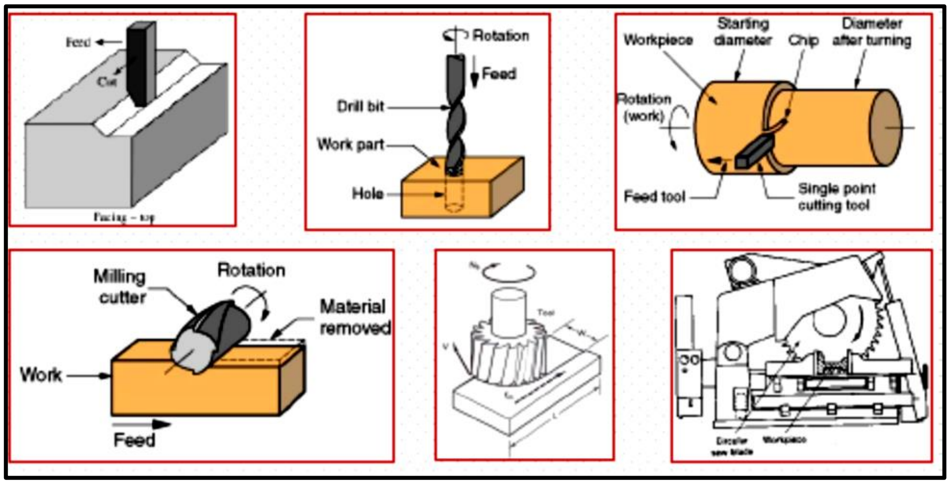
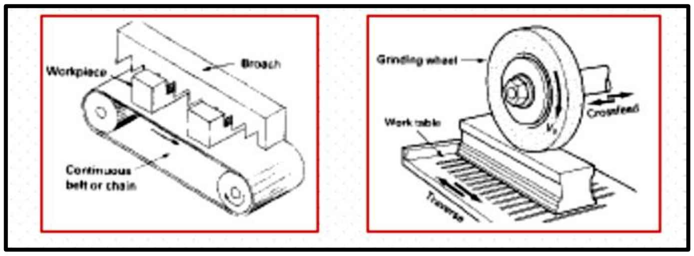
METAL CUTTING (MACHINING) PROCESSES

1.1 INTRODUCTION

Metal cutting, commonly called machining, is the removal of unwanted portions from a block of material in the form of chips so as to obtain a finished product of desired size, shape, and finish. There are seven basic machining and chip formation processes

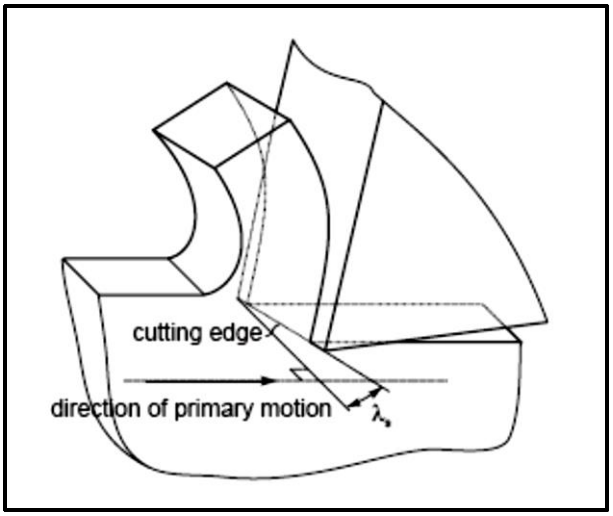
- Turning
- Milling
- Drilling
- Sawing
- Shaping (planning)
- Broaching
- Grinding and abrasive machining





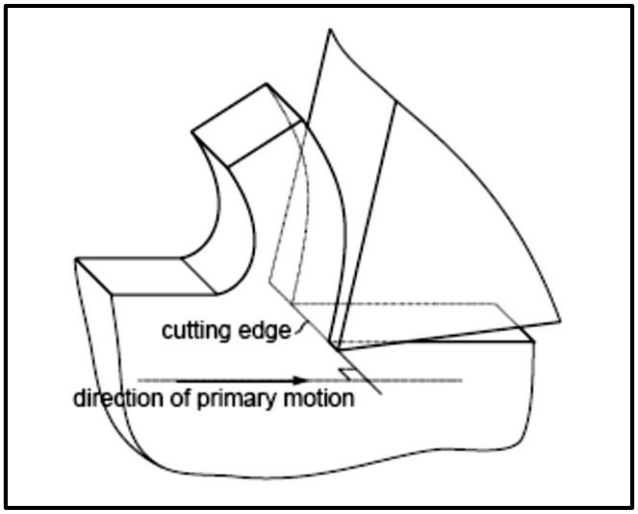
1.2 Geometry of the single point tool

***Oblique Cutting**: The cutting edge is set at an angle (the tool cutting edge inclination λs). This is the case of three-dimensional stress and strain conditions.*



