MECHANICAL ENGINEERING SCIENCE (UE24ME141A)

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MECHANICAL ENGINEERING SCIENCE

Unit4

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Chapter 1 – Machining Processes

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INTRODUCTION TO MACHINING PROCESSES

- **Machining is the process of removing the excess material from the work piece in the form of chips, by forcing the cutting tool with one or more cutting edges.**

- Casting processes and the metal working processes are the primary manufacturing processes where the metal is first shaped into an intermediate shape which is normally brought to its final form with metal cutting process.

- Assembling of parts into workable equipment often requires the mating surfaces to be complementary to each other in terms of form, dimensions and surface finish. The only way this can be achieved is through the use of material removal processes.

MACHINE TOOL

- Machine Tool is a power driven machine to perform machining

- Machine Tool performs three major functions:
  -It rigidly supports the work piece and cutting tool
  -Provides relative motion between work piece and cutting tool
  -Provides range of speeds and feeds

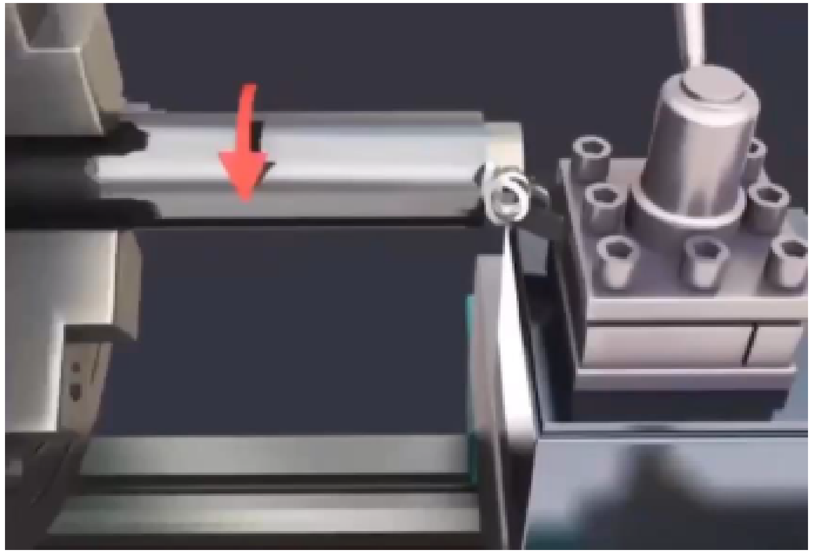
INTRODUCTION TO LATHE

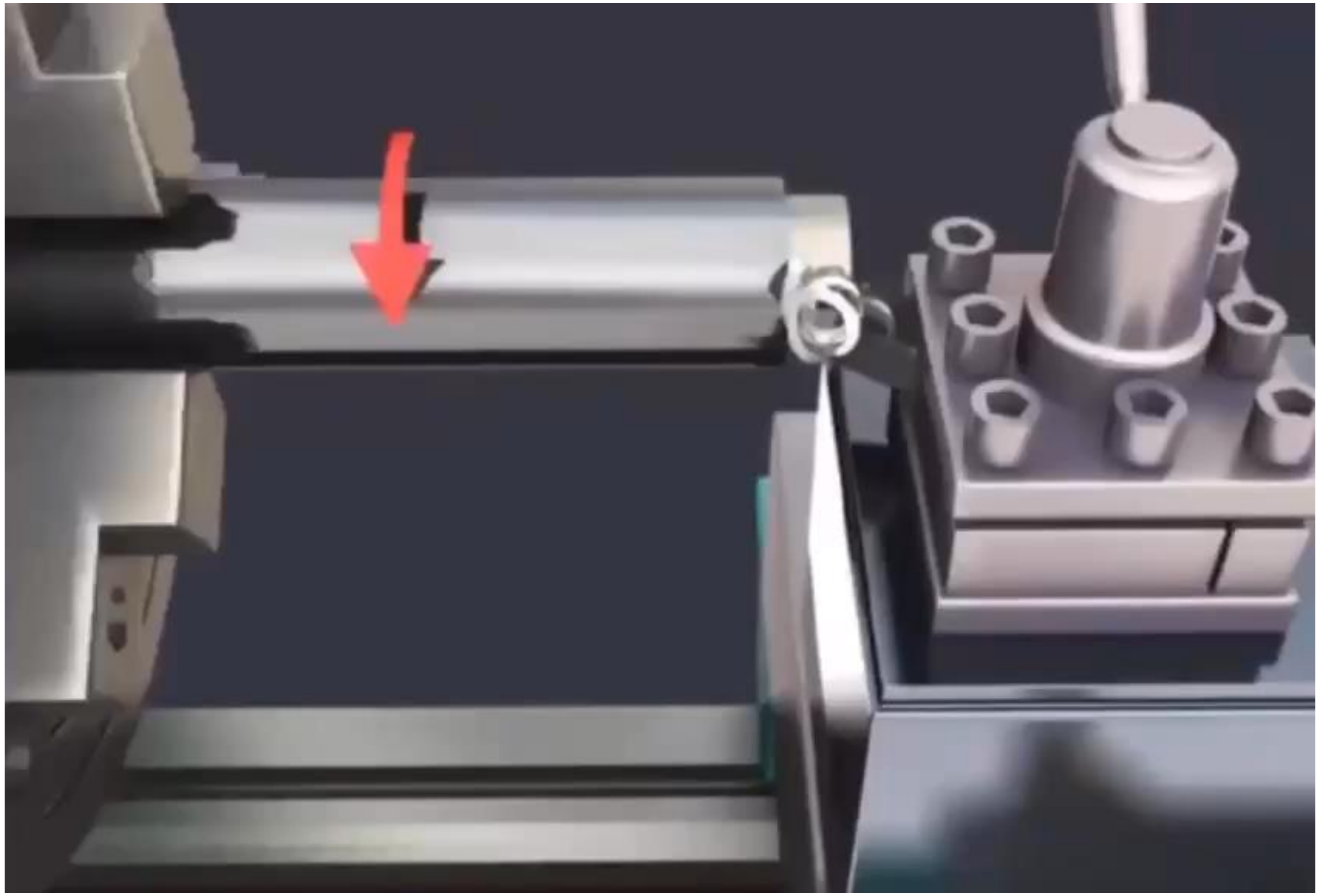
- Lathe is the oldest machine tool invented, starting with the Egyptian tree lathes.

- The principal form of surface produced in a lathe is the **cylindrical surface**. This is achieved by rotating the work piece while the single point cutting tool removes the material by traversing in a direction parallel to the axis of rotation and termed as **turning**.

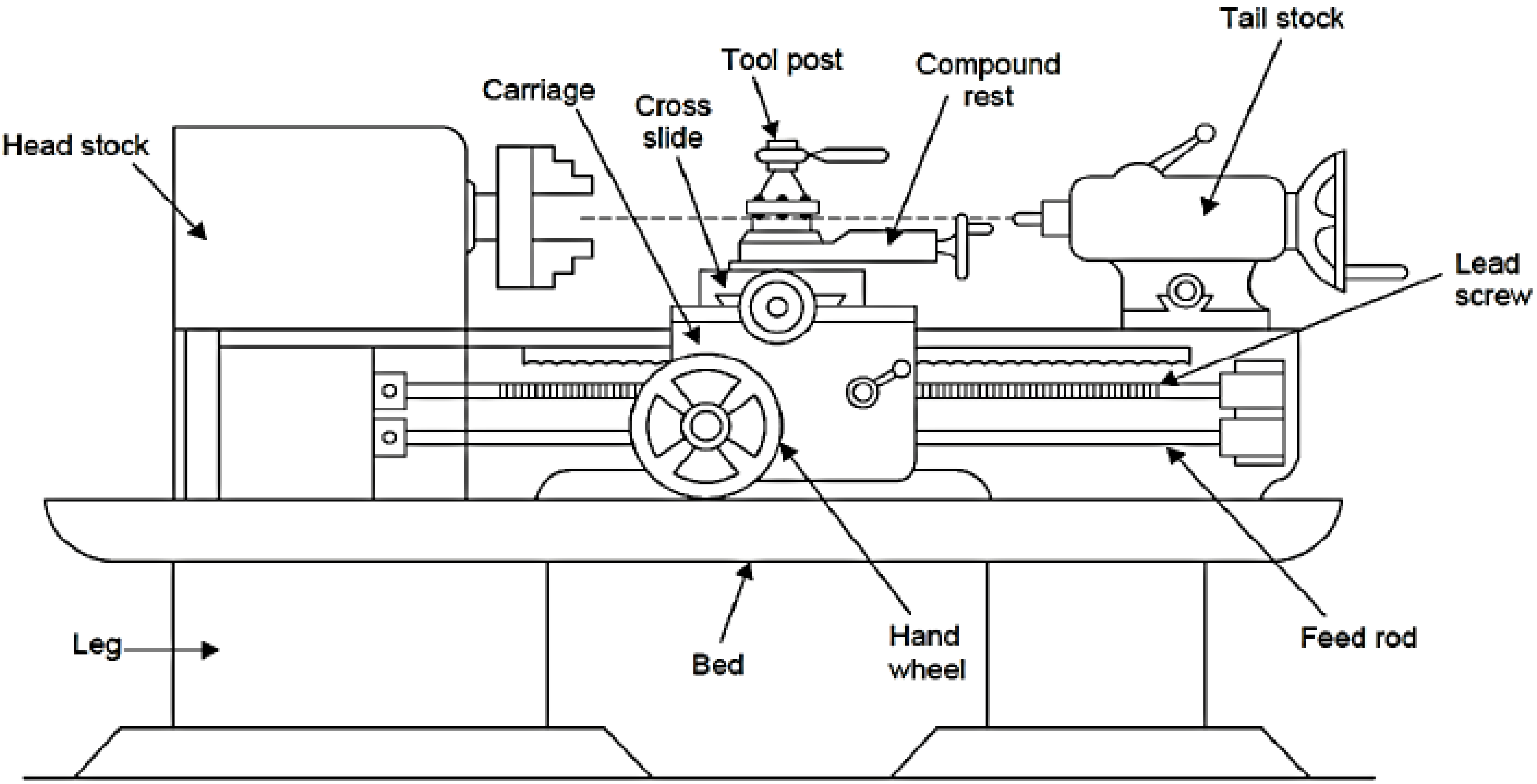
- **Centre lathe** is the most common of the lathes, which derives its name from the way a work piece is clamped by centres (live and dead centres) in a lathe, though this is not the only way in which the job is mounted.

- This is sometimes also called engine lathe in view of the fact that early lathes were driven by steam engines.





TYPICAL PARTS OF LATHE



TYPICAL PARTS OF LATHE

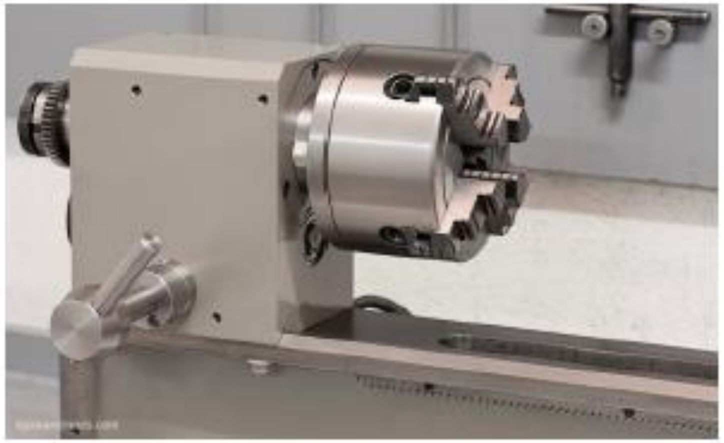
BED

- It's the backbone of the lathe upon which all other components are mounted.
- The top of the bed is formed by guide ways. They act as a guide for accurate movement of carriage and tailstock.
- Made up of cast iron because of good damping and frictional resistance.

TYPICAL PARTS OF LATHE

HEADSTOCK (LIVE CENTRE)

- Is a box like casting mounted at the left end of the machine.
- It contains feed gear box or cone pulley which enables the spindle to rotate at different speeds.
- The gear box distributes the power to the lead screw for threading or to the feed rod for turning.



TYPICAL PARTS OF LATHE

TAILSTOCK (DEAD CENTRE)

- It is mounted on the right side of the machine.
- It is the movable part of the lathe that carries the dead centre in it.
- It can be slided on the bed to support different length of work piece. It can be clamped on the bed at desired location.
- Can be moved laterally for taper turning
- It can be used to carry tool like drill, reamer for making hole.

