NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF MECHANICAL ENGINEERING
COURSE MATERIALS

ME303 MACHINE TOOL AND DIGITAL MANUFACTURING

VISION OF THE INSTITUTION

To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION

NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values.

We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- Established in: 2002
- Course offered : B.Tech in Mechanical Engineering
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of Dr. A P J Abdul Kalam Technological University.

DEPARTMENT VISION

Producing internationally competitive Mechanical Engineers with social responsibility & sustainable employability through viable strategies as well as competent exposure oriented quality education.

DEPARTMENT MISSION

1. Imparting high impact education by providing conductive teaching learning environment.
2. Fostering effective modes of continuous learning process with moral & ethical values.
3. Enhancing leadership qualities with social commitment, professional attitude, unity, team spirit & communication skill.
4. Introducing the present scenario in research & development through collaborative efforts blended with industry & institution.

PROGRAMME EDUCATIONAL OBJECTIVES

PEO1: Graduates shall have strong practical & technical exposures in the field of Mechanical Engineering & will contribute to the society through innovation & enterprise.

PEO2: Graduates will have the demonstrated ability to analyze, formulate & solve design engineering / thermal engineering / materials & manufacturing / design issues & real life problems.

PEO3: Graduates will be capable of pursuing Mechanical Engineering profession with good communication skills, leadership qualities, team spirit & communication skills.

PEO4: Graduates will sustain an appetite for continuous learning by pursuing higher education & research in the allied areas of technology.

PROGRAM OUTCOMES (POS)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and

environmental considerations.

4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and teamwork**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environment
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSO)

PSO1: Students will be able to apply principles of engineering, basic sciences & analytics including multi variant calculus & higher order partial differential equations..

PSO2: Students will be able to perform modeling, analyzing, designing & simulating physical systems, components & processes.

PSO3: Students will be able to work professionally on mechanical systems, thermal systems & production systems.

COURSE OUTCOMES

CO1	Outline the mechanism of chip formation during machining and illustrate tool geometry and tool designation, also determine cutting forces, measure tool wear and assess the economics of machining in metal cutting.
CO2	Demonstrate the working principle, operation and applications of Lathe and drilling machines.
CO3	Demonstrate the working principle, operation and applications of various reciprocating machine tools and calculation of machining time.
CO4	Demonstrate the working principle, operation, applications of milling machines and nomenclature of milling cutters.
CO5	Apply the principle and applications of grinding and super finishing operations.
CO6	Acquire basic knowledge on the importance of digital manufacturing.

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	3		2								3	1	3	3
CO2	3	2										3	1	2	3
CO3	3	2										3	2	2	3
CO4	3	2										3	2	2	3
CO5	3	2										3	2	2	3
CO6	2	2			2							3	1	3	3

Note: H-Highly correlated=3, M-Medium correlated=2, L-Less correlated=1

SYLLABUS

Course code	Course Name	L-T-P-Credits	Year of Introduction
ME303	MACHINE TOOLS AND DIGITAL MANUFACTURING	3-0-0-3	2016

Prerequisite: Nil

Course Objectives: The main objectives of this course are

1. To introduce students to the scientific principles underlying material behavior during manufacturing processes so as to enable them to undertake calculations of forces, tool stresses and material removal rates.
2. To understand various machine tools such as lathe, drilling machine, reciprocating machines etc. and their operations.
3. To impart knowledge of appropriate parameters to be used for various machining operations.
4. To develop knowledge on the importance of milling grinding and super finishing in metal cutting process.
5. To introduce the fundamentals of digital manufacturing.

Syllabus

Introduction to metal cutting, Mechanism of metal removal, Merchants theory, Frictional forces in metal cutting, Thermal aspects of machining, General purpose machine tools, Principle and operation of lathe, Drilling machines, Reciprocating machines, Milling machines, Grinding machines, Super finishing operations, Semi-automatic machine tools, Single and multi-spindle machines, Introduction to digital manufacturing and digital manufacturing science.

Expected outcomes:

The students will be able to

1. Analyze various machining process and calculate relevant quantities such us velocities, forces and powers.
2. Identify and explain the function of the basic components of a machine tool.
3. Understand the limitations of various machining process with regard to shape formation and surface texture.
4. Apply cutting mechanics to metal machining based on cutting force and power consumption.
5. Understand the use of various machine tools and their fields of application.
6. Understand the principle and applications of grinding and super finishing operations.
7. Get a basic knowledge on the importance of digital manufacturing.

Text books

1. Chapman W. A. J., Workshop Technology, Viva books (P) Ltd,1988
2. HMT, Production Technology, Tata McGraw-Hill,2001
3. Zude Zhou, Shane (Shengquan) Xie and Dejun Chen, Fundamentals of Digital Manufacturing Science, Springer-Verlag London Limited,2012

Reference books

1. Acharkan. N., Machine Tool Design Vol. 1 to 4, MIR Publication,2000
2. Chernov, Machine Tools, MIR Publication,1984
3. Ghosh A. And Malic A. K., Manufacturing Science, East West Press, 2010
4. Hajra Choudary, Elements of workshop technology, Vol I & II, Media Publishers, 2010
5. Lihui Wang and Andrew Yeh Ching Nee, Collaborative Design and Planning for Digital Manufacturing, Springer-Verlag London Limited, 2009
6. Malkin Stephen, Grinding Technology: Theory and Applications of Machining with Abrasives, Industrial press, 2008
7. Poul De Garmo, J.T.Black, R.A.Kosher, Materials and Processes in Manufacturing, Prentice Hall of India Pvt. Ltd.,1997.

Course Plan

Module	Contents	Hours	End Sem. Exam. Marks
I	Introduction to metal cutting: Tool nomenclature – Attributes of each tool nomenclature – Attributes of feed and tool nomenclature on surface roughness obtainable	1	15%
	Orthogonal and oblique cutting - Mechanism of metal removal – Primary and secondary deformation shear zones	1	
	Mechanism of chip formation – Types of chips, need and types of chip breakers – Merchant's theory	1	
	Analysis of cutting forces in orthogonal cutting– Work done, power required (simple problems)	1	
	Friction forces in metal cutting – development of cutting tool materials	1	
	Thermal aspects of machining -Tool wear and wear mechanisms	1	
	Factors affecting tool life– Economics of machining (simple problems) Cutting fluids	1 1	
II	General purpose machine tools – Principle and operation of lathe – Types of lathes and size specification	1	15%
	Work holding parts of lathes and their functions – Main operations	1	
	Taper turning and thread cutting – Attachments	1	
	Feeding mechanisms, Apron mechanisms	1	
	Drilling Machines – Types – Work holding devices	1	
	Tool holding devices – Drill machine operations	1	
	Drilling machine tools – Twist drill nomenclature- cutting forces in drilling.	1	
	FIRST INTERNAL EXAMINATION		
III	Reciprocating machines: Shaping machines – Types – Size – Principal parts – Mechanism	1	15%
	Work holding devices – Operations performed – Tools	1	

	Cutting speed, feed and depth of cut – Machining time.	1	
	Slotting machines – Types – Size – Principal parts – Mechanism – Work holding devices	1	
	Operations performed – Tools – Cutting speed, feed and depth of cut	1	
	Planing machines – Types – Size – Principal parts – Mechanism – Work holding devices	1	
	Operations performed – Tools – Cutting speed, feed and depth of cut – Machining time- Surface roughness obtainable.	1	
IV	Milling machines – Types – Principal parts – Milling mechanism	1	15%
	Work holding devices – Milling machine attachments	1	
	Types of milling cutters – Elements of plain milling cutters	1	
	Nomenclature - Cutting forces in milling – Milling cutter materials	1	
	Up milling, down milling and face milling operations	1	
	Calculation of machining time	1	
	Indexing – Simple indexing – Differential indexing	1	
SECOND INTERNAL EXAMINATION			
V	Grinding machines – Classification – Operations – Surface, cylindrical and centreless grinding	1	20%
	Grinding mechanisms – Grinding wheels: Specification – types of abrasives, grain size	1	
	Types of bond, grade, structure – Marking system of grinding wheels – Selection of grinding wheels	1	
	Glazing and loading of wheels – Dressing and Truing of grinding wheels, surface roughness obtainable	1	
	Superfinishing operations: Lapping operation– Types of hand lapping – Lapping machines – Types of honing –Methods of honing	1	
	Types of honing stones – Honing conditions – Cutting fluids – Types of broaches – Force required for broaching – Surface roughness obtainable in lapping, honing and broaching operations.	1	
	Semi-automatic machine tools – Turret and capstan lathes. Automatic machine tools – Single and multi-spindle machines.	1	
V1	Introduction to Digital Manufacturing: Concepts and research and development status of digital manufacturing	1	20%
	Definition of digital manufacturing – Features and development of digital manufacturing.	1	
	Theory system of digital manufacturing science: Operation Mode and Architecture of Digital Manufacturing System	1	
	Operation reference mode of digital manufacturing system – Architecture of digital manufacturing system	1	
	Modeling theory and method of digital manufacturing science	1	
	Critical modeling theories and technologies of digital manufacturing science	1	
	Theory system of digital Manufacturing science – Basic	1	

	architecture model of digital manufacturing system.		
END SEMESTER EXAM			

Question Paper Pattern

Maximum marks: 100 **Time: 3 hrs**

The question paper should consist of three parts

Part A

There should be 2 questions each from module I and II

Each question carries 10 marks

Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part B

There should be 2 questions each from module III and IV

Each question carries 10 marks

Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part C

There should be 3 questions each from module V and VI

Each question carries 10 marks

Students will have to answer any four questions out of 6 (4X10 marks =40 marks)

Note: in all parts each question can have a maximum of four sub questions

QUESTION BANK

MODULE I			
Q:NO:	**QUESTIONS**	**CO**	**KL**
1	Analyze the tool nomenclature of a single point cutting tool with neat sketches.	CO1	K4
2	State the difference between orthogonal and oblique cutting.	CO1	K2
3	What are chips? Explain the types of chips and chip breakers used?	CO1	K2
4	Analyze the cutting force present during orthogonal cutting.	CO1	K4
5	Elaborate on factors affecting the tool life.	CO1	K1
6	What are the different wears in tool	CO1	K2
7	Discuss in details about the different factors related to economics of machining.	CO1	K2
8	Analyze the significance of different angles present in the cutting tool.	CO1	K4
9	Identify different materials used for developing tools.	CO1	K2
MODULE II			
1	What are the important size specifications to be followed during the construction of lathe?	CO2	K2
2	Classify different lathe machines available	CO2	K4
3	Describe with a neat sketch the principle and operation of a lathe.	CO2	K2
4	What are the major differences between three jaw and four jaw chucks?	CO2	K2
5	State and explain the various methods to attain tapered surface in lathe operation.	CO2	K1
6	Elaborate on different tool holding devices used in drilling operation.	CO2	K2
7	Describe the tool nomenclature of a twisted drilling tool.	CO2	K2
8	What are the different work holding parts available in a drilling operation?	CO2	K4

MODULE III

1	Analyze Whitworth and hydraulic quick return mechanism	CO3	K4
2	Identify the various operations performed in shaping machine.	CO3	K2
3	Briefly explain about slotting machine with neat sketch.	CO3	K2
4	rite short notes on various operations performed in planar.	CO3	K1
5	st the various types of planers used in industries.	CO3	K2
6	st few major differences between slotter, shaper and planer	CO3	K2
7	escribe the principal parts of a planar with neat sketches.	CO3	K2
8	rite short notes on Cutting speed, Feed and Depth of cut in planer.	CO3	K4
9	eneralize the various types shaping machines. Explain crank shaper.	CO3	K4

MODULE IV

1	Sketch the Plain Milling cutter Nomenclature elements.	CO4	K4
2	Explain the different angles of cutting.	CO4	K1
3	Classify the various Indexing methods used in Milling.	CO4	K2
4	Briefly explain about calculation of machining time in Milling.	CO4	K1
5	ifferentiate up milling and down milling.	CO4	K1
6	hat are the different types of milling cutters used in Milling?	CO4	K2
7	ith neat sketch analyze plain milling cutter and side milling cutter.	CO4	K4
8	assify the various types of milling machine attachments.	CO4	K2

MODULE V

1	fferentiate between centre less grinding and cylindrical grinding.	CO5	K2
2	w are grinding wheels specified?	CO5	K4
3	plain in details about the characteristics of a grinding wheel in terms of the abrasives used.	CO5	K4
4	hat are the factors considered in the selection of a grinding wheel?	CO5	K2

5	hat are the common faults occurring in a grinding wheel? Explain in details how they are resolved	CO5	K1
6	plain the process parameters of grinding operation	CO5	K2
7	Comment on capstan and turret lathe.	CO5	K2
8	hat is the difference between capstan and turret lathe compared to engine lathe.	CO5	K4
MODULE VI			
1	Define Digital manufacturing system.	CO6	K2
2	What are the different ideas in DM	CO6	K2
3	Analyze the important features of DM	CO6	K4
4	Sketch and explain operation reference mode of DMS.	CO6	K2
5	Illustrate architecture of DMS	CO6	K4
6	What is a product life cycle? Explain with flowchart.	CO6	K2
7	What are the different generalised modelling theories in DMS.	CO6	K1
8	Sketch and explain about GARI	CO6	K2

APPENDIX 1	
CONTENT BEYOND THE SYLLABUS	
S:NO.	**WEB SOURCE REFERENCES**
1	https://www.youtube.com/watch?v=rIdoIKukpnU
2	https://www.youtube.com/watch?v=hg5RlapdEtE
3	https://www.researchgate.net/publication/328419733_Machine_Tools_and_Digital_Manufacturing
4	https://msie4.ait.ac.th/wp-content/uploads/sites/5/2019/10/Digital-Manufacturing-Text-Book-1.pdf
5	http://fisatx.fisat.ac.in/courses/course-v1:FISAT+ME303+2020_T1

MODULE-1

INTRODUCTION TO METAL CUTTING

In Engineering industry, components are made of metals in different shapes, sizes and dimensions. Metals are shaped to the required forms by various processes. These processes can be generally divided into 2 groups.

1. Non cutting shaping process.
2. Cutting shaping process.

In non cutting shaping process the metal is shaped under the action of heat, pressure or both. Here there is no chip formation. This group includes operations like forging, drawing, spinning, drawing, extrusion etc.

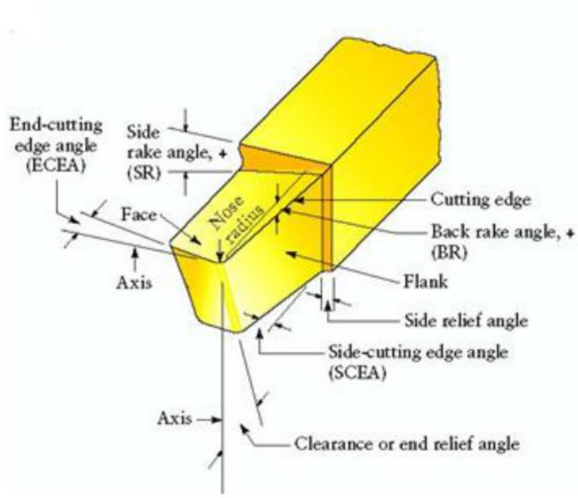
In cutting shaping process the required shape of metal is obtained by removing the unwanted material from the work piece in the form of chips. This group includes operations like turning, boring, milling, drilling, shaping, broaching etc. These operations are known as machining or metal cutting operations.

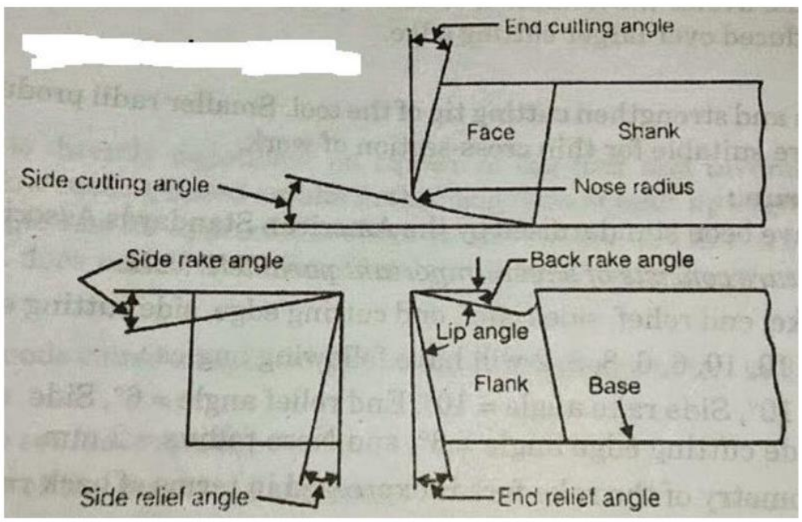
Machining Definition

Machining is a manufacturing process in which jobs are produced to the desired shape, dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tools moved past the work surface.

TOOL NOMENCLATURE

Nomenclature means systematic naming of the various parts and angles of a cutting tool.





Part	Description
Shank	It is the body of the tool which is ungrounded.
Face	It is the surface over which the chip slides.
Base	It is the bottom surface of the shank.
Flank	It is the surface of the tool facing the work piece. There are two flanks namely end flank and side flank.
Cutting edge	It is the junction of the face end the flanks. There are two cutting edges namely side cutting edge and end cutting edge.
Nose	It is the junction of side and end cutting edges.

1. **Back rake angle**

The back rake angle is the angle between the face of the tool and a line parallel to the base of the shank in a plane parallel to the side cutting edge.

It is the slope given to the face of the tool. Slope is given from nose along the length of the tool**.**

2. **Side rake angle**

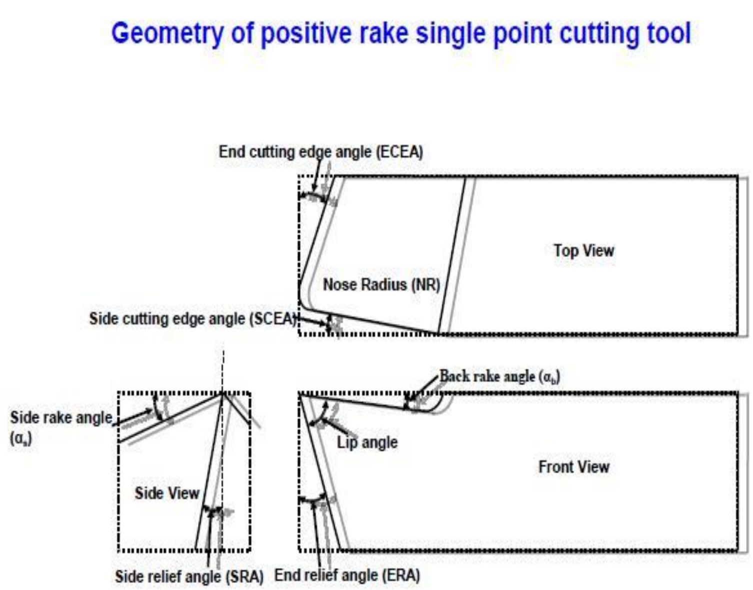
It is the angle by which the face of the tool is inclined sideways.

It is also the slope given to the face of the tool.

Slope is given from nose along the width of the tool

The side rake angle and the back rake angle combine to form the effective rake angle. This is also called true rake angle or resultant rake angle of the tool.

Positive Rake angle



Positive rake or increased rake angle reduces compression, the forces, and the friction, yielding a thinner, less deformed and cooler chip.

But increased rake angle reduces the strength of the tool section, and heat conduction capacity.

Positive rake angles is recommended

Machining low strength material

Low power machine

Long shaft of small diameter

Low cutting speed

Negative Rake angle

To provide greater strength at the cutting edge and better heat conductivity, zero or negative rake angles are employed on carbide, ceramic, polycrystalline diamond, and polycrystalline cubic boron nitride cutting tools.

Negative rakes increases tool forces but this is necessary to provide added support to the cutting edge. Negative rake

Increase edge strength

Increases life of the tool

Increases the cutting

force High cutting speeds

Requires ample power

Negative rake angles is recommended

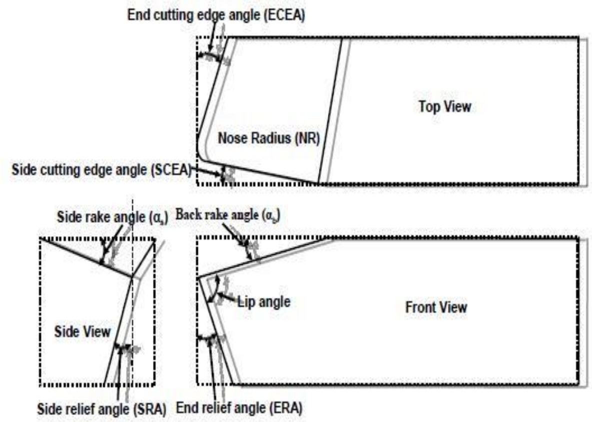
Machining high strength alloy

Heavy impact loads

High speed cutting

With rigid set- up

Geometry of negative rake single point cutting tool



Zero rake angle

To simplify design and manufacturing of the form tools. Increases tool strength

Avoids digging of the tool into the workpiece

Brass is turned with zero rake angle

Relief angles or clearance angle

Relief angles are provided to minimize physical interference or rubbing contact with machined surface and the work piece.

1. Side relief angle

2. End relief angle

Small relief angles are essential when machining hard and strong materials and they should be increased for the weaker and softer materials.

3. **Side relief angle:**

It is the angle between side flank surface and a line perpendicular to the shank of the tool.

The Side relief angle prevents the side flank of the tool from rubbing against the work when longitudinal feed is given. Larger feed will require greater side relief angle.

4. **End relief angle**

It is the angle between end flank surface and a line perpendicular to the shank of the tool measured in a plane perpendicular to the base of the tool.

The End relief angle prevents the end flank of the tool from rubbing against the work.

Cutting edge angle

These are provided to form the cutting edge.

2 cutting edge angles are their

1. Side cutting edge angle

2. End cutting edge angle

5. **Side cutting edge angle** : It is the angle between the side cutting edge and axis of the tool
6. **End cutting edge angle**: It is the angle between the end cutting edge and axis of the tool
7. **Lip angle or cutting angle** It is the angle between the face and end surface of the tool.
8. **Nose radius** It is the radius of the curved surface joins the side cutting edge & end cutting edge

ATTRIBUTES OF EACH TOOL NOMENCLATURE

1. **Rake angle**

The rake angle has the following function:

- It allows the chip to flow in convenient direction.
- It reduces the cutting force required to shear the metal and consequently helps to increase the tool life
- To reduce the power consumption for cutting.
- It provides sharpness to the cutting edge.
- It improves the surface finish

2. **Clearance angle**

- Reduce tool wear
- Increase tool life.
- Must be positive (3deg – 15deg.)

3. **Cutting Edge angle**

Side cutting edge angle The following are the advantages of increasing this angle, D

It increases tool life as, for the same depth of cut; the cutting force is distributed on a wider surface D

It diminishes the chip thickness for the same amount of feed and permits greater cutting speed. D It dissipates heat quickly for having wider cutting edge. ™

4. Nose radius (Functions of Nose Radius)

- Greater nose radius clears up the feed marks caused by the previous shearing action and provides better surface finish.
- It provides strengthening of the tool nose and better surface finish..
- If nose radius increased cutting force and cutting power increased.
- All finish turning tool have greater nose radius than rough turning tools

Tool signature

- It is the system of designating the principal angles of a single point cutting tool.
- The signature is the sequence of numbers listing the various angles, in degrees, and the size of the nose radius.
- There are several systems available like American standard system (ASA), orthogonal rake system (ORS), Normal rake system (NRS), and Maximum rake system (MRS).
- The system most commonly used is American Standard Association.

(ASA), which is:

- Bake rake angle, Side rake angle, End relief angle, Side relief angle, End cutting Edge angle, Side cutting Edge angle and Nose radius.

For example a tool may designated in the following sequence:

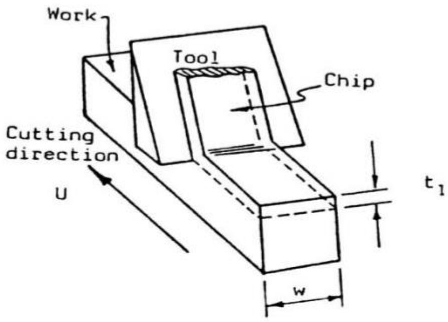
8-14-6-6-6-15-1

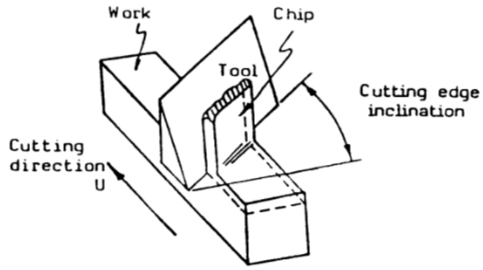
1. Bake rake angle is 8
2. Side rake angle is 14
3. End relief angle is 6
4. Side relief angle is 6
5. End cutting Edge angle is 6
6. Side cutting Edge angle is 15
7. Nose radius is 1 mm.

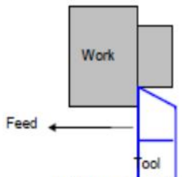
METHODS OF METAL

CUTTING Orthogonal Cutting

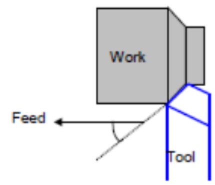
Oblique Cutting







Orthogonal cutting



Oblique cutting

Difference between Orthogonal(2 D) Cutting &Oblique (3D) Cutting

Orthogonal metal cutting	Oblique metal cutting
Cutting edge of the tool is perpendicular to the direction of tool travel.	The cutting edge is inclined at an angle less than 90° to the direction of tool travel.
The direction of chip flow is perpendicular to the cutting edge.	The chip flows on the tool face making an angle.
The chip coils in a tight flat spiral	The chip flows side ways in a long curl.
For same feed and depth of cut the force which shears the metal acts on a smaller areas. So the life of the tool is less.	The cutting force acts on larger area and so tool life is more.
Produces sharp corners.	Produces a chamfer at the end of the cut
Smaller length of cutting edge is in contact with the work.	For the same depth of cut greater length of cutting edge is in contact with the work.

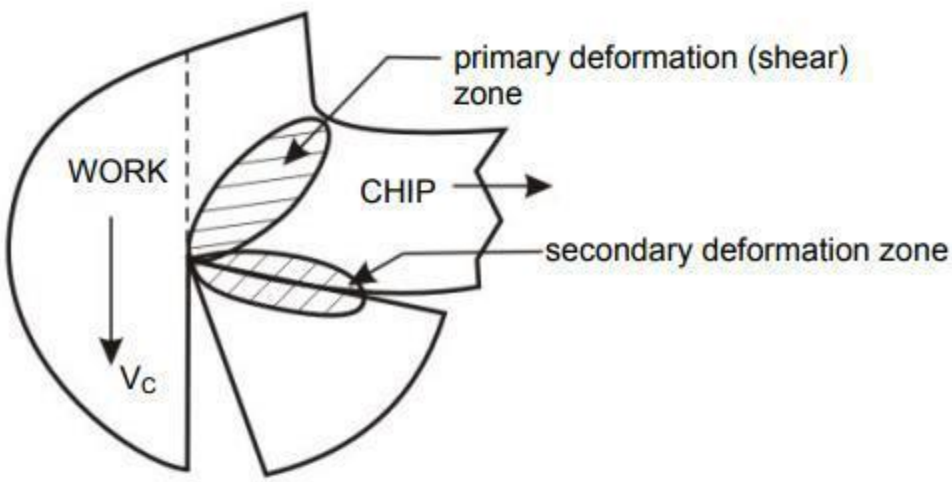
MECHANISM OF CHIP FORMATION

When the tool advances into the work piece, the metal in front of the tool is severely stressed. The cutting tool produces internal shearing action in the metal. The metal below the cutting edge yields and flows plastically in the form of chip. Compression of the metal under the tool takes place. When the ultimate stress of the metal is exceeded, separation of metal takes place. The plastic flow takes place in a localized area called as shear plane. The chip moves upward on the face of the tool.

The outward or shearing movement of each successive element is arrested by work hardening and the movement transferred to the next element.

The process is repetitive and a continuous chip is formed.

The plane along which the element shears, is called shear plane

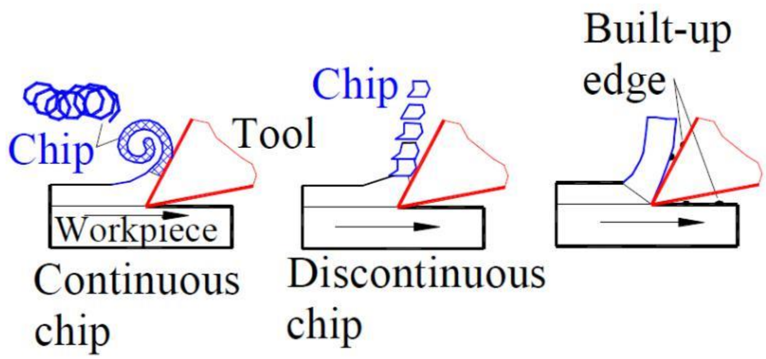


Primary and secondary deformation zones in the chip.

TYPES OF CHIPS

There are three different types of chips. They are

1. Continuous chips,
2. Discontinuous chips
3. Chips with built up edge(BUE)



Types of chip depends on

Work material (ductile, brittle)

Cutting tool geometry (rake angle, cutting angle etc.)

Cutting velocity and feed rate.

Types of cutting fluid and method of application.

Continuous chips

- When the cutting tool moves towards the work piece there occurs a plastic deformation of the work piece and the metal is separated without any discontinuity and it moves like a ribbon.

- The conditions that favor the production of continuous chips is small chip thickness, high cutting speed, sharp cutting edge, large rake angle in cutting tool and fine feed, smooth tool face and efficient lubricating system.

- Such chips are produced while machining ductile materials like mild steel, copper and aluminum. Because of plastic deformation of ductile material long and continuous chips are produced.

- This is desirable because it produces good surface finish, low power consumption and longer tool life.

- These chips are difficult to handle and dispose off. Further the chips coil in a helix and curl around work and tool and may injure the operator when it is breaking. The tool face is in contact for a longer period resulting in more frictional heat. However this problem could be rectified by the use of chip breakers.

Discontinuous chips :

- These chips are produced when cutting more brittle materials like bronze, hard brass and gray cast iron.

- Since there chips break up into small segments the friction between chip and tool reduces resulting in better surface finish.
- These are convenient to handle and dispose off.

- Discontinuous chips are produced in ductile materials under the conditions such as large chip thickness, low cutting speed, small rake angle of tool etc.

- If these chips are produced from brittle materials, then the surface finish is fair, power consumption is low and tool life is reasonable however with ductile materials the surface finish is poor and tool wear is excessive .

Chips with built up edge(BUE) :

- This is nothing but a small built up edge sticking to the nose of the cutting tool. These built up edge occurs with continuous chips.

- When machining ductile materials due to conditions of high local temperature and extreme pressure the cutting zone and also high friction in the tool chip interface, there are possibilities of work material to weld to the cutting edge of tool and thus forming built up edges.

- This weld metal is extremely hard and brittle. This welding may affect the cutting action of tool.

- Successive layers are added to the build up edge. When this edge becomes large and unstable it is broken and part of it is carried up the face of the tool along with chip while remaining is left in the surface being machined. Thus contributing to the roughness of surface.

- Conditions favoring the formation of build up edge are low cutting speed, low rake angle, high feed and large depth of cut, ductile material,Cutting fluid absent or in adequate This formation can be avoided by the use of coolants and taking light cuts at high speeds. This leads to the formation of crater on the surface of the tool.

Reduction or Elimination of BUE

Increase
↑ Cutting speed
↑ Rake angle
↑ Ambient work piece temperature.

Reduce
↓ Feed
↓ Depth of cut

Use
- Cutting fluid
- Change cutting tool material (as cermets).

CHIP BREAKERS

During machining, long and continuous chip will affect machining. It will spoil tool, work and machine. It will also be difficult to remove metal and also dangerous. The chip should be broken into small pieces for easy removal, safety and to prevent damage to machine and work. The function of chip breakers is to reduce the radius of curvature of chips and thus break it.

Types of chip breakers

The chip breaker classified into groove type and obstruction type

1.Groove type chip breaker: A small groove is provided behind the leading cutting edge of the tool insert on the rake face . The geometry of groove determines the radius of chip curvature.

2.Step type

In this a step is ground on the face of the tool along the cutting edge.

3.Clamp type

In this a thin carbide plate or clamp is brazed brazed or screwed on the face of the tool.

ANALYSIS OF CUTTING FORCES IN ORTHOGONAL METAL CUTTING

Assumptions in orthogonal metal cutting

1. No contact at the flank i.e. the tool is perfectly sharp.

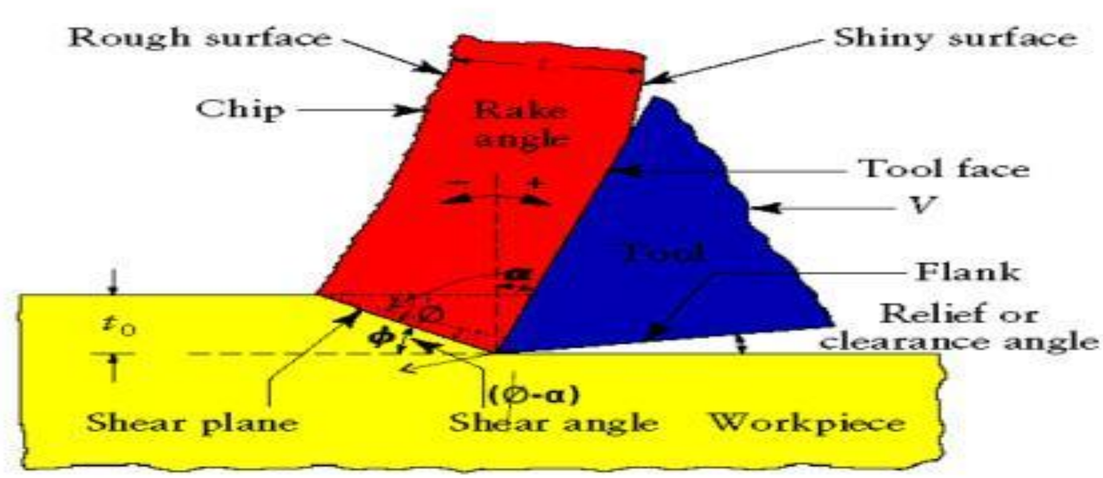
2. No side flow of chips i.e. width of the chips remains constant.

3. Uniform cutting velocity.

4. A continuous chip is produced with no built up edge.

5. The chip is considered to be held in equilibrium by the action of the two equal and opposite resultant forces R and R1 and assume that the resultant is collinear.

Metal cutting Terminologies



Chip thickness ratio (r) or cutting ratio.

The outward flow of the metal causes the chip to be thicker after the separation from the parent metal. That is the chip produced is thicker than the depth of cut.