Orthogonal cutting: The cutting edge is straight and is set in a position that is ***perpendicular*** *to the direction of primary motion.*

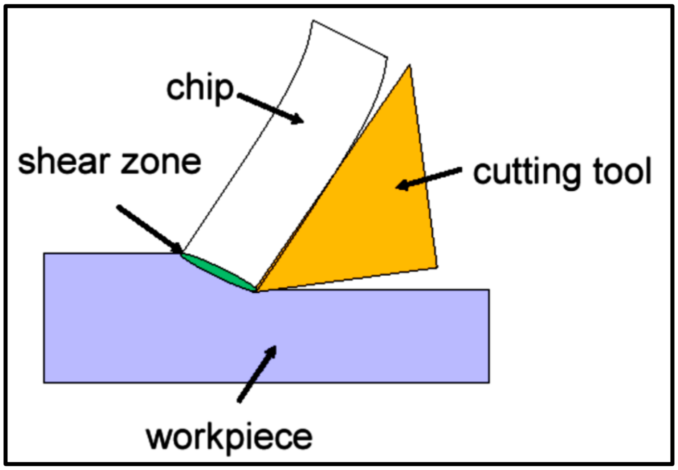
This allows us to deal with stresses and strains that act in a plane.

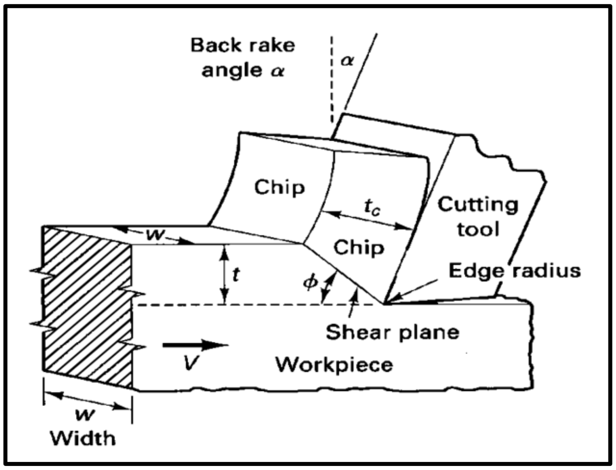


Probably the simplest model to analyze is the "Single Point Tool, Orthogonal Cutting" model. It is easier to visualize this model in terms of the turning process. Cutting is achieved by moving the tool relative to the part; it is convenient to separate the relative velocity into two components: cutting speed, ***V***, and feed rate***, f***.

Chip formation is a localized shear deformation resulting in the failure of the workpiece material immediately ahead of the cutting edges of the tool due to the force applied to the workpiece by the cutting tool, and relative motion between the tool and the workpiece. During ***orthogonal*** machining, shearing takes place along a plane making an angle, which is called the shear angle ϕ, with the horizontal.

This action transforms a volume of metal with thickness *t* and *w* (undeformed chip thickness and width, respectively) into a chip with thickness *tc* and width *w*.





Important observations during metal cutting are:

1. Distortion of the workpiece and the cutting tool due to the cutting force applied by the cutting tool.

2. Generation of heat due to the work required to deform the workpiece and the chip, friction between the face of the tool and the chip, friction between the flank of the tool and the workpiece.

3. High-strength materials require larger forces than do materials of lower strength, causing greater tool and workpiece deflections; increased friction force and heat generation, and temperature; and requirement of greater work input.

4. Highly ductile materials permit extensive plastic deformation of the chip during cutting, which increases work, heat generation, and temperature; they also result in continuous chips which remain in contact longer with the tool face, thus causing more frictional heat generation.

5. Brittle materials cause small segments of chips due to the brittle failure along the shear zone. Such chips are called discontinuous or segmented chips, and provide fairly good surface finish.