TYPICAL PARTS OF LATHE

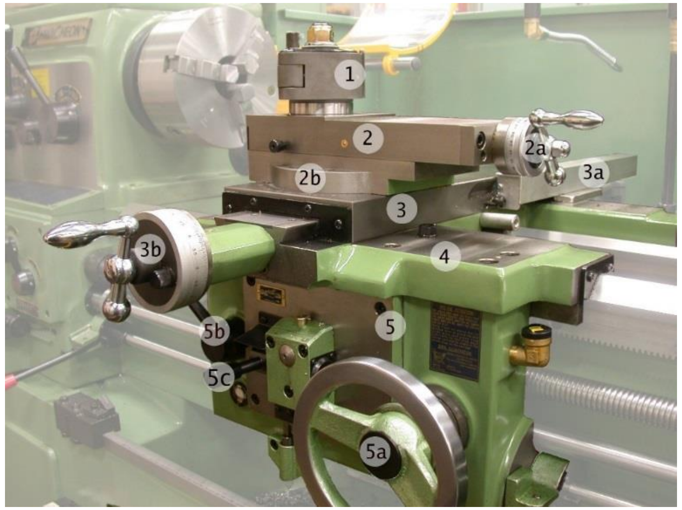
CARRIAGE ASSEMBLY

- **CROSS SLIDE:** On the upper surface of the saddle is the cross slide. This moves the tool at right angle to spindle axis.

- It can either be operated by the means of the cross slide hand wheel or may be given power feed through the apron mechanism.

- **COMPOUND REST:** The compound rest is mounted on the upper surface of the cross slide. This can be swiveled so that the tool can move at an angle to the spindle axis.

- **TOOL POST:** This is mounted on the compound rest and carries the cutting tool.



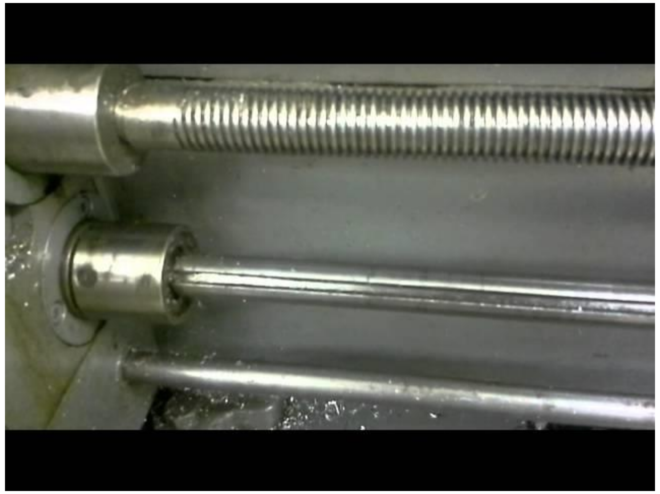
TYPICAL PARTS OF LATHE

FEED ROD

- Feed rod is long shaft used to drive the **apron mechanism** for cross and longitudinal power feed during turning. It is powered by the set of gears from the headstock.

LEAD SCREW

- It is a long threaded shaft geared to the headstock. Closing a split nut around the lead screw engages it with the carriage. The lead screw is used for cutting thread accurately and should be disengaged for other operations.



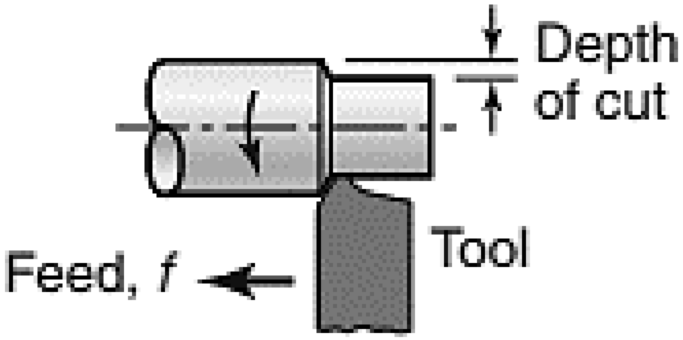
OPERATIONS ON LATHE

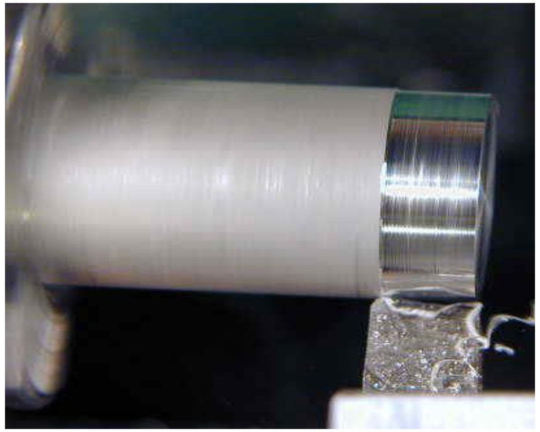
PLAIN TURNING

- Plain turning is by far the most commonly used operation in a lathe.

- In this the work held in the spindle is rotated while the tool is fed past the work piece in a direction parallel to the axis of rotation. The surface thus generated is the cylindrical surface as shown in Fig.

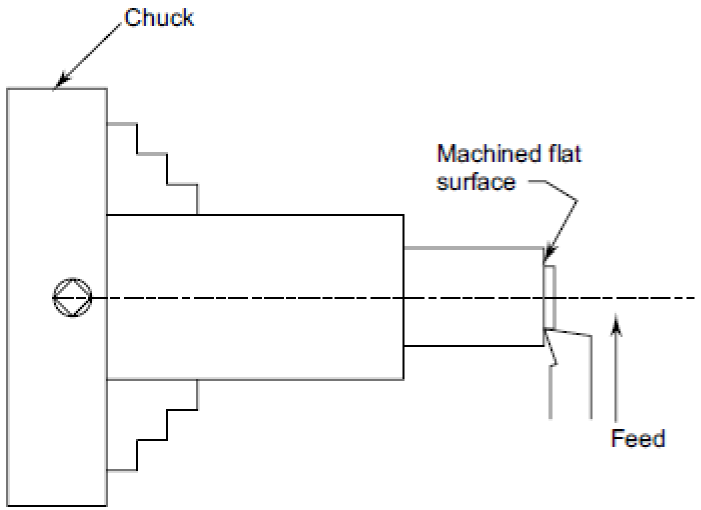
- It is usually done in two stages – rough turning and smooth or finish turning. **Rough turning** involves majority of material removal and it is usually done at high speeds while **smooth turning** is done at lesser speeds and it is involved in finishing the given job to required dimensions.



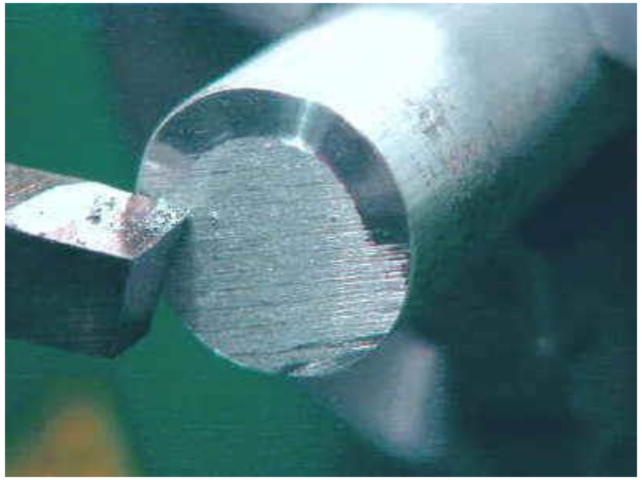


OPERATIONS ON LATHE

FACING



- Facing is an operation for generating flat surfaces in lathes.
- The feed in this case is given in a direction perpendicular to the axis of revolution.
- The tool used should have a suitable approach angle so that it would not interfere with the work piece during the tool feeding.



OPERATIONS ON LATHE

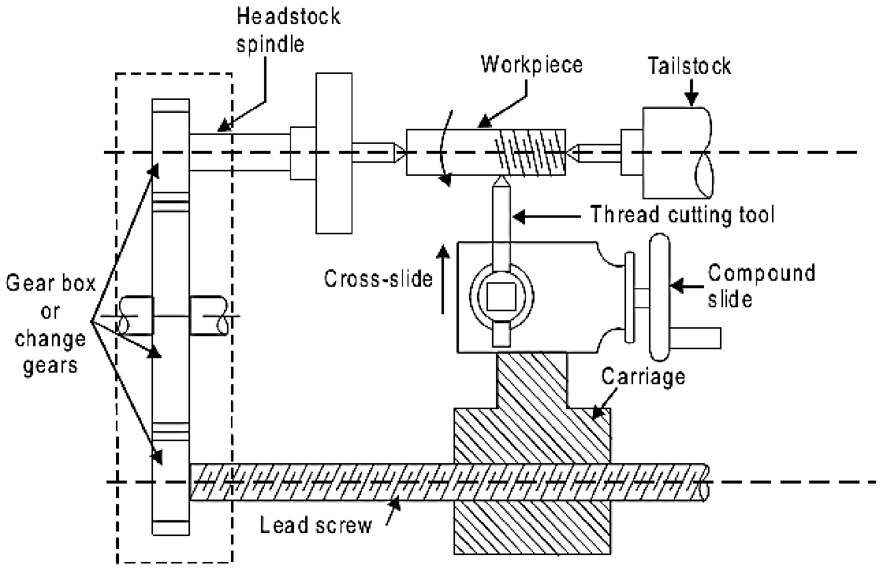
THREAD CUTTING

- A screw thread may be defined as a ridge of uniform cross section that follows a helical or spiral path on the outside or inside of a cylindrical surface.

- The cutting tool, the shape of which depends on the type of thread to be cut, is mounted on a holder and moved along the length of the workpiece by the lead screw on the lathe.

- This movement is achieved by the **engagement of a split nut (also called a half nut) inside the apron of the lathe.**

- The axial movement of the tool in relation to the rotation of the workpiece determines the pitch of the screw thread.



OPERATIONS ON LATHE

THREAD CUTTING

- The axial feed is automatically generated when cutting a thread by means of the lead screw, which drives the carriage. When the lead screw rotates a single revolution, the carriage travels a distance equal to the pitch of the lead screw.

- Consequently, if the rotational speed of the lead screw is equal to that of the spindle (that of the workpiece), the pitch of the resulting cut thread is exactly equal to that of the lead screw.

- The pitch of the resulting thread being cut, therefore, always depends upon the ratio of the rotational speeds of the lead screw and the spindle.

$$\frac{\text{Pitch of lead screw}}{\text{Desired pitch of workpiece}} = \frac{\text{rpm of workpiece}}{\text{rpm of lead screw}}$$

OPERATIONS ON LATHE

THREAD CUTTING

It is required to cut screw threads of 2 mm pitch on a lathe. The lead screw has a pitch of 6 mm. If the spindle speed is 60 rpm, then the speed of the lead screw will be

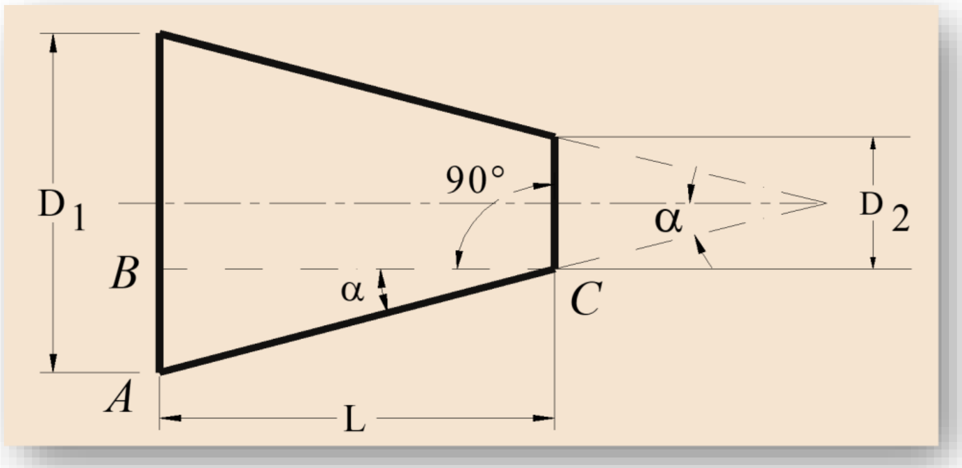
(A) 10 rpm (B) 20 rpm (C) 120 rpm (D) 180 rpm

OPERATIONS ON LATHE

TAPER TURNING

- Taper turning is the process of producing a conical surface from a cylindrical shaped workpiece.