Let t= chip thickness before cutting(uncut chip thickness)

tc = chip thickness after cutting (cut chip thickness)

Then **Chip thickness ratio (r) =(** t / tc)

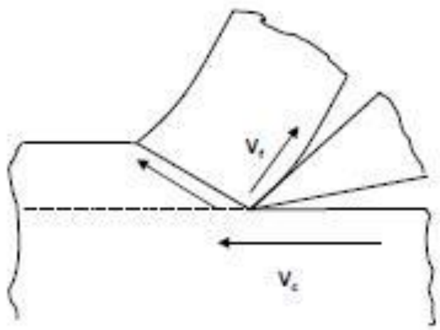
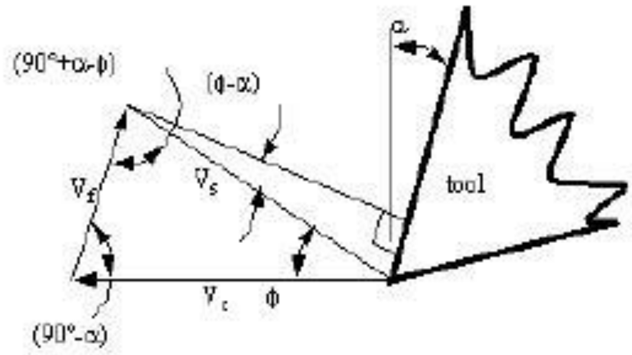
Chip thickness ratio is always less than unity. If the ratio **r** is large the cutting action is good.

Chip reduction co efficient, **K = (1 / r)**

When metal is cut there is no change in volume of the metal

VELOCITY RELATIONSHIP IN ORTHOGONAL METAL CUTTING

The relationship of different velocities in orthogonal metal cutting is shown in figure. Let the velocities are shown in figure

Vc= Velocity of tool relative to work or the cutting velocity

Vf= Velocity of chip flow relative to tool

Vs= Velocity of displacement of the chip along the shear plane relative to work ,or the velocity of shear.

Of the above 3 velocities cutting velocity Vc is always known . The other 2 can be computed with the help of the following relations.

Analytically,

$$\frac{v_c}{\sin(90-(\phi-\alpha))} = \frac{v_f}{\sin\phi} = \frac{v_s}{\sin(90-\alpha)}$$

$$\frac{v_c}{\cos(\phi-\alpha)} = \frac{v_f}{\sin\phi} = \frac{v_s}{\cos\alpha}$$

where,
V_c = cutting velocity (ft./min.) - as set or measured on
V_s = shearing velocity
V_f = frictional velocity

$$v_f = \frac{v_c \sin\phi}{\cos(\phi-\alpha)} \qquad \left[r = \frac{\sin\phi}{\cos(\phi-\alpha)}\right]$$

$$v_f = v_c \times r$$

Volume of material per unit time = Volume of material flowing up the chip

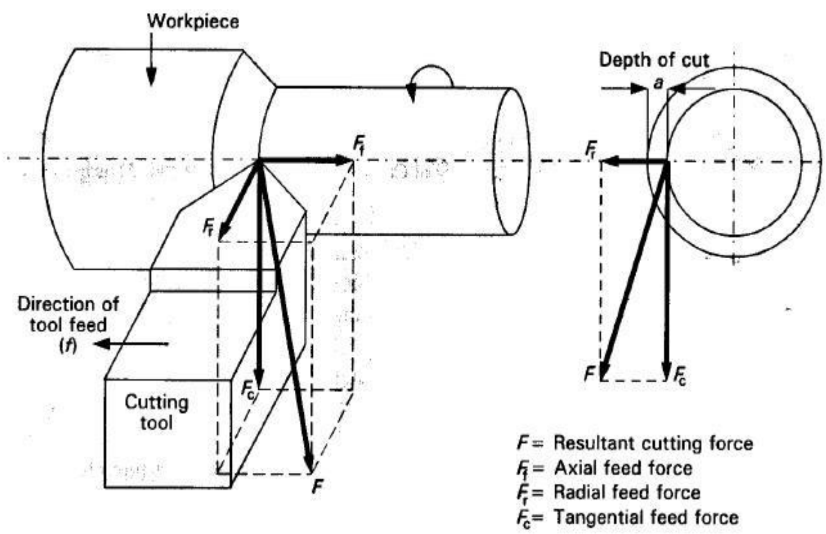
$$\Rightarrow v_c \times t_0 \times w = v_f \times t_c \times w$$

$$v_s = \frac{v_c \cos\alpha}{\cos(\phi-\alpha)}$$

$$\Rightarrow v_f = v_c \times r \quad \text{As, } r = \frac{t_0}{t_c}$$

CUTTING FORCES

The force system in general case of conventional turning process



The largest magnitude is the vertical force Fc which in turning is larger than feed force Ff, and Ff is larger than radial force Fr.

For orthogonal cutting system Fr is made zero by placing the face of cutting tool at 90 degree to the line of action of the tool.

$$\overline{R} = \overline{F}_x + \overline{F}_y + \overline{F}_z$$
$$= \overline{F}_c + \overline{F}_f + \overline{F}_r$$

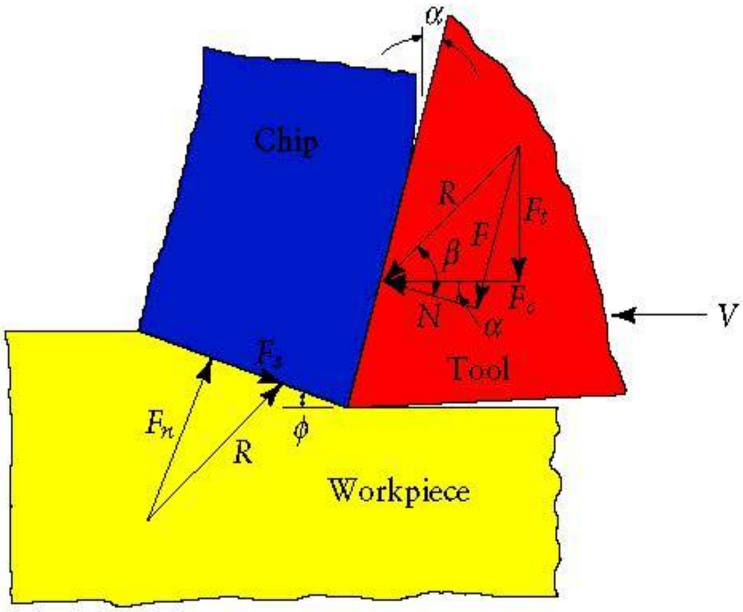
Tangential Force (Cutting Force) ($\overline{F}_c$), Feed Force ($\overline{F}_f$), Radial Force ($\overline{F}_r$)

In orthogonal cutting

$$\overline{R} = \overline{F}_c + \overline{F}_t$$

Thrust Force ($\overline{F}_t$)

Forces acting on Chip in two-dimensional cutting



Fs = Shear Force, which acts along the shear plane, is the resistance to shear of the metal in forming the chip.

Fn = Force acting normal to the shear plane, is the backing up force on the chip provided by the workpiece. (Compressive force)

F = Frictional resistance of the tool acting against the motion of the chip as it moves upward along the tool.

N = Normal to the chip force, is provided by the tool.

Fc = Cutting force ,

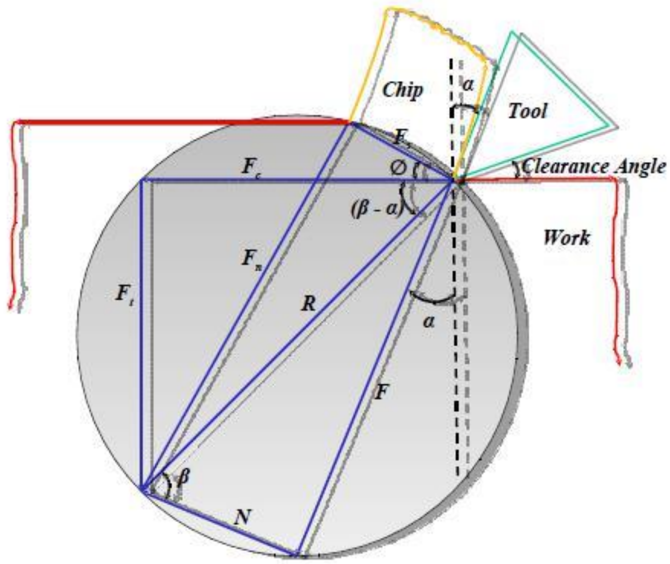
Ft = Feed force or thrust force

Merchant's Circle Diagram

The following is a circle diagram. Known as Merchant's circle diagram, which is convenient to determine the relation between the various forces and angles. In the diagram two force triangles have been combined and R and R/ together have been replaced by R. the force R can be resolved into two components Fc and Ft. Fc and Ft can be determined by force dynamometers.

$$R = F_c + F_t$$

The rake angle (α) can be measured from the tool, and forces F and N can then be determined. The shear angle (f) can be obtained from it's relation with chip reduction coefficient. Now Fs & Fn can also be determined.



The procedure to construct a merchants circle diagram

Set up x-y axis labeled with forces, and the origin in the centre of the page. The cutting force (Fc) is drawn horizontally, and the tangential force (Ft) is drawn vertically. (Draw in the resultant (R) of Fc and Ft.

Locate the centre of R, and draw a circle that encloses vector R. If done correctly, the heads and tails of all 3 vectors will lie on this circle.

Draw in the cutting tool in the upper right hand quadrant, taking care to draw the correct rake angle (α) from the vertical axis.

Extend the line that is the cutting face of the tool (at the same rake angle) through the circle. This now gives the friction vector (F).

A line can now be drawn from the head of the friction vector, to the head of the resultant vector (R). This gives the normal vector (N). Also add a friction angle (**β**) between vectors R and N. Therefore, mathematically, R = Fc + Ft =F+N.

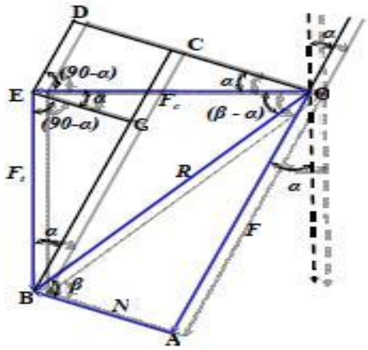
Draw a feed thickness line parallel to the horizontal axis. Next draw a chip thickness line parallel to the tool cutting face.

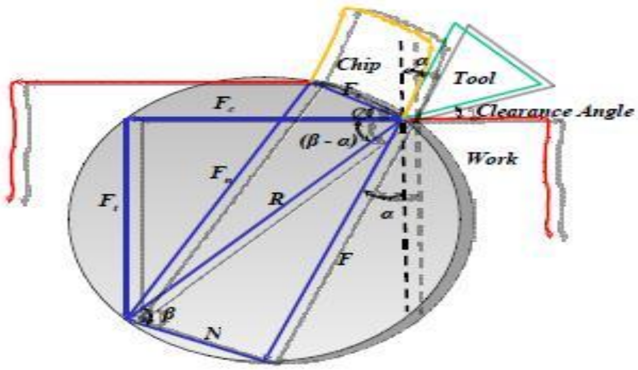
Draw a vector from the origin (tool point) towards the intersection of the two chip lines, stopping at the circle. The result will be a shear force vector (Fs). Also measure the shear force angle between Fs and Fc.

Finally add the shear force normal (Fn) from the head of Fs to the head of R. Use a scale and protractor to measure off all distances (forces) and angles

Relationship of various forces acting on the chip with the horizontal and vertical cutting force from Merchant circle diagram

Frictional Force System





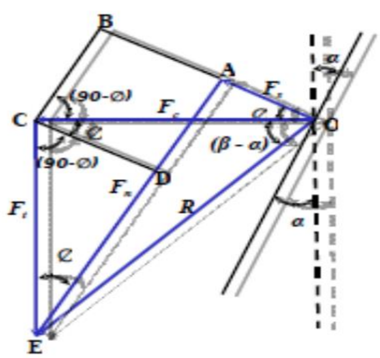
$$F = OA = CB = CG + GB = ED + GB$$
$$\Rightarrow F = F_C \sin\alpha + F_t \cos\alpha$$
$$N = AB = OD - CD = OD - GE$$
$$\Rightarrow N = F_C \cos\alpha - F_t \sin\alpha$$

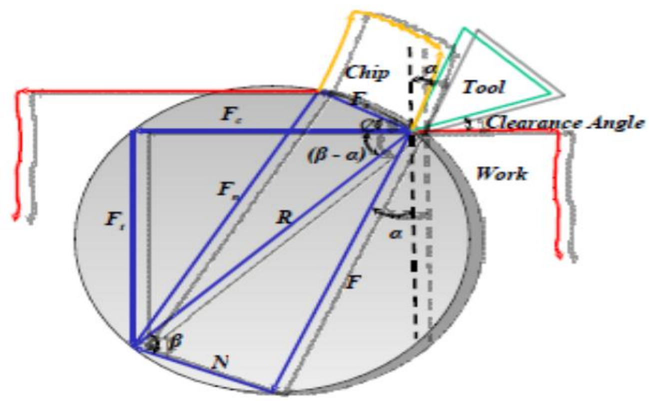
The coefficient of friction

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

Where $\beta = Friction\ angle$

Shear Force System

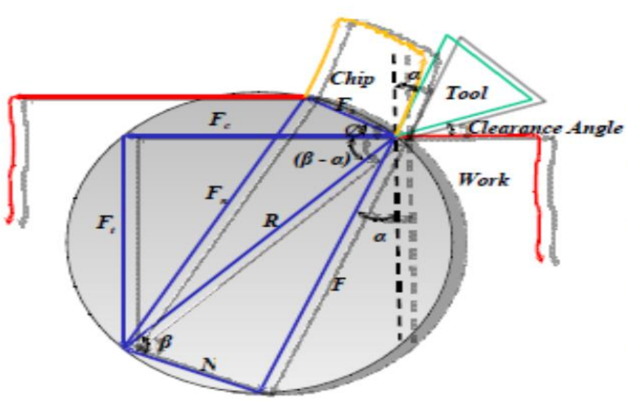




$$F_S = OA = OB - AB = OB - CD$$
$$\Rightarrow F_S = F_C \cos\phi - F_t \sin\phi$$
$$F_N = AE = AD + DE = BC + DE$$
$$\Rightarrow F_N = F_C \sin\phi + F_t \cos\phi$$

Also:

$$F_N = F_S \tan(\phi + \beta - \alpha)$$



$$F = F_C \sin\alpha + F_t \cos\alpha$$
$$N = F_C \cos\alpha - F_t \sin\alpha$$
$$F_S = F_C \cos\phi - F_t \sin\phi$$
$$F_N = F_C \sin\phi + F_t \cos\phi$$
$$F_N = F_S \tan(\phi + \beta - \alpha)$$

CUTTING TOOL MATERIALS

Properties required for a Cutting tool material

Hardness:

The tool material must be harder than the work piece material.

Higher the hardness, easier it is for the tool to penetrate the work material

Hot hardness

Hot Hardness is the ability of the cutting tool must to maintain its Hardness and strength at elevated temperatures.

This property is more important when the tool is used at higher cutting speeds, for increased productivity

Toughness

Inspite of the tool being tough, it should have enough toughness to withstand the impact loads that come in the start of the cut to force fluctuations due to imperfections in the work material

Wear Resistance

Wear resistance means the attainment of acceptable tool life before tools need to be replaced.

Low friction:

The coefficient of friction between the tool and chip should be low. This would lower wear rates and allow better chip flow.

Thermal characteristics:

Since a lot of heat is generated at the cutting zone, the tool material should have higher thermal conductivity to dissipate the heat in shortest possible time, otherwise the tool temperature would become high, reducing its life

The commonly used cutting tool materials are

1. Carbon steel
2. Medium alloy steel
3. High Speed Steel (1900)
4. Cemented Carbides(1926-30)
5. Ceramics (1950s)
6. Stellites

7. Abrasives
8. CBN(Cubic Boron Nitride) (1962)

9. Diamond

Carbon steel

These are the oldest of the tool materials No sufficient hardness and wear resistance Low thermal resistance value

Low hot hardness value (200- 250 ºC)

Limited to low cutting speed operation (12 m/min)

Inexpensive, easily shaped, sharpened.

Used in tools like-files, core drills ,short reamers etc

Composition C 0.7 to 1%,Si 0.5%, Mn 0.5%

Medium alloy steel

Similar to carbon steel with the addition of other elements like Cr,Mo,W Hot hardness value (250-300ºC)

Composition C up to 1.3 %, Si up to 0.4%, Mn 0.25-.75%

Cr 0.4 to 0.8 % W 1 to 5 % Fe (balance)

High Speed Steel

Mostly used in industries

They can be used at higher cutting speed(2 to 3 times higher than for C Steel) . So it is called HSS.

Hot hardness value (900ºC)

Good wear resistance

High toughness

Good for positive rake angle tools

Widely used alloy steel

Alloy of Tungsten, Chromium, Vanadium, Cobalt& Molybdenum They are of 3 types:

Tungsten HSS (denoted by T), Molybdenum HSS (denoted by M). Cobalt HSS (Super HSS)

5. <u>18-4-1 HSS</u>

6. <u>Cobalt HSS (Super HSS)</u>

1. Molybdenum HSS

W-6% C r-4% V-2% Mo-6%

Cemented Carbides

Composing of Carbon , Tungsten Carbide, Titanium Carbide.

Manufacturing

1. Mixed (tungsten + pure carbon) at 1500 ºC in the ratio of 94:6 by weight
2. New compound(now tungsten carbide) mixed with cobalt to control the toughness of the tool
3. Above homogeneous mixture pressed at 1000 to 4200 kg/cm²
4. Then heated with the presence of H_2
5. Cut into different shapes

Ceramics

Low heat conductivity(Used without coolant)

Quite brittle

Cannot be used for tools operating in interrupted cuts

High temp. Resistance (Up to 1200 ºC)

Cutting speed more than 40 times of HSS

Manufacturing

Aluminium oxide powder is taken in mould and pressed at a pressure of 300 kg/cm² and then sintered at 2000 ºC.

Tool tip is prepared and brazed or clamped to the shank of cutting tool

Stellites

Non ferrous cast Alloy

Cobalt	40-48%
Chromium	30 - 35%
Tungsten	10 -20 %
C-Content	1.8-2.5%

1. High hardness
2. Good wear resistance
3. High temperature hardness(Up to1000 ºC)
4. No Toughness

5. Not widely used in metal cutting because it is too brittle.

6. Used for cutting rubber, plastic

CBN(Cubic Boron Nitride)

1. Hardest tool material available next to diamond

2. This material consist of atoms of nitrogen and boron.

3. High hardness, tensile strength, wear resistance

4. Traded in the name of BOROZON

5. A thin layer of (0.5 mm) CBN is applied to cemented carbide tools to improve machining performance

Diamond

- Hardest , incompressible
- Readily conduct heat , Low coefficient of friction
- Cutting speed 50 times greater than HSS
- Temp Resistance up to1650 ºC
- Used for cutting glass, plastics
- high wear resistance

Coated carbide tools

1. Coated with layer of optimum thickness of Titanium carbide ,Titanium carbonitride,and titanium nitride

1. Layer coated is carried out by chemical vapour deposition process

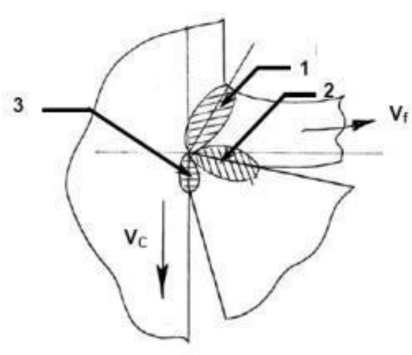
THERMAL ASPECTS OF MACHINING

According to the first law of thermodynamics, when work is transformed into heat, the quantity of heat produced is equivalent to the quantity of work. Heat generated, through conversion of mechanical energy. The three distinct sources of heat in metal cutting are given below:

The shear zone, 1,where the primary plastic or shear deformation takes place The chip-tool interface, 2, where secondary plastic deformation due to

friction between the heated chip and tool takes place.

The work- tool interface, 3, at flanks where frictional rubbing occurs



Sources of heat in metal cutting

For example, in a typical study of machining mild steel at 30 m/min at about 750 deg of cutting temperature at tool-chip interface, the distribution of total energy developed at the shear zone is as follows

Energy at chip – 60 percent

Energy to workpiece – 30 percent

Energy to tool - 10 percent

The rate of energy consumption during orthogonal cutting is given by Wc = Fc Vc Where FC = Cutting force , N

Vc = cutting speed , m/min

When a material is deformed clastically, the energy used is stored in the material as strain energy and no heat is generated. However, when a material is deformed plastically almost all the energy used is converted into heat.

In metal cutting , the material is subjected to extremely high strains and elastic deformation forms a very small proportion of the total deformation, hence all the energy is assumed to be converted into heat.

Thus Q = Fc Vc / J where J is mechanical equivalent of heat

The cutting energy is converted into heat in two principal regions of plastic deformation The shear zone or primary deformation zone AB Secondary deformation zone BC.

EFFECTS OF THE HIGH CUTTING TEMPERATURE ON TOOL AND WORK

High cutting temperatures are detrimental to both the tool and the job. The major portion of the heat is taken away by the chips. But it does not matter because chips are thrown out. So attempts should be made such that the chips take away more and more amount of heat leaving small amount of heat to harm the tool and the job. The possible detrimental effects of the high cutting temperature on cutting are:

On tool

Rapid tool wear , which reduces tool life

Cutting edges plastically deform and tool may loose its hot hardness

Thermal flaking and fracturing of cutting edges may take place due to thermal shock

Built up edge formation

Dimension inaccuracy of work duet to thermal distortion and expansion and contraction during and after machining

Surface damage by oxidation, rapid corrosion, burning etc.

Tensile residual stresses and microcracks at the surface and sub surfaces.

DETERMINATION OF CUTTING TEMPERATURE

1.Calorimetric method – quite simple and low cost but inaccurate and gives only grand average value

1. Decolourising agent – some paint or tape, which change in colour with variation of temperature, is pasted on the tool or job near the cutting point; the as such colour of the chip (steels) may also often indicate cutting temperature

3.Tool-work thermocouple – simple and inexpensive but gives only average or maximum value

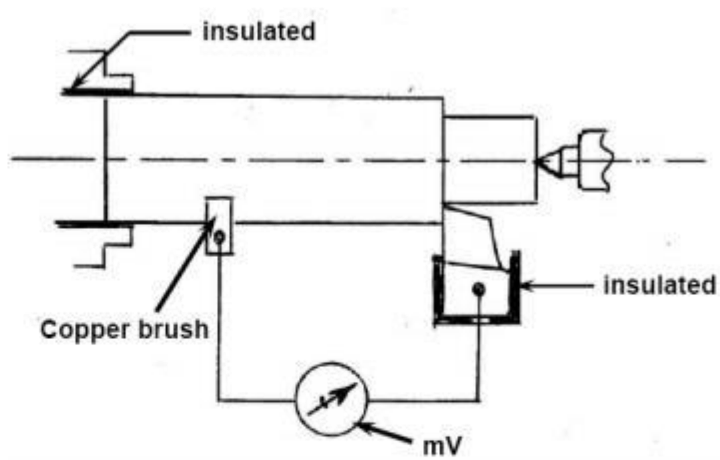
1. **Moving thermocouple technique**

5.Embedded thermocouple technique

6.Photo-cell technique

7.Infra ray detection method

Tool work thermocouple technique



In a thermocouple two dissimilar but electrically conductive metals are connected at two junctions. Whenever one of the junctions is heated, the difference in temperature at the hot and cold junctions produce a proportional current which is detected and measured by a milli-voltmeter.

In machining like turning, the tool and the job constitute the two dissimilar metals and the cutting zone functions as the hot junction as shown in Figure . Then the average cutting temperature is evaluated from the mV after thorough calibration for establishing the exact relation between mV and the cutting temperature.

TOOL WEAR

Mainly 4 types of wear

5. **Flank Wear**
6. **Crater Wear**
7. **Chipping off of the cutting edge**

Rounding of the cutting edge.

2. Flank Wear: Wear occurred on the flanks of the cutting tool**.**

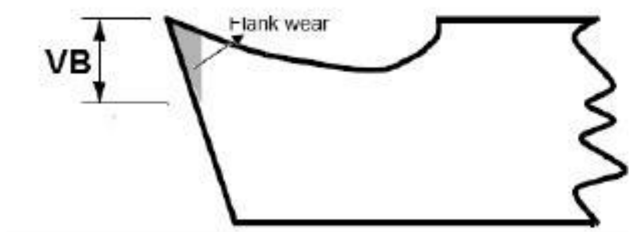
Reasons

Abrasion by hard particles and inclusions in the work piece.

Shearing of the micro welds between tool and work material.
Abrasion by fragments of built-up-edge ploughing against the clearance face of the tool.

At low speed flank wear predominates.

If MRR increased flank wear increased.



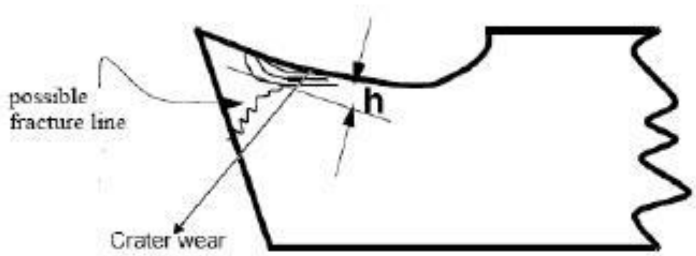
3. Crater Wear

More common in ductile materials which produce continuous chip.

Crater wear occurs on the rake face of the cutting tool in the form of a crater.

At very high speed crater wear predominates

For crater wear temperature is main culprit and tool defuse into the chip material & tool temperature is maximum at some distance from the tool tip.



4. Chipping of cutting edge

Tool material is too brittle

Weak design of tool, such as high positive rake angle

As a result of crack that is already in the tool

Excessive static or shock loading of the tool

WEAR MECHANISMS

Abrasion wear:

occurs when hard constituents of one surface moves to the other side of material

Amount of wear depends on hardness of contacting surface.

Constituents causing wear are harder than the matrix of the cutting tool**.**

Adhesion wear:

occurs when two surfaces are brought into contact under normal loads and form welded junctions

When shear load is applied, this junction breaks

Depends on characteristics of tool and work material

Occurs at very low cutting speeds

Diffusion wear:

Atoms move from one lattice point to another

Caused due to increase in temperature

Occurs when localized temperature is increased sufficiently

Chemical or oxidation wear

The fresh metal will quickly react with oxygen in air to form a fresh oxide layer, which will then be scraped off again by asperities in the following cycle.

Such an "oxidation - scrape", or "chemical - mechanical" cycle repeats during the oxidation wear process, producing wear debris of finely powdered oxide

TOOL LIFE

Tool life is the time a tool will operate satisfactorily until it is dulled.

Tool failure is mainly happened as tool wear.

Taylor's Tool Life Equation

based on Flank Wear

Causes

- Sliding of the tool along the machined surface
- Temperature rise

$$VT^n = C$$

Where, V = cutting speed (m/min)

T = Time (min)

n = exponent depends on tool material

C = constant based on tool and work material and cutting condition.

Extended or Modified Taylor's equation

$$VT^n f^a d^b = C$$

Where: d = depth of cut

f = feed rate

Values of Exponent 'n'

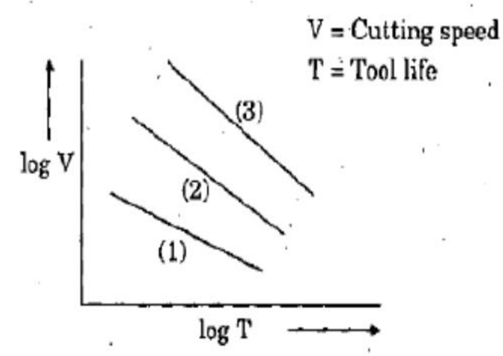
n = 0.08 to 0.2 for HSS tool

= 0.1 to 0.15 for Cast Alloys

= 0.2 to 0.4 for carbide tool

= 0.5 to 0.7 for ceramic tool

Tool Life Curve



In the graph slope of the line represent the value of n

FACTORS AFFECTING TOOL LIFE

1. Cutting speed
2. Feed and depth of cut
3. Tool geometry
4. Tool material
5. Cutting fluid
6. Work material
7. Rigidity of work, tool, and machine

Cutting speed: Cutting speed has the greatest influence on tool life. As the cutting speed increases the temperature also rises. The heat is more concentrated on the tool than on the work and the hardness of the tool matrix changes so the relative increase in the hardness of the work accelerates the abrasive action. Thus more tool wear occurs.

Feed and depth of cut: The tool life is influenced by the feed rate also. With a fine feed the area of chip passing over the tool face is greater than that of coarse feed for a given volume of swarf removal, but to offset this chip will be greater hence the resultant pressure will nullify the advantage.

Tool Geometry: The tool life is also affected by tool geometry. A tool with large rake angle becomes weak as a large rake reduces the tool cross-section and the amount of metal to absorb the heat.

Tool material: Physical and chemical properties of work material influence tool life by affecting form stability and rate of wear of tool.

Cutting fluid: It reduces the coefficient of friction at the chip tool interface and increases tool life.

CUTTING FLUIDS

Cutting fluid may be defined as substance which is applied to a tool during a cutting operation to facilitate removal of chips and heat

FUNCTIONS OF CUTTING FLUIDS IN MACHINING

1. To lubricate chip, tool &work piece
2. To cool the cutting tool and work piece
3. To help carry away the chips from the cutting zone.
4. To lubricate some the moving parts of MT
5. To improve the surface finish
6. To prevent the formation of built-up –edge
7. To protect the work against the rusting
8. To improve surface finish,MRR

REQUIREMENTS OF CUTTING FLUID

1. Long life,
2. free from oxidation
3. High thermal conductivity
4. Low viscosity
5. Should be transparent
6. No fire or Accidental Hazards
7. Should have high flash point
8. Low price ,Easily available

1. categories

Straight oils

Soluble oils

Semi-synthetic fluids

Synthetic fluids

Straight oils

are the oldest class of engineered metal removal fluids used in machining operations in an undiluted form.

They are composed of a base mineral or petroleum oil and often contains polar lubricants such as fats,

vegetable oils and esters as well as extreme pressure additives such as Chlorine, Sulphur and Phosphorus.

Straight oils provide the best lubrication and the poorest cooling characteristics among cutting fluids.

Chemically stable and lower in cost

Soluble Oil

form an emulsion when mixed with water.

The concentrate consists of a base mineral oil and emulsifiers to help produce a stable emulsion.

They are used in a diluted form (usual concentration = 3 to 10%) Provide good lubrication and heat transfer performance.

They are widely used in industry and are the least expensive among all cutting fluids.

Semi-synthetic fluids

1. are essentially combination of synthetic and soluble oil fluids
2. have characteristics common to both types.
3. The cost and heat transfer performance of semi-synthetic fluids lie between those of synthetic and soluble oil fluids.

Synthetic Fluids

1. contains no petroleum or mineral oil base
2. are formulated from alkaline inorganic and organic compounds along with additives for corrosion inhibition.
3. They are generally used in a diluted form (usual concentration = 3 to 10%).
4. Synthetic fluids often provide the best cooling performance among all cutting fluids.

Elements of Metal Cutting :

Cutting speed : It is the distance traveled by work surface related to the cutting edge of Tool

$v = \pi dN / 1000$ m / min

Feed (s) : The motion of cutting edge of tool with reference to one revolution of work piece. unit is mm/rev

Depth of cut (t) : It is measured perpendicular to axis of work piece and in straight turning in one pass. This can be estimated from the relation

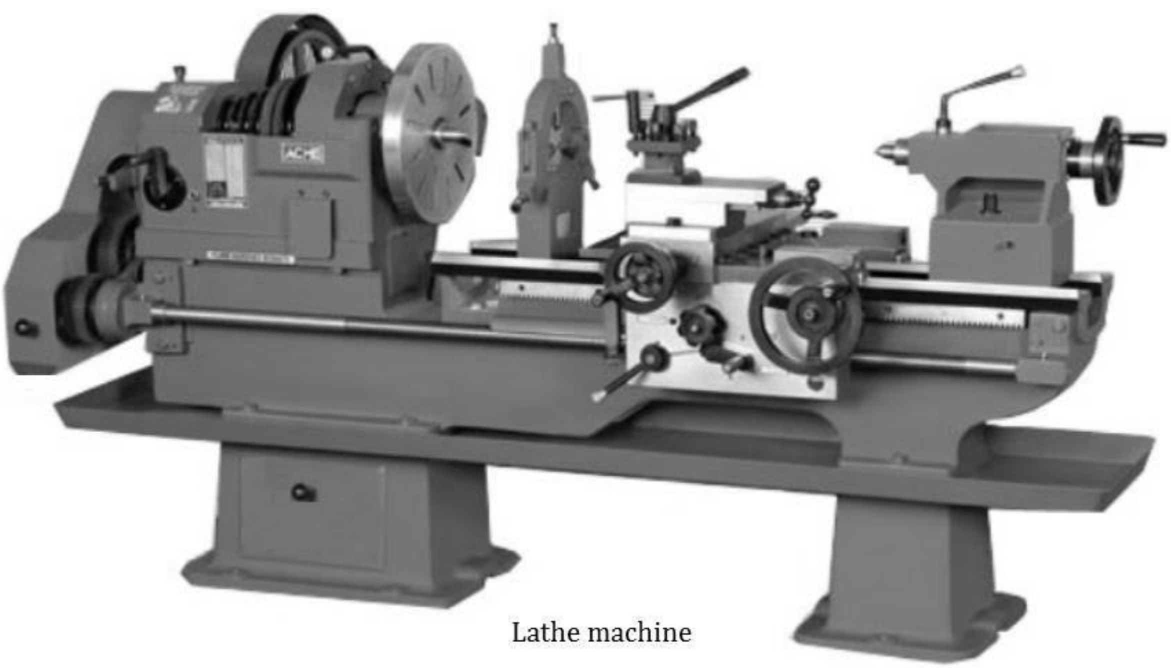
$t = (D - d) / 2$ mm

MODULE-2

LATHE

Introduction

The lathe is a machine tool, which holds the work piece between two rigid and strong supports called centers or in a chuck or face plate which revolves. The cutting tool is rigidly held and supported in a tool post, which is held against the revolving work. The normal cutting operations are performed with the cutting tool fed either parallel or at right angles to the axis of the work.