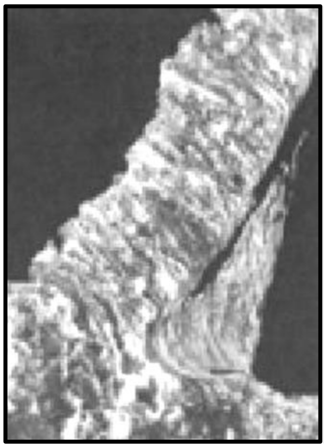
Discontinuous chips Are also observed when cutting with:

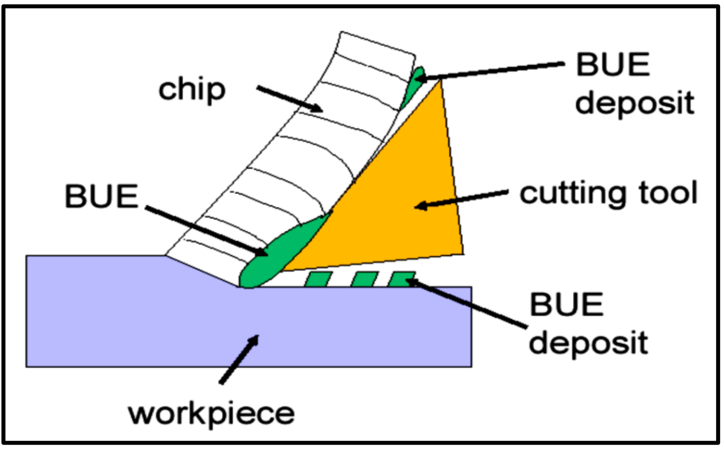
- Small rake angle
- Large depth of cut
- Machining ductile materials at ● low cutting speed ● large feed

Continuous Chip with Built-up Edge

Built-up Edge During machining, a thin layer of the workpiece material may get deposited on the surface of the tool. Due to high stresses, this layer becomes work-hardened; subsequently, more and more layers can get deposited above it, thus affecting the shape of the tool. Such deposition is called a built-up edge, and causes poor surface finish.

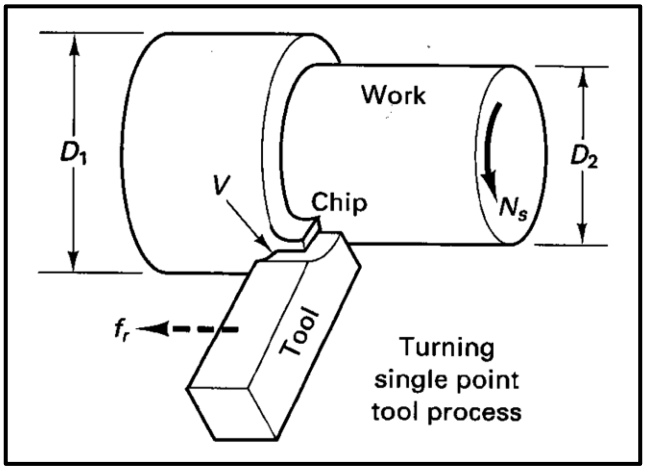
This undesirable occurrence causes vibration, poor surface finish, and shorter tool life.





Formation of built-up edge can be eliminated or minimized by 1) reducing the depth of cut; 2) increasing the cutting speed (while decreasing the depth of cut or/and feed); 3) increasing the rake angle; 4)using a cutting fluid (coolant).

1.3 Cutting Tool Geometry - Single Point Cutting Tool



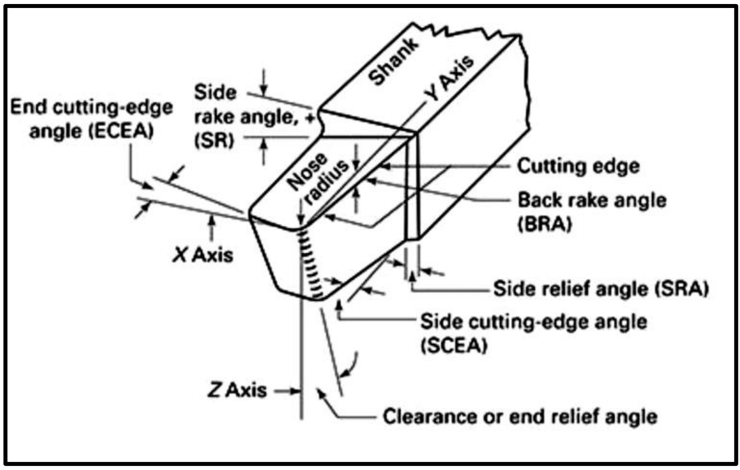
Important surfaces and angles on a typical HSS single-point cutting tool used in shaping or turning operations are:

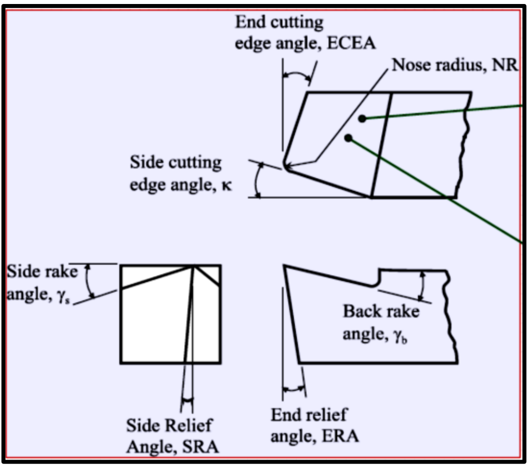
● ***Face*** is surface of the tool over which the chip flows.

● ***Flank*** is the surface of the tool which is in contact with the workpiece.

- ***Rake angles*** are used to define the inclination of the face and its determine the ‘knife-edge’ of the tool.
- The ***face*** is inclined backwards with respect to the cutting edge, so that the chip is directed upward from the machined surface.
- ***Relief angles*** are used to define the inclination of the surfaces of the tool which are in contact with the workpiece (e.g. flank). These surfaces are inclined, so that the rubbing of the tool on to the workpiece is prevented.

- ***True rake*** is defined as the inclination of the tool face at the cutting edge as measured in the direction of actual chip flow.
- The ***clearance angles*** eliminate as much friction as possible
- The ***nose radius*** is essential because it is not possible to make a very sharp leading edge, and even if we make one, such an edge will fracture after very little use.





Small rake angles cause high compression, tool forces, and friction which result a thick, highly deformed, hot chip.

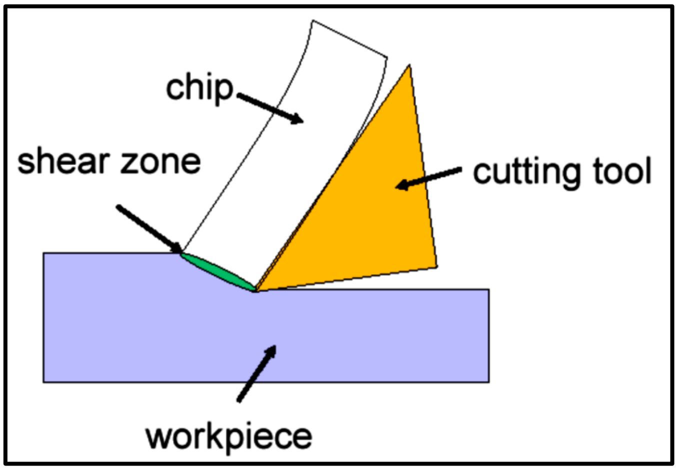
Large rake angles reduce compression, the forces, and the friction resulting in a thinner, less deformed, and cooler chip.

On the other hand ***larger positive rake angles*** cause reduced strength of the cutting tool due to the reduced tool section and reduced capacity to conduct heat away from the cutting edge.

In order to provide greater strength at the cutting edge and better heat conductivity, zero or negative rake angles are used on sintered carbide or ceramic cutting tools.

Shear Plane

Most cutting action is actually due to failure under shear. This is shown in the schematics below. Angle between tool face and shear plane is about 90 degrees.