- The taper to be produced is usually represented in terms of half taper angle.



$$\tan \alpha = \frac{D_1 - D_2}{2L}$$

OPERATIONS ON LATHE

TAPER TURNING

➢ A number of methods are available for cutting tapers in a lathe. They are:

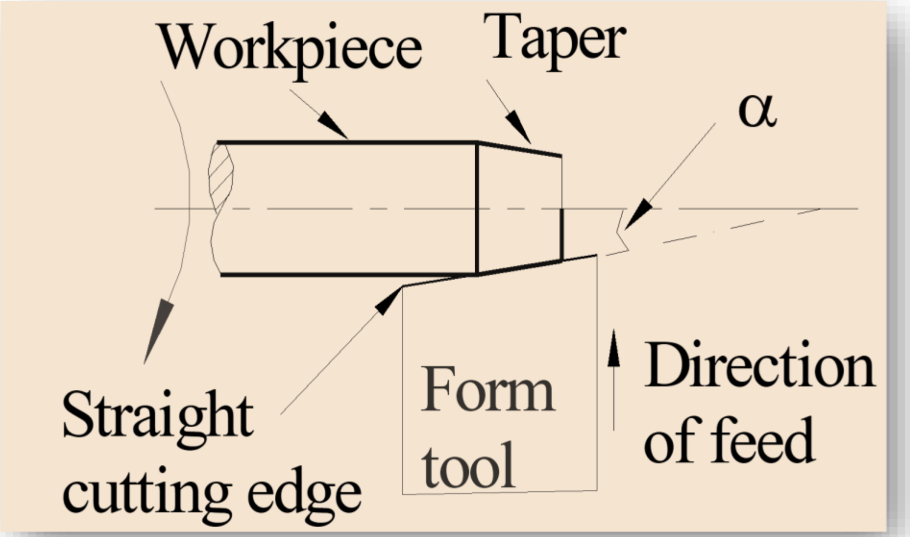
- **using form tools**
- **swivelling the compound rest**
- **offsetting the tailstock**
- **using taper turning attachment**

OPERATIONS ON LATHE

TAPER TURNING

Form tool method –

- A method that is normally used for production applications is the use of special form tool for generating the tapers.
- The feed is given by plunging the tool directly into the work. This method is useful for short tapers, where the steepness is of no consequence, such as for chamfering.



OPERATIONS ON LATHE

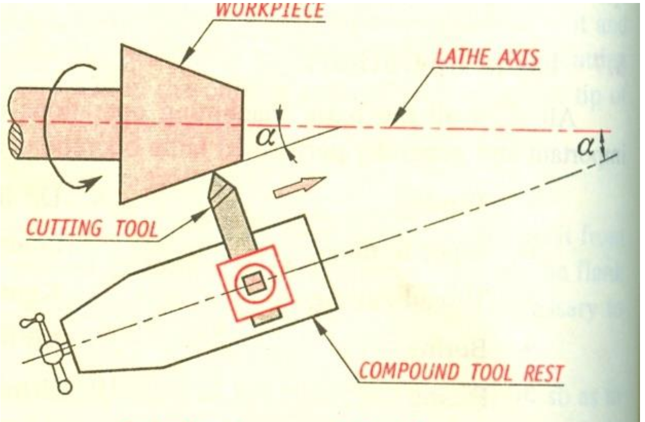
TAPER TURNING

Swivelling compound rest –

- It is possible to swivel the compound rest to the desired angle of the taper for cutting the tapers. The compound rest has a circular base graduated in degrees.

- The tool is then made perpendicular to the work piece and feed is given manually by the operator.

- Some of the features of this method are:
  - ●Short and steep tapers can be easily done.
  - ●Limited movement of the compound rest
  - ●Feeding is by hand and is non-uniform. This is responsible for low productivity and poor surface finish.



Swiveling Compound Tool Rest

OPERATIONS ON LATHE

TAPER TURNING

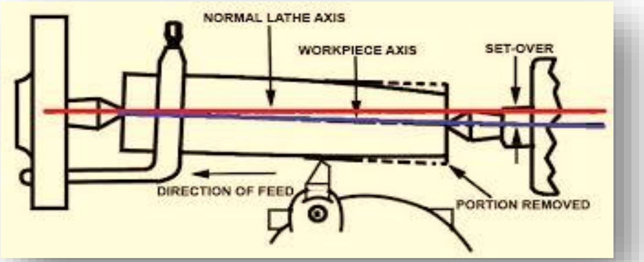
Offsetting the tailstock –

- Still another method sometimes used is the method of offsetting the tailstock from the centre position.

- By offsetting the tailstock, the axis of rotation of the job is inclined by the half angle of taper as shown in Figure.

- The feed to the tool is given in the normal manner parallel to the guideways. Thus the conical surface is generated. The offset that is possible is generally limited, and as such this method is suitable for small tapers over a long length.

- The disadvantage is that the centres are not properly bearing in the centre holes and as such there would be non-uniform wearing taking place.



OPERATIONS ON LATHE

TAPER TURNING

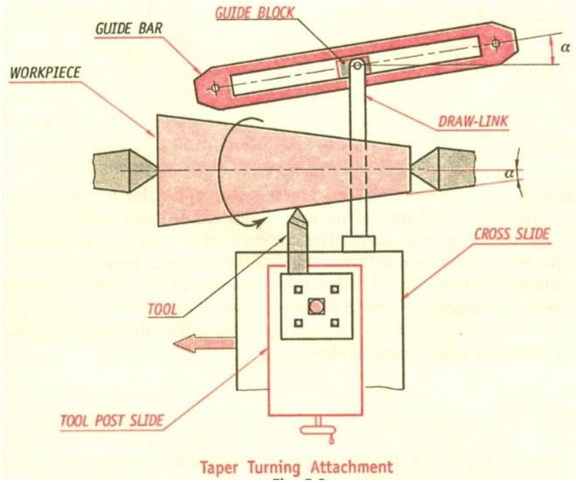
Taper turning attachment method –

- Still another method for turning tapers over a comprehensive range is the use of taper turning attachment.

- In this method a separate slideway is arranged at the rear of the cross slide. This slide can be rotated at any angle to be setup. The block that can slide in this taper slide way is rigidly connected to the cross slide.

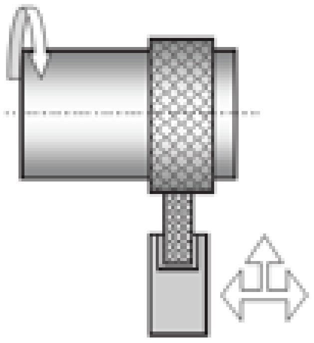
- As the carriage moves for feeding, the block moves in the inclined track of the slide, it gets the proportional cross movement perpendicular to the feed direction, the cross slide and in turn the cutting tool gets the proportional movement. Thus the tool tip follows the taper direction set in the attachment.

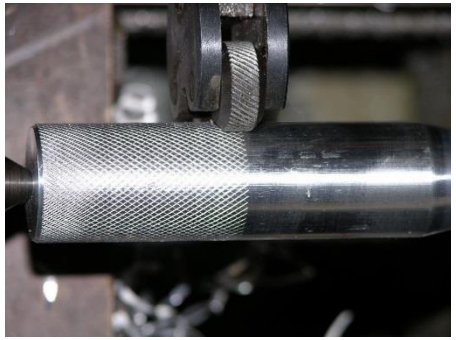
- This method is most commonly used for a range of tapers.



OPERATIONS ON LATHE

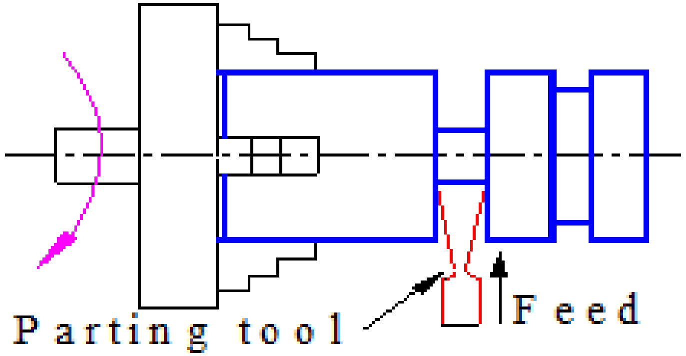
KNURLING





- Knurling is a metal working operation done in a lathe.
- In this a knurling tool having the requisite serrations is forced on to the work piece material, thus deforming the top layers. This forms a top surface, which is rough and provides a proper gripping surface.

PARTING



- Parting and grooving are similar operations. In this a flat nosed tool would plunge cut the work piece with a feed in the direction perpendicular to the axis of revolution. This operation is generally carried out for cutting off the part from the parent material.

WORK HOLDING DEVICE

- The most common form of work holding device used in a lathe is the **chuck**.
- Chucks come in various forms with a varying number of jaws. Of these the **three jaw chuck** or the **self-centering chuck** is the most common one.
- The main advantage of this chuck is the quick way in which the typical round job is centred. All the three jaws move radially inward or outward by the same amount.
- Thus, the jaws will be able to centre any job, whose external locating surface is cylindrical or symmetrical, like hexagonal.
- The independent jaw chuck has **four jaws**, which can be moved in their slots independent of each other, thus clamping any type of configuration. Since each of these jaws could move independently any irregular surface could be effectively centred.

MACHINING TIME

https://www.youtube.com/watch?v=DrWdV4plHc4

- To estimate the machining times, it is necessary to select the proper process parameters. For this purpose it is necessary to know the work piece material and the cutting tool material combinations to arrive at the right combination of the process parameters, cutting speed, feed and depth of cut.

- The cutting speed in turning is the surface speed of the work piece. Thus,

$$V = \frac{\pi D N}{1000}$$

where, V = cutting speed (surface), m/min

D = diameter of the work piece, mm

N = rotational speed of the work piece, rpm

- The diameter, D to be used can be either the initial diameter of the blank or the final diameter of the work piece after giving the depth of cut. However, there is practically not much change in the values obtained by using either of the values. To be realistic, the average of the two diameters would be better.

MACHINING TIME

- The time, t for a single pass is given by

$$t = \frac{L + L_o}{f\,N}$$

where L = length of the job, mm

L_o = over travel of the tool beyond the length of the job to help in the setting of the tool, mm

f = feed rate, mm/rev

MACHINING TIME

- The number of passes required to machine a component depends upon the left-over stock (stock allowance). Also depending upon the specified surface finish and the tolerance on a given dimension, the choice would have to be made as to the number of finishing passes (1 or 2) while the rest of the allowance is to be removed through the roughing passes. The roughing passes, Pr is given by

$$P_r = \frac{A - A_f}{d_r}$$

where A = Total machining allowance, mm
A_f = Finish machining allowance, mm
d_r = Depth of cut in roughing, mm

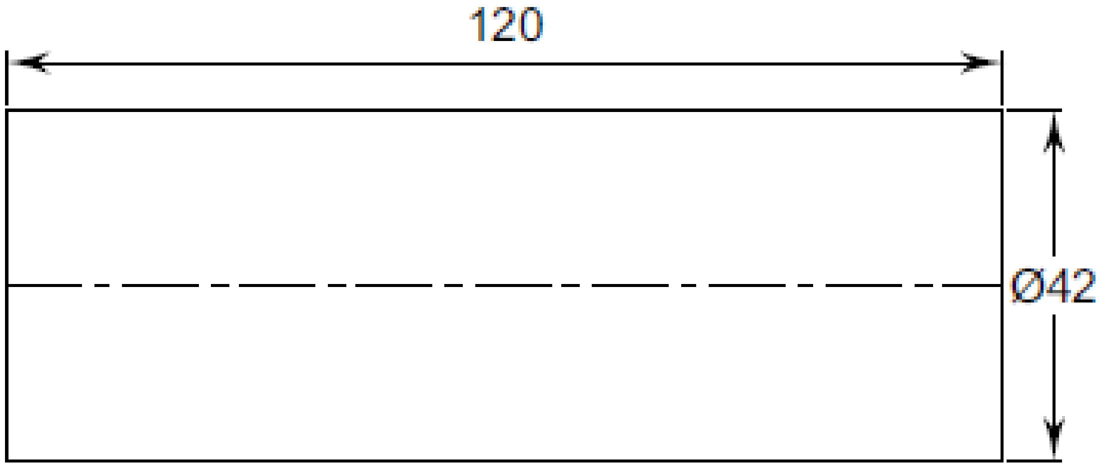
- Similarly the finishing passes, Pf is given by

$$P_f = \frac{A_f}{d_f}$$

where d_f = Depth of cut in finishing, mm

MACHINING TIME

- Estimate the actual machining time required for the component (C40 steel) shown in Fig. below. The available spindle speeds are, 70, 110, 176, 280, 440, 700, 1100, 1760 and 2800. Use a roughing speed of 30 m/min and finish speed of 60 m/min. The feed for roughing is 0.24 mm/rev while that for finishing is 0.10 mm/rev. The maximum depth of cut for roughing is 2 mm. Finish allowance may be taken as 0.75 mm. Blank to be used for machining is 50 mm in diameter.