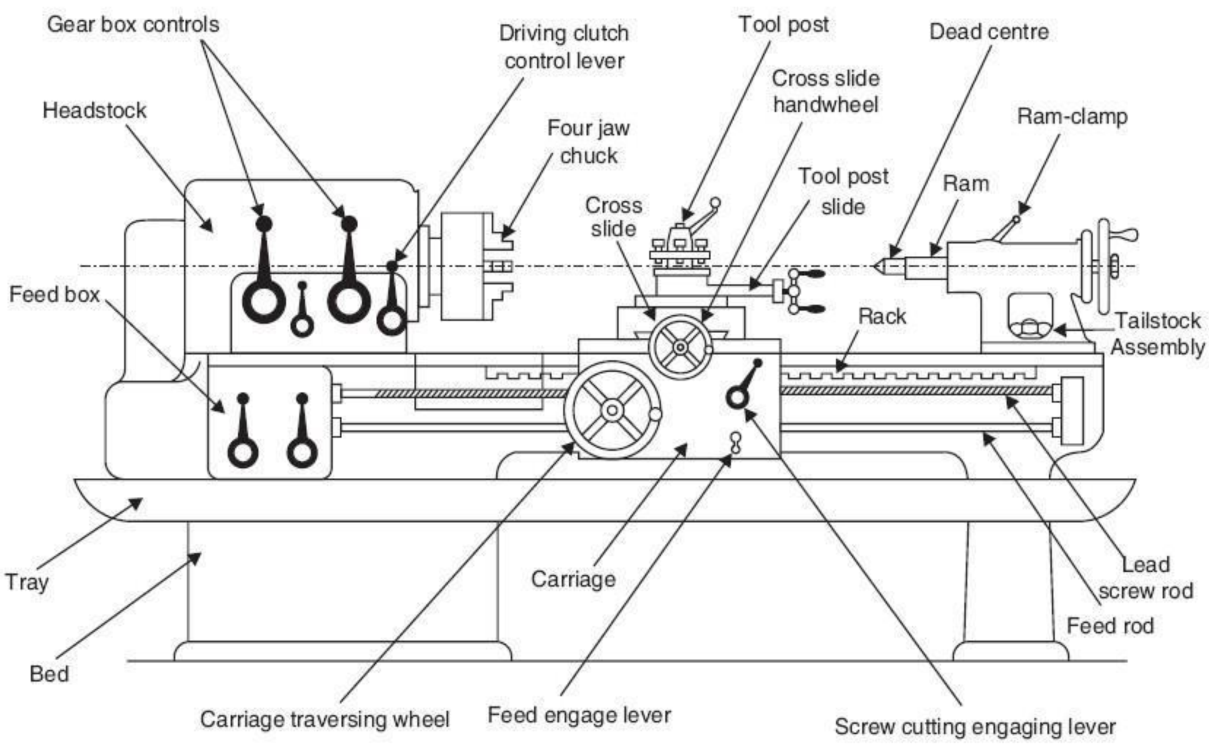
Lathe machine

Common types of lathes

1. Speed lathe
    a. Woodworking lathe
    b. Centering lathe
    c. Polishing lathe
    d. Metal spinning lathe
2. Engine lathe
    a. Belt driven lathe
    b. Individual motor driven lathe
    c. Gear head lathe

3. Bench lathe
4. Tool room lathe
5. Semi-automatic lathe
    a. Capstan lathe
    b. Turret lathe
6. Automatic lathe
7. Special purpose lathe
    a. Wheel lathe
    b. Gap bed lathe
    c. ‘T’ lathe
    d. Duplicating lathe
8. Computer Numeric Control lathe (CNC lathe)

Principal parts of an engine lathe



Engine lathe

1. **Bed:** The bed is a heavy, rugged casting and it carries the headstock and tailstock for supporting the work piece and provides a base for the movement of carriage assembly, which carries the tool.

2. **Headstock**: The headstock is provided in the left hand side of the bed and it serves as housing for the driving pulleys, back gears, headstock spindle, live centre and the feed reverse gear. The headstock spindle is a hollow cylindrical shaft that provides a drive from the motor to work holding devices.

3. **Gear Box**: The quick-change gearbox is placed below the headstock and contains a number of different sized gears.

4. **Carriage**: The carriage is located between the headstock and tailstock and serves the purpose of supporting, guiding and feeding the tool against the job during operation. The main parts of carriage are:

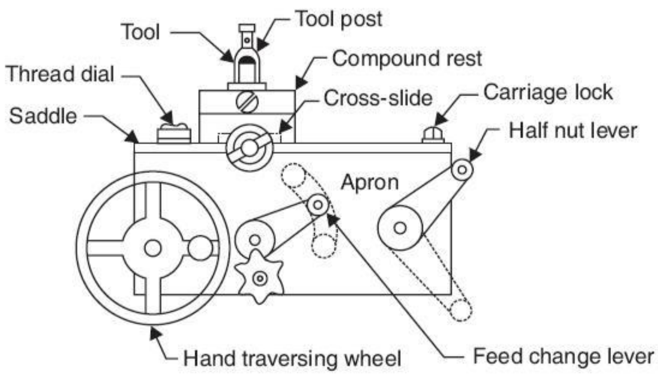
a) **The saddle** is an H-shaped casting mounted on the top of lathe ways. It provides support to the cross-slide, compound rest and tool post.

b) **The cross slide** is mounted on the top of saddle, and it provides a mounted or automatic cross movement for the cutting tool.

c) **The compound rest** is fitted on the top of cross slide and is used to support the tool post and the cutting tool.

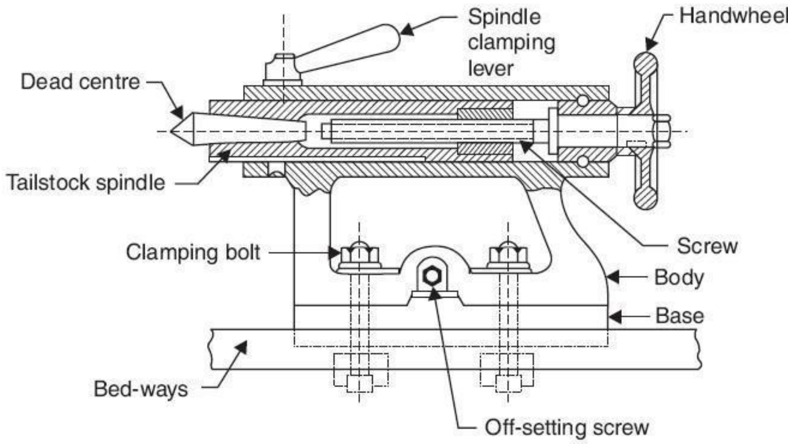
d) **The tool post** is mounted on the compound rest, and it rigidly clamps the cutting tool or tool holder at the proper height relative to the work centre line.

e) **The apron** is fastened to the saddle and it houses the gears, clutches and levers required to move the carriage or cross slide. The engagement of split nut lever and the automatic feed lever at the same time is prevented she carriage along the lathe bed.



Carriage

6. **Tailstock**: The tailstock is a movable casting located opposite the headstock on the ways of the bed. The tailstock can slide along the bed to accommodate different lengths of work piece between the centers. A tailstock clamp is provided to lock the tailstock at any desired position.



Tailstock

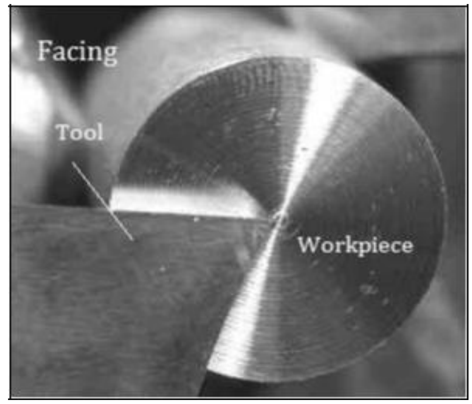
7. **Lead screw:** A lead screw also known as a power screw is a screw, moves the carriage by a precise increment for every rotation of the screw. The lead screw is made with square, acme, or buttress type threads.

Lathe operations

The engine lathe is an accurate and versatile machine, on which many operations can be done on this machine. These operations are:

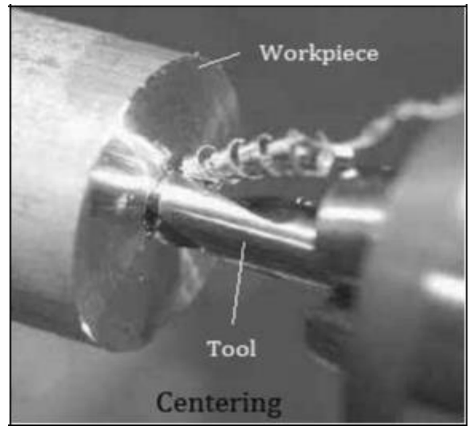
2. Facing
3. Centering
4. Turning
5. Parting
6. Drilling
7. Boring
8. Reaming
9. Knurling
10. Forming
11. Chamfering
12. Thread cutting

Facing



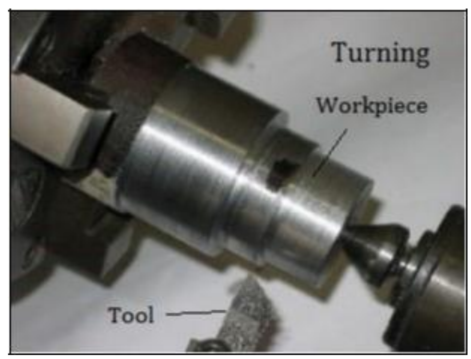
Facing is the process of removing metal from the end of a work piece by using a single point cutting tool, to produce a flat surface. Figure shows the details of facing operation.

Centering



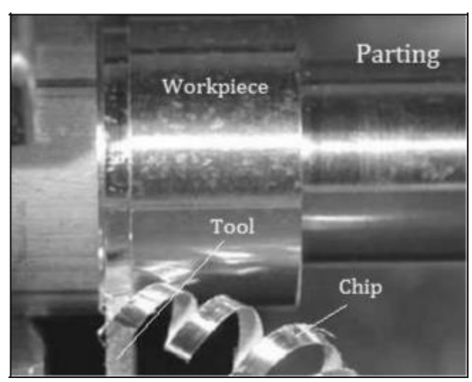
Centering is the process of providing a small tapered hole at end of a work piece by using centering tool, which can helpful to accommodate and support a running centre in the tailstock. Figure shows the details of centering operation.

Turning



Turning is the process of removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal.

Parting



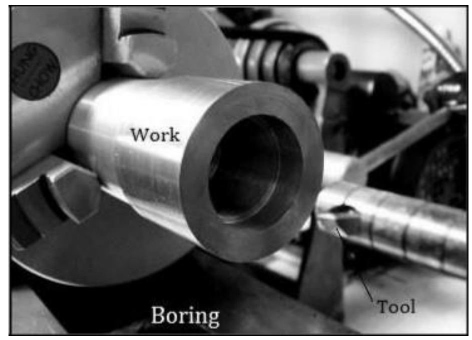
Parting is the process of cut off the work piece at a specific length by using a blade-like cutting tool. It is normally used to remove the finished end of a work piece from the bar stock that is clamped in the chuck.

Drilling

Drilling is the process of making holes at the end face of the work piece by using a drill bit, fixed with drill chuck, clamped at tailstock.

Boring

Boring is the process of enlarging a hole that has already been drilled or cast, by using a single point cutting tool or boring head containing several such tools.

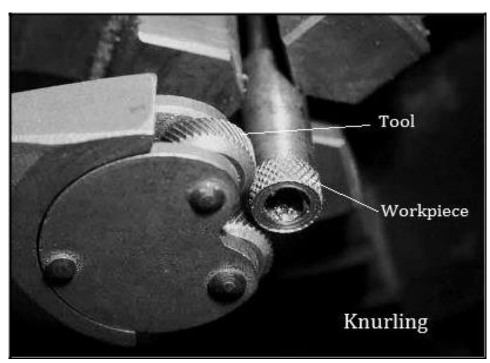


Reaming

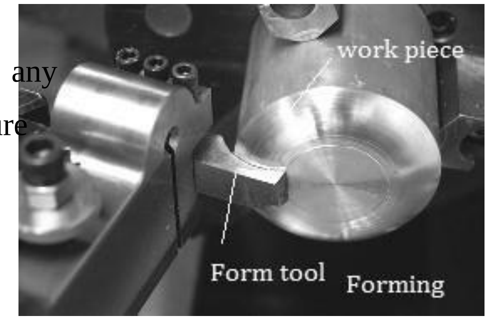
Reaming is the process of finishing a drilled or bored hole with great degree of accuracy. The drilled or bored hole not always is straight or accurate.

Knurling

Knurling is a process of making easy-to-grip geometric pattern on a finished outer surface of work pieces like handles, knobs, rollers, etc. to hold them firmly. Figure shows the details and geometric pattern of knurled grips.

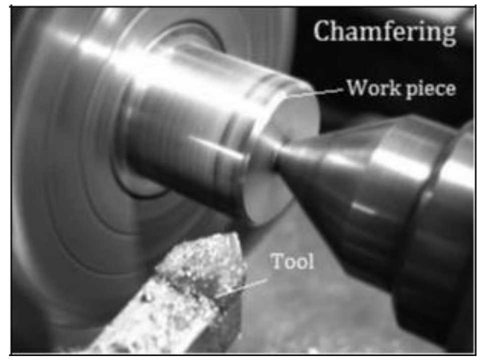


Forming



Forming is a process of produces a convex, concave or any irregular profile on the work piece by using a form tool. Figure shows the details of forming operation.

Chamfering



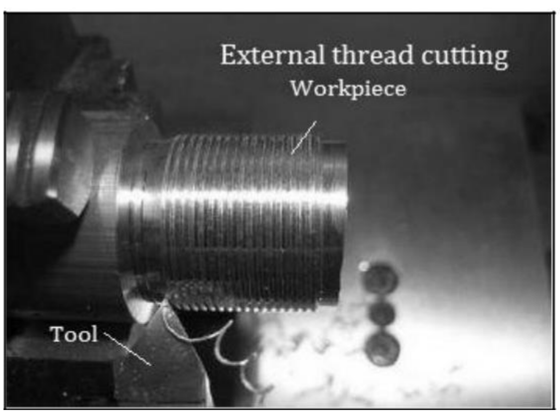
Chamfering is a process of bevelling the extreme end of a work piece. This is done to remove the burrs and sharp edges from the extreme end of the work piece.

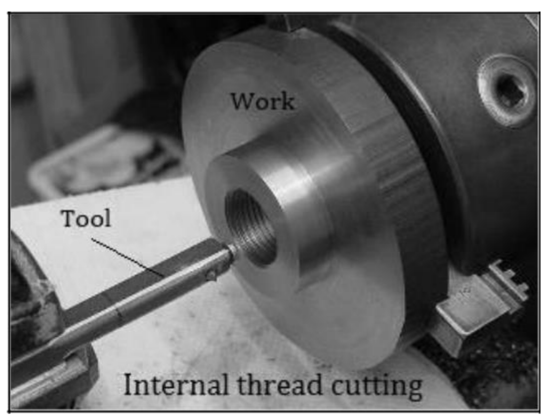
Thread cutting

Thread cutting is a process of cutting very accurate screw threads by using a single point cutting tool,

which is the process of guiding the linear motion of the tool bit in a precisely known ratio to the rotating

motion of the work piece.



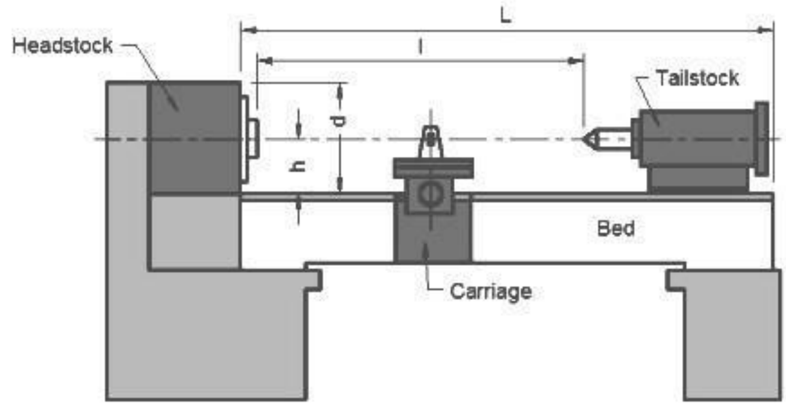


Lathe specifications

In order to identify or to purchase a lathe machine, certain standard of specification must be considered.

Following are some of the important required specifications.

6. Length of bed
7. Length between centres
8. Centre height
9. Swing diameter over bed
10. Horse power of the motor
11. Number of spindle speeds
12. Number of feeds
13. Bore diameter of the spindle
14. Width of the bed
15. Type of the bed
16. Pitch value of the lead screw
17. Spindle nose diameter
18. Floor space required
19. Type of the machine



Specification of a lathe

L - Length of bed   l - Length between lathe centres
h - Centre height   d - Swing diameter over bed

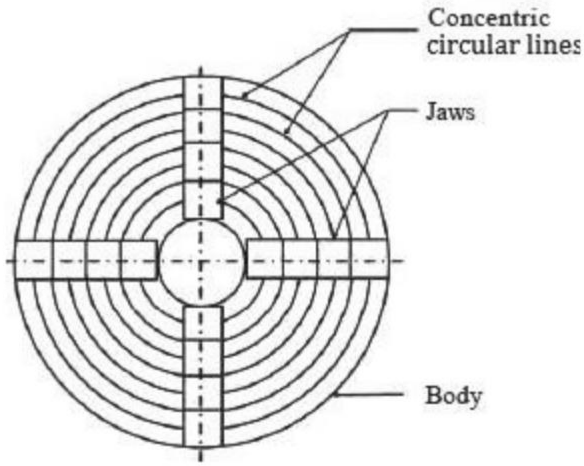
Work holding devices

Work holding devices are used to hold and rotate the work pieces along with the spindle. Following are the different types of work holding devices used in a lathe shop:

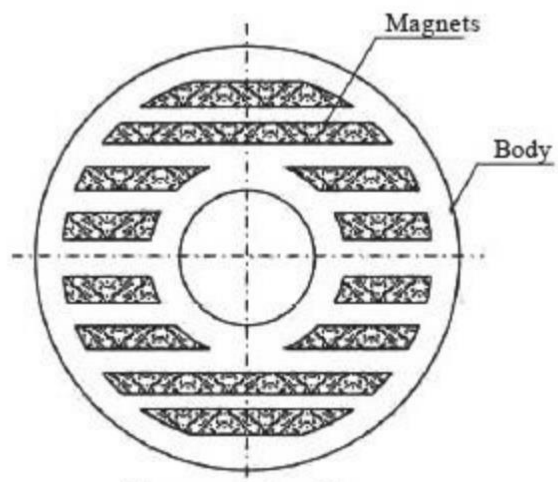
1. Chucks
2. Face plate
3. Driving plate
4. Catch plate
5. Carriers
6. Mandrels
7. Centres
8. Rests

Chucks

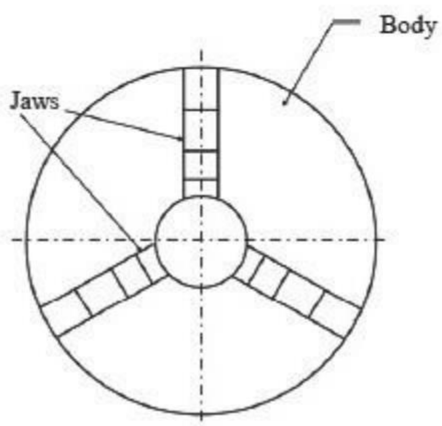
Work pieces of short length, large diameter and irregular shapes, which cannot mounted directly between centres, held quickly and rigidly in chuck. Different types of chucks are, three jaws universal chuck, four jaw independent chuck, magnetic chuck, collet chuck and combination chuck.



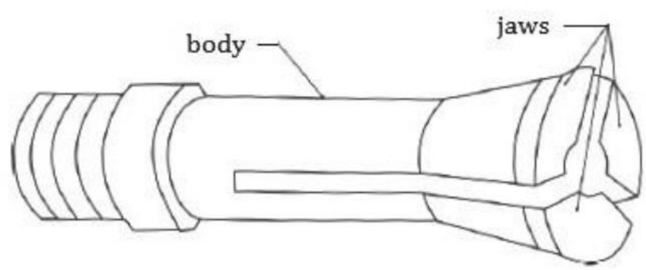
Four jaw chuck



Magnetic chuck



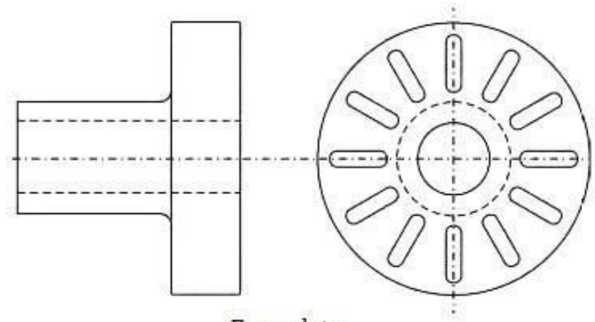
Three jaw chuck



Collet chuck

Face plate

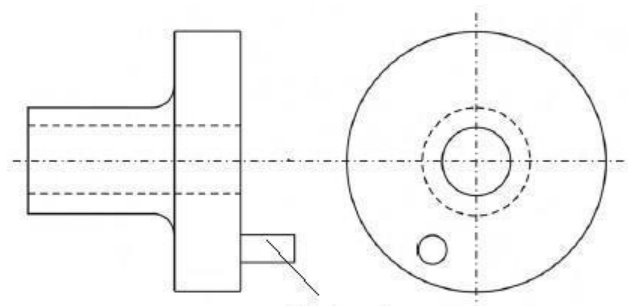
Faceplate is used to hold large, heavy and irregular shaped work pieces, which cannot be conveniently held between centres. It is a circular disc bored out and threaded to fit to the nose of the lathe spindle. It provided with radial plain and 'T' slots for holding the work by bolts and clamps.



Face plate

Driving plate

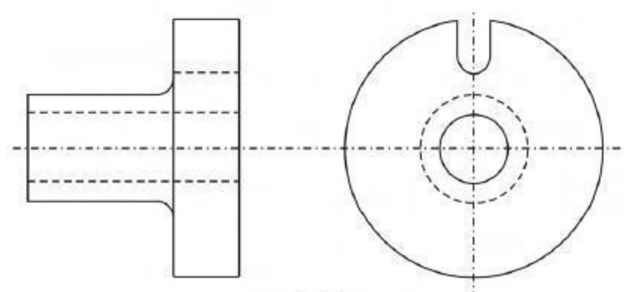
The driving plate is used to drive a work piece when it is held between centres. It is a circular disc screwed to the nose of the lathe spindle. It is provided with small bolts or pins on its face.



Driving plate

Catch plate

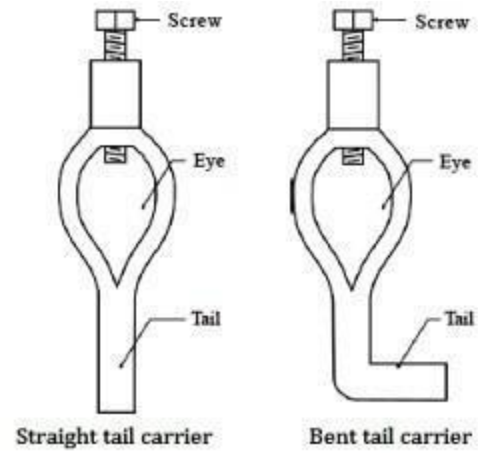
When a work piece is held between centres, the catch plate is used to drive it. It is a circular disc bored and threaded at the centre. Catch plates are designed with 'U' – slots or elliptical slots to receive the bent tail of the carrier.



Catch plate

Carriers

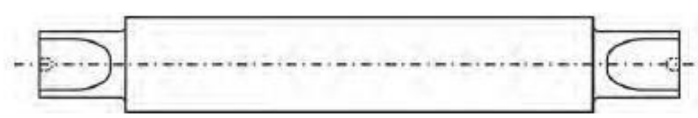
When a work piece is held and machined between centres, carriers are useful in transmitting the driving force of the spindle to the work by means of driving plates and catch plates. The work is held inside the eye of the carrier and tightened by a screw. Carriers are of two types and they are: Straight tail carrier and Bent tail carrier. Straight tail carrier is used to drive the work by means of the pin provided in the driving plate. The tail of the bent tail carrier fits into the slot of the catch plate to drive the work.



Carriers

Mandrels

A previously drilled or bored work piece is held on a mandrel to be driven in a lathe and machined. There are centre holes provided on both faces of the mandrel. The


Plain mandrel

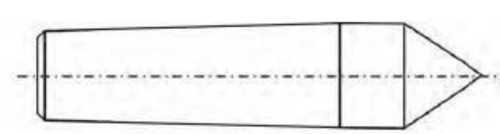
live centre and the dead centre fit into the centre holes. A carrier is attached at the left side of the mandrel. The mandrel gets the drive either through a catch plate or a driving plate. The work piece rotates along with the mandrel. There are several types of mandrels and they are:

7. Plain mandrel 2. Step mandrel 3. Gang mandrel 4. Screwed mandrel 5. Collar mandrel

6. Cone mandrel 7. Expansion mandrel

1.5.6.7 Centres

Centres are useful in holding the work in a lathe. The shank of a centre has Morse taper on it and the face is conical in shape. There are two types of centres, namely

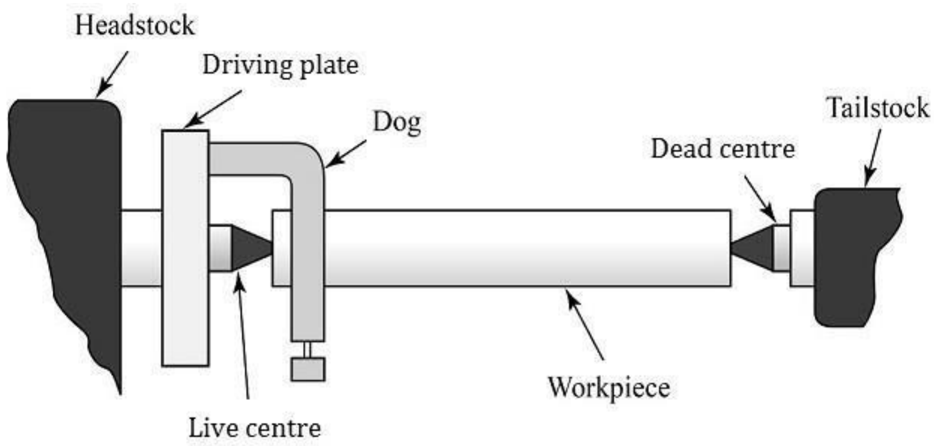

Centre

1. Live centre
2. Dead centre

The live centre is fitted on the headstock spindle and rotates with the work. The centre fitted on the tailstock spindle is called dead centre. Centres are made of high carbon steel and hardened and then tempered. So the tips of the centres are wear resistant. Different types of centres are available according to the shape of the work and the operation to be performed. They are

1. Ordinary centre
2. Ball centre
3. Half centre
4. Tipped centre
5. Pipe centre
6. Revolving centre
7. Inserted type centre

Figure below shows different work holding devices



Holding workpiece between centres

Rests

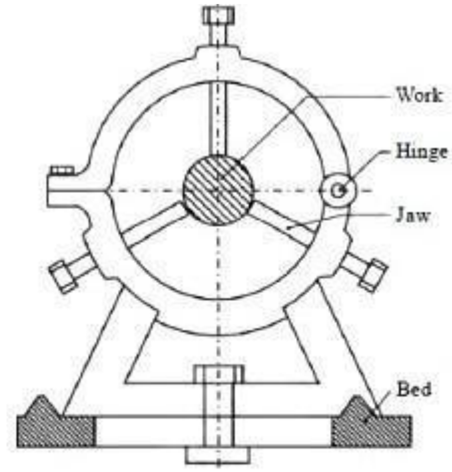
A rest is a mechanical device to support a long slender work piece when it is turned between centres or by a chuck. It is placed at some intermediate point to prevent the work piece from bending due to its own weight and vibrations setup due to the cutting force. There are two different types of rests.

7. Steady rest

8. Follower rest

Steady rest

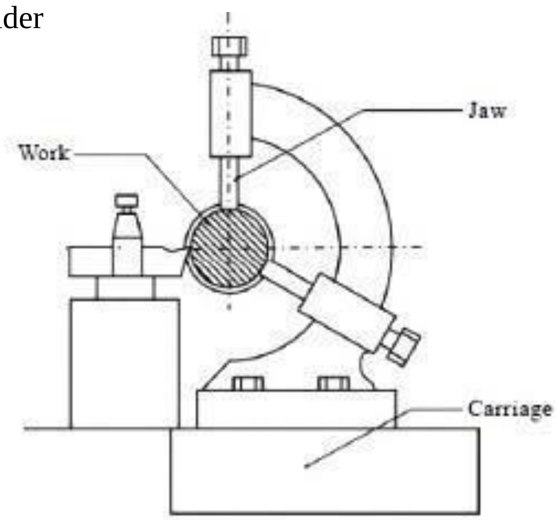
Steady rest is made of cast iron. It may be made to slide on the lathe bed ways and clamped at any desired position where the work piece needs support. It has three jaws. These jaws can be adjusted according to the diameter of the work. Machining is done upon the distance starting from the headstock to the point of support of the rest. One or more steady rests may be used to support the free end of a long work.



Steady rest

Follower rest

A follower rest consists of a "C" like casting having two adjustable jaws which support the work. The rest is bolted to the back end of the carriage and moves with it. Before setting the follower rest, the end of the work piece is machined slightly wider than the jaws to provide the true bearing surface. The tool is slightly in advance position than the jaws, and the tool is fed longitudinally to the carriage, the jaws always follow the tool giving continuous support to the work piece. The follower rest prevents the job from springing away when the cut is made and is used in finish turning operation. The follow rest is normally used with small diameter stock to prevent the work piece from "springing" under pressure from the turning tool.



Follower rest

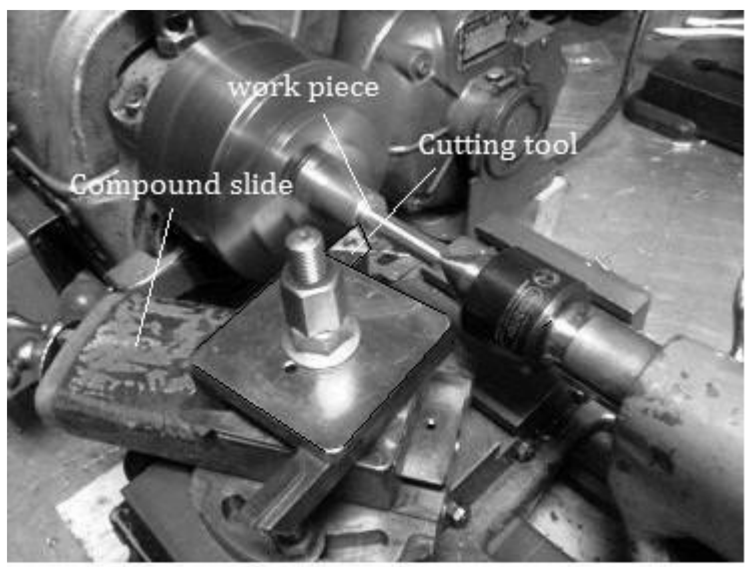
Taper turning

Taper turning is an operation performed on a lathe that feeds a tool at an angle to the length of the work piece in order to create a conical shape. There are different taper turning methods, which are:

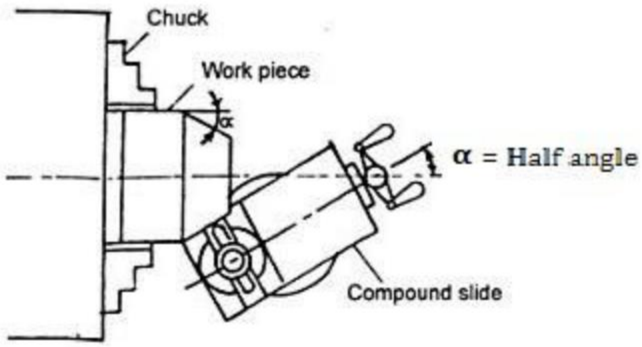
6. Swivelling the compound rest method
7. Form tool method
8. Tailstock set over method
9. Taper turning attachment method
10. Combined feed method

Taper turning by swivelling the compound rest

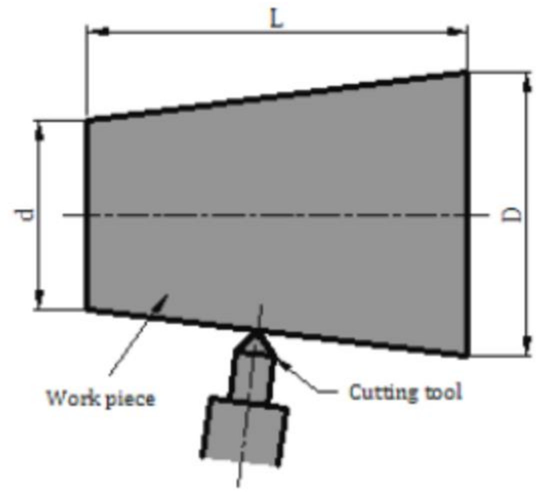
This method employs the principle of turning taper by rotating the work piece on the lathe axis and feeding the tool at an angle to the axis of rotation of the work piece. The tool mounted on the compound rest is attached to a circular base, graduated in degree, which may be swiveled and clamped at any desired angle. Once 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. This method is limited to turning a short taper owing to the limited movement of the cross slide.



Taper turning by swivelling the compound rest



Taper turning by swiveling the compound rest



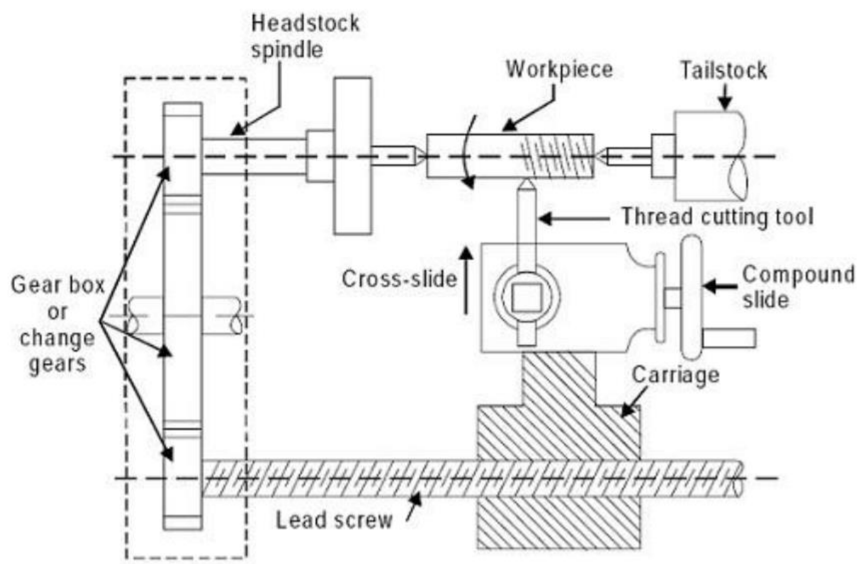
Taper angle, $\tan \alpha = \frac{D-d}{2L}$

D = Major diameter
d = Minor diameter
L = Length of slope

$$\alpha = \tan^{-1}\left(\frac{D-d}{2L}\right)$$

Thread cutting

Thread cutting is an operation of producing helical grooves on round shaped work pieces such as V, square or power threads on a cylindrical surface. Following are the various steps for the threading process.



Thread cutting

- In thread cutting operation the first step is to remove the excess material from the work piece to make its diameter equal to the major diameter of the thread to be cut.
- The shape or form of the thread depends on the shape of the cutting tool to be used. The tool point must be ground so that it has the same angle as the thread to be cut. In a metric thread the included angle of the cutting edge should be ground exactly 60°. Typical angles are 60° for ‘V’ threads, and 29° for ACME threads.
- The top of the nose of the tool should be set at the same height as the centre of the work piece.
- The correct gear ratio is required between the machine spindle and the lead screw. This can be determined in the following manner:

Thread cutting calculations:

To calculate the gears required for cutting a thread of certain pitch can calculated from the following formula:

The gear of the spindle shaft is the driver and the gear on the lead screw is the driven gear.

$$\frac{\text{Driver teeth}}{\text{Driven teeth}} = \frac{\text{Speed of the leadscrew}}{\text{Speed of the spindle}} = \frac{\text{Pitch of the screw to be cut}}{\text{Pitch of the lead screw}}$$

(Note: Often engine lathes are equipped with a set of gears ranging from 20 to 120 teeth in steps of 5 teeth, and one gear with 127 teeth.)