1.4 Cutting Tool Materials

Cutting tool materials should have:

1. High Strength,

2. High impact strength (Toughness) to resist fracture,

3. High hardness and wear resistance at high temperatures,

4. Low coefficient of friction.

5. Favorable cost.

Cutting Tool Materials

1. High Speed Steel (HSS) (1900)

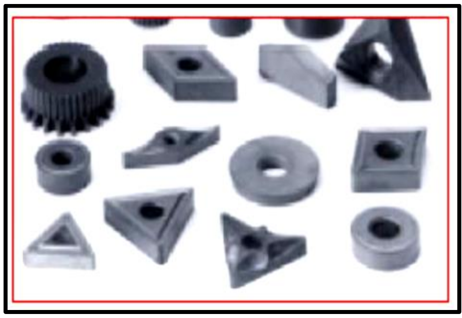
Typical composition of this high alloy steel is 18-4-1 (tungsten 18%, chromium 4%, vanadium 1%). Retains its hardness at temperatures up to 600°C. Compared with tool steel, it can operate at about double the cutting speed with equal life, resulting in its name high-speed steel. HSS is widely used for drills and many types of general-purpose milling cutters and in single-point tools used in general machining.

2. TiN Coated High Speed Steel (HSS) (1980)

Coated HSS provides significant improvements in cutting speeds, with increases of **10** to **20**% being typical. In addition to hobs, gear-shaper cutters, and drills; HSS tooling coated by TiN includes reamers, taps, chasers, spade-drill blades, broaches, band saw and circular saw blades, insert tooling, form tools, end mills, and an assortment of other milling cutters. **Physical vapor deposition** has proved to be the most viable process for coating.

3. Cemented Carbide (Sintered Carbide) (1947)

Nonferrous alloys produced by powder metallurgy. The early versions, which are still widely used, had tungsten carbide as the major constituent and cobalt as a binder. Cemented carbides [made by sintering ~94% Tungsten, ~6% Carbon, and < 1% Cobalt]. Recent types of carbides utilize very fine micro particles dispersed (cemented) in the carbide structure (approx.10% TiC and TaC) for improving toughness and tool life. They can be operated at cutting speeds 200 to 500 % greater than those used for HSS, and they have replaced HSS in many processes.



4. Ceramic (1950s)

Ceramics are made of pure aluminum oxide by powder metallurgy techniques. They can be operated at from two or three times the cutting speed of tungsten carbide, usually requiring no coolant. Usually they are in the form of disposable (throwaway) tips.

Cermets are best suited for finishing. Approximately 70 percent ceramic and 30 percent titanium carbide, are pressed into billets under extremely high pressure and temperature. After sintering, the billets are sliced to the desired tool shapes.

5. Diamond

Hardest material known. Diamond is pure carbon. Diamond machining is done at high speeds with fine feeds for finishing, and produces excellent finishes. Diamond particles are used in grinding wheels. Diamond tools are used for truing the grinding wheels.

.*6. Cubic Boron Nitride (CBN) (1965s)*

Similar to diamond in its polycrystalline structure and is also bonded to a carbide base. Hardest material known other than diamond. Retains it hardness at elevated temperatures (~ 1000°C). Still, CBN should mainly be considered as a finishing tool material because of its extreme hardness and brittleness. Can be used to machine hard aerospace materials.

7. Coated Carbide (1972)

A tough, shock-resistant carbide tool is coated with a thin, hard, crater resistant surface material.

- TiC-coated tools have two or three times the wear resistance of the best uncoated tool with the same breakage resistance. This results in 50 to 100 % increase in the speed for the same tool life.
- Ceramic (Al2O3)-coating permits 90 % speed increase in machining of steel. Gives excellent crater wear resistance.

1.5 Tool Wear (Failure), and Surface Finish

Cutting involves high stresses, high relative velocity between tool and chip/workpiece, and high temperatures of up to 1000°C. A tool may be said to reach end of its life when a further wear causes one, some or all of the followings.

1. Loss of dimensional accuracy of the workpiece,

2. Excessive surface roughness on the workpiece,

3. Increased power requirement of the machine tool,

4. Physical loss of the cutting edge of the cutting tool.

The cutting time accumulated before failure is termed as **tool life**.

1.6 Cutting Fluids

Coolants are used to decrease tool operating temperature and improve cutting performance. A good cutting fluid should act as a lubricant as well as removing the heat (coolant) from the cutting zone. Water is a good coolant, but is a poor lubricant and presents corrosion (rust) hazard.

On the other hand, oil is a good lubricant but is less effective in cooling. In practice, emulsion combinations of oil and water or wax and water are used as cutting fluids.

