given by

$$n_c = v w C$$

Where

v = wheel speed, mm/min

w = crossfeed, mm

C=grits per area on the grinding wheel surface, grits/mm²

 It stands to reason that surface finish will be improved by increasing the number of chips formed per unit time on the work surface for a given width w. Therefore, according to Eq., increasing v and/or C will improve finish.

Forces & Energy

If the force required to drive the work past the grinding wheel were known, the specific energy in grinding could be determined as



Where

U = specific energy, J/mm³

 F_c = cutting force, which is the force to drive the work past the wheel, N

v = wheel speed, m/min

v_w = work speed, mm/min

w=width of cut, mm

d = depth of cut, mm

In grinding, the specific energy is much greater than in conventional machining.

There are several reasons for this.

- ✓ Size effect
- ✓ Negative rake angle
- ✓ Ineffective grain actions

Reasons for High Specific Energy

Size effect

The small chip sizes in grinding cause the energy required to remove each unit volume of material to be significantly higher than in conventional machining—roughly 10 times higher.

Negative rake angles

the individual grains in a grinding wheel possess extremely negative rake angles. The average rake angle is about -30° to -60°. These very low rake angles result in low values of shear plane angle and high shear strains, both of which mean higher energy levels in grinding.

Ineffective grain actions

Not all of the individual grits are engaged in actual cutting. Because of the random positions and orientations of the grains in the wheel, some grains do not project far enough into the work surface to accomplish cutting.

Three Types of Grain Actions

Cutting/shearing: grit projects far enough into the work surface to form a chip and remove material

Plowing: grit projects very less into the work, the work surface is deformed and energy is consumed without any material removal

Rubbing: grit rubs and only rubbing friction occurs, thus consuming energy without removing any material

The size effect, negative rake angles, and ineffective grain actions combine to make the grinding process inefficient in terms of energy consumption per volume of material removed.



Three types of grain action in grinding: (a) cutting/shearing, (b) plowing, (c) rubbing

Cutting Force On Grain

 Using the specific energy relationship, and assuming that the cutting force acting on a single grain in the grinding wheel is proportional to r_gt, it can be shown that-

$$F'_c = K_1 \left(\frac{r_g v_w}{vC}\right)^{0.5} \left(\frac{d}{D}\right)^{0.25}$$

- where Fc' is the cutting force acting on an individual grain, K1 is a constant of proportionality that depends on the strength of the material being cut and the sharpness of the individual grain, and the other terms have been previously defined.
- The practical significance of this relationship is that Fc' affects whether an individual grain will be pulled out of the grinding wheel, an important factor in the wheel's capacity to "resharpen" itself. Referring back to our discussion on wheel grade, a hard wheel can be made to appear softer by increasing the cutting force acting on an individual grain through appropriate adjustments in V_w, v, and d.

Temperature at the Work Surface

- Because of the size effect, high negative rake angles, and plowing and rubbing of the abrasive grits against the work surface, the grinding process is characterized by high temperatures.
- Unlike conventional machining operations in which most of the heat energy generated in the process is carried off in the chip, much of the energy in grinding remains in the ground surface resulting in high work surface temperatures. The high surface temperatures have several possible damaging effects.
- Surface burns and cracks: The burn marks show themselves as discolorations on the surface caused by oxidation. Grinding burns are often a sign of metallurgical damage immediately beneath the surface. The surface cracks are perpendicular to the wheel speed direction. They indicate an extreme case of thermal damage to the work surface.
- Softening of the work surface: High grinding temperatures reduces hot hardness of surface obtained through heat treatment.
- Residual stresses in the work surface: possibly decreasing the fatigue strength of the part

Temperature at the Work Surface

- it has been observed that surface temperature is dependent on energy per surface area ground (closely related to specific energy U).
- Because this varies inversely with chip thickness, it can be shown that surface temperature Ts is related to grinding parameters as follows:

$$T_s = K_2 d^{0.75} \left(\frac{r_g C v}{v_w}\right)^{0.5} D^{0.25}$$

Where $K_2 = a$ constant of proportionality.

The practical implication of this relationship is that surface damage owing to high work temperatures can be mitigated by decreasing depth of cut d, wheel speed v, and number of active grits per square inch on the grinding wheel C, or by increasing work speed vw. In addition, dull grinding wheels and wheels that have a hard grade and dense structure tend to cause thermal problems. Of course, using a cutting fluid can also reduce grinding temperatures.

UNIT 4.1

BROACHING PROCESSES



- Broaching is a machining process for removal of a layer of material of desired width and depth usually in one stroke by a slender rod or bar type cutter having a series of cutting edges with gradually increased protrusion (cutting tooth).
- In shaping, attaining full depth requires a number of strokes to remove the material in thin layers step by step by gradually in feeding the single point tool. Whereas, broaching enables remove the whole material in one stroke only by the gradually rising teeth of the cutter called broach. The amount of tooth rise between the successive teeth of the broach is equivalent to the in feed given in shaping.