To cut metric thread on English lead screws

The cutting of metric thread on a lathe with an English lead screw may be carried out by introducing a translating gear of 127 teeth.

If the lead screw has ‘**n’** threads per inch to cut ’**p‘** mm pitch then,

$$\frac{\text{Driver teeth}}{\text{Driven teeth}} = \frac{\text{Pitch of the screw to be cut}}{\text{Pitch of the lead screw}} = \frac{p}{\frac{1}{n} \text{ x } \frac{127}{5}} = \frac{5pn}{127}$$

The factor **127/5 from the fact that 25.4 mm is equal to 1 inch**. So one translating gear, with 127 teeth is necessary.

DRILLING MACHINE

Drilling machine is a machine tool designed for drilling holes in metallic and non metallic materials. The cutting tool is a multi-point cutting tool, known as drill.

PRINCIPAL PARTS OF THE DRILLING MACHINE

5. **Head**: Head contains the electric motor, v pulleys and v belt which transmit rotary motion to the drill spindle at a no. of speeds.

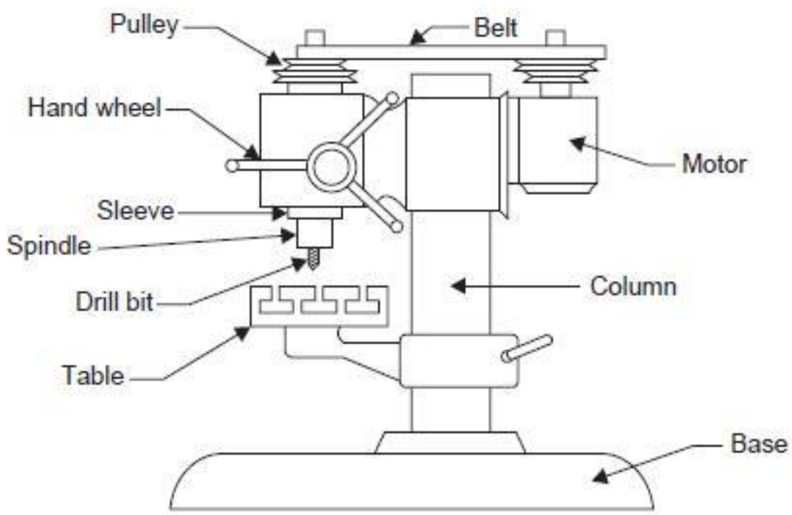
Spindle: spindle is made up of alloy steel. It rotates as well as moves up and down in a sleeve.

Drill chuck: It is held at the end of the drill spindle and in turn it holds the drill bit.

1. **Adjustable table**: It is supported on the column of the drilling machine and can be moved vertically and horizontally. It also carries slots for bolts clamping.

Base: It supports the column, which, in turn, supports the table, head etc.

1. **Column**: It is a vertical round or box section, which rests on the base and supports the head and the table



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DRILLING MACHINE OPERATIONS

The following are the most common operations performed on the drilling machine

Drilling: it is an operation of producing a circular hole in a work piece by forcing a drill in the work piece.

1. **Boring**: it is an operation of enlarging a hole that has already been drilled. Single point cutting tool is used in boring.
2. **Reaming**: Reaming is done with reamers. It is done to generate the hole of proper size and finish after drilling

Tapping: It is an operating of producing internal threads in a hole by means of a tap.

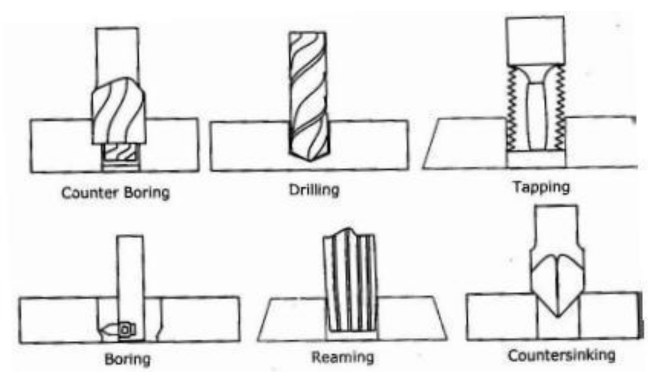
1. **Counter Boring:** It is an operation of enlarging the entry of a drilled hole to accommodate the bolt head etc. Counter boring tool does it.

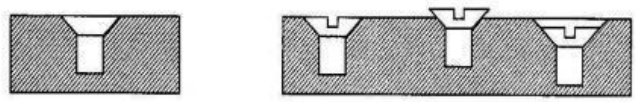
Spot Facing: It is an operation done on the drilled hole to provide smooth seat for bolt head.

1. **Counter Sinking:** It is an operation to bevel the top of a drilled hole for making a conical seat. A counter sunk drill is used in this operation.

8.Trepanning

Trepanning is the operation of producing a hole in sheet metal by removing metal along the circumference of a hollow cutting tool. Trepanning operation is performed for producing large holes





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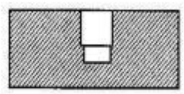
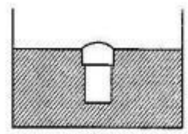
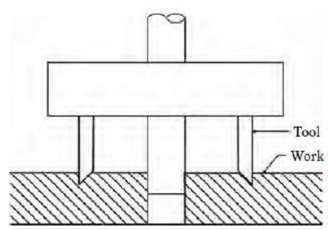
Countersunk hole



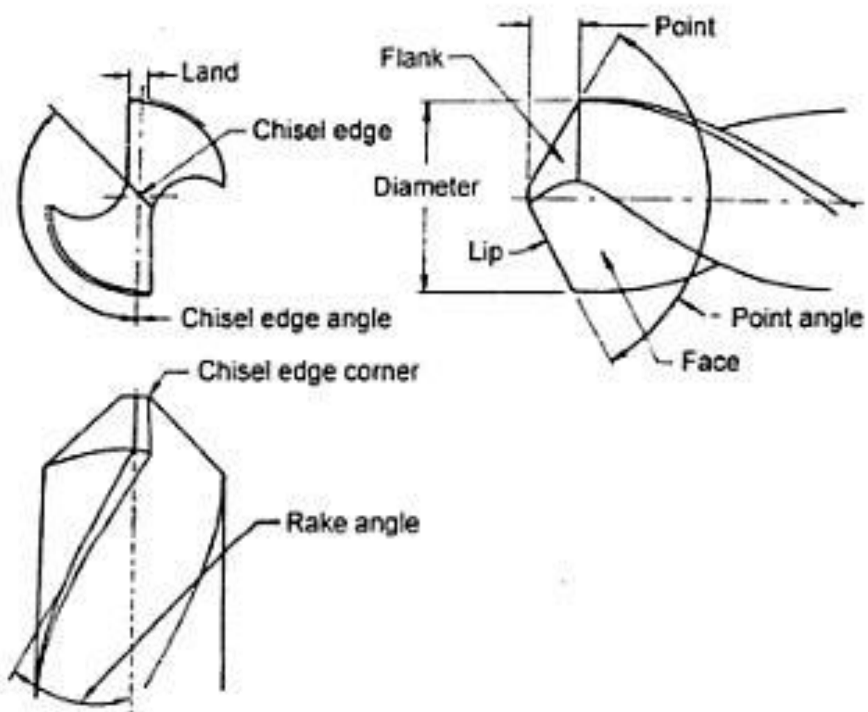
Counterbored hole



Spot faced hole



NOMENCLATURE OF STANDARD TWIST DRILL



AXIS: Imaginary straight line that forms the center line of the drill.

BACK TAPER: Slight decrease in diameter from point towards shank, in the body of the drill.

BODY DIAMETER CLEARANCE: The portion of the land that has been cut away so it will not bind against the walls of the hole.

BODY: Portion of the drill extending from the end of the flutes to the outer corner of the cutting edges. CHISEL EDGE: The edge at the end of the web that connects the cutting lips.

CHISEL EDGE ANGLE: The angle between the chisel edge and the cutting lips (edges)

DRILL DIAMETER: The diameter over the margins of the drill measured at the point.

FLUTES: Grooves formed in the body of the drill to provide cutting edges, to permit removal of chips, and to allow cutting fluid to reach the cutting area. **RELIEF ANGLE**: The relief angle at the outer corner of the lip.

MARGIN: The narrow portion of the land which is not cut away to provide clearance. It stabilizes the drill in the hole.

MARGIN WIDTH: The width of the portion of the drill lands not cut away for clearance.

WEB: The central portion of the body that joins the lands. The extreme end of the web forms the chisel edge on a two-flute drill.

TYPES OF DRILLING MACHINE.

1. Portable drilling machine
2. Sensitive drilling machine

   Bench mounting and floor mounting
3. Upright drilling machine(Round column and box column section)
4. Radial drilling machine

Plain, semi universal and universal

1. Gang drilling machine
2. Multiple spindle drilling machines.
3. Automatic drilling machine
4. Deep hole drilling machine(vertical and horizontal)

Portable drilling machine

1. Can be operated with ease anywhere in the workshop and is used for drilling holes in the work piece in any position which cannot be drilled in a standard drilling machine.
2. Most of the portable drilling machines are driven by motor.

Bench drilling machine

1. These are light duty machines used in small workshops. Also called Sensitive drilling machines, because of its accurate and well balanced spindle.
2. Used for drilling small holes at high speed in light jobs
3. Holes of diameter 1 mm to 15 mm can be drilled.
4. There is no arrangement for any automatic feed of the drill spindle. Feed is purely by hand control.
5. As the operator senses the cutting action, at any instant it is called sensitive drilling machine.

Upright drilling machine

1. These are designed for handling medium sized work pieces.
2. In construction it is similar to sensitive drilling machine but it is heavier than sensitive drilling machine.
3. In this large number of spindle speeds and feeds are available.
4. But it is heavier than sensitive drilling machine

Radial drilling machine

- These are heavy duty and versatile drilling machine used to perform drilling operate on large and heavy work piece. Holes up to 7.5 cm.
- Work piece is marked for exact location and mounted on the work table. Drill bit is then located by moving the radial arm and drill to the marked location. By starting drill spindle motor holes are drilled.

Gang drilling machine

- When a number of single spindle drilling machine columns are placed side by side on a common base and a common work table , the machine is known as gang drilling machine.
- In a gang drilling machine 4 to 6 spindles may be mounted side by side.
- The speed and feed of the spindles are controlled independently.
- Each spindle may be set up properly with different tools for different operations.
- A series of operations may be performed on the work by simply shifting the work from one position to the other on the work table.

Multiple spindle drilling machines

- Used to drill a number of holes in a piece of work simultaneously and to reproduce the same pattern of holes in a number of identical pieces in a mass production work.
- In this several spindles are driven by a single motor and all the spindles holding drills are fed into the work simultaneously.
- Feed may be obtained by raising the table or lowering the drill head.

Deep hole drilling machine

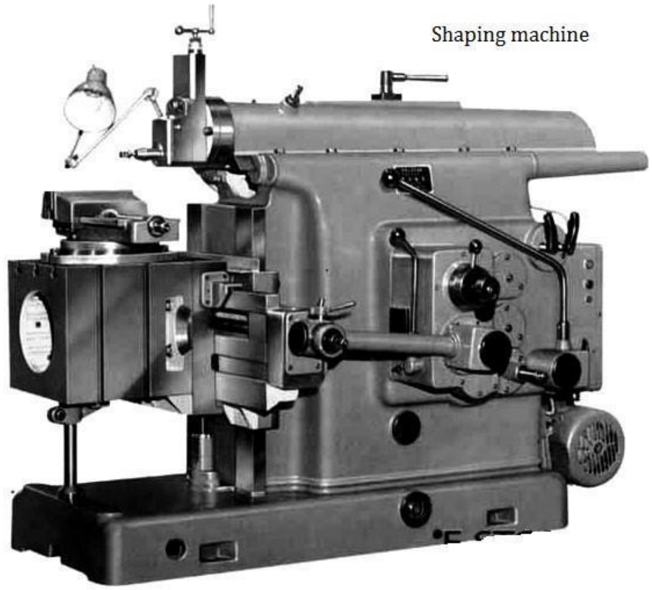
Special machines and drills are required for drilling deep holes in long shaft, crank shaft, rifle barrels

This machine is operated at high speed and low feed.

MODULE-3

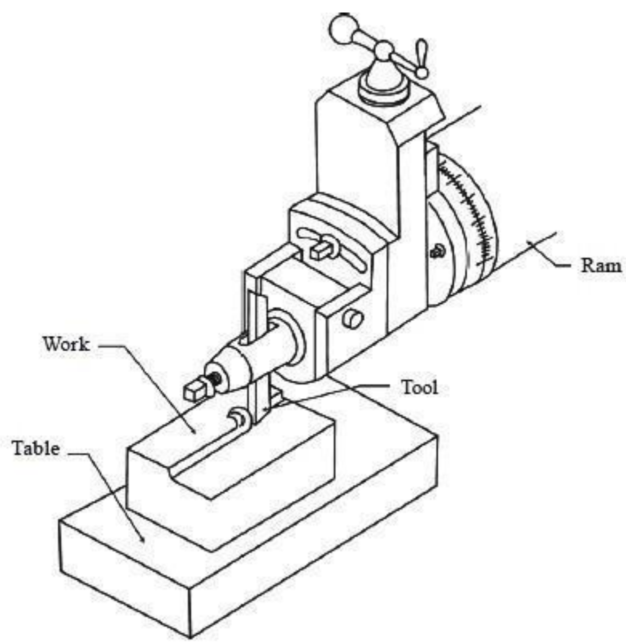
SHAPER

Introduction



Shaping is a process of machining a flat surface which may be horizontal, vertical, inclined, concave or convex using a reciprocating single point tool. A shaping machine is a reciprocating type of machine tool.

The work is held firmly on the table and the ram is allowed to reciprocate over it. A single point cutting tool is attached to the ram. When the ram moves horizontally in the forward direction, the tool removes metal from the work. On the return stroke, metal is not removed. The ram moves at a slow speed during forward stroke. But during return stroke, the ram moves at a faster speed. Though the distances of ram movement during the forward and return stroke remain the same, the time taken by the return stroke is less as it is faster. It is possible by 'Quick return mechanism'. In a shaping machine, a flat horizontal surface is machined by moving the work mounted on the table in a cross direction to the tool movement. When vertical surfaces are machined, the feed is given to the tool. When an inclined surface is machined, the vertical slide of the tool head is swivelled to the required angle and the feed is given to the tool by rotating the down feed hand wheel.



Shaper operations

Common types of shaper

Shapers are classified in many ways, i.e. According to the length of the stroke, type of driving mechanism, direction of travel of the ram, the type of work they do, the types and design of table etc. The different types of shapers are,

2. Crank shaper
3. Hydraulic shaper
4. Universal shaper
5. Standard shaper
6. Draw-cut shaper
7. Horizontal shaper
8. Vertical shaper
9. Geared Shaper
10. Contour shaper
11. Travelling head shaper

Crank shaper

Crank and slotted link mechanism of a crank type shaper converts the rotation of an electric motor into reciprocating movement of the ram. Though the lengths of both the forward and return strokes are equal, the ram travels at a faster speed during return stroke. This quick return is incorporated in almost all types of shaper.

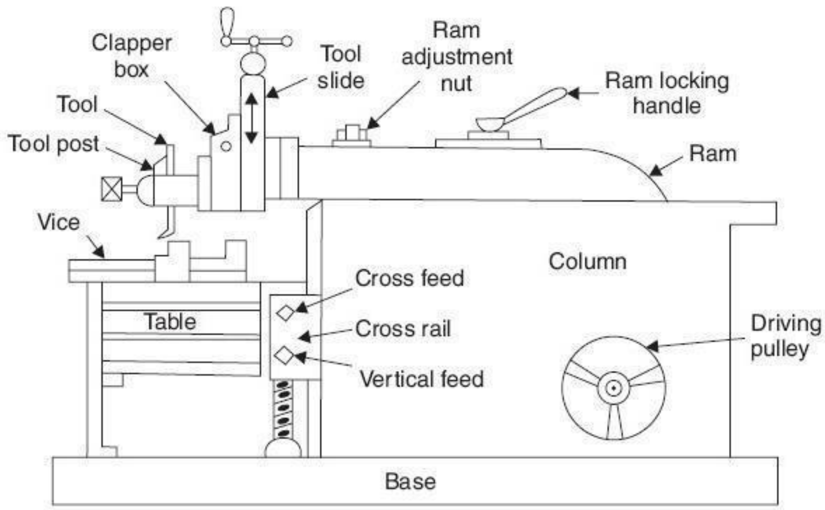
Hydraulic shaper

The ram of a hydraulic shaper is connected to a piston. Oil at high pressure is pumped to the cylinder of the hydraulic system. As the oil pushes the piston, the ram reciprocates. Hydraulic shapers are high power machines and are used for heavy duty work.

Universal shaper

The universal shaper has a special type of table which can be swiveled and positioned at any angle about a horizontal axis. Apart from the cross and vertical travel, the table of a universal shaper can be swiveled to any angle to machine inclined surfaces. In the process, the position of the work in the table need not be changed. These machines are utilised in precision workshops.

Principal parts of a shaper



Principal parts of a shaper

Base

The base is hollow and is made of cast iron. It provides the necessary support for all the other parts of the machine. It is rigidly bolted to the floor of the workshop.

Column

It is a box like casting mounted vertically on top of the base. Two accurate guide ways are machined on the top of the column. The ram reciprocates on these guide ways. The front face of the column is provided with two vertical guide ways. They act as guide ways for the cross rail. Cross rail moves vertically along these guide ways. The column encloses the ram reciprocating mechanism and the mechanism for stroke length adjustment.

Cross rail

It is mounted on the front vertical guide ways of the column. The table may be raised or lowered by adjusting the cross rail vertically. A horizontal cross feed screw is fitted within the cross rail.

Table

It is an important part useful in holding the work firmly on it. It is mounted on the saddle which is located above the cross rail. The top and sides of the table are accurately machined and have T-slots. Work pieces are held on the table with the help of shaper vise, clamps and straps.

Ram

Ram supports the tool head on its front. It reciprocates on the accurately machined guide ways on the top of the column. It is connected to the reciprocating mechanism placed inside the column. The position of ram reciprocation may be adjusted according to the location of the work on the table.

Tool head

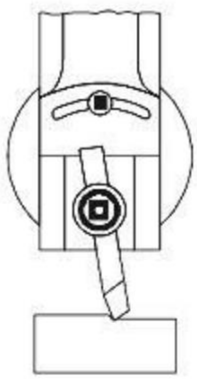
The tool head is fitted on the face of the ram and holds the tool rigidly. It provides vertical and angular feed movement of the tool. The swivel tool head can be positioned at any required angle and the vertical slide can be moved vertically or at any desired angle to machine vertical or inclined surfaces.

Shaper operations

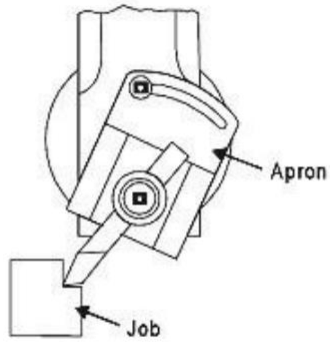
A shaper is a machine tool primarily designed to generate a flat surface by a single point cutting tool. Besides this, it may also be used to perform many other operations. The different operations, which a shaper can perform, are as follows:

2. Machining horizontal surface
3. Machining vertical surface
4. Machining inclined surface
5. Slot cutting

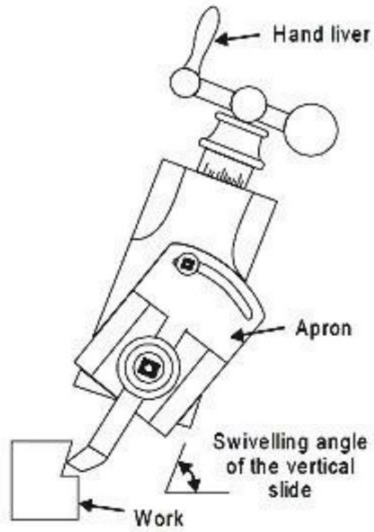
5. Key ways cutting
6. Machining irregular surface
7. Machining splines and cutting gears



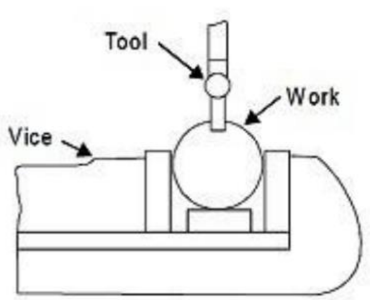
Machining horizontal surface



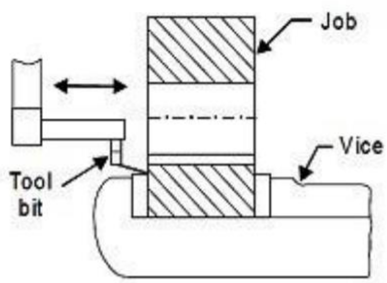
Machining vertical surface



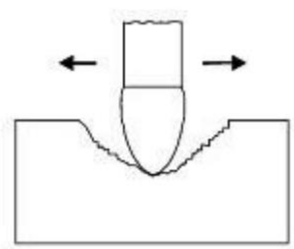
Machining inclined surface



Slot cutting

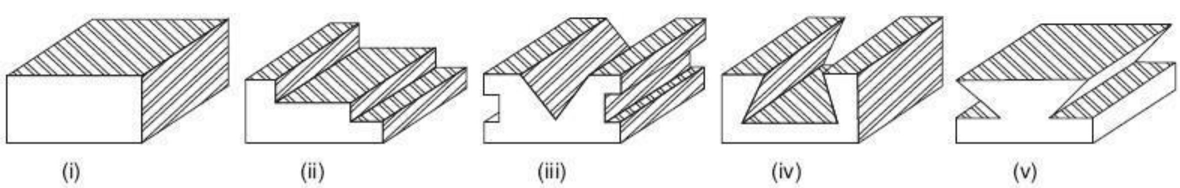


Keyway cutting



Irregular machining

Components manufactured by shaper operations



Components manufactured by shaping processes

Shaper specifications

The size of a shaper is determined by the maximum length of cut or stroke it can make. A standard shaper is usually capable of holding and machining a cube of the same dimensions as the length of stroke. The length of stroke is always the principal dimension, but a number of other details are also required for specifying a shaper fully. The complete specification of a typical shaper is given below.

1. Length of stroke
2. Maximum horizontal travel of table
3. Maximum vertical travel of table
4. Maximum distance from table to ram
5. Maximum vertical travel of tool slide
6. Length and width of table top
7. Length and depth of table side
8. Power of motor

Work holding devices

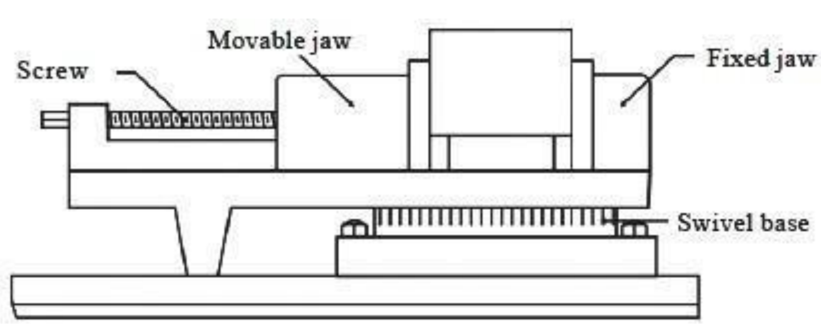
Work pieces can be held and supported on the shaper table directly or by having some special devices. Depending on the size and shape of the work, it may be supported on the table by any one of the following methods.

1. Shaper vise 2. Clamps and stop pins 3. T- bolts & step bolts

1. Angle plate 2. V block

Shaper vise

Vise is the most common and simple work holding device used in a shaper. Different types of vises are used in a shaping machine according to the need and they are:

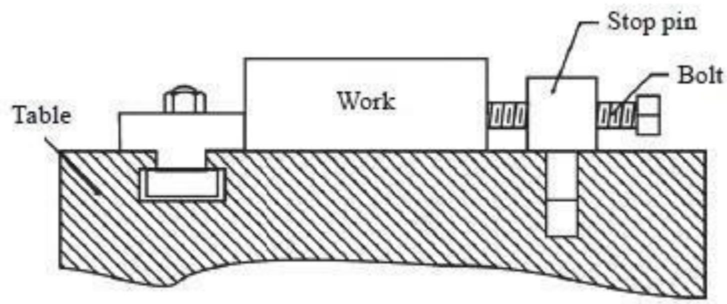


Shaper vise

1. Plain vise 2. Swivel vise 3. Universal vise

Clamps and stop pins

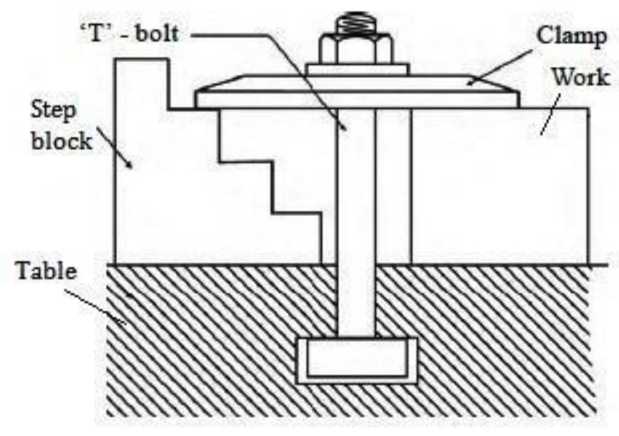
T–bolts are fitted into the T-slots of the table. The work is placed on the table. The work is supported by a rectangular strip at one end and by a stop pin at the other side. The screw is tightened to secure the work properly on the machine table.



Stop pin

T- bolts and step blocks

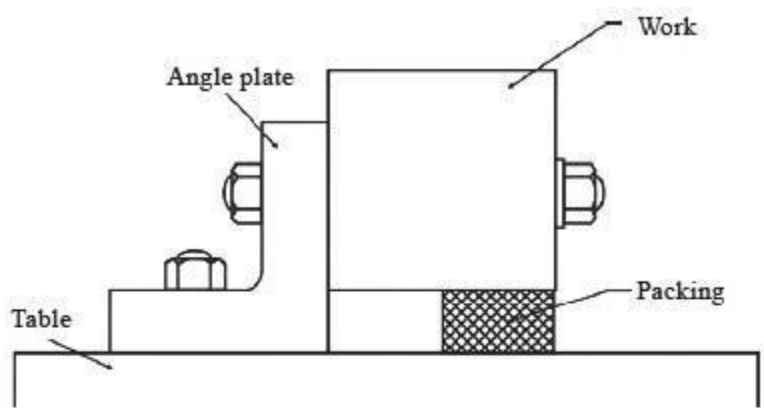
The step blocks are used in combination with T-bolts and clamps to hold the work directly on the machine table. T-bolts are fitted in the T- slots of the machine table. One side of the clamp holds the work and the other side rests on a step of the step block. The different steps of the block are useful in levelling the clamp when holding works of different heights. A nut on the top of the clamp holds the work rigidly.



T-bolt, clamp and step block

Angle plate

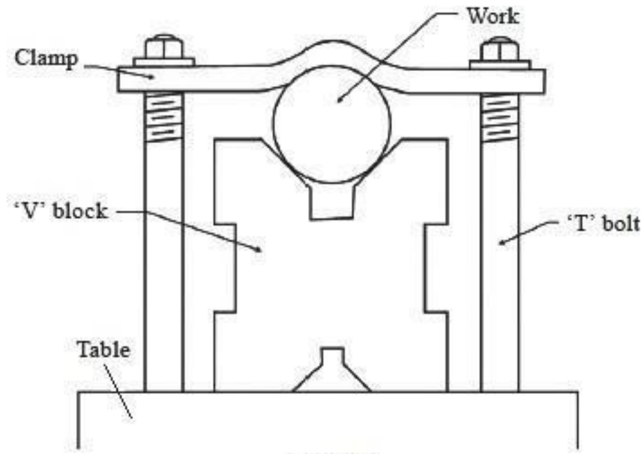
Angle plate resembles the English alphabet 'L'. It is accurately machined to have two sides at right angles. Slots are provided on both the sides. One of the sides is bolted to the machine table and the work pieces are held on the other side.



Angle plate

V – block

V – Block is a metal block having a 'V' shaped groove on it. It is used for holding cylindrical work pieces. Operations like keyway cutting, slot cutting and machining flat surfaces can be performed on the cylindrical work pieces held on a 'V' block.



V block

Tools used in a shaping machine

The materials of the cutting tool used in a shaping machine are as follows:

1. High Carbon Steel
2. High Speed Steel
3. Carbide tipped tool
4. Stellite tool

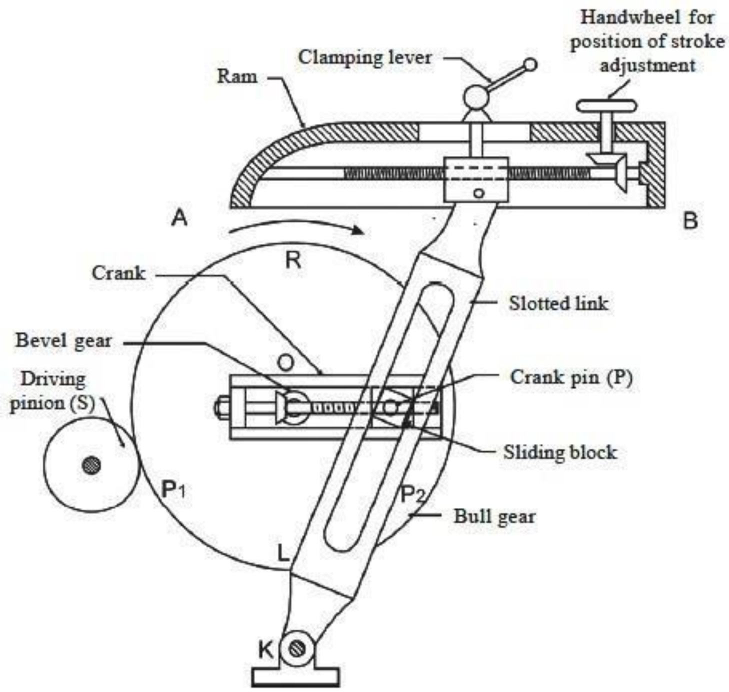
Quick return mechanisms

The ram moves at a comparatively slower speed during the forward cutting stroke. During the return stroke, the mechanism is so designed to make the tool move at a faster rate to reduce the idle return time. This mechanism is known as quick return mechanism. As the ram moves at a faster rate during return stroke, the time taken becomes less. The total machining time decreases and the rate of production increases. The following mechanisms are used for quick return of the ram.

2. Crank and slotted link mechanism
3. Hydraulic mechanism
4. Whitworth mechanism

Crank and slotted link mechanism

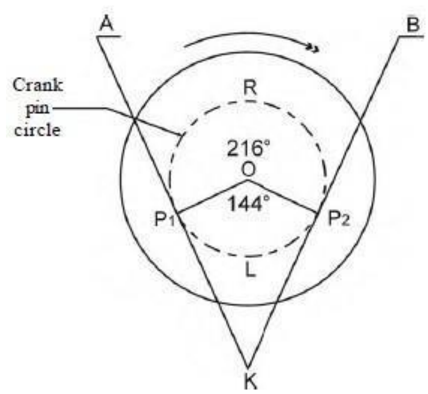
An electrical motor runs the driving pinion (S) at a uniform speed. This pinion makes the bull gear (M) to rotate at a uniform speed. Bull gear is a large gear fitted inside the column. The point ‘O’ is the centre of the bull gear. A slotted link having a long slot along its length is pivoted about the point ‘K’. A sliding block ‘N’ is fitted inside the slot and slides along the length of the slotted link. ‘P’ is the crank pin and ‘OP’ can be considered as a crank. When the bull gear rotates, the sliding block also rotates in the crank pin circle. This arrangement provides a rocking movement to the rocker arm. As the top of the slotted link is connected to the ram, the ram reciprocates horizontally. So, bull gear rotation is converted into the reciprocating movement of the ram.



Crank and slotted link mechanism

Fundamentals of quick return mechanism

As shown in the diagram, ‘KA’ indicates the starting point of the forward cutting stroke and ‘KB’ the end of the cutting stroke. The rotation of the crank ‘OP’ in clockwise direction through the angle P1RP2 refers to the forward cutting stroke. The rotation of the crank in the same direction through the angle P2LP1 refers to the return stroke. As the angle P2LP1 is smaller than the angle P1RP2, the time taken for the return stroke is less than that of forward stroke. So, it is evident that the speed at which the ram travels during return stroke is more. This is known as quick return mechanism.



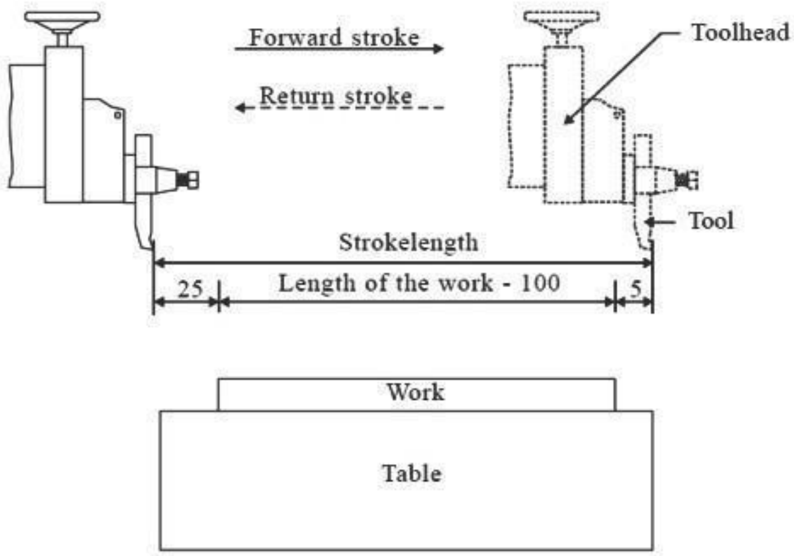
Quick return mechanism of the ram

$$\frac{\text{Time taken for forward cutting stroke angle}}{\text{Time taken for the idle return stroke angle}} = \frac{P1RP2}{P2LP1} = \frac{216°}{144°} = \frac{3}{2}$$

In some machines this ratio can be set as 7/5.

Stroke length calculation and adjustment

The length of the stroke is calculated to be nearly 30mm longer than the work. The position of stroke is so adjusted that the tool starts to move from a distance of 25mm before the beginning of the cut and continues to move 5mm after the end of the cut. Figure shows the adjustment required for the stroke length calculation.