Advantages

1. *Tool life is increased.*

2. *Surface finish of the workpiece is improved.*

3. *Built-up edge formation is prevented.*

4. *Power consumed by the machine tool is reduced.*

5. *Corrosion hazard is reduced.*

6. *Chips are washed away and the cutting zone is kept clear.*

1.7 Turning Operations

Turning is widely used for machining external cylindrical and conical surfaces. The workpiece rotates and a longitudinally fed single point cutting tool does the cutting. Machine tools used for this process are called lathes.

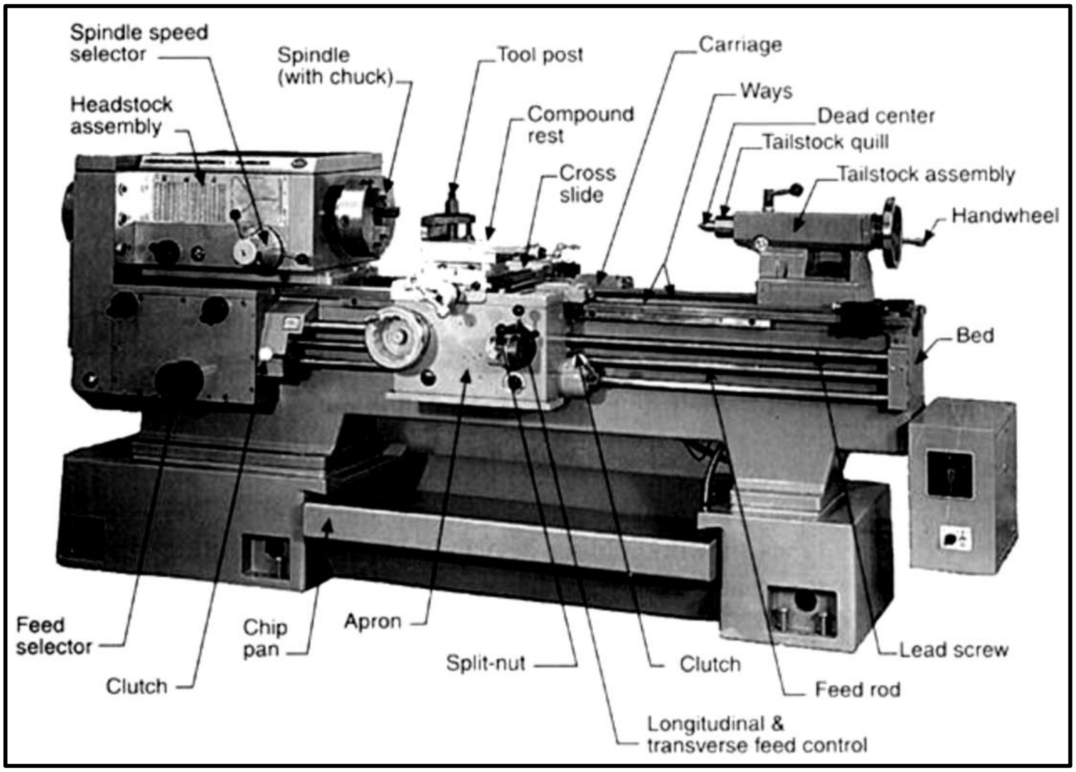


Figure 1. A manual lathe with its important parts labeled

The main turning operations are:

1. Turning (straight, taper, form and contour turning)

2. Boring Enlargement of an existing hole.

3. Facing

4. Cut off or Parting

5. Drilling, Reaming

Examples of components produced by **TURNING** in a lathe.