- Machining by broaching is preferably used for making straight through holes of various forms and sizes of section, internal and external through straight or helical slots or grooves, external surfaces of different shapes, teeth of external and internal splines and small spur gears etc.
- The majority of components that can be broached are pliers, wrenches, clutch pressure plates, jet engine plates, gear splines, gear sectors, rocker-arms, spider splined holes, key ways etc



Figure: Schematic view of finishing hole by broaching

CONFIGURATION OF A PULL TYPE BROACH



Elements of broaching tool

- **Pull end** for engaging the broach in the machine. This locates the broach centrally with the hole to be broached.
- pull end front pilot neck
- Neck of shorter diameter and length, where the broach is allowed to fail, if at all, under overloading
- Front pilot for initial locating the broach in the hole
- Roughing and finishing teeth for metal removal
- Finishing and burnishing teeth for lighter cuts
- Rear pilot and follower rest or retriever for support after the last tooth leaves the workpiece

Broach Tool Design

- Broaches are designed **mostly pull type to facilitate alignment and avoid buckling**. The length of the broach is governed by;
 - Type of the broach; **pull or push type**
 - Number of cutting edges and their pitch depending upon the work material and maximum thickness of the material layer to be removed
 - Nature and extent of finish required.
- Keeping in view that around 4 to 8 teeth remain engaged in machining at any instant, the pitch (or gap), p, of teeth is simply decided from

 $p = 1.25\sqrt{L}$ to $1.5\sqrt{L}$

- where, L = length of the hole or job
- The total number of cutting teeth for a broach is estimated from,
- Tn ≥ (total depth of material) / tooth rise, a1 (which is decided based on the tool – work materials and geometry).
- Broaches are generally made from solid rod or bar. Broaches of large section and complex shape are often made by assembling replaceable separate sections or inserting separate teeth for ease of manufacture and maintenance.

Material of Broach

- Being a cutting tool, broaches are also made of materials having the usual cutting tool material properties, i.e., high strength, hardness, toughness and good heat and wear resistance.
- For ease of manufacture and resharpening the complex shape and cutting edges, broaches are mostly made of HSS (high speed steel).
- To enhance cutting speed, productivity and product quality, Cemented carbide segments (assembled) or replaceable inserts are also used specially for stronger and harder work materials like cast irons and steels.
- TiN coated carbides provide much longer tool life in broaching.
- Since broaching speed (velocity) is usually quite low, ceramic tools are not used.

(a)

(b)



Figure: Terminology of broach teeth geometry

Cut per Tooth

The progressive increase in tooth height from tooth to tooth of a broach is called cut per tooth, step per tooth, or tooth rise.

<u>Pitch</u>

linear distance from the cutting edge of one tooth to the corresponding point of the next tooth

- A relatively large pitch may be required for roughing teeth to accommodate a greater chip load.
- Tooth pitch may be smaller on semi-finishing teeth to reduce the overall length of the broach tool.
- VPitch is calculated so that, preferably, two or more teeth cut simultaneously. This prevents the tool from drifting or chattering.

Cutting teeth

- Three separate sections along the length : the roughing teeth, semi-finishing teeth and finishing teeth.
- The first roughing tooth is the smallest tooth
- Subsequent teeth progressively increase in size up to and including the first finishing tooth.
- The tooth rise, is usually greater along the roughing section and less along the semi-finishing section.
- All finishing teeth are the same size.
- The face is ground with a hook or face angle that is determined by the workpiece material. For instance, soft steel workpieces usually require greater hook angles; hard or brittle steel pieces require smaller hook angles

Tooth land

- The land supports the cutting edge against stresses. A slight clearance or back-off angle is ground onto the lands to reduce friction.
- On roughing and semi-finishing teeth, the entire land is relieved with a back-off angle.
- On finishing teeth, part of the land immediately behind the cutting edge is often left straight, so that repeated sharpening (by grinding the face of the tooth) will not alter the tooth size.

Tooth gullet

- The depth of the tooth gullet is related to the tooth rise, pitch and workpiece material.
- The tooth root radius is usually designed so that chips curl tightly within themselves, occupying as little space as possible.

Chip load

- As each tooth enters the workpiece, it cuts a fixed thickness of material.
- The fixed chip length and thickness produced by broaching create a chip load that is determined by the design of the broach tool and the predetermined feedrate.

<u>Chipbreakers</u>

- Notches, called chipbreakers, are used on broach tools to eliminate chip packing and to facilitate chip removal.
- The chipbreakers are ground into the roughing and semi-finishing teeth of the broach, parallel to the tool axis.
- Chipbreakers on alternate teeth are staggered so that one set of chipbreakers is followed by a cutting edge. The finishing teeth complete the job.
- Chipbreakers are vital on round broaching tools: without the chipbreakers, the tools would machine ring-shaped chips that would wedge into the tooth gullets and eventually cause the tool to break.



Chipbreakers features on (a) a flat broach and (b) a round broach. ¹⁴

Shear angle

- Broach designers may place broach teeth at a shear angle to improve surface finish and reduce tool chatter.
- When two adjacent surfaces are cut simultaneously, the shear angle is an important factor in moving chips away from the intersecting corner to prevent crowding of chips in the intersection of the cutting teeth.