Stroke length calculation

SLOTTING MACHINE

SLOTTER

Introduction

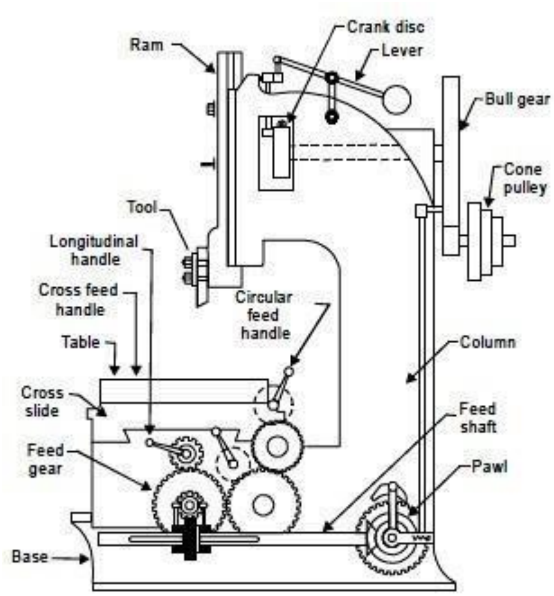
The slotter or slotting machine is also a reciprocating type of machine tool similar to a shaper. It may be considered as a vertical shaper. The machine operates in a manner similar to the shaper, however, the tool moves vertically rather than in a horizontal direction. The job is held stationary. The slotter has a vertical ram and a hand or power operated rotary table.

Slotting machine

Common types of slotting machine

2. Puncher slotting machine
3. General production slotting machine
4. Precision tool room slotting machine
5. Keyseater slotting machine

Principal parts of a Slotting machine



Principal parts of a slotter

Figure shows a slotter and its various parts. The main parts of a slotter are discussed as under:

2. **Bed or Base**

   It is made up of cast iron. It supports column, tables, ram, driving mechanism, etc. The top of the bed carries horizontal ways along which the work table can traverse.

3. **Table**

   It holds the work piece and is adjustable in longitudinal and cross-wise directions. The table can be rotated about its centre.

4. **Hand wheels**

   They are provided for rotating the table and for longitudinal and cross traverse. Column is the vertical member. They are made up of cast iron and it houses the driving mechanism. The vertical front face of the column is accurately finished for providing ways along which the ram moves up and down.

5. **Ram**

   It is provided to reciprocate vertically up and down. At its bottom, it carries the cutting tool. It is similar to the ram of a shaper; but it is more massive and moves vertically, at right angle to the worktable, instead of having the horizontal motion of a shaper.

6. **Cross-slide**

   It can be moved parallel to the face of the column. The circular work-table is mounted on the top of the cross-slide.

Uses of slotting machines

2. It is used for machining vertical surfaces
3. It is used angular or inclined surfaces
4. It is used It is used to cut slots, splines, keyways for both internal and external jobs such as machining internal and external gears
5. It is used for works as machining concave, circular, semi-circular and convex surfaces
6. It is used for shaping internal and external forms or profiles
7. It is used for machining of shapes which are difficult to produce on shaper
8. It is used for internal machining of blind holes
9. It is used for machining dies and punches

Slotting machine operations

Operations which can be performed on the slotting machine are, cutting of:

3. Internal grooves or key ways
4. Internal gears
5. Recesses
6. Concave, circular and convex surfaces etc

Types of slotter tools

A typical set of slotter cutting tools includes the following:

2. Roughing
3. Finishing
4. Right hand
5. Left hand
6. Keyway
7. Scriber

Slotting cutter

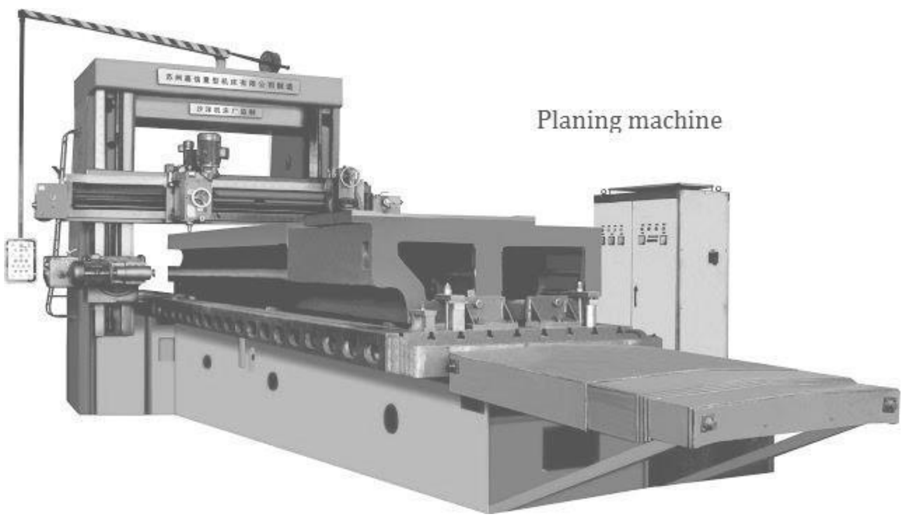
Specifications of slotting machine

2. Maximum ram stroke (mm)
3. Work table diameter (mm)
4. Max distance between tool post to bed (mm)
5. Max distance between ram guide and work table (mm)
6. Motor power (KW)

PLANAR

Introduction

Planer is used primarily to produce horizontal, vertical or inclined flat surfaces by a single point cutting tool. But it is used for machining large and heavy work pieces that cannot be accommodated on the table of a shaper. In addition to machining large work, the planer is frequently used to machine multiple small parts held in line on the platen. Planer is mainly of two kinds namely open housing planer and double housing planer. Figure below shows an image of a double housing planer.

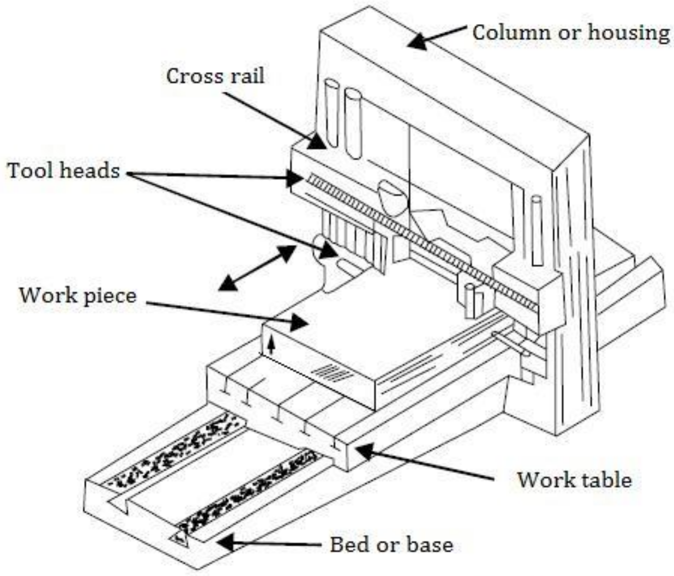


Common types of planers

Following are the common types of planers:

5. Double housing planer
6. Open side planer
7. Pit planer
8. Edge or plate type planer
9. Divided table planer

Principal parts of planer



Principal parts of planer

Following are the mail parts of the double housing planer machine

5. Bed and table
6. Housings
7. Cross rail
8. Tool heads
9. Driving and feed mechanism

Bed and table

The bed is a long heavy base and table made of cast iron. Its top surface is flat and machined accurately. The flat top surface has slots in which the work piece can be securely clamped. The work piece needs rigid fixing so that it does not shift out of its position. The standard clamping devices used on planer machine are: Heavy duty vice, T-holders and clamps, angle plate, planer jack, step blocks and stop. The table movement may be actuated by a variable speed drive through a rack and pinion arrangement, or a hydraulic system.

Housings

The housings are the rigid and upright column like castings. These are located near the centre on each side of the base.

Cross rail

The cross rail is a horizontal member supported on the machined ways of the upright columns. Guide ways are provided on vertical face of each column and that enables up and vertical movement of the cross rail. The vertical movement of the cross rail allows to accommodate work piece of different heights. Since the cross rail is supported at both the ends, this type of planer machine is rigid in construction.

Tool heads

Generally two tool heads are mounted in the horizontal cross rail and one on each of the vertical housing.

Tool heads may be swiveled so that angular cuts can be made.

Driving and feed mechanism

The tool heads may be fed either by hand or by power in crosswise or vertical direction. The motor drive is usually at one side of the planer near the centre and drive mechanism is located under the table.

Planing machine operations

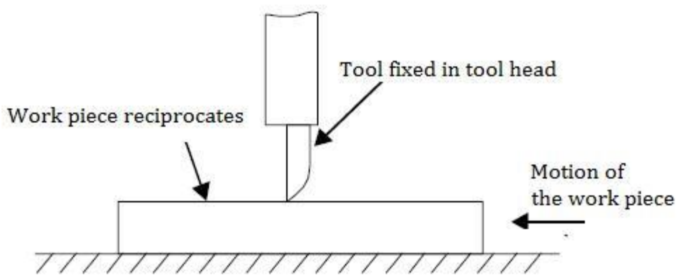
Operations which can be performed on the Planing machine are,

3. Planing flat horizontal
4. Planing vertical surfaces
5. Planing curved surfaces
6. Planing at an angle and machining dovetails.
7. Planing slots and grooves

Planer specifications

6. Length of the stroke
7. Bed length
8. Bed width
9. Centre of vees
10. Length of Table
11. width of Table
12. Maximum width between arms
13. Maximum height under cross rail
14. Tool Post size, etc.

Working principle of planer



Working principle of planing machine

Figure above shows the working principle of a planer. In a planer, the work which is supported on the table reciprocates past the stationary cutting tool and the feed is imparted by the lateral movement of the tool. The tool is clamped in the tool holder and work on the table. Like shaper, the planner is equipped with clapper box to raise the tool in idle stroke. The different mechanisms used to give reciprocating motion to the table are following:

5. Reversible motor drive
6. Open and cross belt drive
7. Hydraulic drive

Work holding devices

Various devices used for holding work pieces on the planer table are:

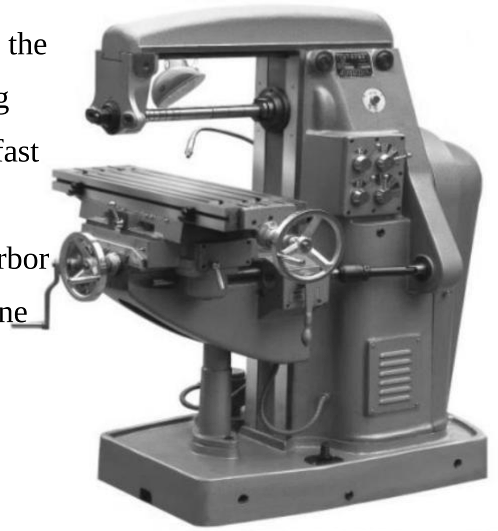
1. Planer vise
2. Step block
3. Planer screw jack
4. V –block
5. End stops
6. Angle plate
7. Clamps
8. Parallel strips
9. Holding-down dogs
10. T -bolts, nuts, washers, packing, wedges

Difference between Shaper, Slotter and Planer

Sl. No.	Shaper	Slotter	Planer
1	The work is held stationary and the tool on the ram is moved back and forth across the work	The work is held stationary and the tool on the ram is moved up and down across the work	The tool is stationary and the work piece on the table travels back and forth under the tool
2	Used for shaping much smaller jobs	It is used for making slots in smaller jobs	Meant for much larger jobs. Jobs as large as 6Mwide and twice as long can be machined
3	It is a light machine	Slotting is light machine	It is a heavy duty machine
4	Can employ light cuts and finer feed	Can employ light cuts and finer feed	Can employ heavier cuts and coarse feed
5	Uses one cutting tool at a time	Shaper uses one cutting tool at a time	Several tools can cut simultaneously
6	Driven using quick- return link mechanism	The rams are either crank-driven or hydraulically driven.	The drive on the planer table is either by gears or by hydraulic means

MODULE-4
MILLING MACHINE
Introduction

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The milling cutter rotates at high speed and it removes metal at a very fast rate with the help of multiple cutting edges. One or more number of cutters can be mounted simultaneously on the arbor of milling machine. This is the reason that a milling machine finds wide application in production work. Milling machine is used for machining flat surfaces, contoured surfaces, surfaces of revolution, external and internal threads, and helical surfaces of various cross- sections.



Universal milling machine

Common types of milling machines

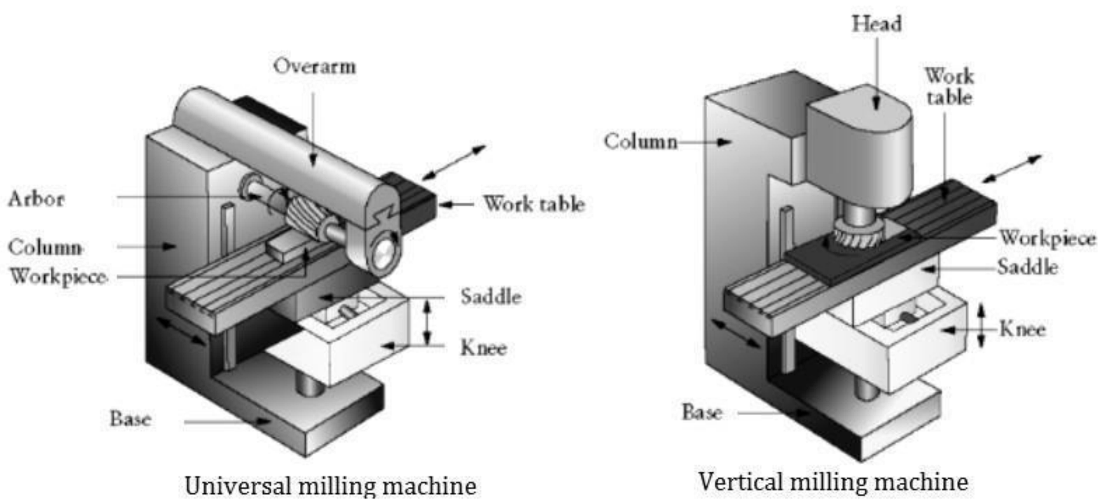
Milling machine rotates the cutter mounted on the arbor of the machine and at the same time automatically feed the work in the required direction. The milling machine may be classified in several forms, but the choice of any particular machine is determined primarily by the size of the work piece to be undertaken and operations to be performed. According to general design, the distinctive types of milling machines are:

2. Column and knee type milling machines
   a) Hand milling machine
   b) Horizontal milling machine
   c) Universal milling machine
   d) Vertical milling machine
3. Planer milling machine
4. Fixed-bed type milling machine
   a) Simplex milling machine.
   b) Duplex milling machine.
   c) Triplex milling machine.
5. Machining center machines
8. Special types of milling machines
   a) Rotary table milling machine.
   b) Planetary milling machine.
   c) Profiling machine.
   d) Duplicating machine.
   e) Pantograph milling machine.
   f) Continuous milling machine.
   g) Drum milling machine
   h) Profiling and tracer controlled milling machine

Principles of milling

In milling machine, the metal is cut by means of a rotating cutter having multiple cutting edges. For cutting operation, the work piece is fed against the rotary cutter. As the work piece moves against the cutting edges of milling cutter, metal is removed in form chips of trochoid shape. Machined surface is formed in one or more passes of the work. The work to be machined is held in a vice, a rotary table, a three jaw chuck, an index head, between centers, in a special fixture or bolted to machine table. The rotatory speed of the cutting tool and the feed rate of the work piece depend upon the type of material being machined.

Principal parts of a milling machine



Principal parts of milling machines

2. Base

It is a foundation member and it carries the column at its one end. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

3. Column

The column is the main supporting member mounted vertically on the base. It is box shaped, heavily ribbed inside and houses all the driving mechanism for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guide way for supporting the knee.

4. Knee

The knee is a rigid grey iron casting which slides up and down on the vertical ways of the column face. An elevating screw mounted on the base is used to adjust the height of the knee and it also supports the knee.

5. Saddle

The saddle is placed on the top of the knee and it slides on guide ways set exactly at 90° to the column face. The top of the saddle provides guide-ways for the table.

5. Table

The table rests on ways on the saddle and travels longitudinally. A lead screw under the table engages a nut on the saddle to move the table horizontally by hand or power. In universal machines, the table may also be swiveled horizontally. For this purpose the table is mounted on a circular base. The top of the table is accurately finished and T -slots are provided for clamping the work and other fixtures on it

6. Overhanging arm

It is mounted on the top of the column, which extends beyond the column face and serves as a bearing support for the other end of the arbor.

7. Front brace

It is an extra support, which is fitted between the knee and the over-arm to ensure further rigidity to the arbor and the knee.

8. Spindle

It is situated in the upper part of the column and receives power from the motor through belts, gears and clutches and transmit it to the arbor.

9. Arbor

It is like an extension of the machine spindle on which milling cutters are securely mounted and rotated. The arbors are made with taper shanks for proper alignment with the machine spindles having taper holes at their nose. The arbor assembly consists of the following components.

1. Arbor	2. Spindle	3. Spacing collars	4. Bearing bush	5. Cutter
6. Draw bolt	7. Lock nut	8. Key block	9. Set screw	

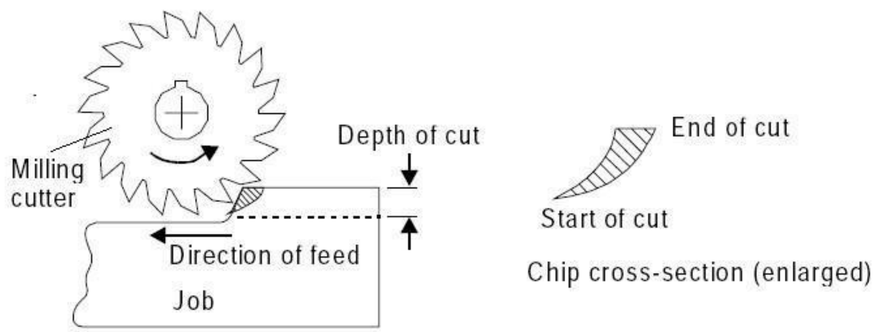
Milling methods

There are two distinct methods of milling classified as follows:

8. Up-milling or conventional milling
9. Down milling or climb milling.

Up-milling or conventional milling

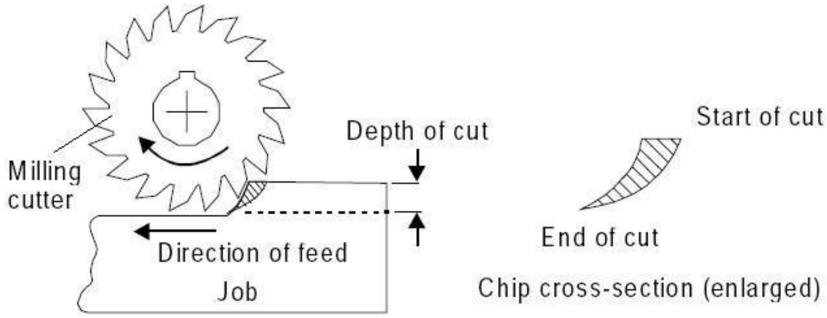
In the up-milling or conventional milling, the metal is removed in form of small chips by a cutter rotating against the direction of travel of the work piece. In this type of milling, the chip thickness is minimum at the start of the cut and maximum at the end of cut. As a result the cutting force also varies from zero to the maximum value per tooth movement of the milling cutter. The major disadvantages of up-milling process are the tendency of cutting force to lift the work from the fixtures and poor surface finish obtained. But being a safer process, it is commonly used method of milling.



Up milling process

Down-milling or climb milling

In this method, the metal is removed by a cutter rotating in the same direction of feed of the work piece. Chip thickness is maximum at the start of the cut and minimum in the end. In this method, there is less friction involved and consequently less heat is generated on the contact surface of the cutter and work piece. Climb milling can be used advantageously on many kinds of work to increase the number of pieces per sharpening and to produce a better finish. With climb milling, saws cut long thin slots more satisfactorily than with standard milling. Another advantage is that slightly lower power consumption is obtainable by climb milling, since there is no need to drive the table against the cutter.



Down milling process

Various milling machine operations

Following different operations can be performed on a milling machine:

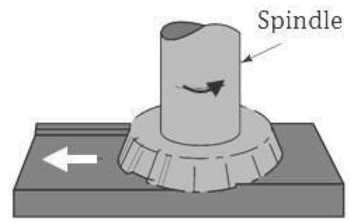
9. Plain milling operation
10. Face milling operation
11. Side milling operation
12. Straddle milling operation
13. Angular milling operation
14. Gang milling operation
15. Form milling operation
16. Profile milling operation
17. End milling operation
18. Saw milling operation
19. Slot milling operation
20. Gear cutting operation
21. Helical milling operation
22. Cam milling operation
23. Thread milling operation

Plain Milling Operation

This is also called slab milling. This operation produces flat surfaces on the work piece. Feed and depth of cut are selected, rotating milling cutter is moved from one end of the work piece to other end to complete the one pairs of plain milling operation.

Face Milling

This operation produces flat surface at the face on the work piece. This surface is perpendicular to the surface prepared in plain milling operation. This operation is performed by face milling cutter mounted on stub arbor of milling machine. Depth of cut is set according to the need and cross feed is given to the work table.



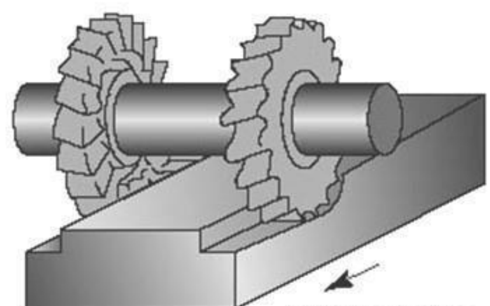
Face milling

Side Milling Operation

This operation produces flat and vertical surfaces at the sides of the work piece. In this operation depth of cut is adjusted by adjusting vertical feed screw of the work piece.

Straddle Milling Operation

This is similar to the side milling operation. Two side milling cutters are mounted on the same arbor. Distance between them is so adjusted that both sides of the work piece can be milled simultaneously. Hexagonal bolt can be produced by this operation by rotating the work piece only two times as this operation produces two parallel faces of bolt simultaneously.



Straddle milling

Angular Milling Operation

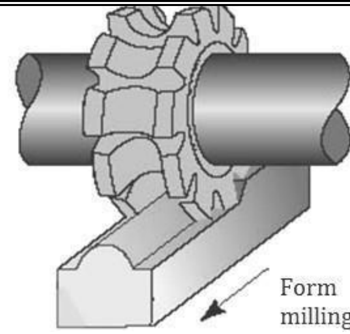
Angular milling operation is used to produce angular surface on the work piece. The produced surface makes an angle with the axis of spindle which is not right angle. Production of 'V" shaped groove is the example of angular milling operation.

Gang Milling Operation

As the name indicates, this operation produces several surfaces of a work piece simultaneously using a gang of milling cutters. During this operation, the work piece mounted on the table is fed against the revolving milling cutters.

Form Milling

This operation produces irregular contours on the work surface. These irregular contours may be convex, concave, or of any other shape. This operation is done comparatively at very low cutter speed than plain milling operation.

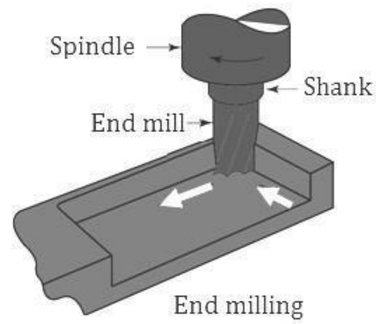


Profile Milling

In this operation a template of complex shape or master die is used. A tracer and milling cutter are synchronized together with respect to their movements. Tracer reads the template or master die and milling cutter generates the same shape on the work piece. Profile milling is an operation used to generate shape of a template or die.

End Milling

End milling operation produces flat vertical surfaces, flat horizontal surfaces and other flat surfaces making an angle from table surface using milling cutter named as end mill. This operation is preferably carried out on vertical milling machine.



Saw Milling

Saw milling operation produces narrow slots or grooves into the work piece using saw milling cutter. This operation is also used to cut the work piece into two equal or unequal pieces which cut is also known as "parting off".

Slot Milling Operation

The operation of producing keyways, grooves, slots of varying shapes and sizes is called slot milling operation. Slot milling operation can use any type of milling cutter like plain milling cutter, metal slitting saw or side milling cutter. Selection of a cutter depends upon type and size of slot or groove to be produced.

Gear Cutting Operation

The operation of gear cutting is cutting of equally spaced, identical gear teeth on a gear blank by handling it on a universal dividing head and then indexing it. The cutter used for this operation is cylindrical type or end mill type. The cutter selection also depends upon tooth profile and their spacing.

Helical Milling Operation

Helical milling produces helical flutes or grooves on the periphery of a cylindrical or conical work piece. This is performed by swiveling the table to the required helix angle, then rotating and feeding the work piece against revolving cutting edges of milling cutter. Helical gears and drills and reamers are made by this operation.

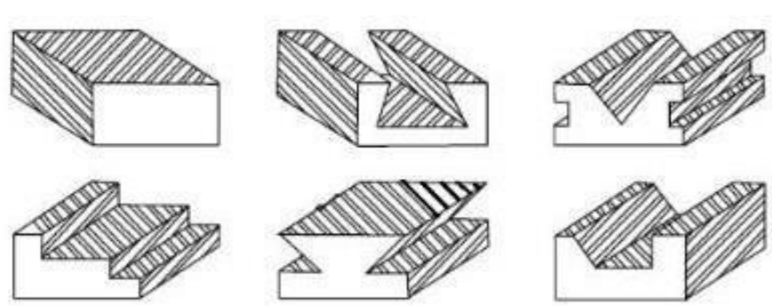
Cam Milling Operation

The operation cam milling is used to produce the cam on milling machine. In this operation cam blank is mounted at the end of the dividing head spindle and the end mill is held in the vertical milling attachment.

Thread Milling Operation

The operation thread milling produces threads using thread milling centres. This operation needs three simultaneous movements revolving movement of cutter, simultaneous longitudinal movement of cutter, feed movement to the work piece through table. For each thread, the revolving cutter is fed longitudinal by a distance equal to pitch of the thread. Depth of cut is normally adjusted equal to the full depth of threads.

Surfaces generated by milling machine



Types of milling cutters

Milling cutters are made in various forms to perform certain classes of work, and they may be classified as:

9. Plain milling cutter
10. Side milling cutter
11. Face milling cutter
12. Angle milling cutter
13. End milling cutter
14. Fly cutter
15. T-slot milling cutter
16. Formed cutter
17. Metal slitting saw

Plain milling cutter

These cutters are cylindrical in shape having teeth on their circumference. These are used to produce flat surfaces parallel to axis of rotation. Depending upon the size and applications plain milling cutters are categorized as light duty, heavy duty and helical plain milling cutters.

Plain milling cutter

Side milling cutter

Side milling cutters are used to remove metals from the side of work piece. These cutters have teeth on the periphery and on its sides. These are further categorized as plain side milling cutters having straight circumferential teeth. Staggered teeth side milling cutters having alternate teeth with opposite helix angle providing more chip space. Half side milling cutters have straight or helical teeth on its circumference and on its one side only. Circumferential teeth do the actual cutting of metal while side teeth do the finishing work.

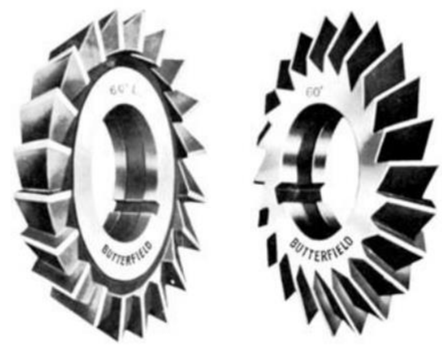
Side milling cutter

Face milling cutter

Face milling cutter

A face mill is an end mill optimised for facing cuts, whose teeth are arranged in periphery. Some face mills are solid in construction, but many others feature indexable teeth, with the cutter body designed to hold multiple disposable carbide or ceramic tips or inserts, often golden in color. When the tips are blunt, they may be removed, rotated (indexed) and replaced to present a fresh, sharp face to the work piece. This increases the life of the tip and thus its economical cutting life.

Angular milling cutter



Single angle Double angle

Angular milling cutter

These cutters have conical surfaces with cutting edges over them. These are used to machine angles other than 90°. Two types of angle milling cutters are available single angle milling cutter and double angle milling cutter.

End milling cutter

End mill cutter

End mills are used for cutting slots, small holes and light milling operations. These cutters have teeth on their end as well as on periphery. The cutting teeth may be straight or helical. Depending upon the shape of their shank, these are categorized as discussed below.

2. **Taper Shank Mill**
   Taper shank mill have tapered shank.
3. **Straight Shank Mill**
   Straight shank mill having straight shank.
4. **Shell End Mills**
   These are normally used for face milling operation. Cutters of different sizes can be accommodated on a single common shank.

Fly cutter

Fly cutters are the simplest form of cutters used to make contoured surfaces. These cutters are the Single-pointed cutting tool with cutting end ground to desired shape. These are mounted in special adapter or arbor. Used in experimental work instead of a specially shaped cutter

T Slot cutter

T slot cutter

These are the special form of milling cutters used to produce ‘T’ shaped slots in the work piece. It consists of small side milling cutter with teeth on both sides and integral shank for mounting.

Formed cutters

Formed cutters may have different types of profile on their cutting edges which can generate different types of profile on the work pieces. Depending upon tooth profile and their capabilities, formed cutters are categorized as given below.

1. **Convex Milling Cutters**

   These cutters have profile outwards at their circumference and used to generate concave semicircular surface on the work piece.

2. **Concave Milling Cutters**

   These milling cutters have teeth profile curve in words on their circumference. These are used to generate convex semicircular surfaces.

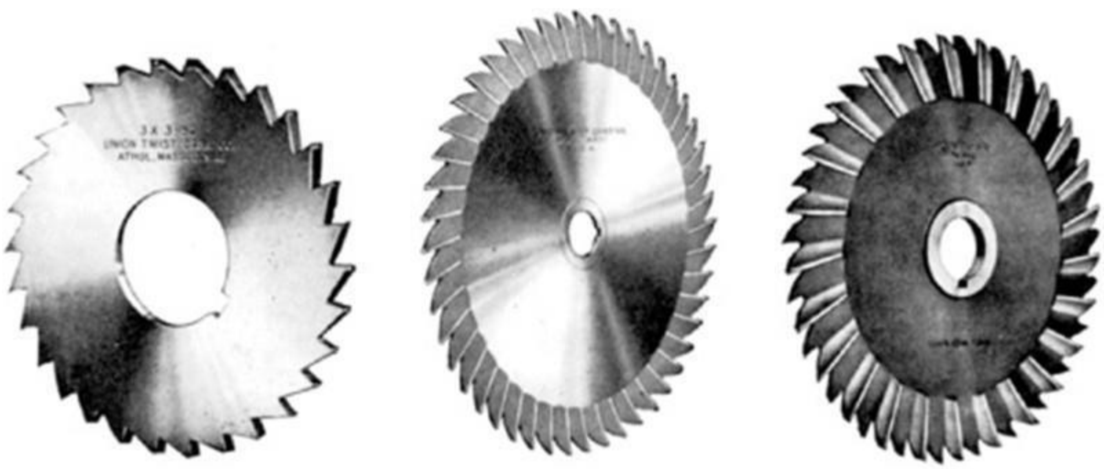
3. **Corner Rounding Milling Cutters**

   These cutters have teeth curved inwards. These milling cutters are used to form contours of quarter circle. These are main used in making round corners and round edges of the work piece.

Formed cutters

Metal slitting saw

These cutters are like plain or side milling cutters having very small width. These are used for parting off operations. It is of two types. If teeth of this saw resembles with plain milling cutter, it is called plain milling slitting saw. If its teeth matches with staggered teeth side milling cutter, it is called staggered teeth slitting saw.



Metal slitting saw

Indexing

Indexing is the operation of dividing the periphery of a work piece into any number of equal parts. For example if we want to make a hexagonal bolt. Head of the bolt is given hexagonal shape. We do indexing to divide circular work piece into six equal parts and then all the six parts are milled to an identical flat surface. If we want to cut 'n" number of teeth in a gear blank. The circumference of gear blank is divided into 'n" number of equal parts and teeth are made by milling operation one by one. The main component used in indexing operation is universal dividing head.

Indexing methods

There are different indexing methods. These are:

4. Direct indexing
5. Simple indexing
6. Compound indexing
7. Differential indexing

Specification of a milling machine

Along with the type of a milling machine, it has to be specified by its size. Generally size of a typical milling machine is designated as given below:

6. Size of the worktable and its movement range table length x table width as 900x275 mm.
7. Table movements: Longitudinal travel x Cross x Vertical as 600x200x400 mm.
8. Number of feeds available (specify their values).
9. Number of spindle speeds (specify their values).
10. Total power available.
11. Spindle nose taper.
12. Floor space required.
13. Net weight.

MODULE-5

GRINDING

Introduction

Grinding is a metal cutting operation performed by means of abrasive particles rigidly mounted on a rotating wheel. Each of the abrasive particles act as a single point cutting tool and grinding wheel acts as a multipoint cutting tool. The grinding operation is used to finish the work pieces with extremely high quality of surface finish and accuracy of shape and dimension. Grinding is one of the widely accepted finishing operations because it removes material in very small size of (micro-chips) chips 0.25 to 0.50 mm. It provides accuracy of the order of 0.000025mm. Grinding of very hard material is also possible.

Advantages of grinding

1. Investment is less and design is simple
2. Surface finishing will be approximate 10 times better as compared to milling and turning process of machining.
3. Dimensional accuracy will be quite good
4. Grinding process could be performed on hardened and unhardened work piece like metals, alloys, carbides, ceramics, composites materials.

Applications of grinding

1. Surface finishing
2. Slitting and parting
3. De-scaling and deburring
4. Grinding of tools and cutters and re-sharpening
5. Internal hole finishing
6. Form finishing

Classification of grinding machines

According to the accuracy of the work to be done on a grinding machine, they are classified as

1. Rough grinding machines
2. Precision grinding machines

Conventional grinding machines can be broadly classified

1. Surface grinding machine
2. Cylindrical grinding machine
3. Internal grinding machine
4. Tool and cutter grinding machine

Surface grinding machines

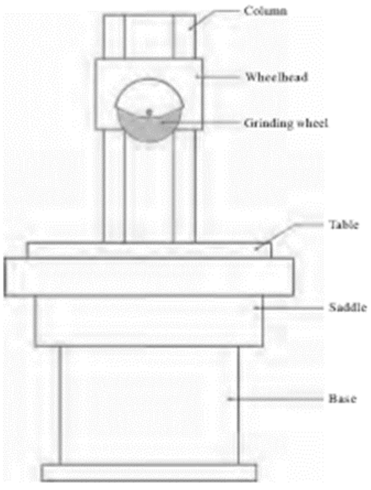
Surface grinding machines are employed to finish plain or flat surfaces horizontally, vertically or at any angle.

There are four different types of surface grinders

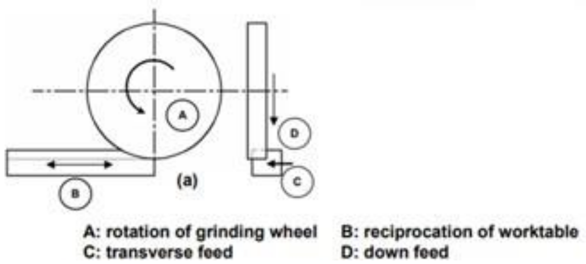
(a) Horizontal spindle and reciprocating table type
(b) Horizontal spindle and rotary table type
(c) Vertical spindle and reciprocating table type
(d) Vertical spindle and rotary table type

Horizontal spindle surface grinding machine

The majority of surface grinders are of horizontal spindle type. The grinding wheel is mounted on a horizontal spindle and the table is reciprocated to perform grinding operation. The periphery of the wheel is used for grinding. The area of contact between the wheel and the work is small, hence the speed is uniform over the grinding surface and the surface finish is good.