MACHINING TIME

Solution Stock to be removed $= \dfrac{50-42}{2} = 4$ mm

Finish allowance = 0.75 mm

Roughing:

Roughing stock available = 4 – 0.75 = 3.25 mm

Since maximum depth of cut to be taken is 2 mm, there are 2 roughing passes.

Given cutting speed, $V = 30$ m/min

$$\text{Average diameter} = \frac{50+42}{2} = 46 \text{ mm}$$

$$\text{Spindle speed, } N = \frac{1000 \times 30}{\pi \times 46} = 207.59 \text{ RPM}$$

The nearest RPM available from the list is 176 RPM as 280 is very high compared to 207 as calculated.

MACHINING TIME

$$\text{Machining time for one pass} = \frac{(120+2)}{0.24\times 176} = 2.898 \text{ minutes}$$

Finishing:

Given cutting speed, $V = 60$ m/min

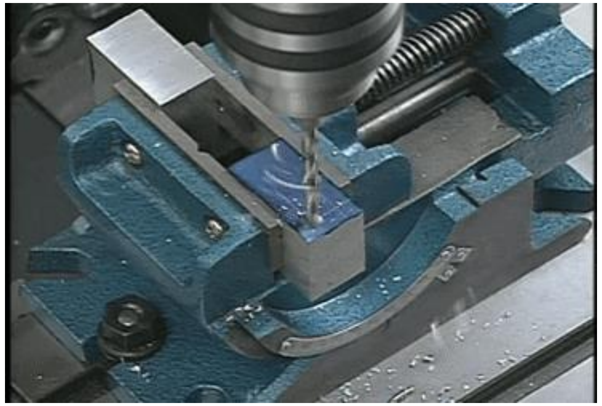
$$\text{Spindle speed, } N = \frac{1000\times 30}{\pi \times 42} = 439.05 \text{ RPM}$$

The nearest RPM available from the list is 440 RPM.

$$\text{Machining time for one pass} = \frac{(120+2)}{0.10\times 440} = 2.77 \text{ minutes}$$

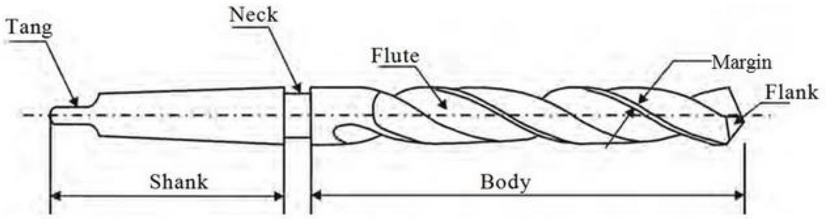
$$\text{Total machining time} = 2\times 2.888 + 2.77 = 8.546 \text{ minutes}$$

DRILLING



- Drilling is the operation of making primarily a hole in a workpiece using a drill bit.

- The stationary work is held in a fixture and rotating tool is fed vertically to make a circular hole.



- The cutting tool used for making holes in solid material is called the **twist drill**.

- It basically consists of two parts; the body consisting of the cutting edges and the shank which is used for holding purpose. This has two cutting edges and two opposite spiral **flutes** cut into its surface.

- These flutes serve to provide clearance to the chips produced at the cutting edges. They also allow the cutting fluid to reach the cutting edges.

DRILLING MACHINES

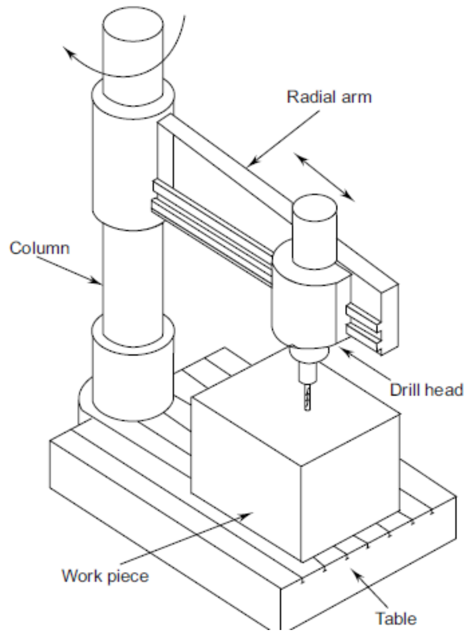
RADIAL DRILLING MACHINE

GANG DRILLING MACHINE

Radial Drilling Machine

- The drill head can move along the radial arm to any position while the radial arm itself can rotate on the column, thus reaching any position in the radial range of the machine.

- They are more convenient to be used for large work pieces, which cannot be moved easily because of their weight, such that the drill head itself will be moved to the actual location on the work piece, before carrying the drilling operation.



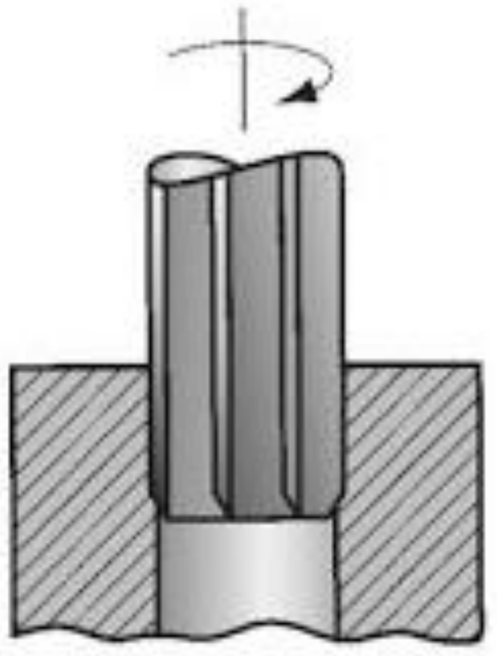
Gang Drilling Machine

- Gang drilling machines have a number of spindles (often equal to four) laid out in parallel. Each of the spindles can have different drills or other hole making operation tools fixed in sequence.

- These are used for volume production with the work pieces located in a jig.

Types of Drilling Machines

Reaming



- Reaming is the operation of finishing a previously drilled hole to bring it to a more exact size and to improve the surface finish of the hole.

- The operation is carried out using a multi tooth revolving tool called reamer which consists of a set of parallel straight or helical cutting edges along the length of the cylindrical body.

- While reaming, the speed of the spindle is reduced to nearly half of that of drilling.

Types of Drilling Machines

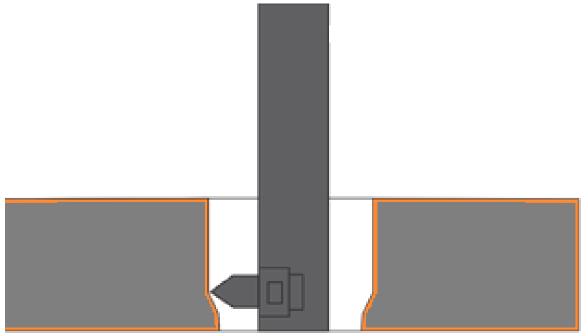
Boring

- Boring is an operation of enlarging a hole.

- The single point cutting tool used for boring operations is mounted in the boring bar of suitable diameter commensurate with the diameter to be bored.

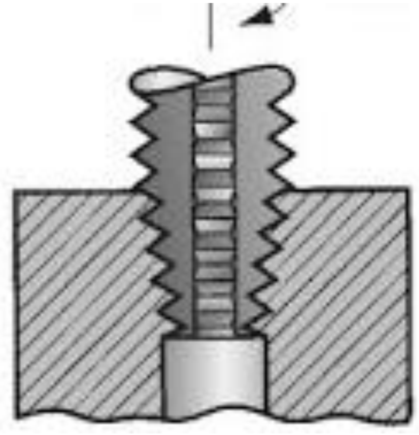
- **Sizing**: Boring brings the hole to the proper size and finish. A drill or reamer can only be used if the desired size is **“standard”**. The boring tool can work to any diameter and it will give the required finish by adjusting speed and feed.

- In addition to enlargement, boring operation corrects the hole loctation and out of roundness, if any, as the tool can be adjusted to remove more metal from one side of the hole than the other.



Types of Drilling Machines

Tapping



- A faster way of producing internal threads in a previously drilled hole is by the use of tapping operation.

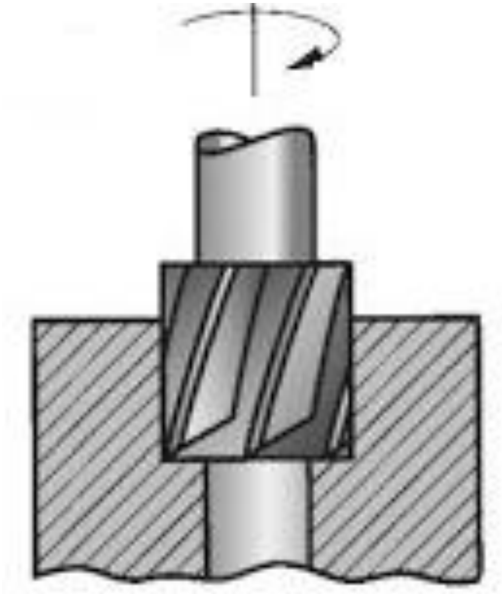
- A tap is a multi fluted cutting tool with cutting edges on each blade resembling the shape of threads to be cut. A tap of the required size is to be used after carrying out the pre-drilling operations. The tapping drill sizes for ISO metric threads are usually available in standard tables.

- While tapping, care has to be taken to see that the tap is started in proper alignment with the hole.

- Sometimes it may become necessary to reverse the tap slightly to break the chips and clear the chip space and then continue in the normal way.

Types of Drilling Machines

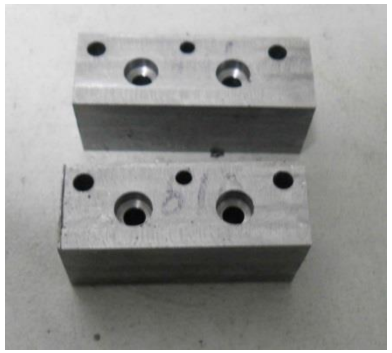
Counter boring



- In the counter boring operation, the hole is enlarged with a flat bottom to provide proper seating for the bolt head or a nut, which will be flush from the outer surface.

- The counter boring can be done by a tool with the cutting edges present along the side as well as the end, while a pilot portion is present for the tool to enter the already machined hole to provide the concentricity with the hole.

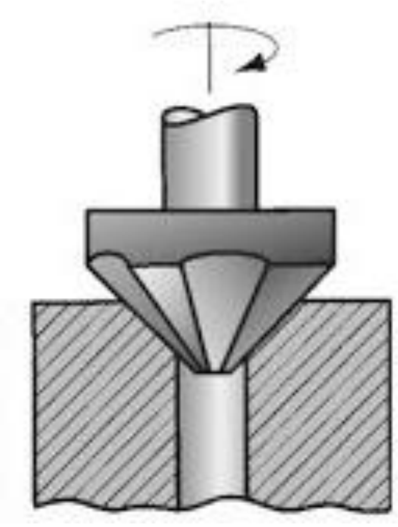
- The pilot should fit snugly in the hole and should have sufficient clearance facilitating the free movement of the tool.



- Generally the speeds and feeds used for counter boring are slightly smaller than those used for the corresponding drilling operation.

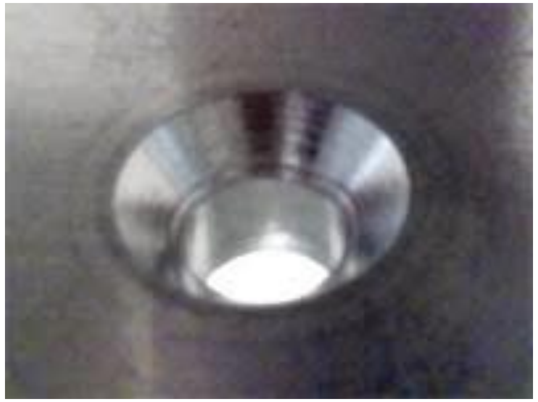
Types of Drilling Machines

Counter sinking



- Counter sinking is also similar to counter boring; except that the additional machining done on a hole is conical to accommodate the counter sunk machine screw head.