Side relief

- When broaching slots, sides of the broach teeth will rub the sides of the slot and cause rapid tool wear unless clearance is provided.
- Grinding a single relief angle on both sides of each tooth does this. Thus, only a small portion of the tooth near the cutting edge, called the side land, is allowed to rub against the slot. The same approach is used for one-sided corner cuts and spline broaches.

 Fig. below shows the general configuration of the broaching teeth and their geometry. The cutting teeth of HSS broaches are provided with positive radial or orthogonal rake (5° to 15°) and sufficient primary and secondary clearance angles (2° to 5° and 5° to 20° respectively).



Fig. Geometry of teeth of broaching tools

Broaching Operation

- 1. Selection of broach and broaching machine
- 2. Mounting and clamping the broach in the broaching machine
- 3. Fixing workpiece in the machine
- 4. Planning tool work motions
- Selection of the levels of the process parameters and their setting
- 6. Conducting machining by the broach.

SELECTION OF BROACH AND BROACHING MACHINE

Suitable broach has to be selected based on

- Type of the job; size, shape and material
- Geometry and volume of work material to be removed from the job
- Desired length of stroke and the broach
- Type of the broaching machines available or to be used

Broaching machine has to be selected based on

- The type, size and method of clamping of the broach to be used
- Size, shape and material of the workpiece
- Strength, power and rigidity required for the broaching machine to provide the desired productivity and process capability.

MOUNTING AND CLAMPING BROACH IN THE MACHINE

- Pull type and push type broaches are mounted in different ways.
- Just before fitting in or removing the broach from the broach pull head (Fig. (a)), the sliding outer socket is pushed back against the compression spring.
- After full entry of the pull end of the broach in the head the socket is brought forward which causes locking of the broach by the radially moving strips as shown in Fig. (b).



MOUNTING AND CLAMPING BROACH IN THE MACHINE

Pull type broaches are also often simply and slight flexibly fitted by a suitable adapter and pin



Figure: Fitting pull type broach by an adapter and a pin

FIXING WORKPIECE IN BROACHING MACHINE

- Broaching is used for mass production and at fast rate. The blanks are repeatedly mounted one after another in an appropriate fixture where the blanks can be easily, quickly and accurately located, supported and clamped.
- In broaching, generally the job remains fixed and the broach travels providing cutting velocity.



Fig. Mounting external broach for surfacing and slotting

FIXING WORKPIECE IN BROACHING MACHINE



Fig. Mounting blank in broaching machine

TOOL – WORK MOTIONS AND PROCESS VARIABLES

- Any machining is associated with 2 to 5 tool work motions as well as cutting velocity, feed and depth of cut as process variables.
- But broaching operation needs only one motion which is cutting motion and is mostly imparted to the tool.
- ✓ In broaching feed is provided as tooth rise. The magnitude of cutting velocity, V_c is decided based on the tool work materials and the capability of the broaching machine.
- ✓ In broaching metals and alloys, HSS broaches are used at cutting velocity of 10 to 20 m/min and carbide broaches at 20 to 40 m/min.
- ✓ The value of tooth rise varies within 0.05 mm to 0.2 mm for roughing and 0.01 to 0.04 mm for finishing teeth.
- ✓ Some cutting fluids are preferably used mainly for lubrication and cooling at the chip tool interfaces.

Types of Broaches

- Internal broaching or External broaching
- Pull type or Push type
- Ordinary cut or Progressive type
- Solid, Sectional or Modular type
- Profile sharpened or form relieved type
INTERNAL BROACHING

Internal broaching tools are used to enlarge and finish various contours in through holes preformed by casting, forging, rolling, drilling, punching etc.

Internal broaching tools are mostly pull type but may be push type also for lighter work.

Applications

- through holes of different form and dimensions
- non-circular holes and internal slots
- internal keyway and splines
- teeth of straight and helical fluted internal spur gears

INTERNAL BROACHING



EXTERNAL BROACHING

External surface broaching competes with milling, shaping and planing and, wherever feasible, outperforms those processes in respect of productivity and product quality. External broaching tools may be both pull and push type.



Fig. Machining external gear teeth by broaching

EXTERNAL BROACHING

Applications

- un-obstructed outside surfacing; flat, peripheral and contour surfaces
- grooves, slots, keyways etc. on through outer surfaces of objects
- external splines of different forms
- teeth of external spur gears or gear sectors

External broaching tools are often made in segments which are clamped in fixtures for operation.



Fig. typical external broaching (a) making slot (b) teeth of gear sector

PULL TYPE AND PUSH TYPE BROACHES

- During operation a pull type broach is subjected to tensile force, which helps in maintaining alignment and prevents buckling.
- Pull type broaches are generally made as a long single piece and are more widely used, for internal broaching in particular.
- Push type broaches are essentially shorter in length (to avoid buckling) and may be made in segments.
- Push type broaches are generally used for external broaching, preferably, requiring light cuts and small depth of material removal.

ORDINARY CUT TYPE AND PROGRESSIVE CUT TYPE BROACH

- Ordinary cut type where the teeth increase in height or **protrusion** gradually from tooth to tooth along the length of the broach. By such broaches, work material is removed in thin layers over the complete form.
- Whereas, **Progressive cut type** broaches have their teeth increasing in width instead of height.