6. Thread cutting

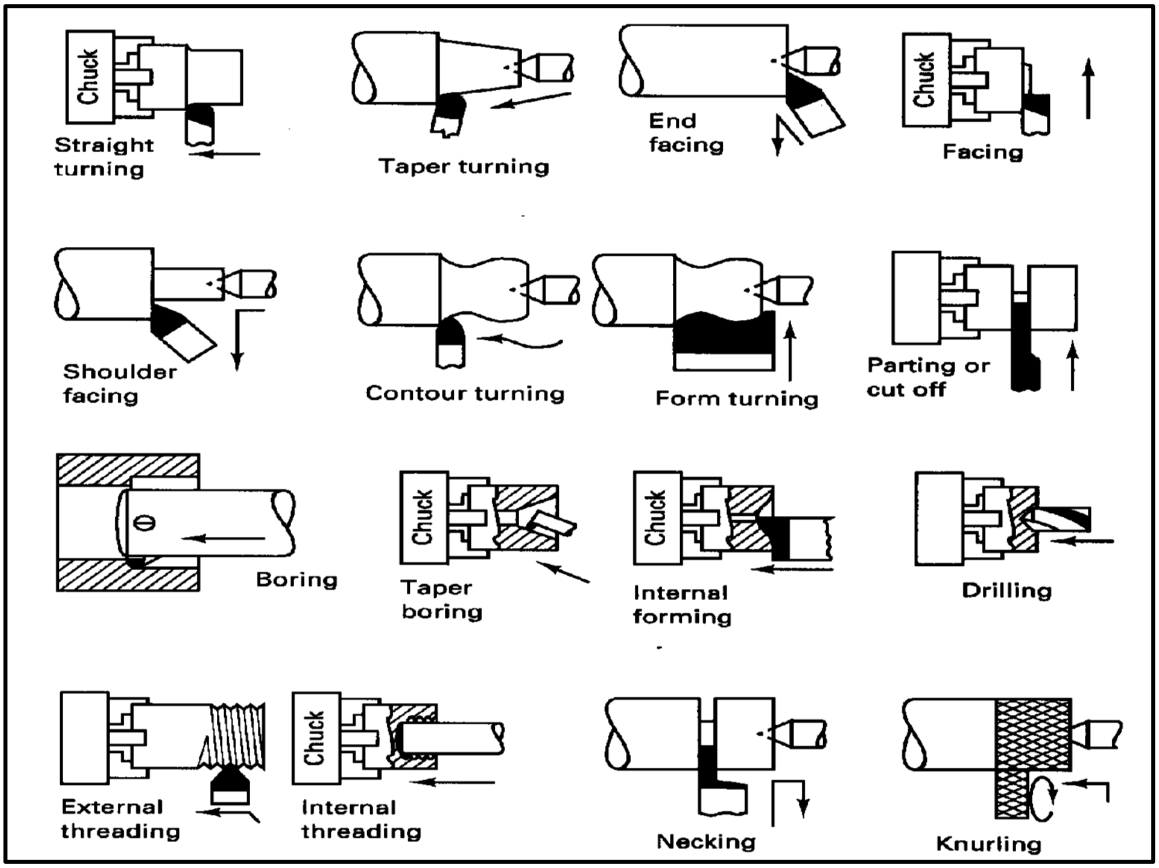
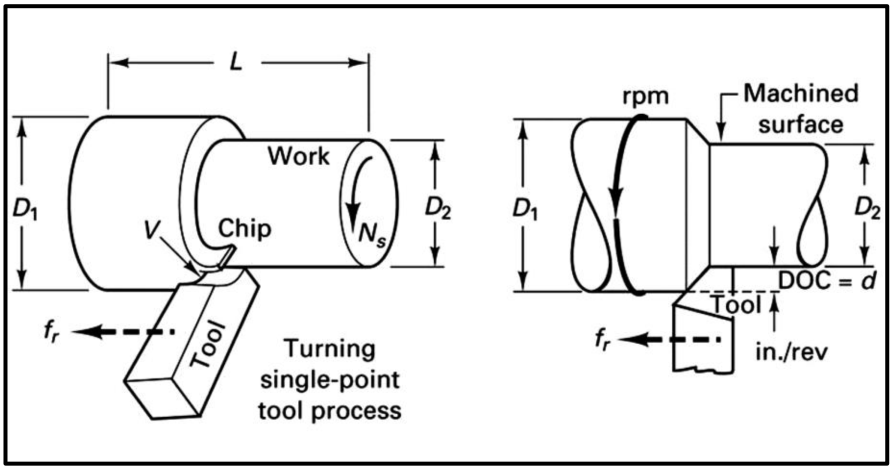


Figure 2. Typical lathe operations

1.7.1 Cutting conditions

Cutting speeds (V) specified for turning are the rotational speed of the workpiece which is being machined.