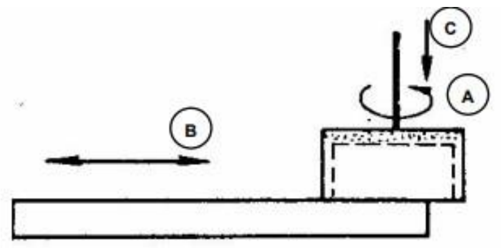


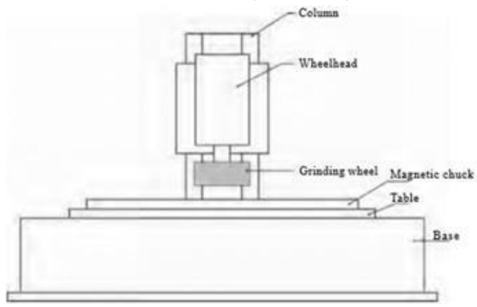
Horizontal spindle surface grinder



Vertical spindle surface grinding machine

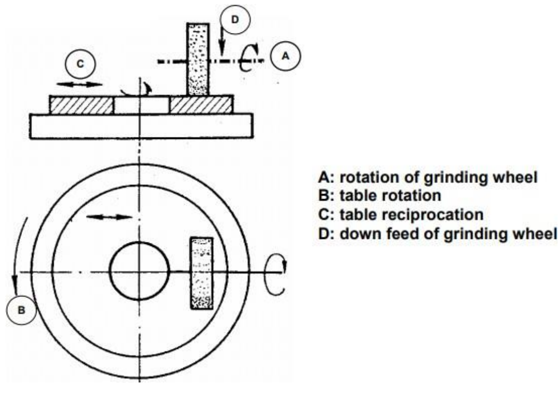
The grinding wheel is mounted on the vertical spindle of the machine which slides vertically on the column. The table is made to reciprocate to perform grinding. The face or sides of the wheel are used for grinding in the vertical type surface grinders. The area of contact is large and stock can be removed quickly but quality is inferior to horizontal grinding.





Horizontal spindle rotary table Surface grinder

The table is moved to perform the grinding operation. This machine has a limitation in accommodation of work piece and therefore does not have wide spread use. By swivelling the worktable, concave or convex or tapered surface can be produced on individual part.



Cylindrical grinding machine

This machine is used to produce external cylindrical surface. Cylindrical grinders are generally used to grind external surfaces like cylinders, taper cylinders, faces and shoulders of work.

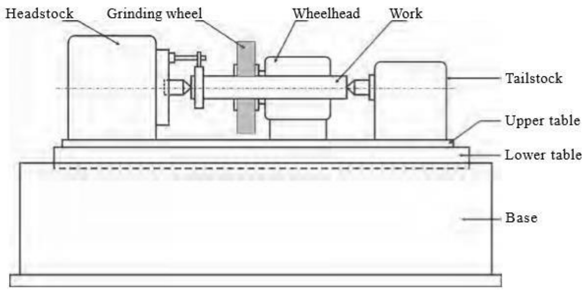
Broadly there are three different types of cylindrical grinding machine as follows:

1. Plain centre type cylindrical grinder
2. Universal cylindrical surface grinder
3. Centre-less cylindrical surface grinder

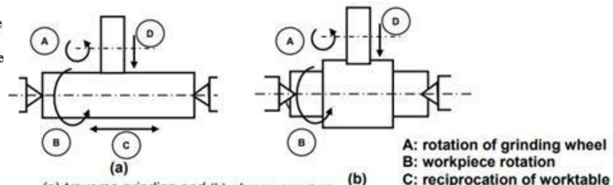
Plain centre type cylindrical grinder/external grinding machine

The work piece is held between head stock and tailstock centres. A disc type grinding wheel performsthegrindingactionwithitsperipheralsurface.Bothtraverseandplungegrindingcan be carried out in this machine as shown. In this grinding wheel is moved into the work. The desired surface is then produced by traversing the work piece across the wheel.

Plunge grinding - The basic movement is of the grinding wheel being fed radially into the work while the later revolves on centres.



Cylindrical grinding machine



(a) traverse grinding and (b) plunge grinding

Universal cylindrical grinding machine

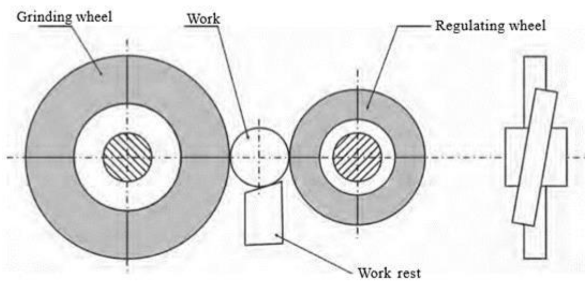
These grinders, in addition to the features offered by plain grinders, are provided with a swiveling headstock and a swiveling wheel head. This permits the grinding of taper of any angle, much greater than is possible in plain grinder.

Universal grinder has the following additional features:

- The centre of the head stock spindle can be used alive or dead.
- The wheel head can be swiveled in a horizontal plane in any angle.
- The headstock can be swiveled to any angle in the horizontal plane.

Centre-less cylindrical grinder

This grinding machine is 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. It is rotated by means of a regulating wheel and ground by the grinding wheel. Centre-less grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the workpiece.



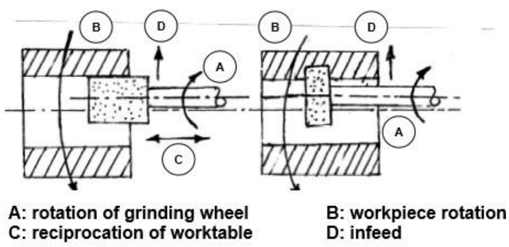
Centreless grinding

Internal grinding machine

This machine is used to produce internal cylindrical surface. The surface may be straight, tapered, grooved or profiled.

Broadly there are three different types of internal grinding machine as follows:

1. Chucking type internalgrinder
2. Planetary internalgrinder
3. Centre-less internalgrinder

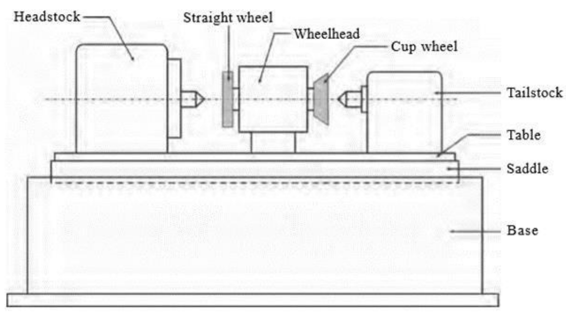


Centre-less internal grinder

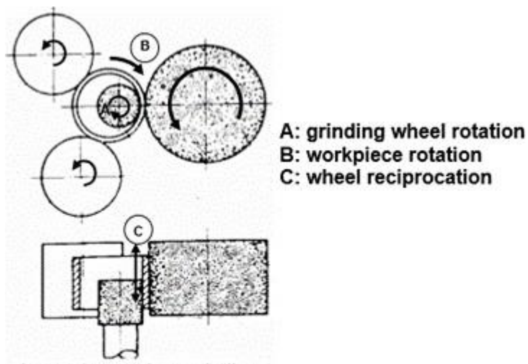
This machine is used for grinding cylindrical and tapered holes in cylindrical parts (e.g. cylindrical liners, various bushings etc). The work piece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel

Tool and cutter grinding machines

Tool and cutter grinders are used mainly to sharpen the cutting edges of various tools and cutters. The can also do surface, cylindrical and internal grinding to finish jigs, fixtures, dies and gauges.



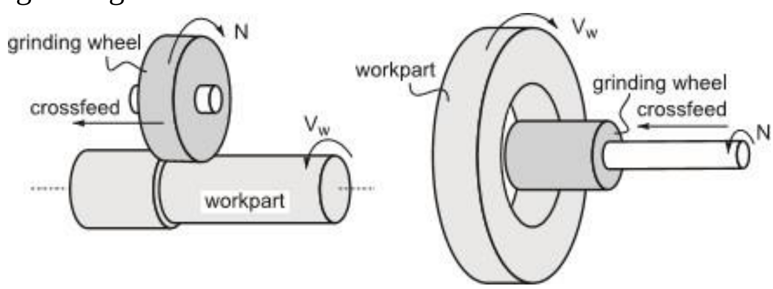
Tool and cutter grinder



Internal centreless grinding

Cylindrical grinding

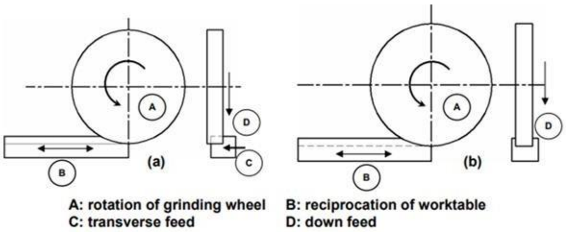
Cylindrical grinding is performed by mounting and rotating the work between centres in a cylindrical grinding machine. The work is fed longitudinally against the rotating grinding wheel to perform grinding.



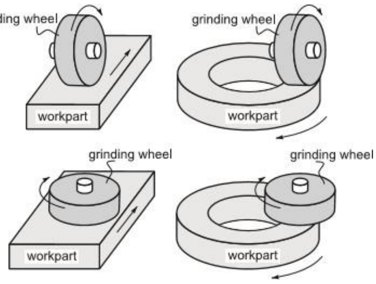
External and internal cylindrical grinding

Surface grinding machines

Surface grinding machines are employed to finish plain or flat surfaces horizontally, vertically. In surface grinding, the spindle position is either horizontal or vertical, and the relative motion of the work piece is achieved either by reciprocating the work piece past the wheel or by rotating it. The possible combinations of spindle orientations and work piece motions yield four types of surface grinding



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



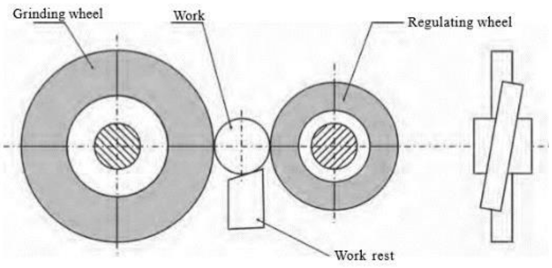
Centre-less grinding

Centre-less grinding is a method of grinding external cylindrical, tapered and formed surfaces on work pieces that are not held and rotated between centres or in chucks. There are two types of centre-less grinding and they are

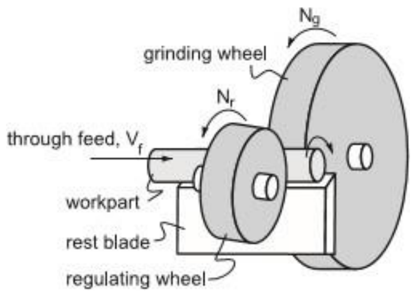
1. External centre-less grinding
2. Internal centre-less grinding

External centre-less grinding

Twowheels-agrindingandaregulatingwheelareusedinexternalcentre-lessgrinding.Both these wheels are rotated in the same direction. The work is placed upon the work rest and rotated between the wheels. The feed movement of the work along its axis past the grinding wheel is obtained by tilting the regulating wheel at a slight angle from the horizontal. An angular adjustment of 0 to 10 degrees is provided in the machine for this purpose.



Centreless grinding



Internal centre-less grinding

The principle of external centre-less grinding is applied to internal centre-less grinding also. Grinding is done on the inner surfaces of the holes. In internal centre-less grinding, the work is supported by three rolls- a regulating roll, a supporting roll and a pressure roll. The grinding wheel contacts the inside surface of the work-piece directly opposite the regulating roll. The distance between the contours of these two wheels is the wall thickness of the work.

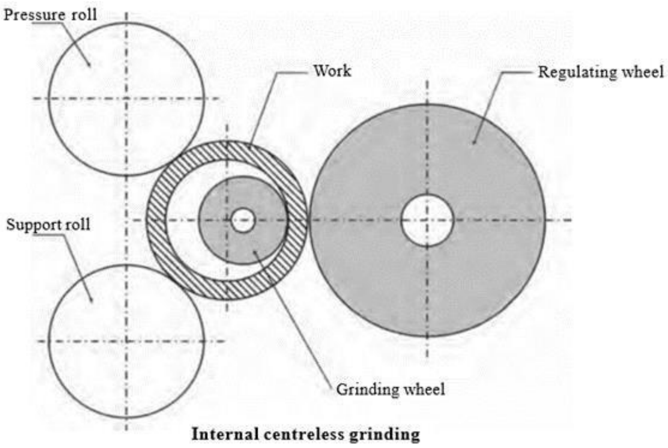
Advantages of centre-less grinding

1. Work piece is supported the entire length, grinding is done very accurately.
2. Small, slender and fragile work pieces can be ground easily.
3. No chucking or other holding devices are required.

4. As the process is continuous, it is best adapted for production work.
5. The size of the work can easily be controlled.
6. Low order of skill is needed in the operation of the machine.

Disadvantages of centre-less grinding

1. In hollow work, there is no certainity that the outer diameter will be concentric with the inside diameter.
2. Works having multiple diameters are not handled easily.



Internal centreless grinding

Universal cylindrical grinding machine

These grinders, in addition to the features offered by plain grinders, are provided with a swiveling headstock and a swiveling wheel head. This permits the grinding of taper of any angle, much greater than is possible in plain grinder.

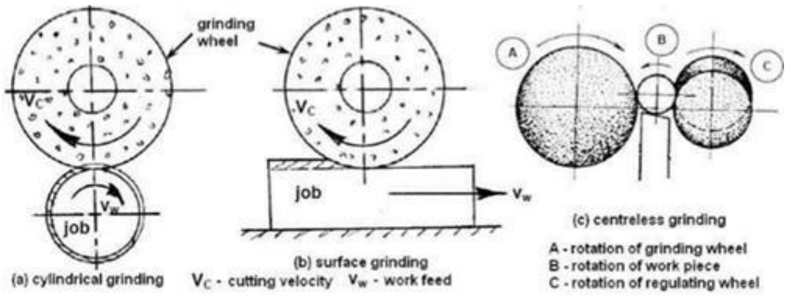
Universal grinder has the following additional features:

- The centre of the head stock spindle can be used alive or dead.
- The wheel head can be swiveled in a horizontal plane in any angle.
- The headstock can be swiveled to any angle in the horizontal plane.

Grinding machine operations

Grinding processes are generally classified based on the type of surface produced.

1. Cylindrical grinding process.
2. Surface grinding process.
3. Centre less grinding process.



Other grinding process

Taper grinding

Taper grinding on long workpieces can be done by swiveling the upper table. If the workpiece is short, the wheel head may be swiveled to the taper angle.

Gear grinding

The teeth of gears are ground accurately on gear grinding machines for their shape. Gear grinding is done by the generating process or by using a form grinding wheel.

Thread grinding

Thread grinding machines are used to grind threads accurately. The grinding wheel itself is shaped to the thread profile. These formed grinding wheels have one or multi threads on them

Wet grinding

The method of spreading a good quantity of coolant over the work surface and wheel faces during grinding is known as ‘wet grinding’. Soda water is used as a coolant. The process of grinding generates high amount of heat generally about 2000°C. Various properties of the work material change due to the heat. In order to reduce the heat generated during grinding, coolant is used. Wet grinding promotes long wheel life and better look of the ground surface. Coolant is pumped from the tank through pipelines.

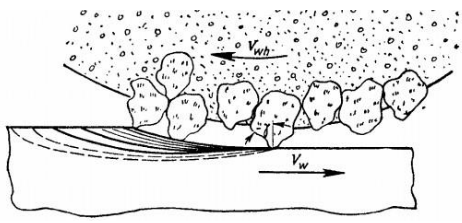
Dry grinding

Drygrindingisthemethodofdoinggrindingoperationwithoutapplyingcoolant.Drygrinding produces undesirable effects on work surfaces. It leads to burring & discoloration of work surfaces. The cutting edges of the grinding wheel lose their cutting capacity. So, dry grinding should better be avoided.

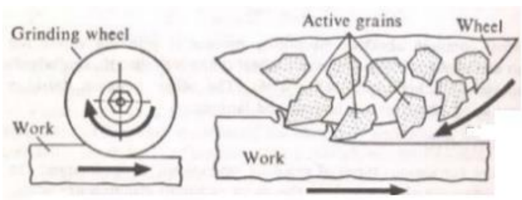
Grinding mechanisms

Material removal is taking place due to the abrasive or rubbing action between the abrasive particles and work piece. The work is fed against the rotating abrasive wheel.

It is a material cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, chemical stability and wear resistance. The grits are held together by a suitable bonding material to give shape of an abrasive tool. Each of the abrasive particles act as a single point cutting tool and grinding wheel acts as a multipoint cuttingtool.



Single grit



Grinding wheel

Grinding wheel consists of hard abrasive grains called grits, which perform the cutting or material removal, held in the weak bonding matrix. Each of the abrasive particles act as a single point cutting tool and grinding wheel acts as a multipoint cutting tool. When grinding is performed with conventional grinding wheels (other than metal-bonded),the worn out grits are removed automatically by the grinding force and the grits beneath come into contact with the workpiece.

A grinding wheel commonly identified by the type of the abrasive material used. The conventional wheels include aluminium oxide and silicon carbide wheels while diamond and CBN (cubic boron nitride) wheels fall in the category of super abrasive wheel.

According to construction, grinding wheels are classified under three categories.

1. Solid grinding wheels
2. Segmented grinding wheels
3. Mounted grinding wheels

Specification of grinding wheel

A grinding wheel requires two types of specification

a) Geometrical specification

b) Compositional specification

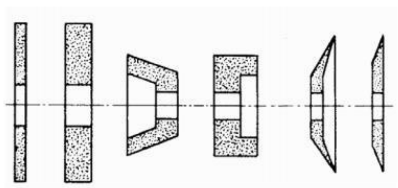
Geometrical specification

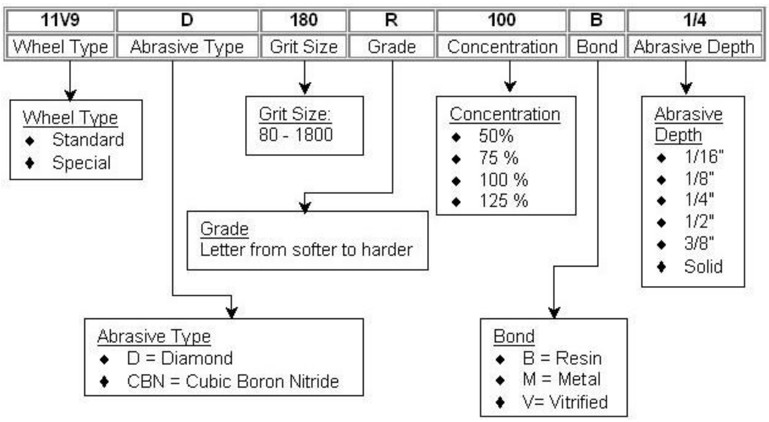
This is decided by the type of grinding machine and the grinding operation to be performed in the work piece. This specification mainly includes

a) Wheel diameter,

b) width and depth of rim

c) the bore diameter.





Compositional specifications

Specification of a grinding wheel ordinarily means compositional specification.

a) the type of grit material

b) the grit size

c) the bond strength of the wheel, commonly known as wheel hardness

d) the structure of the wheel denoting the porosity i.e. the amount of inter grit spacing

e) the type of bond material

Types of abrasives (Abrasives may be classified into two types)

Natural abrasives

- Emery (50 - 60 % crystalline Al_2O_3 + IronOxide),
- Sandstone or Solid Quartz, Corundum (75 - 90 % crystalline Al_2O_3 + IronOxide)
- Diamond.

Artificial abrasives

- Aluminium Oxide(Al_2O_3),
- Silicon Carbide(SiC),
- Artificialdiamond,
- Boron Carbide and Cubic Boron Nitride(CBN).

The abrasives that are generally used are Aluminium oxide, Silicon Carbide, Diamond and Cubic Boron Nitride (CBN).

Aluminium oxide may have variation in properties arising out of differences in chemical compositionandstructureassociatedwiththemanufacturingprocess.PureAl_2O_3grit has sharp freecuttingactionwithlowstrengthandisgoodforfinetoolgrindingoperationonhardferrous materials.

- Regular or brown aluminium oxide (doped with TiO_2) possesses lower hardness and higher toughness is recommended heavy duty grinding to semifinishing.
- Al_2O_3 alloyed with zirconia extremely tough grit suitable for high pressure, high material removal grinding on ferrous material and are not used for precision grinding.

Silicon carbide (SiC)

- Silicon carbide is harder than alumina but less tough. Silicon carbide is also inferior to Al_2O_3 because of its chemical reactivity with iron and steel.
- BlacksiliconcarbideislesshardbuttougherthangreenSiCandisefficientforgrinding soft nonferrous materials. Green silicon carbide contains at least 97% SiC.It is harder than black variety and is used for grinding cemented carbide.

Diamond

- Diamond grit is best suited for grinding cemented carbides, glass, stone, granite, marble, concrete, ceramics, fiber reinforced plastics, ferrite,graphite.
- Natural diamond grit is having very sharp cutting edge and free cutting action and is exclusively used in metallic, electroplated and brazed bond.
- Mono-crystalline diamond grits are known for their strength. Polycrystalline diamond grits are most suitable for grinding of cemented carbide with low pressure. These grits are used in resin bond.

Cubic Boron Nitride (CBN)

Diamond though hardest is not suitable for grinding ferrous materials because of its reactivity. In contrast, CBN the second hardest material, because of its chemical stability is the abrasive material of choice for efficient grinding of HSS, alloy steels. Medium strength crystals used in resin bond for those applications where grinding force is not so high. High strength crystals are used with vitrified or brazed bond where large grinding force is expected. Microcrystalline CBN is known for its highest toughness and auto sharpening character. It can be used in all types of bond.

Grain size

It refers to the actual size of the abrasive particles. The grain size is denoted by the number. The abrasive grains are classified in a screen mesh procedure.

- Large grit: Big grinding capacity, rough work piece surface.
- Fine grit: Small grinding capacity, smooth work piece surface

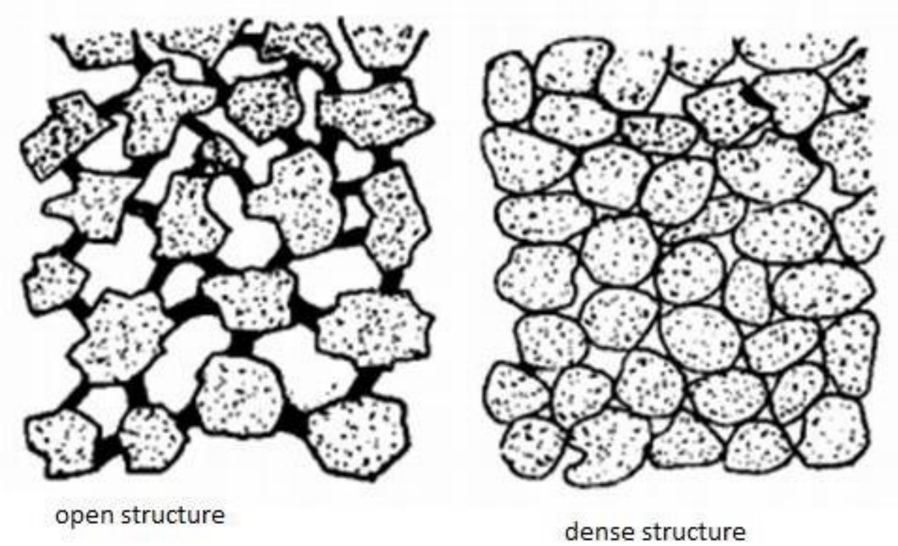
Grain sizes used in grinding wheels typically range between 6 and 600. Grit size 6 is very coarseandsize600isveryfine.Finergritsizesupto1000areusedinsomefinishingoperations Grainsizeisdenotedbyanumberindicatingthenumberofmeshesperlinearinchofthescreen through which the grains pass when they are graded. There are four different groups of the grain size namely coarse, medium, fine and very fine.

Grade

Grade or hardness indicates the strength with which the bonding material holds the abrasive grains in the grinding wheel. This means the amount of force required to pull out a single bonded abrasive grit by bond fracture. It does not refer to the hardness of the abrasive grain. 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.

Structure

The wheel structure indicates spacing of the abrasive grains in the wheel. It is measured on a scale that ranges from open to dense. Open structure means more pores and fewer grains per unit wheel volume, and vice versa. Open structure is recommended for work materials that tend to produce continuous chips, while denser structure is used for better surface finish and dimensional precision



Types of bond

A bond is an adhesive substance that is employed to hold abrasive grains together in the form ofgrindingwheels.Differentgrindingwheelsaremanufacturedbymixinghardabrasiveswith suitable bonds.

Bonds are classified into two types:

1. Organic - Resinoid, Rubber, Shellac &Oxychloride
2. Non - Organic - Metallic, Vitrified &Silicate

Common bonds

1. Vitrified bond(V)
2. Rubber bond(R)
3. Silicate bond(S)
4. Metal bond(M)
5. Shellac bond(E)
6. Oxychloride bond(O)
7. Resinoid bond(B)
8. Electroplated bond
9. Brazed bond

Vitrified bond (V)

Itcanalsobesafelyusedinwetgrinding.Itcannotbeusedwheremechanicalimpactorthermal variations are like to occur. This bond is also not recommended for very high speed grinding because of possible breakage of the bond under centrifugal force.

- The raw materials of bonds are clay, feldspar, and glass.
- Fired at a temperature about1200℃.
- Strong abrasives holding strength and high rigidity.
- Applicable to a wide variety of work materials such as carbon steels and alloy steels.
- Very suitable for precision grinding.
- Vitrified wheels hold form extremely well and produce a high rate stock removal

Rubber bond (R)

It's made with rubber as a bond, and the rubber wheel is used as the regulating wheels for center-less grinding. 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.

Silicate bond (S)

Silicate wheels are made by mixing abrasive grains with silicate of soda. The mixture is mouldedinamouldanddriedforseveralhours.Silicatebondedwheelsarelightgreyincolour. These wheels are having a fairly high tensile strength.

Metal bond (M)

Metalbondisextensivelyusedwithsuperabrasivewheels.Extremelyhightoughnessofmetal bonded wheels makes these very effective in those applications where form accuracy as well as large stock removal is desired. Metal bonds include various different bronze alloys. Metal bond is extensively used with super abrasive wheels.

Benefits of Metal Bond:

- Long wheel life
- Superior form holding
- Excellent for interrupted cuts
- Retain shape and size during extreme grinding
- accuracy as well as large stock removal

Shellac bond (E)

Shellac bonded grinding wheels are relatively strong but not rigid. At present use of shellac bond is limited to grinding wheels engaged in fine finish of rolls. Thin wheels that are strong but possess some elasticity have shellac bond. They can produce high polish and are used in grinding such parts as camshaft and mill rolls.

Shellac is a resin. Shellac bonded grinding wheels are relatively strong but not rigid. Shellac bond wheels are made by mixing the abrasive grains with shellac in mixer. After the mixture has been rolled or pressed into desired wheel shapes they are then hardened by baking for several hours at about 160 deg.

Oxy-chloride bond (O)

Oxy chloride Bond: This bond is produced by mixing abrasive grains with oxide and chloride of magnesium. It is less common type bond, but still can be used in disc grinding operation. It is used under dry condition. It is produced by mixing abrasive grains with oxide and chloride of magnesium.

Resinoid bond (B)

Conventional abrasive resin bonded wheels are widely used for heavy duty grinding because of their ability to withstand shock load. This bond is also known for its vibration absorbing characteristics and finds its use with diamond and CBN in grinding of cemented carbide and steel respectively. Fiberglass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation.

- The raw materials of bonds are synthetic resin like phenolicresin.
- Resin bonded products provide soft cutting action in precision grinding,
- Due to its strength and impact resistance, resin bonded products are used for rough grinding applications

	Cutting capacity	Stability of shape	Temperature resistance	Thermal conductivity	Dressing capability
Resin	↑	→	→	→	↑
Metal	→	↑	↑	↑	→
Vitrified	↑	→	↑	↓	↑
Metal-vitrified	→	↑	↑	↓	↓

↑ = excellent → = good ↓ = inadequate

Electroplated bond

The individual diamond grits are bonded through an electroplated nickel layer. Presently it is the only bond for making wheels for abrasive milling and ultra- high speed grinding. This bond allows large 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. There are several advantages to electroplated technology:

- The ability to manufacture tight-tolerance forms.
- Lower initial cost, compared to vitrified, resin and metal bonded super abrasive wheels.
- Free cutting, resulting in higher material removal rates, less power required
- Elimination of time associated with dressing.
- The ability to strip and re-plate the core.

Brazed bond

This is relatively a recent development, allows crystal exposure as high 60-80%. In addition, grit spacing can be precisely controlled. This bond is 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.

Marking system of grinding wheels

The standard marking system for conventional abrasive wheel can be as follows:

W A 60 K 5 V05

where

- The number 'W' is manufacturer's identification number indicating exact kind of abrasive used.
- The letter'A'denotes h at the type of abrasive is Aluminium Oxide(Al_2O_3).Incase of Silicon Carbide (SiC) the letter 'C' issued.
- The number '60' specifies the average grit size in inch mesh. For a very large size grit this number may be as small as 6 where as for a very fine grit the number can be600.
- The letter 'K' denotes the hardness of the wheel. The letter symbol can range between 'A' and 'Z', 'A' denoting the softest grade and 'Z' denoting the hardest one.
- The number '5' denotes the structure or porosity of the wheel. This number can be any value between 1 to 20, '1' indicating high porosity and '20' means low porosity.
- The letter code 'V' means that the bond material used is vitrified.
- The number '05' is a wheel manufacturer's symbol identifier.

Selection of grinding wheels

Selection of grinding wheel depends upon the following factors:

1. Physical and chemical characteristics of the work material
2. Grinding conditions (Work speed, Wheel speed, cooling)
3. Type of grinding (stock removal grinding or form finish grinding)
4. Types of grinding machine.

The process parameters of grinding are defined by the kinematic and geometric parameters. Kinematic parameters are: cutting speed (vs) and work piece speed(vw) and feed(s) if there is movement. The geometrical parameters are: wheels diameter Ds, work piece diameter (Dw), depth of cut (a), the length of contact (l) and chip thickness (h).

Glazing and loading of grinding wheels

Glazing

It is the condition of the grinding wheel in which the cutting edges or the face of the wheel takes a glass-like appearance. 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

Thewheelisloadediftheparticlesofthemetalbeinggroundadheretothewheel.The openings or pores of the wheel face are filled up with the metal. It is caused by grinding as offer material or by using a very hard bonded wheels and running it very slowly. It may also take place if very deep cuts are taken by not using the right type of coolant.

Chattering

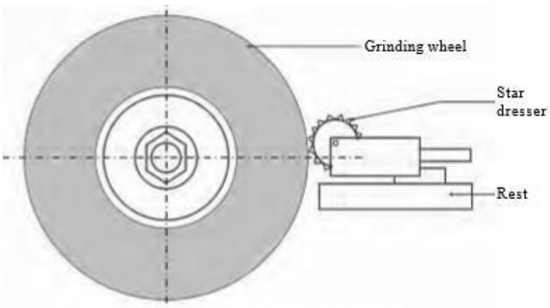
The wavy pattern of criss-cross lines is visible on the ground surface some times. This condition is known as chattering. It takes place when the spindle bearings are not fitted correctly and because of the imbalance of the grinding wheel.

Dressing of grinding wheel

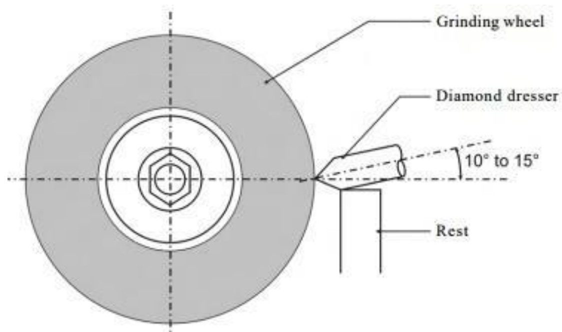
Dressing is the process of breaking away the glazed surface so that sharp particles are again presented to the work. **Dressing** means bringing back its cutting edges by removing the deposited metal chips.

In grinding operations, small chips of work piece material can become lodged in the cutting surface of the grinding wheel. In addition, if the wheel bonding hardness is excessive, dulled abrasive grains can remain in the grinding wheel. Both of these conditions will impair the cutting efficiency, and these particles must be removed as needed to maintain proper cutting action. This process, termed dressing is important in obtaining good results in grinding.

The common types of wheel dressers known as “Star” dressers or diamond tool dressers are used for this purpose. A star dresser consists of a number of hardened steel wheels on its periphery. The dresser is held against the face of the revolving wheel and moved across the face to dress the wheel surface



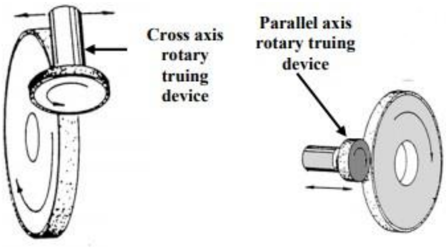
Dressing of a grinding wheel (Star wheel method)



Truing of grinding wheels

Establishes concentricity. Truing a wheel will bring every point on its cutting surface concentric with the machine spindle. This concentricity is important for achieving smooth and accurate grinding conditions. The cutting surface of a new wheel will run out slightly due to the clearance between the wheel bore and machine spindle Truing is also required on a new conventionalwheeltoensureconcentricitywithspecificmountingsystem.Whenanewwheel is installed on the grinder, it must be trued before use.

Diamond tool dressers are set on the wheels at 15° and moved across with a feed rate of less than 0.02mm. A good amount of coolant is applied during truing. Rotary powered truing devices are the most widely recommended truing tool in long run mass production and are not ideally suited for those wheels with large diameters.



Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operations for super abrasive wheel

Super-finishing operations

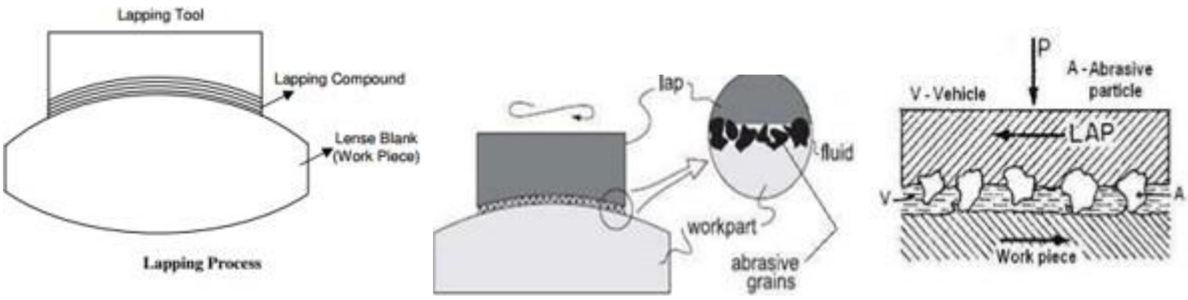
To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with high dimensional and geometrical accuracy but also with high surface finish. The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction. Unfortunately, normal machining methods like turning, milling or even classical grinding cannot meet this severe requirement.