SOLID, SECTIONAL AND MODULE TYPE BROACHES

- Broaches are mostly made in single pieces especially those used for pull type internal broaching.
- But some broaches called sectional broaches, are made by assembling several sections or cutter-pieces in series for convenience in manufacturing and resharpening and also for having little flexibility required by production in batches having interbatch slight job variation.
- External broaches are often made by combining a number of modules or segments for ease of manufacturing and handling.



PROFILE SHARPENED AND FORM RELIEVED TYPE

Like milling cutters, broaches can also be classified as

Profile sharpened type broaches;

 Such cutters have teeth of simple geometry with same rake and clearance angles all over the cutting edge. These broaches are generally designed and used for machining flat surface(s) or circular holes.

Form relieved type broaches

 These broaches, being used for non-uniform profiles like gear teeth etc. have teeth where the cutting edge geometry is more complex and varies point – to – point along the cutting edges. Here the job profile becomes the replica of the tool form. Such broaches are sharpened and resharpened by grinding at their rake faces unlike the profile sharpened broaches which are ground at the flank surfaces.

Broaching Machines

Unique characteristics of broaching operation are

- For producing any surface, the form of the broach always provides the generatrix and the cutting motion provides the directrix.
- Hence design, construction and operation of broaching machines, requiring only one such linear motion, are very simple.

Specifications

- Type; horizontal, vertical etc.
- Maximum stroke length
- Maximum working force (pull or push)
- Maximum cutting velocity possible
- Power
- Foot print

Classification

According to purpose of use

 Δ general purpose

 Δ single purpose

 Δ special purpose

According to nature of work

 Δ internal broaching

 Δ external (surface) broaching

According to configuration

 Δ horizontal

 Δ vertical

According to number of slides or stations

 Δ single station type

 Δ multiple station type

 Δ indexing type

According to tool / work motion

 Δ intermittent (one job at a time) type

 Δ continuous type

Horizontal Broaching Machine





- Mostly all are pull type.
- Both internal and external broaching can be done.
- Consists of a box type bed having length is twice the length of stroke.
- All modern machines are provided with hydraulic drive housed in the bed.
- Job located in the adapter which is fitted on front vertical face.
- Small end is connected to hole of the job, then connected to pulling end which is mounted on front end of ram.
- Ram is connected to hydraulic drive.
- Rear end is supported by guide.

Vertical Broaching Machine

- Occupies less floor space
- Are more rigid as the ram is supported by base
- Mostly used for external or surface broaching though internal broaching is also possible and occasionally done.



High Production Broaching Machine

Speed of production is further enhanced by;

 Δ incorporating **automation** in tool – job mounting and releasing

Δ **increasing number of workstations** or slides for simultaneous multiple production

 Δ quick changing the broach by turret indexing Δ continuity of working



Continuous broaching

Broaching Advantages

- High dimensional and form accuracy and surface finish
- close tolerances needed for interchangeable mass production achieved. The accuracy of surface finish is of the order of 0.1 micron
- Roughing and finishing in single stroke of the same cutter giving high production rate (much higher than milling, planing, boring etc.)
- Needs only one motion (cutting), so design, construction, operation and control are simpler
- Extremely suitable and economic for mass production
- Any form that can be reproduced on a broaching tool can be machined by broaching process.
- Simple operation with possibility of automating the process.
- Long life since each tooth of a broach passes over the work only once per pass.
- A broad range of materials are successfully broached with proper broach design and setup conditions.

Broaching Limitations

- Only through holes and surfaces can be machined
- Usable only for light cuts, i.e. low chip load and unhard materials
- Cutting speed cannot be high
- Defects or damages in the broach (cutting edges) severely affect product quality
- Design, manufacture and restoration of the broaches are difficult and expensive
- Separate broach has to be procured and used whenever size, shape and geometry of the job changes
- High tooling cost, economic only for volume production
- Surface to be broached should not have any obstruction.
- Workpiece to be broached should be rigid and strong to withstand heavy tool forces encountered during cutting operation.
- The process of broaching is not recommended for the removal of large amount of stock and short run jobs.
- All the elements of the broached surfaces must be parallel to the axis of the travel. Obviously it is not possible to broach the entire surface of a tapered hole.

Objective

- Numerical Control (NC)
- Computer Numerical Control(CNC)
- Difference between NC & CNC
- Types of CNC machines
- Elements of CNC System

Numerical Control

- Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers and symbols.
- It is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium, as opposed to controlled manually.
- Most **NC** today is **computer numerical control** (CNC), in which **computers** play an **integral** part of the control.



History of CNC

- 1949:US Air Force asks MIT to develop a "numerically controlled" machine.
- 1952:Prototype NC machine demonstrated (punched tape input).
- 1980:CNC machines (computer used to link directly to controller).
- 1990:DNC: external computer "drip feeds" control programmer to machine

tool controller.