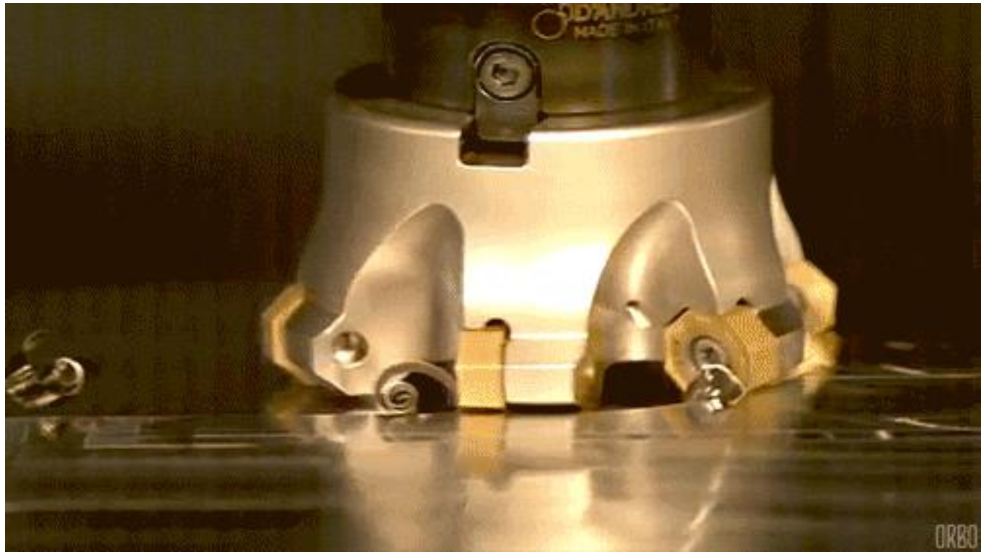
- Again the depth of counter sinking should be large enough to accommodate the screw head fully flush with the surface.



MILLING

- In milling, the work piece is fed into a rotating milling cutter, which is a multi-point tool as shown.

- It is unlike a lathe, which uses a single point cutting tool. The tool used is called milling cutter.

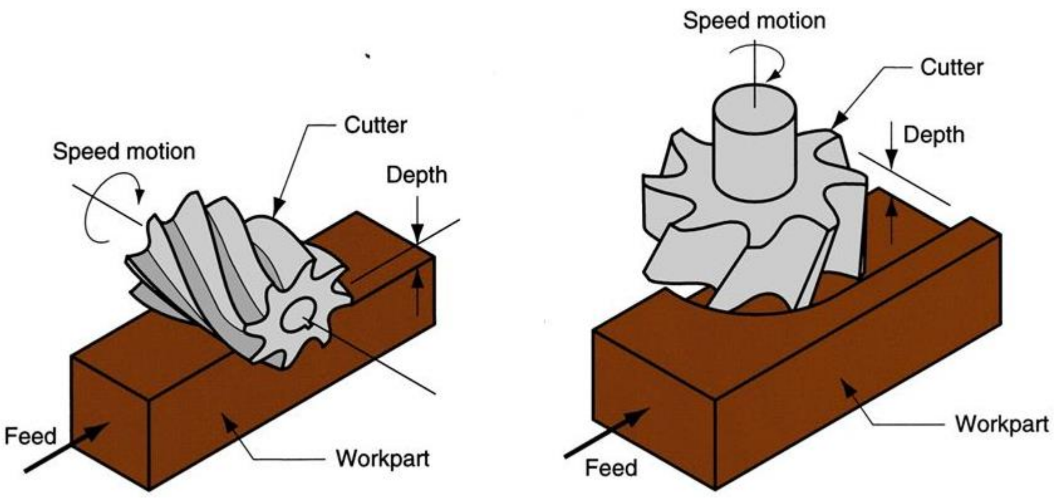


MILLING

- Milling operation can be classified into two broad categories: **Peripheral Milling, Face Milling.**

- In peripheral milling the surface generated is **parallel** with the axis of rotation of cutter. This type of milling is carried out in Horizontal milling machine.

- In face milling surface generated is **at right angle** to the cutter axis. This type of milling is carried out in Vertical milling machine.



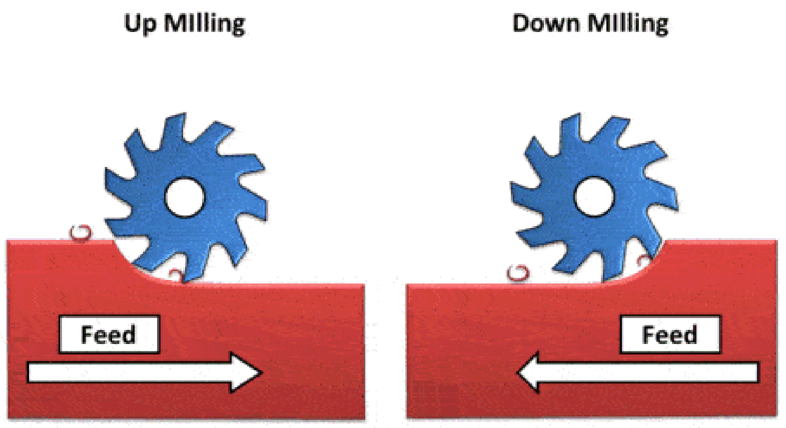
UP AND DOWN MILLING

- Based on the directions of movement of the milling cutter and the feeding direction of the work piece, there are two possible types of milling:

● **Up milling (conventional milling)**
● **Down milling (Climb milling)**

- In up milling the cutting tool rotates in the **opposite direction** to the table movement. This tends to lift the work piece from the table.

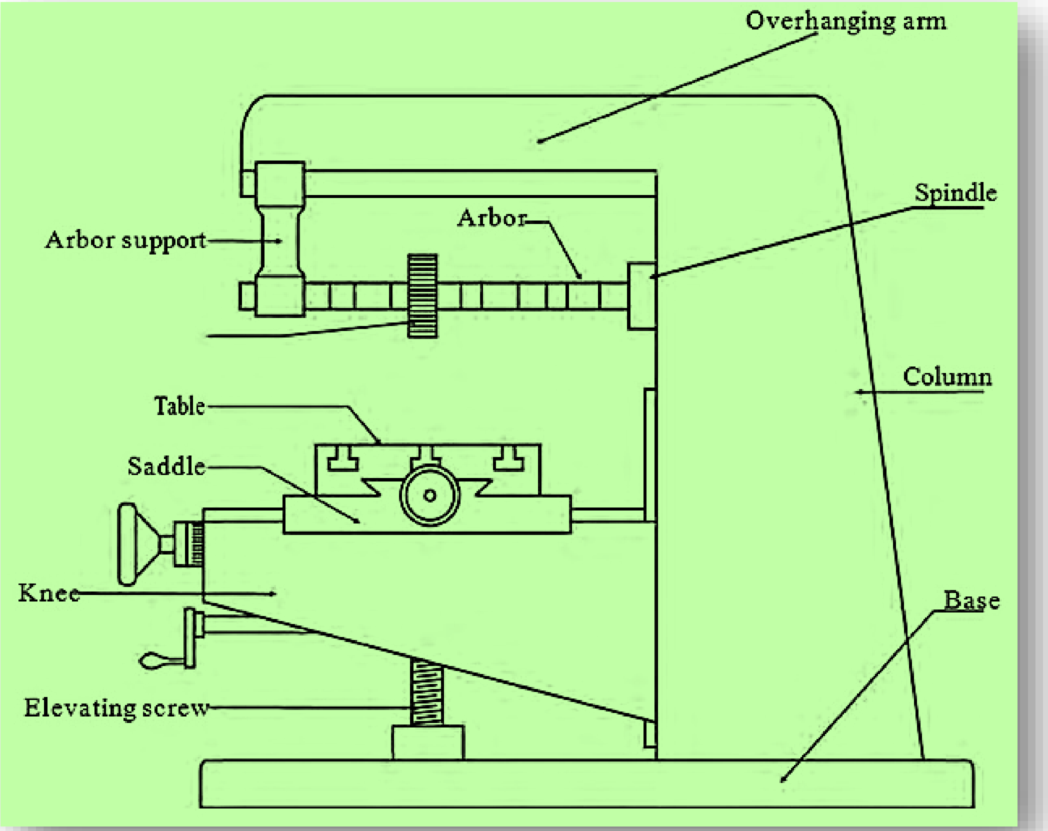
- In down milling the cutting tool rotates in the **same direction** as that of the table movement. The cutting force will act downwards and as such would keep the work piece firmly in the work holding device.



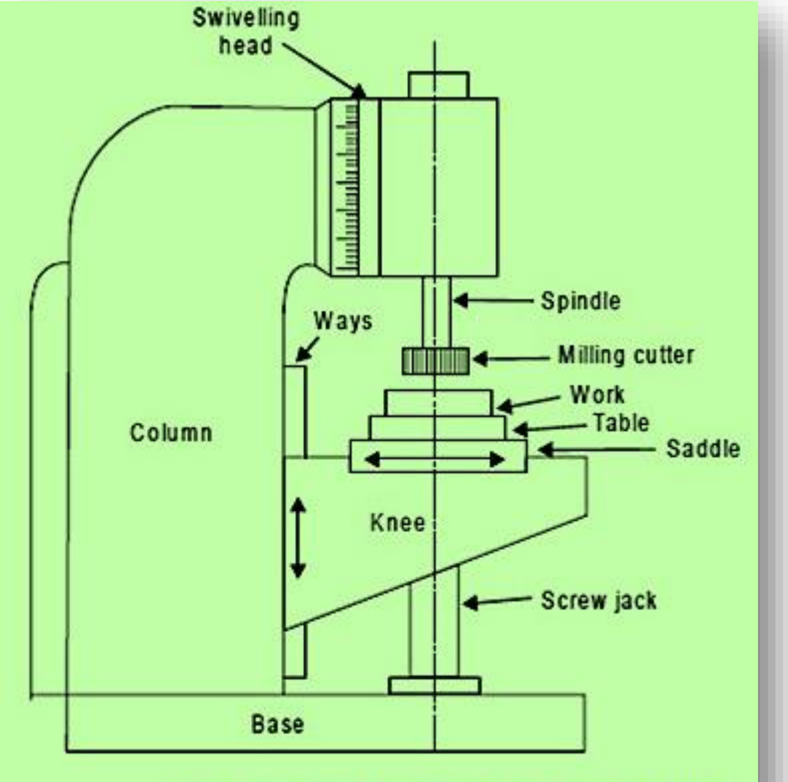
UP AND DOWN MILLING

UP MILLING	DOWN MILLING
In up milling cutter rotates against the direction of feed	Cutter rotates with the direction of feed
In this process, heat is diffused to the work piece which causes the change in metal properties	In down milling most of the heat diffuse to the chip without change the work piece properties
Progressive chip formation	Chip size is maximum at start and decreases with the feed

HORIZONTAL MILLING MACHINE



VERTICAL MILLING MACHINE



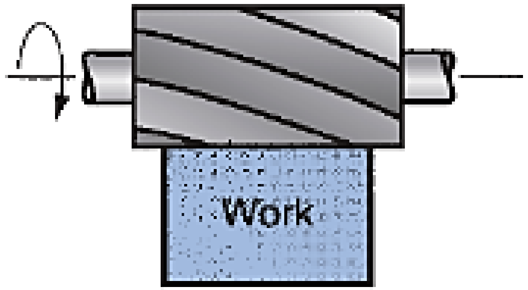
A column and knee type milling machine

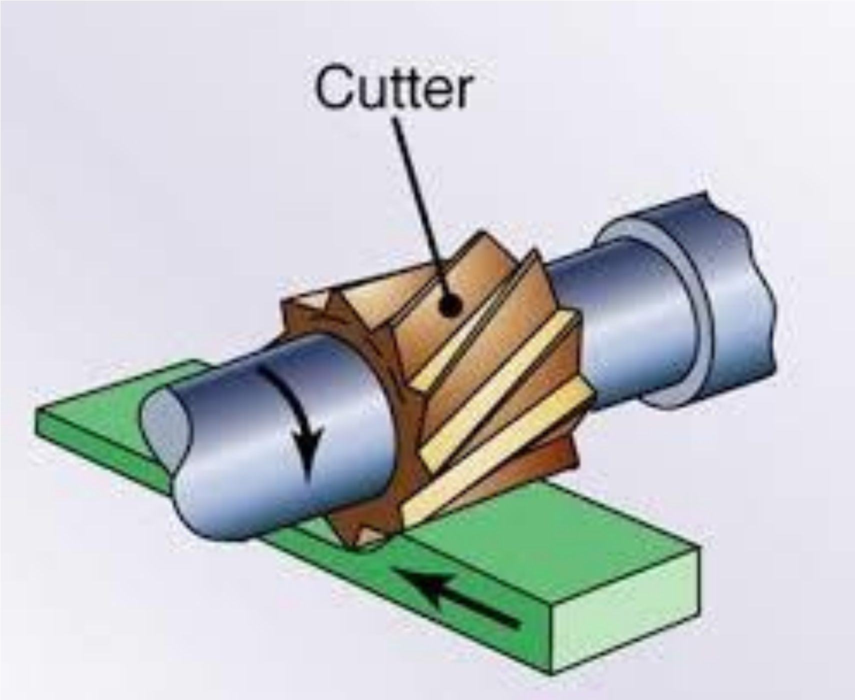
Sl No.	HORIZONTAL MILLING MACHINE	VERTICAL MILLING MACHINE
1	Spindle is horizontal and parallel to the worktable	Spindle is vertical and perpendicular to the worktable
2	Cutter cannot be moved up and down	Cutter can be moved up and down
3	Cutter is mounted on the arbor	Cutter is directly mounted on the spindle
4	Spindle cannot be tilted	Spindle can be tilted for angular cutting
5	Operation such as plan milling, gear cutting, form milling, straddle, gang milling etc.., can be performed	Operation such as slot milling, T- slots, flat milling and also different drilling operations can be performed

MILLING OPERATIONS

SLAB MILLING

- The basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides.