1. Lapping
2. Honing
3. Polishing
4. Buffing
5. Electroplating

Lapping operation

Lapping is a machining process in which two surfaces are rubbed together with an abrasive compound between them, by hand movement or using a machine. Lapping is a surface finishing process used on flat or cylindrical surfaces. The fluid with abrasive particles very small free abrasive grains (aluminum oxide and silicon carbide, with grit sizes between 300 and 600) is referred as lapping compound. It appears as a chalky paste. Normally the fluid used in lapping compound is oil or kerosene.

Lapping is used to produce optical lenses, metallic bearing surfaces, gauges, and other parts requiring very good finishes and extreme accuracy.



Another method of lapping is the abrading of a surface by means of a lap (which is made of a material softer than the material to be lapped), which has been charged with the fine abrasive particles. The abrasive embeds within the softer material, which hold sit and permit sit to score across and cut the harder material.

Advantages

- Less distortion to the work as no clamping is required for the work
- Low heat generation
- Geometrically true surface.
- Extreme accuracy of dimension.
- Refinement of the surface finish
- Close fit between mating surfaces (High tolerance and dimensional accuracy)

Disadvantages

- Skill is required for the process
- MRR is low
- Cleaning of lapping compound is required

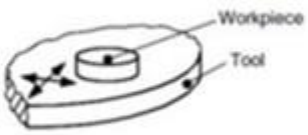
Flat lapping is most often used to process parts that require tight control of thickness and parallelism. It can correct surface irregularities and remove subsurface damage caused by sawing or grinding, producing dimensionally accurate flat parts to high tolerances.

Types or Lapping methods

1. Hand lapping for flatwork.
2. Machine lapping.

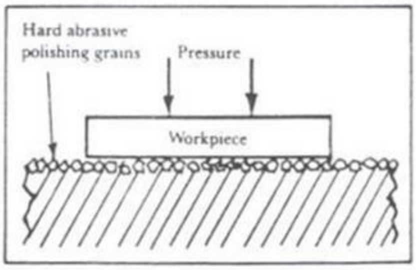
Hand lapping

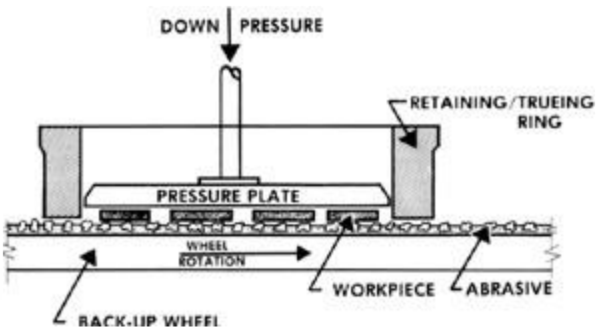
Hand lapping of flat surface is carried out by rubbing the component over accurately finished flat surface of master lap usually made of cast iron block. Abrading action is accomplished by very fine abrasive powder slurry. Manual lapping requires high personal skill because the lapping pressure and speed have to be controlled manually. Lapping machines accomplish the process with greater consistency and efficiency.



Lapping machines

These machines are fairly simple pieces of equipment consisting of a rotating table, called a lapping plate, pressure plate and conditioning ring. During lapping the abrasive compound is applied to the rolls rotating in the same direction while the work piece is fed across the rolls. Machine lapping can also employ abrasive paper or abrasive cloth as the lapping medium. In lapping process, cast iron plate with loose abrasive carried in a vehicle can be used. or bonded abrasive plates may also be used.





Types of lapping machines

Lapping machine can be also classifying as single side and double side lapping machines.

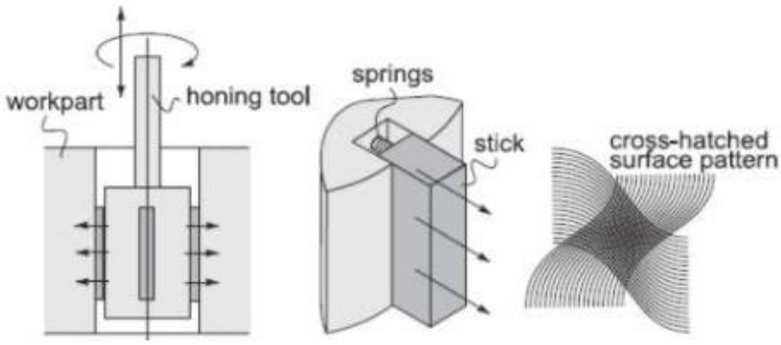
1. Vertical axis lapping machine: laps flat or round surfaces between two opposed laps on vertical spindle
2. Centre-less roll lapping machine using bonded abrasive wheel designed for continuous production of round parts such as piston rings, bearing races, valve tappets and shaft etc. (similar to centre-less grinding)
3. Flat lapping machine using circular lap plate

Honing

Itisanabrasiveprocessusedforfinishingpreviouslymachinedsurface.Itisgenerallyusedfor finishingdrilledorboredholes.Thetoolusedinthisprocessiscalledashone.Honeisabonded abrasivestonemadeintheformofastick.Thisprocessisusedprimarilytoremovethegrinding or the tool marks left on the surface by previous operations and finishing the holes. However, itcanbeusedforexternalcylindricalsurfacesaswellasflatsurfaces.Typicalapplicationsare the finishing of cylinders for internal combustion engines, bearing spindles and gears. Honing can be done on materials like plastic, silver, brass, aluminium, cast iron and steel

The advantages of honing are:

- Correction of geometrical accuracy.
- Dimensional accuracy.
- Surface texture improvement
- Cross hatched finish to retain lubrication
- Straightness and finish.



In addition to the surface finish of about0.1µm, honing produces a characteristic cross hatched surface that tends to retain lubrication during operation of the component, thus contributing to its function and service life. With conventional abrasive honing stick, several strokes are necessary to obtain the desired finish on the work piece. However, with introduction of high performance diamond and CBN grits it is now possible to perform the honing operation in just one complete stroke.

Types of honing

1. Manual honing process
2. Machine honing

Manual honing process

On this process a suitable quantity of coolant is used along with the honing stone hence this process is called as wet process. In this process the hone is continuously rotated and the work piece is moved front and back with the help of hand.

Machine honing

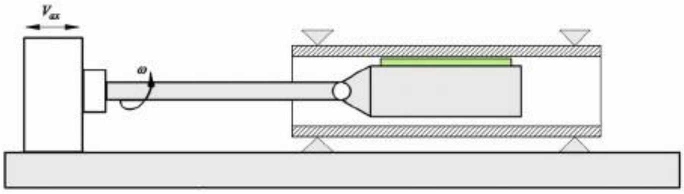
The process of honing can be done on any type of machines such as lathes and drilling machines. These small machines will fail to yield accurate results in mass production. So a regular honing machine is to be used in order to obtain a good result. A honing machine is relatively accurate and perfect

Honing machine

The honing machines are of two types - Vertical & Horizontal

Horizontal honing machines

Longer jobs are machined with the help of these machines. These machines carry a horizontal spindle on which honing tool is mounted. The work piece is held in a horizontal position and rotated about its own axis. This type of machine is meant for very longer jobs. On some machines the work piece is mounted on the table and it reciprocates to and fro. The hone rotates about its own axis and also slightly oscillates.

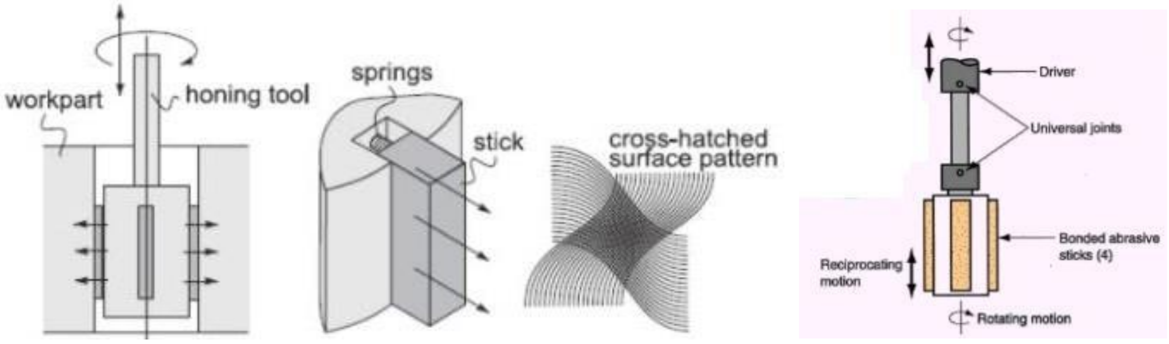


Vertical honing machines

In this type of machining process, the tool as well as the work piece is held vertically. These machinesareavailableinmorespindletypes.Theworkpieceisstableandthetoolreciprocates. Fixtures are present to hold the work piece in correct position. Vertical types of honing machines are generally suitable for shorter jobs.

Methods of honing

Honing is a finishing process performed by a honing tool called as hone which contains a set of three to a dozen and more bonded abrasive sticks. The sticks are equally spaced about the periphery of the honing tool. The sticks are held against the work surface with controlled light pressure, usually exercised by small springs. The honing tool is given a complex rotational and oscillatory axial motion, which combine to produce across hatched lay pattern of very low surface roughness. A cutting fluid must be used in honing to cool and lubricate the tool and to help remove the chips. A common application of honing is to finish the holes.



The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface. The critical process parameters are:

- Rotation speed.
- Oscillation speed.
- Length and position of the stroke.
- Honing stick pressure

Types of honing stones

Thehoningstoneiscomposedofabrasivegrainsthatareboundtogetherwithanadhesive.There are many types of hones but all consist of one or more abrasive stones that are held underpressureagainstthesurfacetheyareworkingon.Thechoiceofabrasivematerialisusually drivenbythecharacteristicsoftheworkpiecematerial.Withconventionalabrasivehoningstick, several strokes are necessary to obtain the desired finish on the work piece. From aluminum oxide and silicon carbide to diamond and **cubic boron nitride** (CBN) hone stone are using with different grain size and bond types.

However, with introduction of high performance diamond and CBN grits it is now possible to perform the honing operation in just one complete stroke. Honing stick with CBN grit can maintain sharp cutting condition with consistent results over long duration.

Honing conditions

- Spindle speed
- Length of hone
- Diameter/bore length
- Reciprocating speed
- Cross hatch pattern

Linear speed, tangential speed, pressure of abrasive stones on the work piece and a kind of coolant are used. On the other hand, parameters related to abrasive stones are type of abrasive, grain size of abrasive, type of binder and density of abrasive.

Cutting fluids

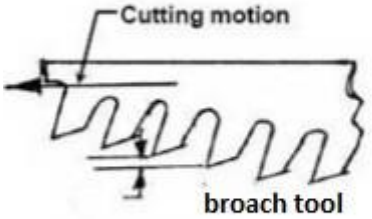
Thehoneisusuallyturnedintheborewhilebeingmovedinandout.Specialcuttingfluids are usedtogiveasmoothcuttingactionandtoremovethematerialthathasbeenabraded.**Honing oil** is a liquid, solution or emulsion used to aid in the cutting or grinding of metal, typically by abrasive tools or stones, and may or may not contain oil. It can also be called machining oil, tool oil, cutting fluid, and cutting oil. There are many different kinds of "honing oils" to suit different needs. The two most common classes of honing oil are petroleum based (typically mineral oils), and non-petroleum (typically water or vegetable oil) based. Common additives include chlorine, sulfur, rust inhibitors, and detergents

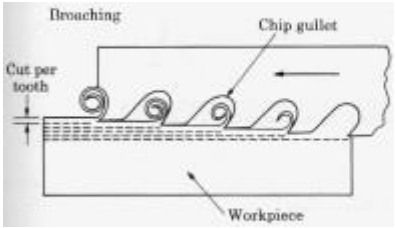
Special cutting fluids are used to give a smooth cutting action and to remove the material that has been abraded.

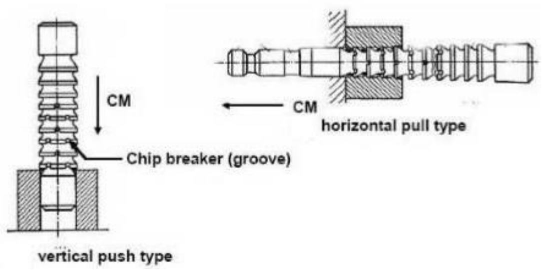
Broaching process

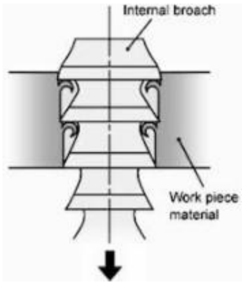
Basic principles of broaching

Broaching is a machining method in which a series of cutting teeth each remove a portion of stock as the cutting tool (broach) moves past or through the work piece. It removes layers of material in one stroke by a rod or bar type cutter with gradually increased protrusion. Each tooth removes a predetermined amount of material in a predetermined location. Broaching is preferably used to machine internal and external surfaces such as holes of circular, square, or irregular shapes, keyways, splines and teeth of internal gears.









Metal removal process in broaching operation is similar to **shaping process** except it uses a series of progressive teeth which can cut more material in a single pass. 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.

Advantages of broaching

1. Very high production rate (much higher than milling, planing, boring etc.).
2. High dimensional and form accuracy and surface finish of the product.
3. Roughing and finishing in single stroke of the same cutter.
4. Needs only one motion (cutting), so design, operation and control are simpler.
5. Extremely suitable and economic for mass production.
6. Any type of surface, internal or external can be generated with broaching.

Limitations

1. Only through holes and surfaces can be machined.
2. Usable only for light cuts,
3. Cutting speed cannot be high.
4. Design, manufacture and restoration of the broaches are difficult and expensive.
5. Separate broach has to be used when the size, shape and geometry of the job changes.
6. Economic only when the production volume is large.

Types of Broaches

A broach is a multiple –edges cutting tool that has successively higher cutting edges along the length of the tool. Broaching is getting more and more widely used, wherever feasible, for high productivity as well as product quality. Various types of broaches have been developed and are used for wide range of applications.

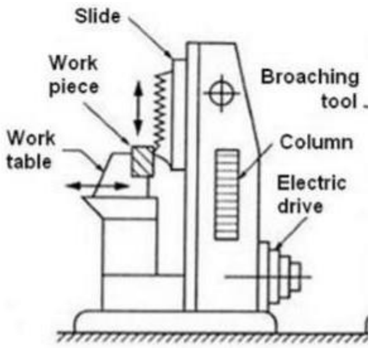
Broaches may be classified in various ways according to

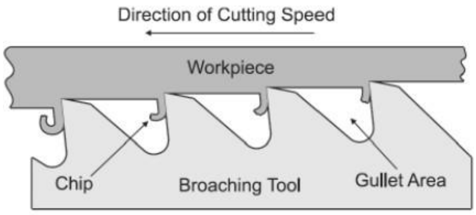
1. Type of operation: (Internal or external broaching)
2. Method of operation: (Pull type or Push type)
3. Type of construction:(Solid, build up, progressive cut, inserted tooth, rotorcut)
4. Function:(surface keyway, round hole, spines)
5. Progressive – cut type broaches have their teeth increasing in width instead of height Ordinary – cut type where the teeth increase in height or protrusion gradually from tooth to tooth along the length of the broach.

Internal broaching tools are used to enlarge and finish various contours in through holes. Externalbroachesareusedtocutsplinesandteethonoutersurfaces,grooves,slots, keyways etc.

Pull type broaches are generally made as a long single piece is in tension and having more number of teeth with high material removal.

Push type broaches are essentially shorter in length (to avoid buckling) is pushed through the work piece. Push type broaches are generally used for external broaching, preferably, requiring light cuts and small depth of material removal.

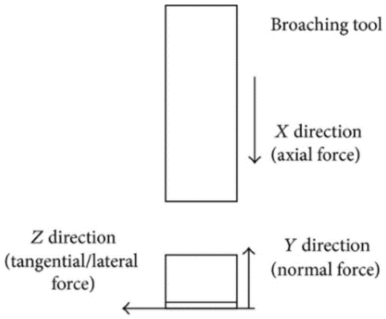




Mechanism of cutting in broaching

Force required for broaching

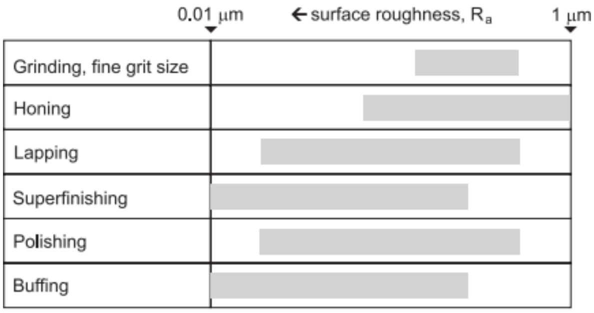
Cutting forces acting along the cutting velocity and tangential forces



Surface roughness obtainable in lapping, honing and broaching operations.

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.

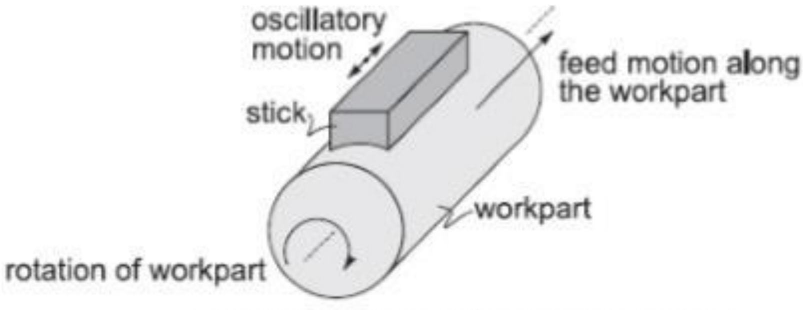
Process	Diagram of resulting surface	Height of micro irregularity (μm)
Precision Turning	Roughness	1.25-12.50
Grinding		0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super Finishing		0.01-0.25



- Shaping Process character: High MRR, medium Surface finish, dimension control
- Broaching - High MRR, Very good surface, dimension control, Expensive
- Drilling, Reaming, Boring- High MRR, Cheap, Medium-high surface, dimension control
- Turning- high MRR, high surface finish, dimension control
- Surface finish is maximum with lapping, then honing and broaching operations

Super finishing operations

Super finishing is a micro finishing process that produces a controlled surface condition on parts which is not obtainable by any other method. It is abrasive process which utilizes either abondedabrasivelikehoningforcylindricalsurfacesoracupwheelforflatsurfaces.Fig.4.38 schematically shows the super finishing process.



Schematics of the super finishing process.

Super finishing is a finishing operation similar to honing, but it involves the use of 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.

Semiautomatic and Automatic Lathes

Automation is incorporated in a machine tool or machining system as a whole for higher productivity with consistent quality aiming meeting the large requirements and overall economy. Such automation enables quick and accurate auxiliary motions, i.e., handling operations like tool– work mounting, bar feeding, tool indexing etc. repeatably with minimum human intervention but with the help of special or additional mechanism and control systems. These systems may be of mechanical, electro-mechanical, hydraulic or electronic type or their combination.

It is already mentioned that according to degree of automation machine tools are classified as,

- Non automatic where most of the handling operations irrespective of processing operations, are done manually, like centre lathes etc.
- Semiautomatic
- Automatic where all the handling or auxilliary operations as well as the processing operations are carried out automatically.

Main limitations of centre lathes

- The setting time for the job in terms of holding the job is large.
- Only one tool can be used in the normal course.
- 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 if proper care is not taken by the operator.

The conventional general purpose automated lathes can be classified as

Semi-automatic

(a) capstan lathe (ram type turret lathe)
(b) turret lathe
(c) multiple spindle turret lathe
(d) copying (hydraulic) lathe

Automatic

(a) Automatic cutting off lathe
(b) Single spindle automatic lathe
(c) Swiss type automatic lathe
(d) multiple spindle automatic lathes

Semi-automatics machine tools

Semi-automatics are employed for machining work from separate blanks. The operator loads and clamps the blanks, starts the machine and unloads the finished work. The characteristic features of semi - automatic lathes are:

- Some major auxiliary motions and handling operations like bar feeding, speed change, tool change etc. are done quickly and consistently with lesser human involvement.
- The operators need lesser skill and putting lesser effort and attention.
- Suitable for batch or small lot production.
- Costlier than centre lathes of same capacity.

Classification of semi-automatics

Depending upon the number of work spindle, these machines are classified as:

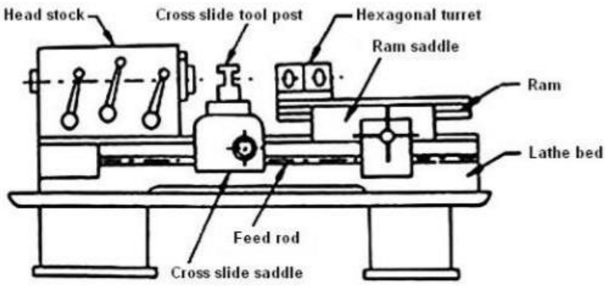
- Single spindle semi-automatics
- Multi spindle semi-automatics

The machine may also be built in two designs:

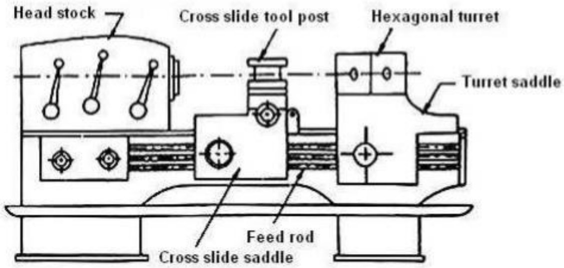
- Centre type.
- Chucking type.

Capstan and Turret lathes

The semiautomatic lathes, capstan lathe and turret lathe are very similar in construction, operation and application.



Basic configuration of a Capstan lathe



Basic configuration of a Turret lathe

Comparison of capstan and turret lathes

Sl . No.	Capstan lathe	Turret lathe
1	Turret head is mounted on a ram which slides over the saddle.	Turret head is directly mounted on saddle. But it slides on the bed.
2	The turret movement is limited.	The turret moves on the entire length of the bed without any restriction.
3	Hence shorter work piece can be machined.	Longer work piece can be machined.
4	Its construction does not provide rigidity due to overhanging of ram beyond the bed.	It provides rigidity and strong.
5	It is suitable for light duty applications.	It is suitable for heavy duty applications.
6	Turret head can be moved manually.	Turret head cannot be moved manually.
7	The maximum size of 60 mm diameter work can be accommodated.	It can accommodate only from 125 to 200mm.
8	No cross-wise movement to turret.	Facing and turning are usually done by cross-wise movement of turret.
9	Overhung type of cross-slide is not used.	Overhung type of cross-slide is provided for some specific operations.

(a) Bed

(b) Headstock

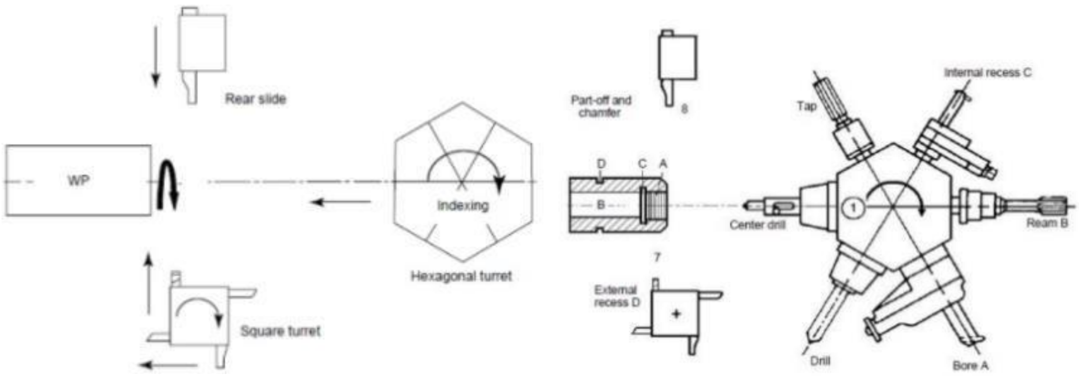
(c) Cross slide and saddle

(d) Turret

The turret is a hexagonal-shaped tool holder intended for holding six or more tools. Each face of the turret is accurately machined. Through the centre of each face accurately bored holes are provided for accommodating shanks of different tool holders. The centre line of each hole coincides with the axis of the lathe when aligned with the headstock spindle. In addition to these holes, there are four tapped holes on each face of the turret for securing different tool holding attachments.

Working principle of capstan and turret lathes

The work pieces are held in collets or chucks. A bar feeding mechanism is used for automatic feeding of bar stock. At least eleven tools can be set at a time in turret and capstan lathes. Six tools are held on the turret faces, four tools in front square tool post and one parting off tool at the rear tool post. While machining, the turret head moves forward towards the job. After each operation, the turret head goes back. The turret head is indexed automatically and the next tool comes into machining position. The indexing is done by an indexing mechanism. The longitudinal movement of the turret corresponding to each of the turret position can be controlled independently. By holding different tools in the turret faces, the operations like drilling, boring, reaming, counter boring, turning and threading can bed one on the component. Four tool sheld on the front tool post are used for different operations like necking, chamfering, form turning and knurling. The parting off tool in the rear tool post is used for cutting off the work piece. The cross wise movements of the rear and front tool posts are controlled by pre- stops.



Comparison of centre lathe and Turret and capstan lathes

Capstan and turret lathes are production lathes used to manufacture any number of identical pieces in the minimum time. These lathes are development of centre lathes.

In contrast to centre lathes, capstan and turret lathes:

- Are relatively costlier.
- Are requires less skilled operator.
- Possess an axially movable indexable turret (mostly hexagonal) in place of tailstock
- Holds large number of cutting tools; up to four in indexable tool post on the front slide, one in the rear slide and up to six in the turret (if hexagonal) as indicated in the schematic diagrams.
- Are more productive for quick engagement and overlapped functioning of the tools in addition to faster mounting and feeding of the job and rapid speed change.
- Enable repetitive production of same job requiring less involvement, effort and attentionoftheoperatorforpre-settingofwork-speedandfeedrateandlengthoftravel of the cutting tools.
- Are suitable and economically viable for batch production or small lot production.
- Capable of taking multiple cuts and combined cuts at the same time.

Automatic lathes

Automatics as their name implies are machine tools with a fully automatic work cycle. Automation is incorporated in machine tool systems to enable faster and consistently accurate processingoperationsforincreasingproductivityandreducingmanufacturingcostinbatchand massproduction.Thereductioninnumberofsetupsandtotalmachiningtimeenablestheparts to be produced at an economical cost in an automatic lathe.

These are machine tools in which the components are machined automatically. The working cycle is fully automatic that is repeated to produce identical parts without participation of the operator. All the working and idle operations are performed in a definite sequence by the control system adopted in the automats which is set up to suit a given work.

Advantages of automats over conventional lathes

1. Mass production of identical parts.
2. High accuracy is maintained.
3. Time of production is minimized.
4. Unskilled labor is enough. It minimizes the labor cost.
5. One operator can be utilized to operate more than one machine.
6. Scrap loss is reduced by eliminating operator error.

Comparison of automats and semiautomatics

Sl . No.	Automats	Semi automatics
1	Loading and unloading of work piece are done automatically by the machine.	Loading and unloading are done manually.
2	Feeding of bar stock and bringing the tools to correct machining positions are done automatically.	These are done manually.
3	A single operator can attend a number of machines when they are arranged together as a group.	An operator can attend to only one or two machines at a line.
4	Production time and cost less.	Not so less.
5	Best suitable for production of small size components.	Suitable for large size components.
6	Initial cost of machine is high.	Initial cost is lower than that of automatic lathe.

Automatic lathe working

Runs fully automatically continuously over a long duration repeating the same machining cycle for each product. Provided with up-to fiver a dial tool slides which a removed by cams mounted on a cam shaft and with higher spindle speeds.

1. Automatic Bar/stock/work piece feeding after the completion of one product
2. Indexing of tool
3. Cam or hydraulic drive for cross slide etc.

Advantage

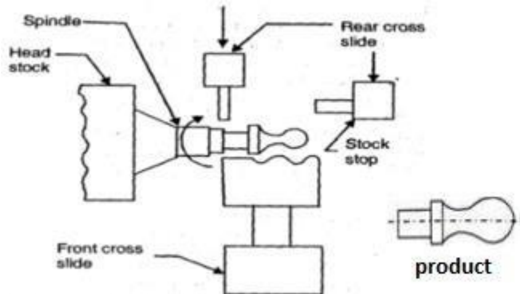
1. It is used to manufacture precision turning of small parts.
2. It has many tool slides.
3. Wide range of speed is available.
4. It is rigid in construction.
5. Simple design of can is enough.
6. Many working stations are available.
7. Micro-meter tool setting is possible

Automatic lathes are also classified into some distinguished categories based on constructional features, operational characteristics, number of spindles.

- Single spindle
    - Automatic cutting off lathes
    - Automatic (screw cutting)lathe
    - Swiss type automatic lathe
- Multi-spindle automatic lathe

Single and multi-spindle machines.

These machines have only one spindle. So, one component can be machined at a time. These crossslides(crossfeedoftool)areoperatedbydisccamsorhydraulicmechanismwhichdraws thepowerfromthemainspindlethroughcycletimechangegears.Spindlespeedsarechanged to suit work piece diameter/material requirements by means of change gears in the headstock. Essentially used for large volume of production of relatively smaller size.



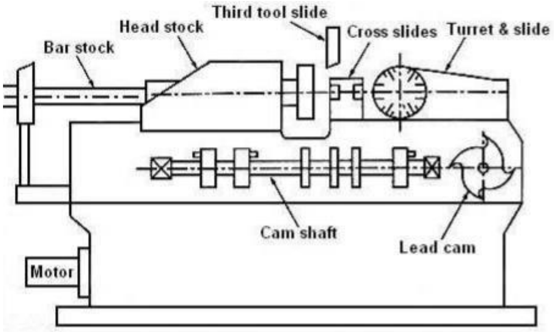
Automatic Cutting-off Machine

Description of above figure

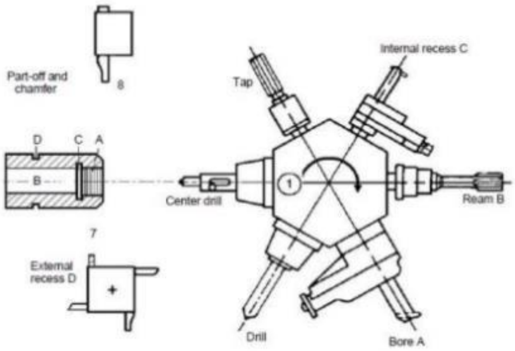
The required length of work piece (stock) is fed out with a cam mechanism, up to the stock stop which is automatically advanced in line with the spindle axis, at the end of each cycle. The stock is held in the collect chuck of the rotating spindle. The machining is done by tools held in cross slides operating only in the crosswise direction. The form tool held in the front tool slide produces the required shape of the component. The parting off tool in the rear tool slide is used to cut off the component after machining.

Single spindle automatic screw type machine

This is very similar to capstan and turret lathes with reference to tool layout, but all the tool movementsarecamcontrolled,suchthatfullautomationinmanufacturingisachieved.Thisis designed for machining complex external and internal surfaces on parts made of bar stock or of separate blanks.



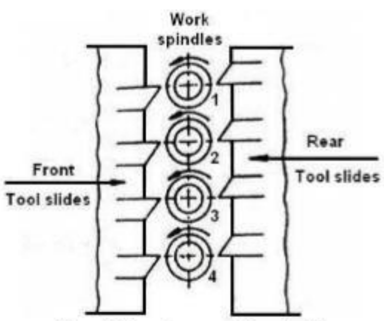
Single spindle automatic screw cutting machine



The bar stock is pushed through stock tube in a bracket and its leading end is clamped in rotating spindle by means of a collet chuck. The bar is then fed out for the next part by stock feeding mechanism. Longitudinal turning and machining of the central hole are performed by tools mounted on turret slide. The cut off and form tools are mounted on the cross-slides. At the end of each cut, turret slide is withdrawn automatically and indexed to bring the next tool into position. One revolution of camshaft produces one component. It is used for producing small jobs, screws, stepped pins, taper pins, bolts, etc.

Multi-spindle machines

The multi spindle automats are the fastest type of production machines and are made in a varietyofmodelswith2, 4, 5, 6 or 8 spindles. Each of the spindles is provided with its own set of tools for operation. As a result, more than one work piece can be machined simultaneously in these machines. In contrast to the single spindle automat, where one turret face at a time is working on one spindle, the multi spindle automat has all turret faces working on all spindles at the same time. The production rate of a multi spindle automat, however, is less than that of the corresponding number of single spindle automats. Machining of the inner and outer races in mass production of ball bearings are, for instance, machined in multi-spindle automatic lathes.



Parallel action multi spindle automat

Comparison of single spindle automat and multi spindle automat

Sl . No.	Single spindle automat	Multi spindle automat
1	There is only one spindle.	There are 2,4,5,6 or 8 spindles.
2	Only one work piece can be machined at a time.	More number of work pieces can be machined at a time.
3	The rate of production is low.	The rate of production is high.
4	Machining accuracy is higher.	Machining accuracy is lower.
5	Tool setting time is less.	Tool setting time is more.
6	Tooling cost is less.	Tooling cost is more.
7	Economical for shorter as well as longer runs.	Economical for longer runs only.
8	The time required to produce one job is the sum of all turret operation times.	The time required to produce one job is the time of the longest cut in any one spindle.
9	Tools in turret are indexed.	Work pieces held in spindles are indexed (Progressive action machine)

MODULE-6

Digital Manufacturing

Original manufacturing was accomplished by hand, but most modern manufacturing operations are highly mechanized and automated. Today manufacturing is no longer a single skill or technology, but a science including engineering science, organization science, information science and so on.

With the rapid changes in market demand, global economic competition and the rapid development of high-tech, the profound revolution in the manufacturing industry, the depth and width of manufacturing activities are greatly expanded, and the manufacturing industry is developing in the direction of automation, intelligence, integration, network and globalization. Science and technologies, such as microelectronics, automation, computers, telecommunications, networks and informatics, have undergone rapid development. Manufacturing industry gradually shifts from the traditional energy-driven state to being information-driven.

Manufacturing engineers use 3D modeling software to design the tools and machinery necessary for their intended applications. The software allows them to design the factory floor layout and the production flow. This technique lets engineers analyze the current manufacturing processes and allows them to search for ways to increase efficiency in production before production even begins.

Digital manufacturing is the use of an integrated, computer-based system comprised of simulation, three-dimensional (3D) visualization, analytics and various collaboration tools to create product and manufacturing process definitions simultaneously. Digital production is based on maximum interaction among the automated design and management systems governing the whole product life cycle, including resources and personnel.

Digital manufacturing would allow for, first, the shortening of development time and cost, second, the integration of knowledge coming from different manufacturing processes and departments, third, the decentralized manufacturing of the increasing variety of parts and products in numerous production sites, and, fourth, the focusing of manufacturing organizations working efficiently with other companies and suppliers, on the basis of effective IT-based cooperative engineering.

Digital Manufacturing is a manufacturing process which, with the support of technologies such as virtual reality, computer networks, rapid prototyping and database, is based on customer demand so as to analyze, organize and recombine the product information, process information and resource information, implement the product design and function simulation as well as rapid prototyping, and then to perform rapid production to meet customer demand and quality standards.