$$N = 1000 * V / \pi D$$

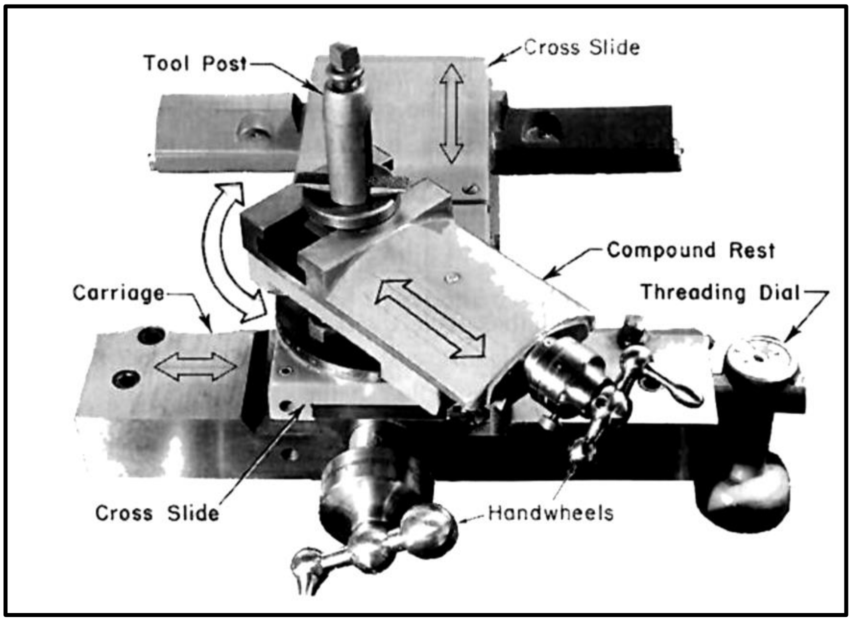
N –Workpiece rotational speed (rpm)
V -Cutting speed (m/min)
D -Workpiece diameter (mm)

Feed rate (F) is the axial advance of the tool along the workpiece during each revolution of the workpiece. It is expressed in mm/rev.

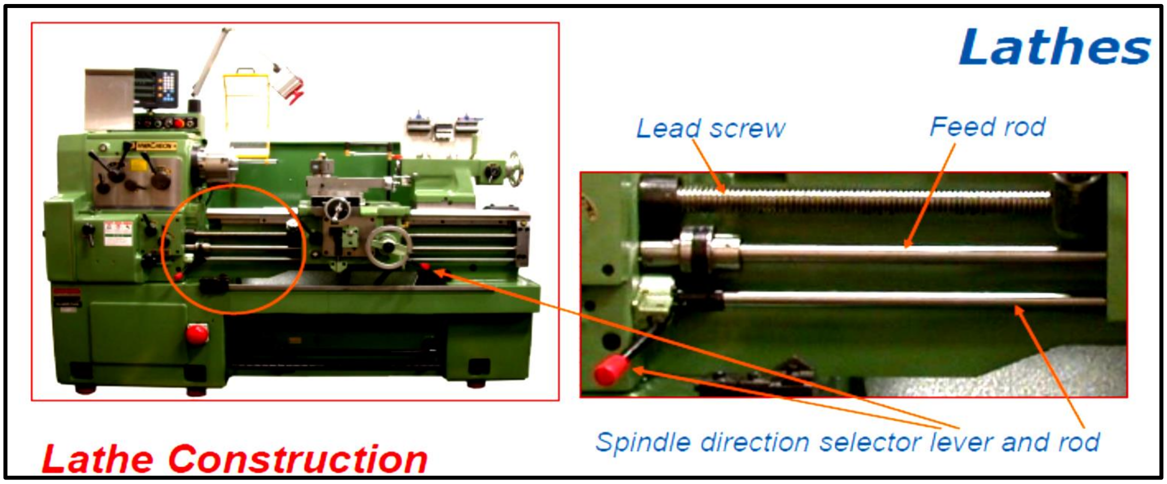
1.7.2 Lathe Construction

The essential components of a lathe are:

- Bed
- Headstock assembly
- Tailstock assembly
- Carriage assembly
- Quick-change gear box
- Lead screw
- Feed rod



Feed rod provides powered motion of the cross slide and the carriage for operations other than thread cutting. Lead screw is used to transmit the motion to the carriage for thread cutting.



1.7.3 Size Designation of Lathes

The size of a lathe is designated by two dimensions.

- The the maximum diameter of work that can be rotated on a lathe.
- The maximum distance between centers.

1.7.4 Types of Lathes

1. **Engine Lathes** The most frequently used one in manufacturing.
2. **Bench Type Lathe**
3. **Turret Lathes** Turret lathes are suitable for quantity production, since Two turrets, one on the tailstock, and the other on the cross slide,
5. **Multiple-Spindle Screw Machines**