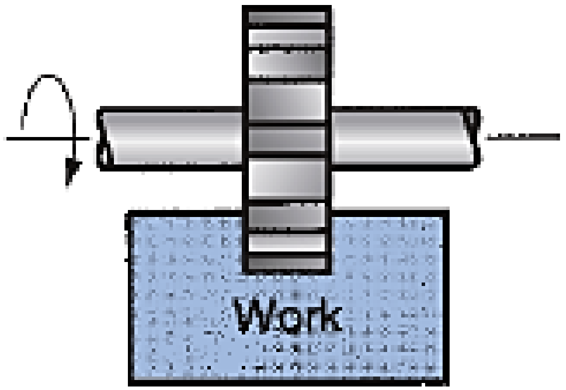




MILLING OPERATIONS

SLOTTING

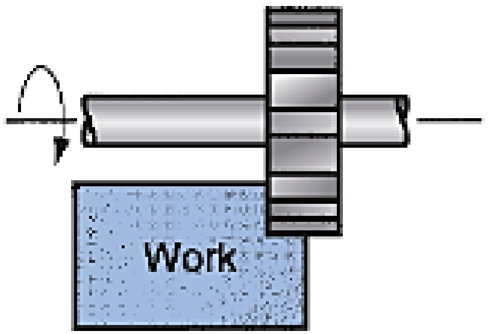
- Here the width of the cutter is less than the workpiece width, creating a slot in the work (when the cutter is very thin, this operation can be used to mill narrow slots).

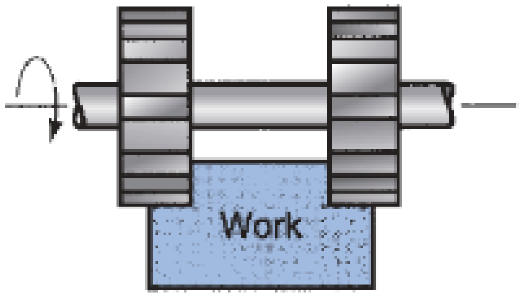


MILLING OPERATIONS

SIDE AND STRADDLE MILLING

- **Side milling** – Cutter machines the side of the workpiece.
- **Straddle milling** – It is same as side milling, but cutting takes place on both sides of the work.

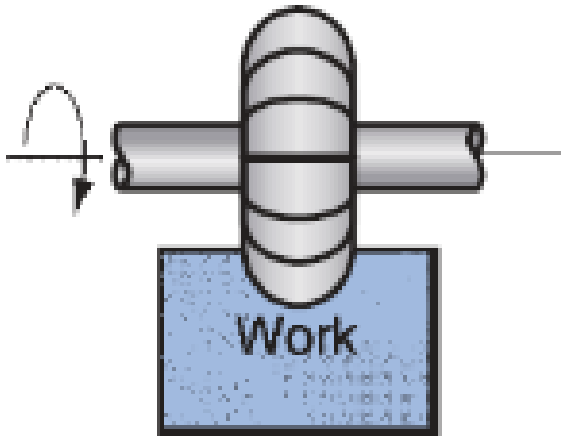




MILLING OPERATIONS

FORM MILLING

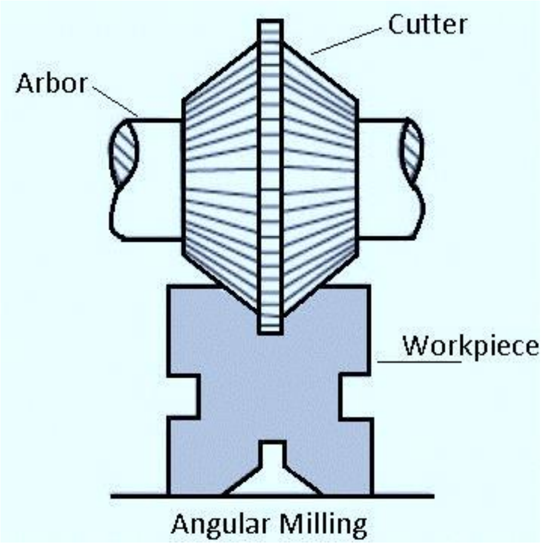
- The milling teeth have a special profile that determines the shape of the slot that is cut in the work.



MILLING OPERATIONS

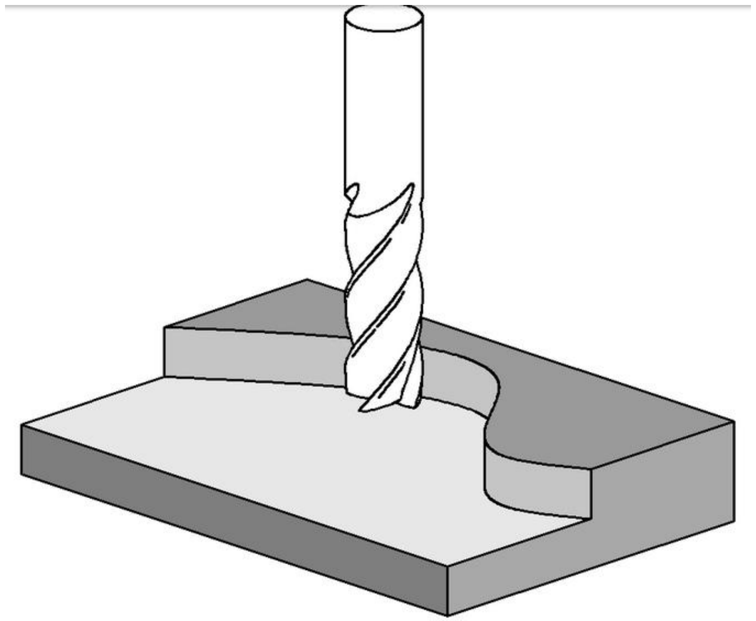
ANGULAR MILLING

- Its operation of producing angular surface on the workpiece. A single or double cutter can be used to produce shapes like V grooves in the V- blocks



MILLING OPERATIONS

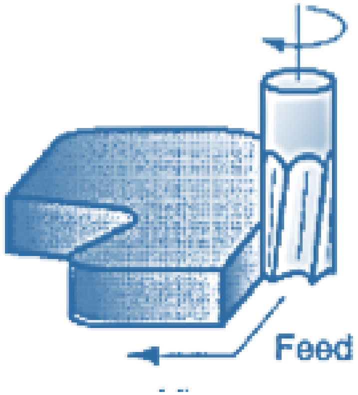
END MILLING



- End milling is the operation performed for producing flat surfaces, slots, grooves or finishing the edges of the workpiece by means of a tool called ***end mill*** or ***end milling cutter***.

- The cutter has teeth on the end as well as the periphery (sides) and hence can be configured to cut with both its end and the sides.

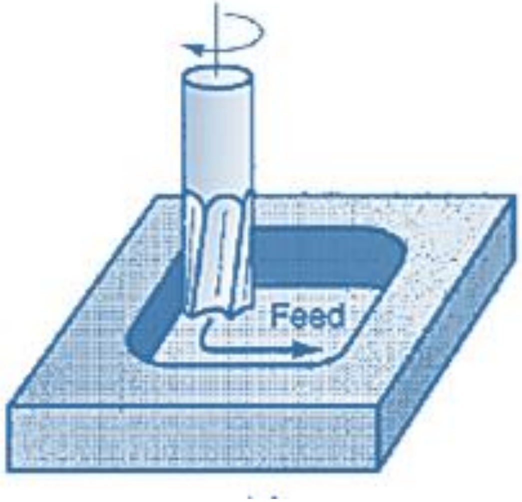
- **Profile milling** – It is a form of end milling done on the perimeter of a workpiece and can produce nearly any shape that has interior radii at least as large as that of the cutter.

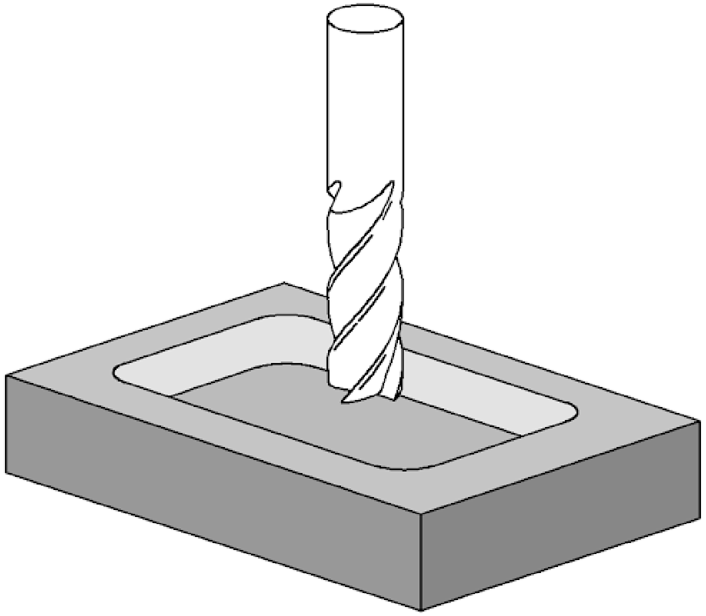


MILLING OPERATIONS

END MILLING

- **Pocket Milling** - Another form of end milling used to mill shallow pockets into flat parts.



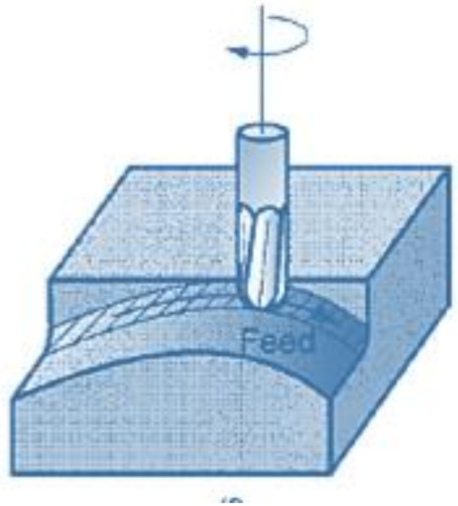


MILLING OPERATIONS

END MILLING

- **Surface Contouring** - A ball-nose cutter (rather than square-end cutter) is fed back and forth across the work along a curvilinear path at close intervals to create a three-dimensional surface form.

- Contouring can be used to produce tooling such as injection molds and forming dies.



GRINDING

- Grinding is a process carried out with a grinding wheel made up of abrasive grains for removing very fine quantities of material from the work piece surface.

- The required size of abrasive grains are thoroughly mixed with the bonding material and then pressed into a disc shape of given diameter and thickness.

- Grinding is a process used for
  - Machining materials which are too hard for other machining processes such as tool and die steels and hardened steel materials,
  - Close dimensional accuracy of the order of 0.3 to 0.5 mm, and
  - High degree of surface smoothness such as Ra = 0.15 to 1.25 mm.

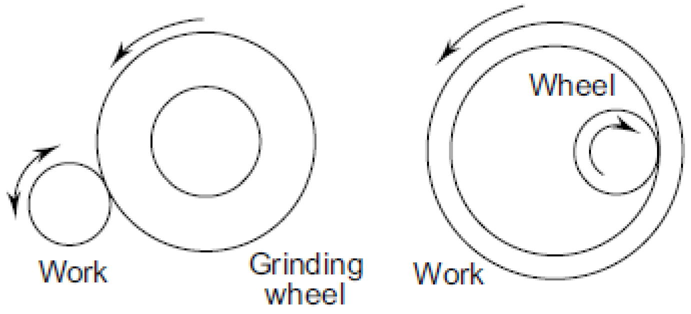
GRINDING

- Grinding operations are generally classified based on the type of surface produced. The grinding operations possible can be classified into
  - Cylindrical grinding for generating cylindrical surfaces
  - Surface grinding for generating flat surfaces, and
  - Centre less grinding for generating axi-symmetric shapes.

- The **cylindrical grinding** machine is used generally for producing external cylindrical surfaces. The machine is very similar to a centre lathe. Typical movements in a cylindrical grinding machine are shown in Fig.

- The grinding wheel is located similar to the tool post, with an independent power driven at high speed suitable for grinding operation. Both the work and the grinding wheel rotate counter clockwise.