Basic Components of an NC System

- 1. Program of instructions
 - Called a part program in machining
- 2. Machine control unit
 - Controls the process
- 3. Processing equipment
 - Performs the process



Part program

- A series of coded instructions required to produce a part.
- Controls the movement of the machine tool and on/off control of auxiliary functions such as spindle rotation and coolant.
- The coded instructions are composed of letters, numbers and symbols.
- The program input device is the means for part program to be entered into the CNC control.
- Three commonly used program input devices are punch tape reader, magnetic tape reader, and computer via RS-232-C communication.

Part program

- Word address format
- Program Coding Systems
 - -Binary
 - Decimal
 - -BCD
- Part Program Input
 - Paper tape (now obsolete)
 - Manual Data Input (MDI)
 - Direct Numerical Control (DNC)

Machine Control Unit

The machine control unit (MCU) is the heart of a NC and CNC system. It is used to perform the following functions:

- To read the coded instructions.
- To decode the coded instructions.
- To implement interpolations (linear, circular, and helical) to generate axis motion commands.
- To feed the axis motion commands to the amplifier circuits for driving the axis mechanisms.
- To receive the feedback signals of position and speed for each drive axis.
- To implement auxiliary control functions such as coolant or spindle on/off and tool change.

Principle of operation of a NC machine tool



Elements of NC tool operation



Controller

NC part programming



Configuration of a typical NC machine: (a) the machine control unit, (b) hand wheel dial, and (c) closed-loop control.

Control of axis motion in a NC machine tool



Elements CNC tool operation



Principle of operation of a CNC machine tool







Why NC?

- For the parts having complex contours, that cannot be manufactured by conventional machine tools.
- For jobs requiring very high accuracy and repeatability.
- For jobs requiring many set-ups and/or the setups very expensive.
- The parts that are subjected to frequent design changes and consequently require more expensive manufacturing methods.
- Inspection time is reduced, since all the parts in a batch would be identical provided proper care is taken about the tool compensations and

Advantages of NC

- Nonproductive time is reduced
- Greater accuracy and repeatability
- Lower scrap rates
- Inspection requirements are reduced
- More complex part geometries are possible
- Engineering changes are easier to make
- Simpler fixtures
- Shorter lead times
- Reduce parts inventory and less floor space
- Operator skill-level requirements are reduced

Other Applications of NC

- Rapid prototyping and additive manufacturing
- Water jet cutting and abrasive water jet cutting
- Component placement machines in electronics assembly
- Coordinate measuring machines
- Wood routers and granite cutters
- Tape laying machines for polymer composites
- Filament winding machines for polymer composites

Disadvantages of NC

- Higher investment cost
 - CNC machines are more expensive
- Higher maintenance effort
 - CNC machines are more technologically sophisticated
- Part programming issues
 - Need for skilled programmers
 - Time investment for each new part
 - Repeat orders are easy because part program is already available

Common NC Machining Operations



(c)

NC vs CNC

S.No.		
	NUMERICAL CONTROL (NC) MACHINE:	COMPUTER NUMERICAL CONTROL (NC) MACHINE:
1.	Input method: Punched tape, punched card and other such media.	Input method: programs are fed directly into the computer by small key board similar to our traditional key board.
2.	Programs should be changed in punched card and then fed to machine.	We can modify the program in computer.
3.	Operation parameters could not be changed.	Operation parameters can be changed.
4.	It has no memory storage.	We can store programs using the memory storage in computer.
5,	Run off the "Tape" each time of machine cycle.	It have the facility of running the program without actually running it ON the machine tool.
6.	NC machine cost is less.	CNC machine cost is high.
7.	Maintenance is less.	Maintenance is high.
8.	Accuracy is less.	It has more accuracy.
9.	High skill operator required.	High skilled not required.
10.	It is less flexible.	It is highly flexible.
11.	It required more time to perform a operation	It requires less time.
CNC Machine working





Other operations in CNC



CNC Plasma Cutter





CNC Electric Discharge Machining

CNC Engraving

Computer Numerical Control Additional Features

- Storage of more than one part program
- Program editing at the machine tool
- Fixed cycles and programming subroutines
- Adaptive control
- Interpolation
- Positioning features for setup to help operator align work part on machine tool table
- Acceleration and deceleration computations
- Communications interface
- Diagnostics

Automatic Functions in Tool spindle

- Starting and stopping of machine tool spindle
- **Controlling** the spindle **speed**
- **Positioning** the **tool** tip at desired locations and **guiding** it along desired paths by automatic control of the **motion** of slides
- Controlling the **rate** of **movement** of the tool tip (i.e. feed rate)
- Changing of tools in the spindle.

Finding directions in a Right Hand Co-ordinate System



(a) Axis designation for horizontal Z



NC Coordinate Systems



(a) For flat and block-like parts and (b) for rotational parts

Designating the Axes

• First axis to be identified is the Z-axis. This is followed by the X and Y axes respectively.



Vertical axis Milling machine



Axes designation for CNC turning center



CNC Horizontal axis boring mills in 3 and 4 axes versions



5 axes CNC Vertical axis machining center configuration



Types of CNC machines

• Based on Control Loops:

Open loop or Closed loop

• Based on Motion Type:

Point-to-Point or Continuous path

• Based on Power Supply:

	Electric	or	Hydraulic	or	Pneumatio
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Based on Positioning System

Incremental or Absolute

Control Loops

• **Open loop systems** have no access to the real time data about the performance of the system and therefore no immediate corrective action can be taken in case of system disturbance.