The conception of DM originated from the technology of Numerical Control (NC) or Computer Numerical Control (CNC) and the CNC machine tool. Digital design and digital management have fully developed along with the advancement of CAD and the development of material requirements planning (MRP). In the last years, with the support of virtual reality, computer network, rapid prototyping, multi-media and so on, the simulation and prototype manufacturing of the design and the functions of product can be quickly realized by rapidly analyzing, planning and recombining, coordinating and sharing of all kinds of information (e.g., product information, process information, control information and resources information), to manufacture the product according to the user's requirements as soon as possible.

Design information, process information, manufacturing information, management information and manufacturing knowledge and skill, are transmitted in the form of digital signals among manufacturing enterprises through the digital network. Speaking of global manufacturing, all users issue their demands through a digital network and enterprises can design and manufacture the corresponding product according to their own predominance with the help of dynamic alliances. The product itself will become a digital code or a digital mark in the currency along with the appearance of digital logistics. It is clear that the concept of DM is the result of the merging process of digital technology, network information technology, manufacturing technology and also the unavoidable result of the digitizing process in manufacturing enterprises, manufacturing systems and production systems. In the DM environment, individuals, enterprises, shop floors, devices, sales agents and markets form the nodes in the network over the Internet. On the other hand, DM contains the Control-Centered DM, Design- Centered DM, Management- Centered DM and Manufacturing-Centered DM. Currently, networked manufacturing is the implementation of the globalization of DM, virtual manufacturing is the entity of the digital factory, and digital products and e-commence are the dynamic federation ofDM.

Industrial internet of things platform combined with 3D factory visualization connects people, processes and devices

- Fully smart-connected enterprise
- Real-time generation and visualization of facts
- Real-time control of all processes in supply chain
- New cyber-physical systems and relations

Benefits of Digital Manufacturing

Digital manufacturing can help manufacturing companies improve their productivity in both manufacturing planning and production processes.

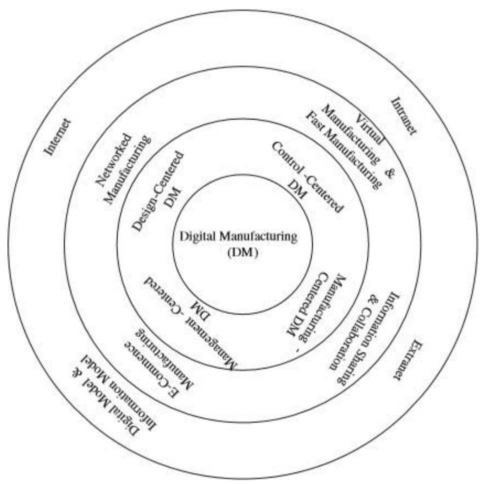
1. Shortened product development;
2. Early validation of manufacturing processes;
3. Faster production ramp-up;
4. Faster time to market;
5. Reduced manufacturing costs;
6. Improved product quality;
7. Reduction in errors;
8. Increase inflexibility.

9. Innovate more easily
10. Freedom to Redesign

Concepts and Research and Development Status of Digital Manufacturing

DM becomes a new manufacturing mode to adapt to the increasingly complex product structure, increasingly personalized, diversified consumptive demand and large manufacturing network, and naturally becomes an important feature in the future development of the manufacturing industry. The twenty-first century, which is marked by ‘‘network’’ and ‘‘informatization’’, will change the way of obtaining, processing, exchanging and using information and knowledge by human and will propel an unprecedented improvement of people’s lifestyle, production patterns and social structure.

The conception of DM originated from the technology of Numerical Control (NC) or Computer Numerical Control (CNC) and the CNC machine tool. The concept of DM is the result of the merging process of digital technology, network information technology and manufacturing technology. In the DM environment, individuals, enterprises, shop floors, devices, sales agents and markets form the nodes in the network over the Internet. Other hand, DM contains the Control-Centered DM, Design Centered DM, Management-Centered DM and Manufacturing- Centered DM.



Concept of DM

In manufacturing enterprises, all sorts of information (graphic, data, knowledge, and technique) are in digital form, transmitting through digital networks. Digital-manufacturing technologies will transform every link in the manufacturing value chain, from research and development, supply chain, and factory operations to marketing, sales, and service. Digital connectivity among designers, managers, workers, consumers, and physical industrial assets will unlock enormous value and change the manufacturing landscape forever.

- Simulation and prototype manufacturing of the design and the functions of product can be quickly realized by rapidly analyzing (using virtual reality, computer network, rapid prototyping)
- Planning and recombining, coordinating and sharing of all kinds of information (e.g., product information, process information, control information and resources information)

to manufacture the product according to the user's requirements as soon as possible.

Features of Digital Manufacturing

Establishing a digital model of products and presenting the digital definition of the entire process of the product lifecycle in a way that the computer can understand.

- Digital expression of product and process has exclusive meaning and is reusable
- In the network environment, manufacturing activities have independence in distance, time and location.
- Digital manufacturing allows for the whole manufacturing process to be created virtually before it is implemented physically. This enables designers to see the results of their process before investing time and money into creating the physical plant.
- The effects caused by changing the machines or tooling processes can be seen in real-time.
- Optimization of a parts manufacturing process.
- Digital manufacturing systems often incorporate optimization capabilities to reduce time, cost, and improve the efficiency of most processes. These systems improve optimization of floor schedules, production planning, and decision making. The system analyzes feedback from production, such as deviations or problems in the manufacturing system, and generates solutions for handling them.

Definition of digital manufacturing

Digital Manufacturing can be defined as a manufacturing process supported by technologies like virtual reality, computer networks, rapid prototyping and database, is based on customer demand so as to analyze, organize and recombine the product information, process information and resource information, implement the product design and function simulation as well as rapid prototyping, and then to perform rapid production to meet customer demand and quality standards.

Digital manufacturing means that the design, simulation and production of a product are completed in a digital environment. Digital manufacturing is a technology based manufacturing approach that focuses on simulation and simultaneous definition of product and production process to optimize transition from a virtual to physical world.

Industrial internet of things platform combined with 3D factory visualization connects people, processes and devices

- Fully smart-connected enterprise
- Real-time generation and visualization of facts
- Real-time control of all processes in supply chain
- New cyber-physical systems and relations

Different digital manufacturing ideas

On the other hand, DM contains the Control-Centered DM, Design Centered DM, Management-Centered DM and Manufacturing-Centered DM.

- Control- centered DM
- Design – centered DM
- Management – centered DM
- Manufacturing - centered DM

Control- centered DM

Digital control can make manufacturing processes automatic, detect and control parameters of the manufacturing process, notify faults and even propose decision making and the suggestion of maintenance. With the development of network and computer technologies more than one NC machine tool could make the production processes of a number of workshops automatic.

The controller or control system in each piece of equipment will become a node in the Internet, which leads to the manufacturing process developing in the direction of automation. with a larger scale and at a higher level. It is the so-called DM idea that takes control for center.

Design - centered DM

The product design information in CAD will be transformed into information about a product's manufacturing and processing rules. The processing machines will be combined and ordered according to the scheduled procedure and work stages. Digital manufacturing will integrate of CAD/CAPP/CAM software's.

It transforms all plans including manufacturing, detecting, assembling, etc., and all information involving product oriented design, manufacturing, processing, management, cost accounting, etc., into data that are understood by the computer and are shareable in all the phases of the manufacturing process, which makes the CAD/CAPP/CAM integrative.

Management - centered DM

Management- centered DM integrates the various MRP/PDM/MIS/ERP technologies. Enterprise management activities are easily integrated and synthesize using above technologies. Using ERP, the logistic, information flow, capital flow, work flow in enterprise management activities are easily integrated and synthesized.

Material requirements planning (MRP),Product data management (PDM) or Product information management (PIM), management information system (MIS), Computer-aided process planning (CAPP)

Manufacturing - centered DM

Establish an intelligence model, in order to analyze, process, optimize and control the data and information in the whole manufacturing process and manufacturing system. Realize the optimization of the manufacturing process, the high performance of manufacturing equipment, the high reliability of product quality and production link, as well as customer satisfaction, which form the manufacturing as the center of DM.

Theory system of digital manufacturing science

Digital Manufacturing consists of mathematical basic theories including product demand, product design and simulation, management of the product manufacturing process, operational control of production equipment, management of product quality, product sales and maintenance and other aspects, and the all-digital analysis, design, operation and management of basic scientific questions, as well as the digital operating environment sustaining the entire product lifecycle, and the theoretical system.

Theory system is constructed based on its research object and content.

- Research object - digital manufacturing system
- Research contents - basic theory and key technology of the DM

Steps of theory system

1. Analyzes the actual demand of operation in the digital manufacturing system, and proposes the operation reference mode and architecture of the digital manufacturing system
2. Analyzes the modeling theory and method of the digital manufacturing science; based on the two previous sections
3. Puts forward the theory system of digital manufacturing based on above two to describe the DM system globally, the abstract modeling of system science is used asfollows

Operation Mode and Architecture of Digital Manufacturing System

Operation mode can be defined as the institutional or organizational arrangements that are used in order to conduct a business activity, such as the **manufacturing** of goods, servicing customers, sourcing various inputs

After receiving orders, a conceptual design and general design are first carried out, followed by a computer simulation or rapid prototyping process, and process planning engineering, the process of CAM and CAQ, until finally the product is formed. The stable operation mode that supports digital manufacturing systems should include a great deal of subsystems as shown in figure. The functions of subsystems in the digital manufacturing system are independent, but the subsystems have interrelated.

Operation mode of DM

Operation mode subsystems of digital manufacturing

- **The management and decision-making systems of manufacturing individual or alliance**

This is the core management and decision-making system of the entire manufacturing organization, responsible for handling plans, operations, detection, control and maintenance in the enterprise, and is the backbone of the entire system.

- **Market analysis and evaluation system**

This is mainly responsible for collecting market information, tracking existing market products analyzing new market demand and evaluating the value and feasibility analysis.

- **Product collaborative design and simulation system**

This system takes charge of coordinating members in the manufacturing organization and also ensures that all equipment and devices in the manufacturing environment are carefully planned and built, controlled collaboratively and run reliably.

- **Product quality management system**

This is responsible for the quality detection and management of products, which ensures that quality products reach the market.

- **Product marketing system**

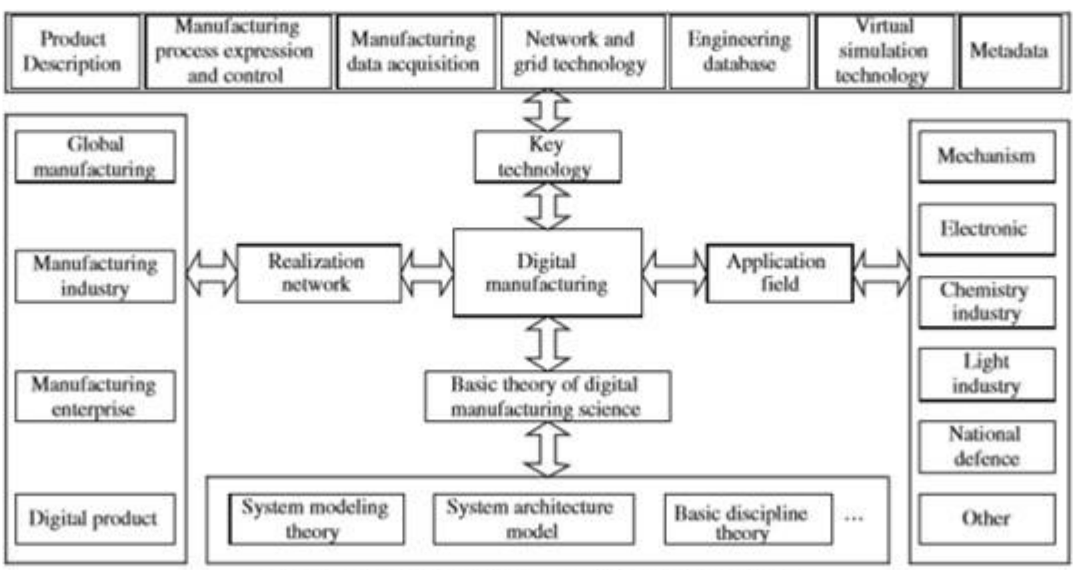
This system is responsible for the formulation and implementation of the product marketing strategy and the commercialization of products in order to gain the biggest sales return and achieve the goal of product manufacturing.

- **Customer servicesystem**

This is responsible for the maintenance and service of products to ensure the correct use of products, to gain market reputation, and promote the social benefits of products.

Architecture of Digital Manufacturing System

It establishes the basic architecture of the entire research subject. The architecture of a, digital manufacturing system should be constructed on the basis of the basic theory of digital manufacturing science. The system architecture model defines the basic research objects and contents of the digital manufacturing system, and establishes the basic organization structure, function structure, operation and control structure of the digital manufacturing



Architecture of digital manufacturing system

system.

From the definition and the operation reference mode of the digital manufacturing system, the architecture of digital manufacturing system can be easily established and should include the basic theories of digital manufacturing science, the key technology of the digital manufacturing system, the network and application fields of digital manufacturing, and so on.

The key technology of digital manufacturing system includes

1. Product description technology refers to the use of digital technology to describe product information, including description and expression norms
2. Manufacturing process expression and control technology includes how to express and control various certain and uncertain manufacturing processes, and the examples of uncertain manufacturing processes include the process of tool wear, market development.
3. Manufacturing data acquisition, storage and processing, include the acquisition, expression, storage, processing and application of manufacturing knowledge.
4. Network and grid technology refer to the network support technology which guarantees the collaborative design and production of the system.
5. Engineering database technology: data storage and a management in a manufacturing system
6. Virtual and simulation technologies include virtual design, manufacturing process simulation and digital prototyping.
7. Metadata is data about data, by which we can understand the name, purpose and usage of data.

Modeling Theory and Method of Digital Manufacturing Science

The model, is an idealized abstract and simplified method of the system which reflects the main components in the system and the mutual relationship and effects among these components. Its specific target is to support the analysis and synthesis of the system through understanding and expressing the system better; to support the design of new systems or the reconstruction of existing systems; and to support the monitoring and control of the system operation.

The modeling idea of digital manufacturing science expresses the digital manufacturing system abstractly, and the digital manufacturing system is analyzed, synthesized and optimized through studying its structures and characteristics. The digital manufacturing model is an indispensable tool in the whole lifecycle of the digital manufacturing system. This whole lifecycle includes data acquisition, data processing, data transmission, implementation of control, affairs management and decision support, and so on. Accordingly, it would be the basic theory for analyzing and solving problems in digital manufacturing science.

In digital manufacture, the objects that need to be described by model include:

(1) Product.

The life-cycle of a product needs a variety of product and process models to be described;

(2) Resources.

Various resources in the digital manufacturing system need the corresponding models to be described, such as manufacturing equipment, funds, various materials, persons, computing devices, and kinds of application software;

(3) Information.

It is necessary to establish the appropriate information model for information acquisition, processing and usage in the whole process of digital manufacture;]

(4) Organization and decision-making.

This is an important approach for actualizing the optimal decision-making for modeling organization and the decision-making process in digital manufacture;

(5) Production process.

This is the premise that the modeling production process will realize the optimization of the production and scheduling process in the manufacturing system;

(6) Network environment modeling.

The various objects mentioned above are modeled when the digital manufacturing system is in a network environment.

Digital manufacturing modeling abstractly expresses every object and process of the entire lifecycle of digital manufacturing through an appropriate modeling method, and analyzes, synthesizes, optimizes and simulates them through researching their structures and features. The target that digital modeling is pursuing is firstly to establish the model of the entire digital system and then to establish the important models aiming at one or more objects mentioned above by using a specific modeling method.

The classifications of the digital manufacturing model

By form

- Global structure model (such as the architecture of manufacturing system)
- Local structure model (such as the FMS model)
- Product structure model
- Scheduling model of production planning

By modeling methods

- Mathematical model
- Graphic conceptual model
- Hybrid diagram –analysis model

By function

- Structure description model
- System analysis model
- System design and implementation model
- System operation and management model

Critical Modeling Theories and Technologies in Digital Manufacturing Science

Critical Theory, in basic terms, is any theory founded on critique, and is used in many differentfields. Its main points are the problem definition and understanding, the search for solutions, evaluation, and iteration. Analysis is breaking down the problem into parts and finding the relationships between them. Synthesis is thinking about other ways to solve the problem either by incorporating new information or combining the parts in a different way.

Finally, evaluation is making a judgment about the results using the evidence at hand. “A well-defined problem is halfsolved”.

Modelling and analysing method in manufacturing industry

1. IDEF
2. GRAI/GIM
3. CIMOSA
4. ARISarchitecture
5. PERA
6. PetriNet
7. Object-oriented analysis(OOA IDEF Modeling Method

IDEF (Integrated Computer-Aided Manufacturing (ICAM) DEFinition)

It is designed to model the decisions, actions and activities of an organization or system. Since there are a number of tools within the IDEF family, they have been assigned numbers. The IDEF methods have been defined up to IDEF14.

1. IDEF0 is used to produce a function model which is a structured representation of the functions of a manufacturing system or environment and of the information and objects which interrelate those functions.
2. IDEF1 is used to produce an information model which represents the structure of information needed to support the functions of a manufacturing system or environment.
3. IDEF2 is used to produce a dynamics model which represents the time varying behavior of functions, information, and resources of a manufacturing system or environment.

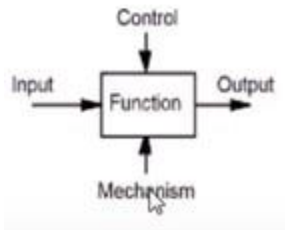
We confine the description of IDEF family to IDEF0 model only for the basic understanding

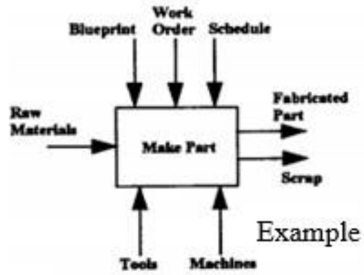
Description of IDEF0

The IDEF0 functional modeling method is designed to model the decisions, actions, and activities of an organization or system. It is a modelling technique based on combined graphics and text are presented in an organized and systematic way to gain understanding or support systems level design and integration activates.

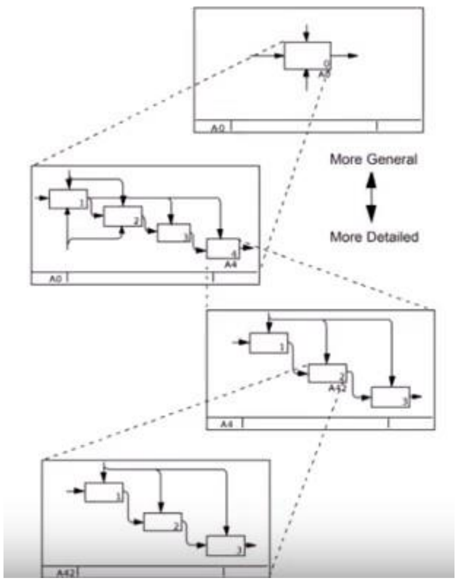
Within IDEF0, functions are represented by boxes, and interfaces are represented by arrows. An input is transformed into an output by an activity (function) performed by a mechanism and governed by a control.

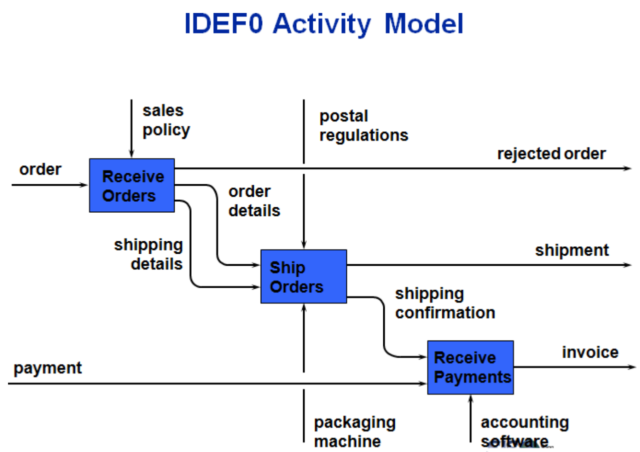
- Models consists of boxes and arrows.
    - Boxes represents functions(activities/action/process/task)
    - Arrows represents objects/data (input, output, control and mechanism)
        - Input: (data, information and materials etc.)
        - Mechanism: (tool, devices, asset, knowledge and resources etc.)
        - Control: (time, regulations and constrained.)

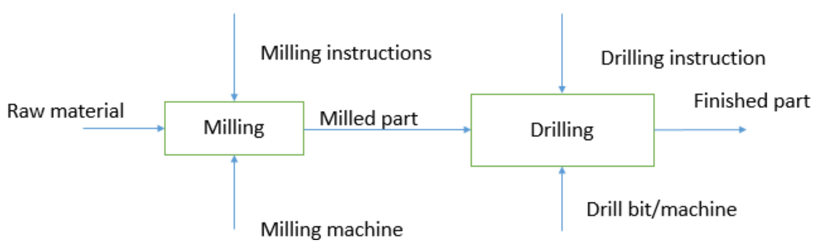




IDEF diagrams are hierarchical- Top level function to low level functions Graphic diagram of a part/component/product functions are broken down or decomposed into more detailed or simple functions as shown.







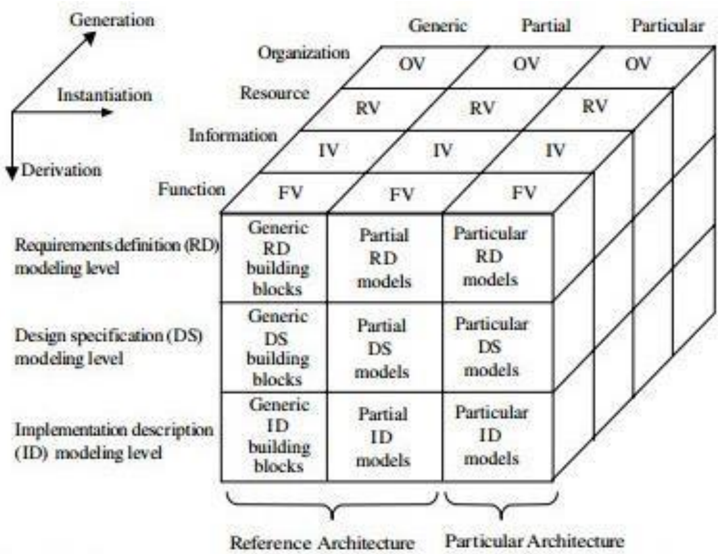
- IDEF0 : Function modeling
- IDEF1 : Information modeling
- IDEF1X : Data modeling
- IDEF2 : Simulation model design
- IDEF3 : Process description capture
- IDEF4 : Object-oriented design

- IDEF5 : Ontology description capture
- IDEF6 : Design rationale capture
- IDEF7: Information system auditing
- IDEF8 : User interface modelling
- IDEF9 : Business constraint discovery
- IDEF10: Implementation architecture modeling
- IDEF11: Information artifact modeling
- IDEF12: Organization modeling
- IDEF13: Three schema mapping design
- IDEF14 : Network design

CIMOSA (Computer Integrated Manufacturing Open System Architecture)

It is an enterprise modelling framework to integration of machines, computers and people known as the CIMOSA cube.

A framework is a fundamental structure defining concepts to model and build an enterprise. The modeling framework provides a reference architecture and a particular architecture. It contains three modeling levels (requirements definition, design specification, implementation description) and four views (function, information, resource, organization). With a set of common building blocks, the CIMOSA Reference Architecture provides the base for evolutionary enterprise modelling. This allows different people to model different areas of the enterprise but provides the integrity of the overall model.



CIMOSA Modeling Framework.

GRAI-GIM Modeling Method

GRAI stands for Graphs with Results and Action Inter-related. The GRAI method can represent and analyze the operation of all or part of a production activity. GIM stands for GRAI integrated methodology

The GRAI engineering method can be used to re-engineer the way in which products are designed (taking the product, the process and the design organization into consideration).

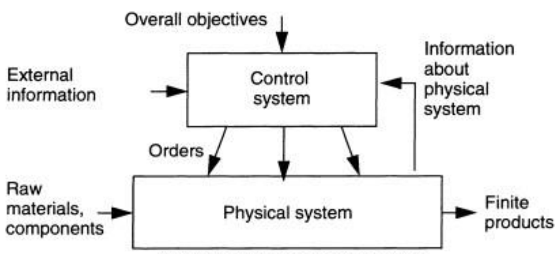
A manufacturing system may be split into two parts

- Physical system composed of the people, facilities, materials and techniques which has the aim of transforming the raw material components into a final product
- The control system whose purpose is to control the physical system in accordance with the objectives defined.

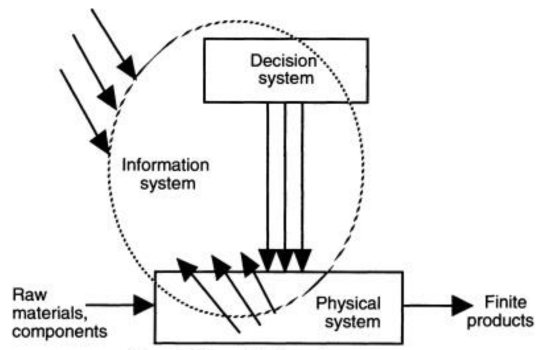
The control system can also be split into two subsystems

1. A decision system
2. An information system.

The goal of the first one is to make the necessary decisions in order to define the orders to be transmitted to the physical system; the second one enables the transmission, processing and memorization of the information needed. Information system acts as a link between the physical and the decision systems and with the environment as well. The decision system and the information system are strongly linked.



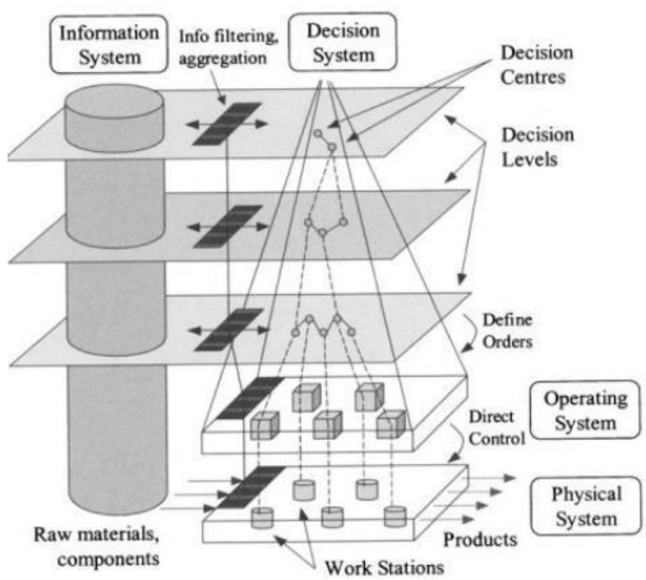
Splitting of a manufacturing system.



The decision and information systems.

GRAI is sub-divided into two parts,

1. GRAI **grid** explains the decision-making functions and the relation between them.
2. GRAI **net** modeling explains the operation of production activity



Object oriented modeling

Object oriented models help in understanding problems, communicating with experts from a distance, modeling enterprises, and designing programs and database. Object oriented models are represented by diagrams.

In OOM the modeling passes through the following processes:

- System Analysis
- System Design
- Object Design, and
- Final Implementation.

System Analysis:

In this stage a statement of the problem is formulated and a model is built by the analyst in encouraging real-world situation. Actually, the analysis model is a concise, precise abstraction and agreement on how the desired system must be developed.

System Design:

This is the stage where the whole system is divided into subsystems, based on both the system analysis model and the proposed architecture of the system.

Object Design: At this stage, a design model is developed based on the analysis model which is already developed in the earlier phase of development. The object design decides the data structures and algorithms needed to implement each of the classes in the system.

Final Implementation: At this stage, the final implementation of classes and relationships developed during object design takes place a particular programming language, database, or hardware implementation (if needed).

Whole object oriented modeling is covered by using three kinds of models for a system description. These models are:

- object model,
- dynamic model
- functional model.

Object models are used for describing the objects in the system and their relationship among each other in the system. The dynamic model describes interaction among objects and information flow in the system.

Petri Nets

A **Petri net**, also known as a place/transition (PT) **net**. Any system consists of a number of activities and the system can be modeled by listing the states of the system, before and after those activities. An activity brings the system from one state to another i.e. activity causes state- transition. All such state-transitions, when graphically represented, are called state-transition diagram.

A Petri net is a graph which consists of two types of nodes: **places** and **transitions** connected by directed arcs. It is a graphical and mathematical modeling tool which describes the dynamic characteristics of a distributed system.

- Place =circle,
- transition = bar or box.
- An arc connects a place to a transition or a transition to palace.

Petri Nets and their concepts have been extended and developed, and applied in a variety of areas: Office automation, work-flows, flexible manufacturing, programming languages, protocols and networks, hardware structures, real-time systems, performance evaluation, operations research, embedded systems, defence systems, telecommunications, Internet, e-commerce and trading, railway networks, biological systems.

Generalized Modeling Theory

A generalized model of the whole digital manufacturing system is created by using set theory and relation theory and models related to the system architecture, such as the function model, organization model, information model, operation and control model are established.

Modeling steps are as follows.

(1) System Modeling Principle:

The key elements of the system's abstract description are the system target, system object and system relation.

(2) Basic Modeling Method ‘‘Analysis—Synthesis’’Method.

- Analysis. The large-scale system is decomposed into subsystems, to determine a main component set of the system and relation set is determined.
- Synthesis. In this step, the analysis results should be synthesized to determine the solving scheme and evaluating method

(3) Integral modeling process of system

The target set for the system is determined according to the needs of the organization and operation process involved.

where U – Market product demand

M – Member set of potential manufacturing alliance

T – Goal of product manufacturing

E_q – Set of network supporting equipment

E_s – Set of software for network supporting equipment

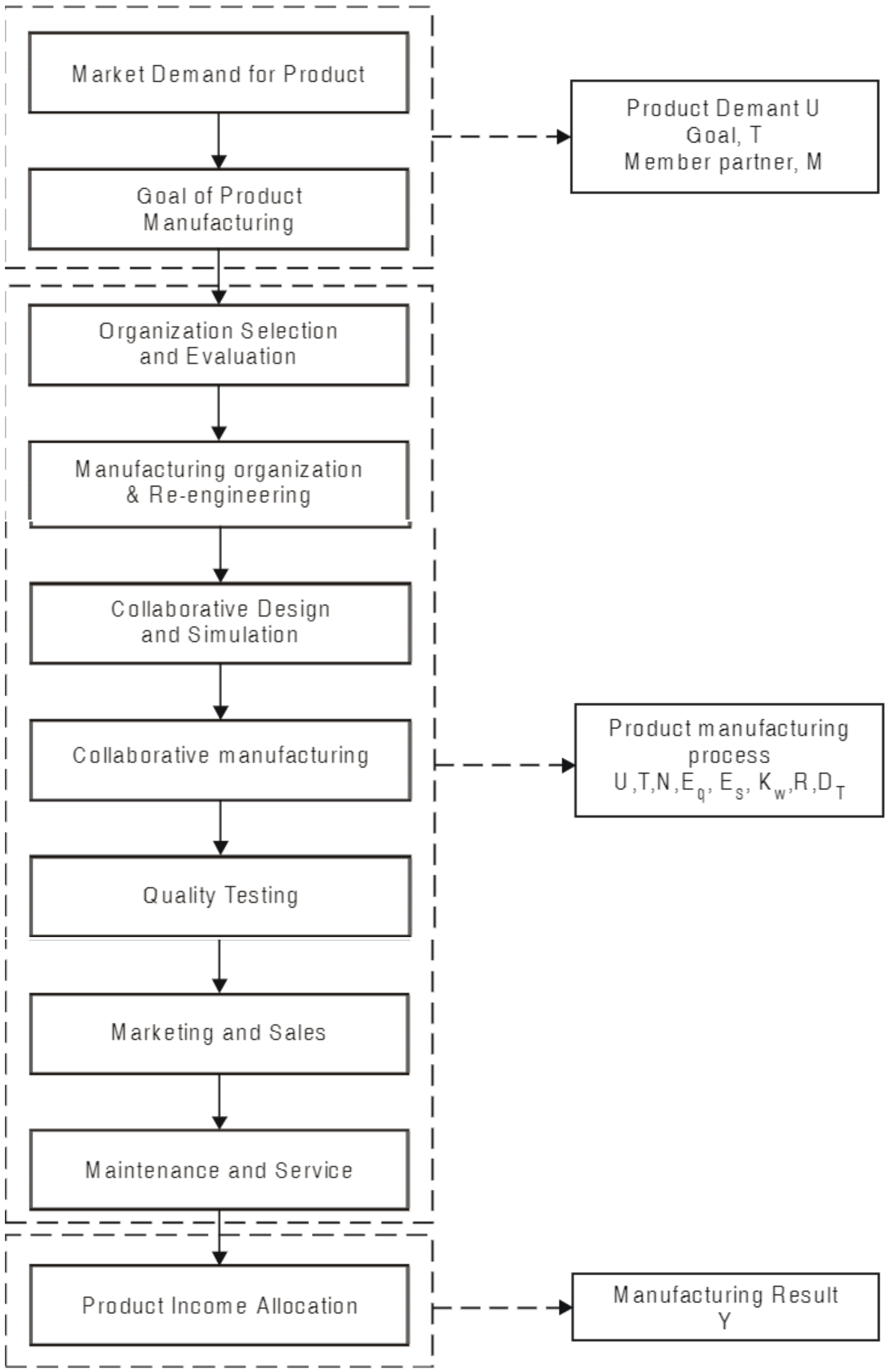
K_w – Set of generalized knowledge

R_E – Set of product manufacturing resource

D_T – Set of technology supporting digital systems operation

P – Approach solving problem

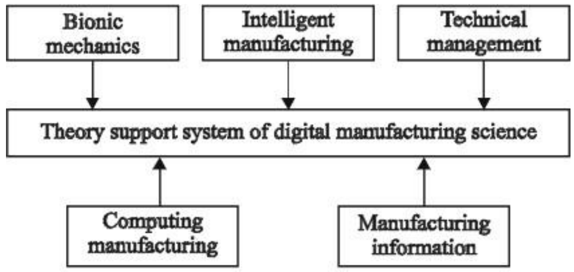
G – Evaluation function



Generalized model $DMS = \{ U, M, T, E_q, E_s, K_w, R_E, D_T, P, G \}$

Theory of digital manufacturing science

Digital manufacturing science is formed by multiple disciplines across many fields are shown in figure.



Theory system of DM Science

Since the DM system is complex, describing in globally using a precise model of system science is difficult. A generalized model, the abstract definition of the DM system is obtained. So to definitively describe the DM system globally, abstract modeling of system science is used as follows

Organization structure Model of DM system

The organization structure model should be built in accordance with the key elements of the constructing system and the operation characteristics of the DM system

Function Model of Digital Manufacturing System

The purpose of function model of the DM system is to analyze the compulsory functions and requirements of the DM system. To clarify the relationship between different functions. To provide guidance for the specific design and implementation of the system

Information Model of Digital manufacturing system

Although the management of the whole system is centralized, it is physically distributed form on the topological structure. So, the aim of information model of the system is to provide reasonable and convenient information storage. To use approaches for the optimization of the organization and operation structure

Operation and Control Model of DM system

The operation and the control model is used for implementing the system function and organization structure and for designing a specific operation support platform.

The model will determine the research object and system architecture of the DM system. Modeling methods like IDEF, GRAI and Petri nets are used.