- The work that is normally held between centres is rotated at much lower speed compared to that of the grinding wheel.

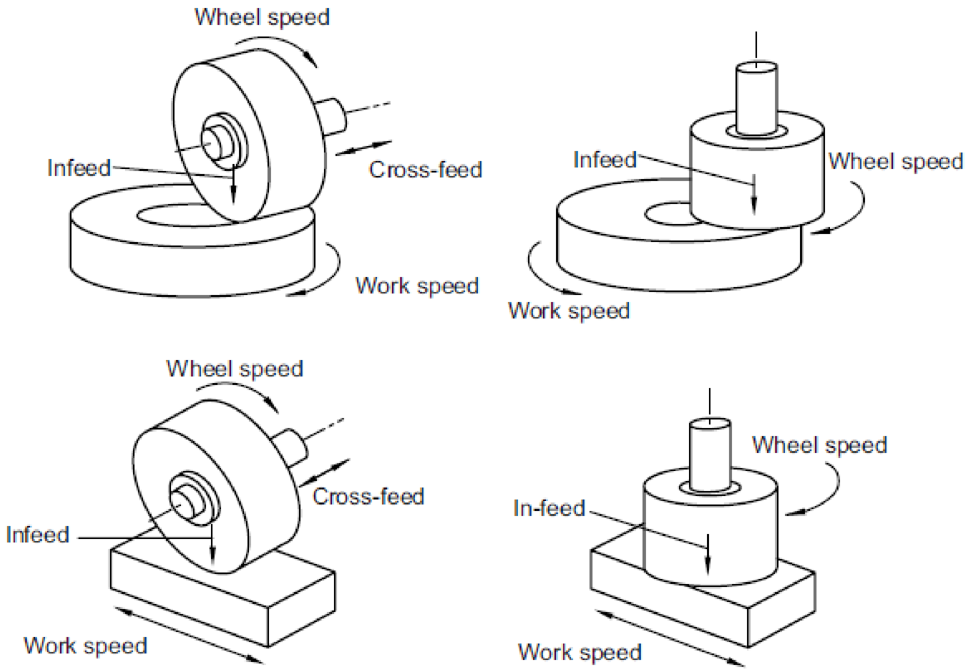


(a) Cylindrical grinding

GRINDING

- Surface grinding machines are generally used for generating flat surfaces. By far these are used for the largest amount of grinding work done in most of the machine shops.

- These machines are similar to milling machines in construction as well as motion. There are basically four types of machines depending upon the spindle direction and the table motion as shown. They are –
- Horizontal spindle and rotating table
- Vertical spindle and rotating table
- Horizontal spindle and reciprocating table
- Vertical spindle and reciprocating table



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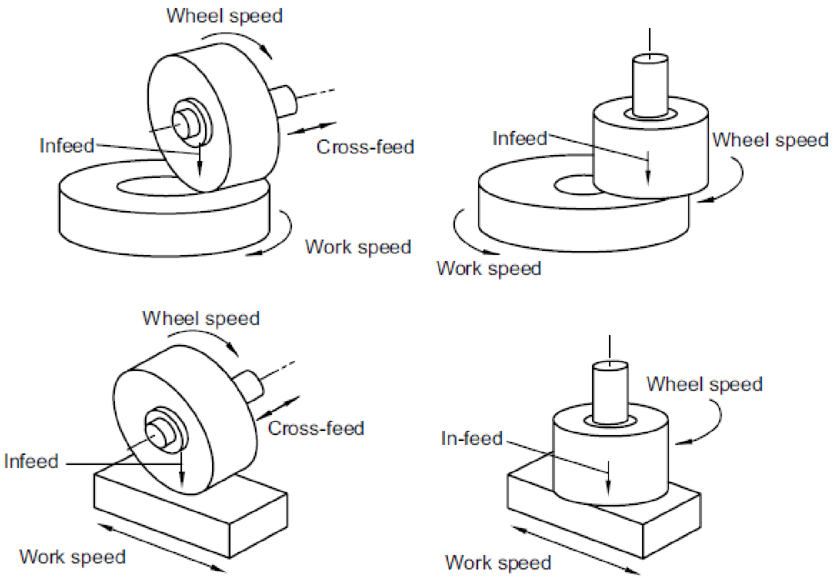


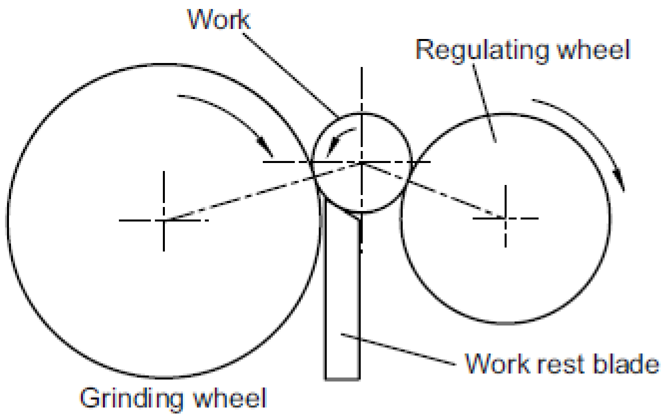
GRINDING

- Centre less grinding makes it possible to grind cylindrical work pieces without actually fixing the work piece using centres or a chuck. As a result no work rotation is separately provided.

- The process consists of two wheels, one large grinding wheel and another smaller regulating wheel. The work is held on a work rest blade. The regulating wheel is mounted at an angle to the plane of the grinding wheel.

- The centre of the work piece is slightly above the centre of the grinding wheel. The work piece is supported by the rest blade and held against the regulating wheel by the grinding force.

- As a result the work rotates at the same surface speed as that of the regulating wheel. The regulating wheel is generally a rubber or resinoid bonded wheel with wide face. The axial feed of the work piece is controlled by the angle of tilt of the regulating wheel.



NUMERICAL CONTROL

- Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers and symbols.

- Basically a NC machine runs on a program fed to it. The program consists of precise instructions about the methodology of manufacture as well as the movements. For example what tool to be used, at what speed, at what feed and to move from which point to which point in what path.

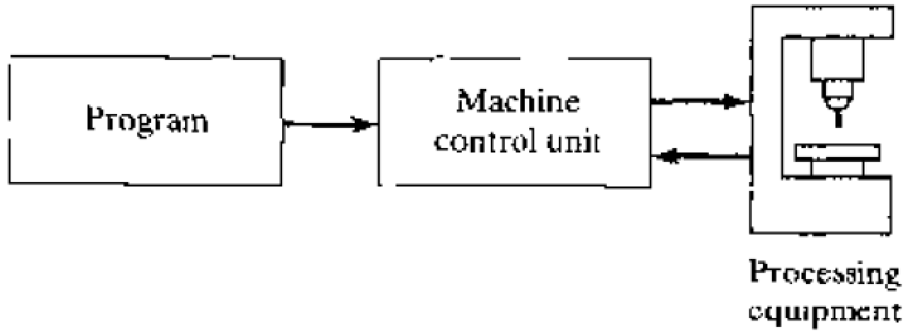
- In NC machine tools one or more of the following functions may be automatic:
  (a) starting and stopping of machine tool spindle
  (b) controlling the spindle speed
  (c) positioning the tool tip at desired locations and guiding it along desired paths by automatic control of the motion of slides
  (d) controlling the rate of movement of the tool tip (i.e. feed rate)
  (e) changing of tools in the spindle.

BASIC COMPONENTS OF NC SYSTEM

- The program of instructions is the detailed step by step commands that direct the actions of the processing equipment.

- In machine tool applications, the program of instructions is called a **part program**.

- The individual commands refer to positions of a cutting tool relative to the worktable on which the workpart is fixtured. Additional instructions are usually included such as spindle speed, feed rate, cutting tool selection and other functions.



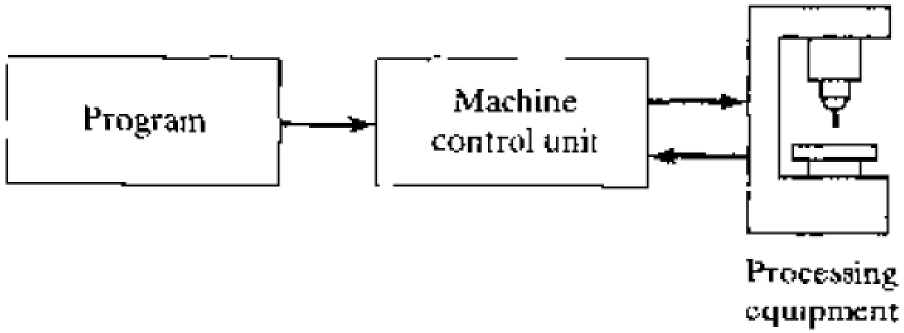
NC Part Program Code	Comments
N001 G21 G90 G92 X0 Y-050.0 Z010.0;	Define origin of axes.
N002 G00 X070.0 Y030.0;	Rapid move to first hole location.
N003 G01 G95 Z-15.0 F0.05 S1000 M03;	Drill first hole.
N004 G01 Z010.0;	Retract drill from hole.
N005 G00 Y060.0;	Rapid move to second hole location.
N006 G01 G95 Z-15.0 F0.05;	Drill second hole.
N007 G01 Z010.0;	Retract drill from hole.

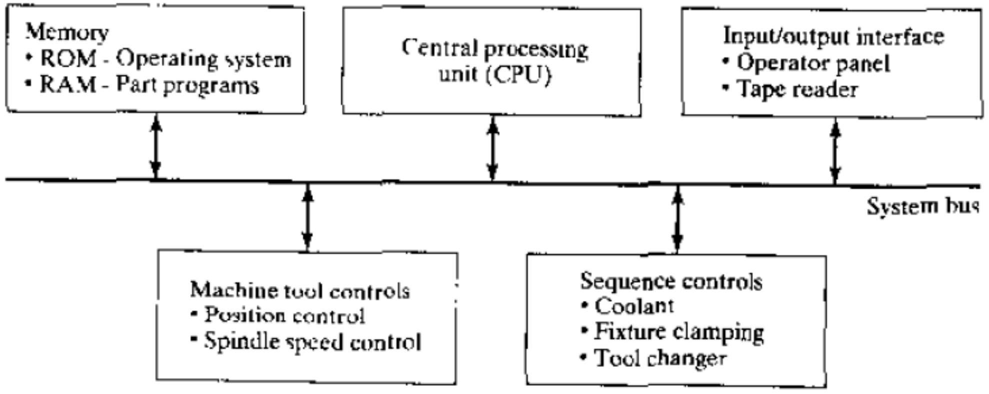
BASIC COMPONENTS OF NC SYSTEM

- Computer numerical control (CNC) is defined as an NC system whose machine control unit is based on a dedicated microcomputer rather than on a hard-wired controller.

- The MCU consists of the following components and subsystems:
  (1) central processing unit
  (2) memory,
  (3) I/O interface.
  (4) controls for machine tool axes and spindle speed and
  (5) sequence controls for other machine tool functions.

- These subsystems are interconnected by means of a system bus. as indicated in the figure.





CNC MACHINING CENTRES

- A machining centre is a computer controlled machine capable of performing a variety of cutting operations on different surfaces and directions on a workpiece.

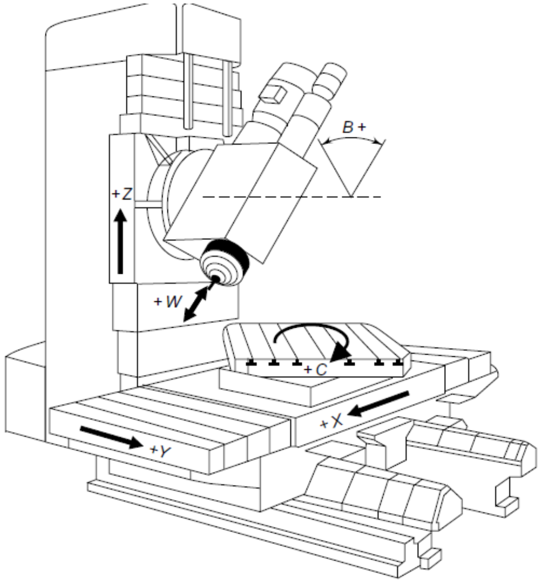
- The CNC machining centres can be broadly categorised into two varieties:
  - Vertical axis machining centre, and
  - Horizontal axis machining centre.

VERTICAL AXIS MACHINING CENTRE

- The vertical axis machining centres or VMC as is popularly abbreviated, are generally more versatile in terms of the tool being able to generate more complex surfaces compared to the horizontal axis.

- Most of the general machines come with 3 axes. Additional axes will be added to cater to the machining of more complex geometries.

- For example the spindle head can be swivelled in one or two axes (about X or Y axis). These are required for machining sculptured surfaces.