Open Loop Systems



Control Loops

• In a **close loop system**, feed back devices closely monitor the output and any disturbance will be corrected in the first instance. Therefore high system accuracy is achievable.



Block Diagram of a Close Loop System

Close Loop Systems



Motion Control Systems

Point-To-Point Control in CNC Drilling of Three Holes in Flat Plate

- System moves to a location and performs an operation at that location (e.g., drilling)
- Also applicable in robotics



Motion Control Systems

Continuous Path Control in CNC Profile Milling of Part Outline

- Also called contouring systems in machining
- System performs an operation during movement (e.g., milling and turning)



Computer Numeric Control



Elements of a CNC System

- Input Device
- Central Processing Unit/ Machine Control Unit
- Machine Tool
- Driving System
- Feedback Devices
- Display Unit

Input Devices

- Floppy Disk Drive
- USB Flash Drive
- Serial Communication
- Ethernet communication
- Conversational Programming

Central Processing Unit/ Machine Control Unit

- The **CPU** is the **heart** of a **CNC** system.
- It accepts the information stored in the memory as part program.
- This data is **decoded** and **transformed** into specific position **control** and velocity **signals**.
- It also **oversees** the movement of the **control axis** or spindle and whenever this does not match with the programmed values, a corrective action as taken.

Central Processing Unit/ Machine Control Unit



Cutting Tools

- Most are made from high speed steel (HSS), tungsten carbide or ceramics.
- Tools are designed to direct waste away from the material.
- Some tools need coolant such as oil to protect the tool and work.





https://giphy.com/explore/cnc-machine https://gfycat.com/gifs/search/milling+machine

Driving System

- The requirement is that the **driving system** has to response **accurately** according to the **programmed** instructions.
- The motor is coupled either directly or through a gear box to the machine lead screw to moves the machine slide or the spindle.
- Three types of electrical motors are commonly used:
 - 1. DC Servo motor
 - 2. AC Servo motor
 - 3. Stepper motor

SERVO MOTORS

- Servomotors are special electromechanical devices that produce precise degrees of rotation.
- Servomotors are also called control motors as they are involved in controlling a mechanical system.
- The servomotors are used in a closed-loop servo system
- Input is sent to the servo amplifier, which controls the speed of the servomotor.
- In many servo systems, both velocity and position are monitored.
- Servomotors provide accurate speed, torque, and have ability of direction control.

DC Servo Motor

- The principle of operation is based on the **rotation** of an **armature** winding in a **permanently** energized **magnetic** field.
- The armature winding is connected to a **commutator**, which is a cylinder of insulated copper **segments** mounted on the shaft.
- **DC** current is passed to the **commutator** through carbon **brushes**, which are connected to the **machine terminals**.



DC Servo Motor

- The change of the motor speed is by varying the armature voltage and the control of motor torque is achieved by controlling the motor's armature current.
- In order to achieve the necessary dynamic behavior it is operated in a closed loop system equipped with sensors to obtain the velocity and position feedback signals.



AC Servo Motor

- In an AC servomotor, the rotor is a **permanent magnet** while the **stator** is equipped with **3-phase windings**.
- Magnetic force is generated by a permanent magnet and current which further produce the torque.
- It has no brushes so there is little noise/vibration. This motor provides high precision control with the help of high resolution encoder.
- The **speed** and **position** of the motor is notified by the **encoder**, which can be **incremental** or **absolute**.

AC Servo Motor

- The stator is composed of a core and a winding. The rotor part comprises of shaft, rotor core and a permanent magnet.
- Digital encoder can be of optical or magnetic type. It gives digital signals, which are in proportion of rotation of the shaft.





Servo system block diagram

Advantages of servo motors

- Provides high intermittent torque, high torque to inertia ratio, and high speeds
- Work well for velocity control
- Available in all sizes
- Quiet in operation
- Smoother rotation at lower speeds

Disadvantages of servo motors

- More expensive than stepper motors
- Require tuning of control loop parameters
- Not suitable for hazardous environments or in vacuum
- Excessive current can result in partial demagnetization of DC type servo motor

Stepper Motor

- The stepper motor is known by its property to convert a train of input pulses (typically square wave pulses) into a precisely defined increment in the shaft position.
- Each pulse moves the shaft through a fixed angle.
- Multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron.
- The electromagnets are **energized** by an **external** driver **circuit** or a micro controller. In that way, the motor can be turned by a **precise** angle.



What does Stepper means?

- To make the motor shaft turn, first, **one electromagnet** is given power, which **magnetically attracts** the gear's teeth.
- When the gear's teeth are aligned to the first electromagnet, they are **slightly** offset from the **next electromagnet**.
- This means that when the **next** electromagnet is turned **on** and the first is turned **off**, the gear **rotates** slightly to align with the next one.
- From there the process is **repeated**. Each of those rotations is called a "**step**", with an integer number of steps making a full rotation.



Stepper Motor types

Types of stepper motors:

- Permanent Magnet
 Employ permanent magnet
 - Low speed, relatively high torque
- Variable Reluctance
 - Does not have permanent magnet
 - Low torque
Permanent magnet (PM) stepper motor

- Rotor is a permanent magnet.
- PM motor rotor has no teeth and is designed to be magnetized at a right angle to its axis.
- Figure shows a simple, 90° PM motor with four phases (A-D).
- Applying current to each phase in sequence will cause the rotor to rotate by adjusting to the changing magnetic fields.
- Although it operates at fairly low speed, the PM motor has a relatively high torque characteristic.
- These are low cost motors with typical step angle ranging between 7.5° to 15°



Permanent magnet stepper

Variable Reluctance Motor

- The cylindrical rotor is made of soft steel and has four poles.
- It has four rotor teeth, 90° apart and six stator poles, 60° apart.
- Electromagnetic field is produced by activating the stator coils in sequence.
- It attracts the metal rotor. When the windings are energized in a reoccurring sequence of 2, 3, 1, and so on, the motor will rotate in a 30° step angle.
- In the non-energized condition, there is no magnetic flux in the air gap, as the stator is an electromagnet and the rotor is a piece of soft iron; hence, there is no detent torque.



Variable reluctance stepper motor

Hybrid stepper motor

- Hybrid stepping motors combine a permanent magnet and a rotor with metal teeth to provide features of the variable reluctance and permanent magnet motors together.
- The number of rotor pole pairs is equal to the number of teeth on one of the rotor's parts.
- The hybrid motor stator has teeth creating more poles than the main poles windings.
- When a winding is energized, north and south poles are created, depending on the polarity of the current flowing.
- These generated poles attract the permanent poles of the rotor and also the finer metal teeth present on rotor.



Hybrid stepper

Advantages of stepper motors

- Low cost
- Ruggedness
- Simplicity of construction
- Low maintenance
- Less likely to stall or slip
- Will work in any environment
- Excellent start-stop and reversing responses

Disadvantages of stepper motors

- Low torque capacity compared to DC motors
- Limited speed
- During overloading, the synchronization will be broken. Vibration and noise occur when running at high speed.

- CNC uses a stepper motor to rotate the lead screw. A stepper motor is driven by series of electrical pulses generated by MCU (Machine Control Unit).
- For **each pulse** the motor rotates a fraction of revolution called **Step Angle**, it is given by:

 $\alpha = 360/n_s$ (Degrees/Pulse)

Where, n_s = Number of step angles for the motor (an integer)

 If n_p is the pulses received by the motor then angle through which motor rotates is:

$$A_m = n_p^* \alpha$$

- Lead Screw is connected to the motor shaft through a gear box.
- Angle of the lead screw rotation taking the gear ratio into account is given by

$$A = n_p^* \alpha / r_g$$

$$r_g = Gear ratio = A_m/A = N_m/N$$

- N_m= RPM of motor, N= RPM of lead Screw
- A: Angle of Rotation(A_m/r_g), **p**=Lead screw pitch
- The linear movement of worktable is given by:

 Total number of pulses required to achieve a specified x-position increment is calculated by:

$$n_p = \frac{360 * r_g * x}{p * \alpha} = \frac{n_s * x * r_g}{p}$$

Where , \mathbf{n}_{s} = 360/ α

- Control pulses are transmitted from pulse generator at a certain frequency which drives the work table at the corresponding velocity.
- The rotational speed of lead screw depends on the frequency of the pulse train

$$N = \frac{60 * f_p}{n_s * r_g}$$

Equation (1)

N = RPM of lead screw, $f_p = frequency of pulse train (Hz, Pulses/sec)$

• The table travel speed in the direction of lead screw axis is determined by:

$$V_t = f_r = N * p$$

Equation (2)

Where, V_t = Table travel speed (mm/min) f_r = Table feed rate (mm/min)

• The required pulse train frequency to drive the table at a specified linear travel rate by combining equations (1) and (2):

$$f_p = \frac{f_r * n_s * r_g}{60 * p}$$

Numerical

Q1. The shaft of a stepping motor is connected directly to the X-axis leadscrew of the machine table. The pitch of the leadscrew is 3.0mm. The number of step angles on the stepping motor is 200.

- a) Determine how closely the position of the table can be controlled, assuming that there are no mechanical errors in the positioning system.
- b) What is the required frequency of the pulse train and the corresponding rotational speed of the stepping motor in order to drive the table at a travel rate of 100 mm/min?

a) The motor position can be controlled to 200 increments corresponding to the number of step angles. One revolution of the motor provides a table movement of 3.0mm, which corresponds to the pitch of the leadscrew. Therefore, the table position can be controlled in the increments of

b) To drive the table at 100 mm/min, there must be 100/3.0=33.333 rotations of the leadscrew per minute. The pulse rate must therefore be

> f_p= (200 pulses/rev)(33.333 rotations/min)/(60s/min) = 111.11 pulses/s

Numerical

Q2. The work table of a positioning system is driven by a leadscrew whose pitch=6.0mm. The leadscrew is connected to the output shaft of a stepping motor through a gearbox whose ratio is 5:1(5 turns of the motor to one turn of the leadscrew). The stepping motor has 48 step angles. The table must move a distance of 250mm from its present position at a linear velocity =500mm/min. a) Determine how many pulses are required to move the table the specified distance and

b)the required motor speed and pulse rate to achieve the desired table velocity.

Ans 4 Given Distance x=250mm Gear ratio = 5:1 Pitch p=6mm Number of step angles n_s =48 Linear velocity v = 500mm/min a) Leadscrew rotation angle A= 360x/p = 360(250)/6 = 15,000⁰ Step angle α = 360/ n_s = 360/48= 7.5⁰ Number of pulses to move the table 250mm is

 $n_p = 360x(gear ratio)/p\alpha = A(gear ratio)/p\alpha = 15000(5)/7.5 = 10,000 puls$

b) Rotational speed of the leadscrew N = v/p = 500/6 = 83.333 rev/min

c) Rotational speed of the motor N_m= N (gear ratio) = 5 (83.333) = 416.667 rev/min Pulse rate to achieve the desired table velocity

 $f_p = v n_s(\text{gear ratio})/60p = 500(48)(5)/60(6)=333.333 \text{Hz}.$

LINEAR MOTION DRIVES

- Linear motion drives are mechanical transmission systems which are used to convert rotary motion into linear motion.
- The conventional thread forms like 'V' or square are not suitable in CNC because of their high wear and less efficiency.
- Therefore CNC machines generally employ ball screw for driving their workpiece carriages.
- These drives provide backlash free operation with low friction-wear characteristics.
- These are efficient and accurate in comparison with that of nut-and-screw drives. Most widely used linear motion drives are ball screws.

Ball Lead Screws

- Ball lead screw is the heart of the drive system.
- Advantages of ball lead screw are:
- Precise position and repeatability
- High Speed capability
- Less Wear
- Longer life



Ball Lead Screws



Feedback Devices

Two types of feed back devices normally used are:

1. Positional Feed Back Devices

1.Linear Transducers - a device mounted on the machine table to measure the actual displacement of the slide in such a way that backlash of screws, motors etc. would not cause any error in the feed back data.



Feedback Devices

1.2 Rotary Encoders: a device to measure the angular displacement. It cannot measure linear displacement directly so that error may occur due to the backlash of screw and motor etc.



Rotary Encoders



The closed loop feedback control system



The absolute encoder disc for rotary position measurement.





Operation of a digital rotary encoder for position measurement



The encoder disc mounted on the lead screw



Principle of optical grating for position measurement in linear scales



The linear scale fixed to the machine tool structure



Analysis of Positioning NC Systems

- Precision in NC positioning three measures:
 - 1. Control resolution
 - 2. Accuracy
 - 3. Repeatability

Positioning NC Systems

Three measures of precision:

- 1. Control resolution distance separating two adjacent addressable points in the axis movement
- 2. Accuracy maximum possible error that can occur between the desired target point and the actual position taken by the system
- 3. Repeatability defined as $\pm 3\sigma$ of the mechanical error distribution associated with the axis

Control Resolution, Accuracy, and Repeatability



Velocity Feedback Device

- The actual speed of the motor can be measured in terms of voltage generated from a tachometer mounted at the end of the motor shaft.
- The voltage generated by the DC tachometer is compared with the command voltage corresponding to the desired speed.
- The difference of the voltages is used to actuate the motor to eliminate the error.



Display Unit

Interface between the machine and the operator. The Display Unit displays:

- position of the machine slide
- spindle RPM
- feed rate
- part programs
- graphics simulation of the tool path.



Interpolation Methods

- 1. Linear interpolation
 - Straight line between two points in space
- 2. Circular interpolation
 - Circular arc defined by starting point, end point, center or radius, and direction
- 3. Helical interpolation
 - Circular plus linear motion
- 4. Parabolic and cubic interpolation
 - Free form curves using higher order equations

Linear interpolation

- The axis of the spindle moves in the orthogonal movement from the beginning to the end of the path
- The program is divided into short straight lines.
- More line better is the approximation of the actual path.



Circular Interpolation

- The axis of spindle moves in a series of straight line cord segment to generate a circular motion
- More segment better will be the approximation.

 Approximation of a curved path in NC by a series of straight line segments, where tolerance is defined on (a) inside, (b) outside, and (c) both inside and outside of the actual curve



Absolute and Incremental Positioning

- An ABSOLUTE movement moves TO A COORDINATE based on your ZERO
 POINT.
- An **INCREMENTAL** movement moves **A DISTANCE** based on your **CURRENT POSITION**. An incremental movement does not take your part zero point into consideration.
Absolute vs. Incremental Positioning

The work head is presently at point (20, 20) and is to be moved to point (40, 50)

• In absolute positioning, the move is specified by

x = 40, y = 50

In incremental positioning, the move is specified by x = 20, y = 30



Summary

- Numerical Control (NC)
- Computer Numerical Control(CNC)
- Difference between NC & CNC
- Types of CNC machines
- Elements of CNC System