HORIZONTAL AXIS MACHINING CENTRE

- By its very configuration, the horizontal axis machining centre or popularly called HMC is sturdier than the vertical configuration and hence is used for heavier work pieces with large metal removal rates.

- Since these machines provide for heavier metal removal rates, the cutting tools used would normally be big. As a result, the tool magazine will have to provide larger place for each tool.

- This results in the tool magazines for HMC to become heavier. Also, they are normally provided with tool magazines having higher capacity.

CNC TURNING CENTRE

- Majority of the components machined in the industry are of the cylindrical shape. Hence the CNC lathes, more appropriately called turning centres, are also important machine tools.

- The major change to be noticed in the turning centres is the early adoption of the slant bed to allow for a better view of the machining plane as well as for easy placement of the various devices involved in the machining zone.

- Most of the turning centres are also provided with a tool turret which may have a capacity of 8 to 12 tools of various types.

MECHANICAL ENGINEERING SCIENCE

Chapter 2 – Automation, Robotics, Control Systems and Industry 4.0

Srinivasa Prasad K S
Department of Mechanical Engineering

MECHANICAL ENGINEERING SCIENCE

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INTRODUCTION TO INDUSTRIAL ROBOTICS

- An industrial robot is a general purpose, programmable machine possessing certain ***anthropomorphic characteristics.***

- The most obvious anthropomorphic characteristic of an industrial robot is its mechanical arm, that is used to perform various industrial tasks.

- Other human like characteristics are the robot's capability to respond to sensory inputs, communicate with other machines and make decisions. These capabilities permit robots to perform a variety of useful tasks.

Reasons for the commercial and technological importance of industrial robots include the following –

1) Robots can be substituted for humans in **hazardous or uncomfortable work environments**.

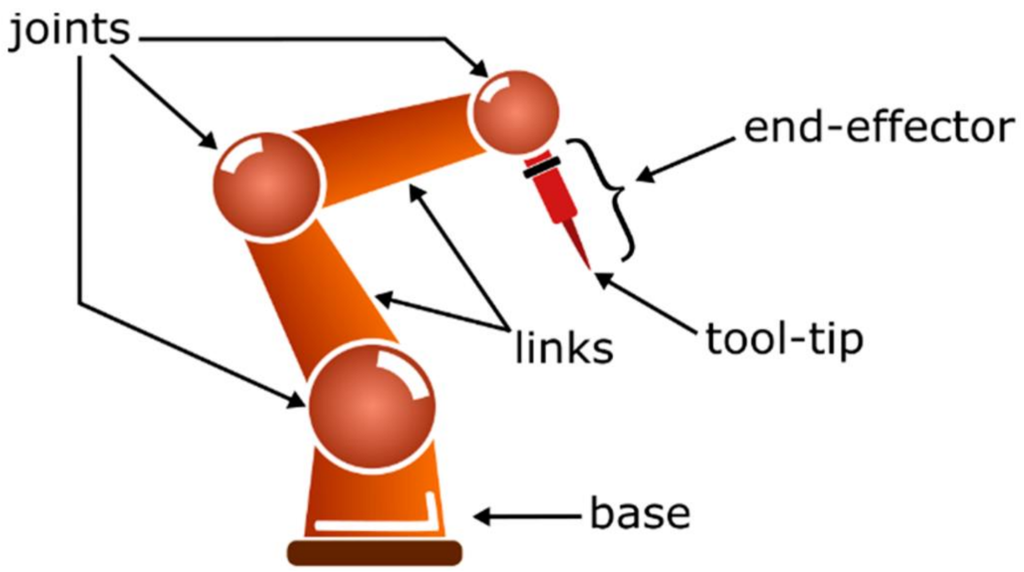
2) A robot performs its work cycle with a **consistency and repeatability** that cannot be attained by humans.

3) Robots can be **reprogrammed**. When the production run of the current task is completed, a robot can be reprogrammed and equipped with necessary tooling to perform an altogether different task.

4) Robots are controlled by computers and can therefore be connected to other computer systems to achieve **computer integrated manufacturing**.

Robot Anatomy

- The manipulator of an industrial robot is constructed of **a series of joints and links**. Robot anatomy is concerned with the types and sizes of these joints and links and other aspects of the manipulator's physical construction.

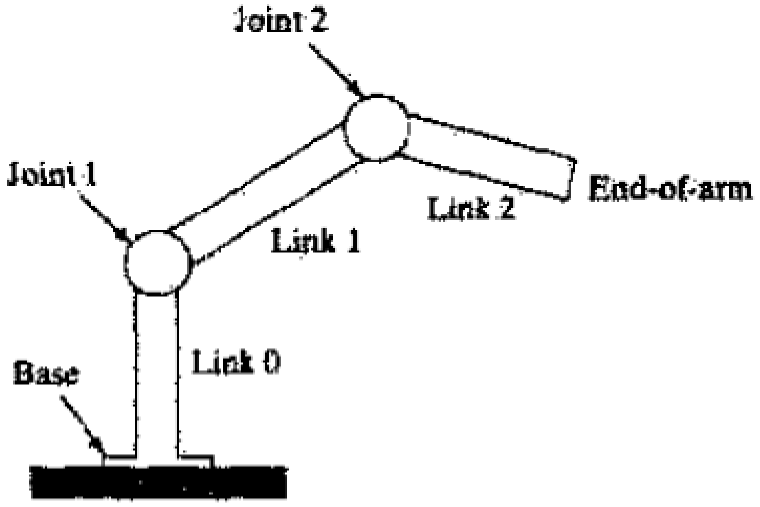


Joints and Links

- A joint of an industrial robot is similar to a joint in the human body. It provides relative motion between two parts of the body.

- Connected to each joint are two links, **an input link and an output link**. Links are the rigid components of the robot manipulator.

- The purpose of the joint is to provide controlled relative movement between the input link and the output link.



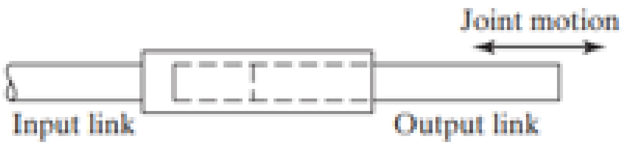
Most robots are mounted on a stationary base on the floor. Let us refer to that base and its connection to the first joint as link 0. It is the input link to joint 1, the first in the series of joints. The output link of joint 1 is link 1. Link 1 is the input link to joint 2, whose output link is link 2 and so forth.

Types of Joints

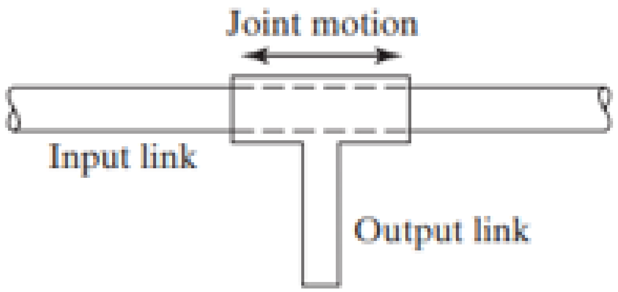
- Nearly all industrial robots have mechanical joints that can be classified into one of five types: two types that provide translational motion and three types that provide rotary motion. The five joints are:

- **Rotational joint**
- **Linear joint**
- **Twisting joint**
- **Orthogonal joint**
- **Revolving joint**

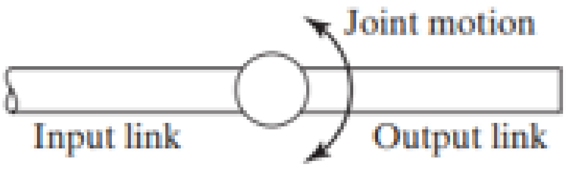
Types of Joints

JOINT	DESCRIPTION	SCHEMATIC
Linear joint	Type L joint; the relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links parallel	

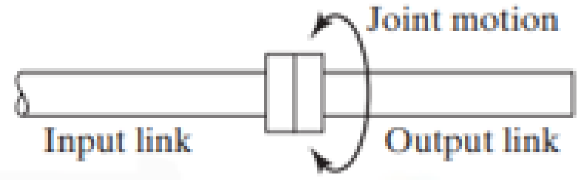
Types of Joints

JOINT	DESCRIPTION	SCHEMATIC
Orthogonal joint	Type O joint; the relative movement between the input link and the output link is a translational sliding motion, but the output link is perpendicular to the input link	

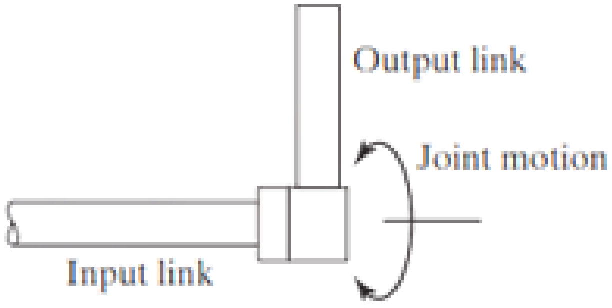
Types of Joints

JOINT	DESCRIPTION	SCHEMATIC
Rotational joint	Type R joint; this provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links	

Types of Joints

JOINT	DESCRIPTION	SCHEMATIC
Twisting joint	Type T joint; this provides rotary motion, but the axis of rotation is parallel to the axes of the two links	

Types of Joints

JOINT	DESCRIPTION	SCHEMATIC
Revolving joint	Type V joint; the axis of the input link is parallel to the axis of rotation of the joint, and the axis of the output link is perpendicular to the axis of rotation	

Robot Configurations

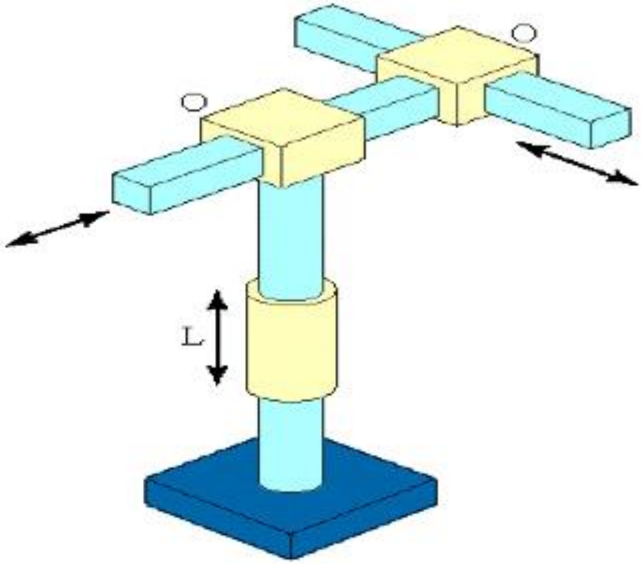
- A robot manipulator can be divided into two sections: a **body and arm assembly** and a **wrist assembly.**

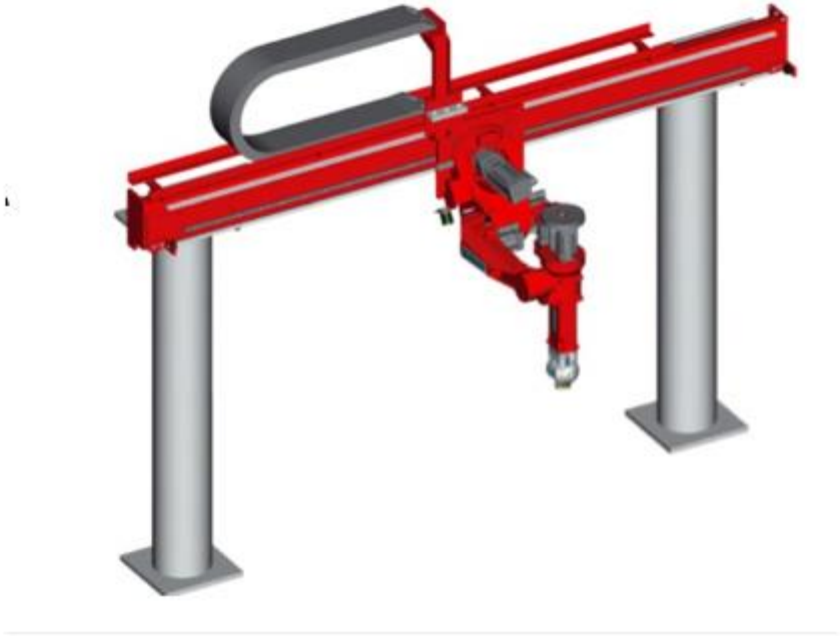
- At the end of the manipulator's wrist is a device related to the task that must be accomplished by the robot. The device called an **end effector** is usually either
  (1) a gripper for holding a work part
  (2) a tool for performing some process.

- The body and arm of the robot is used to position the end effector and the robot's wrist is used to orient the end effector.

Body and Arm Configurations

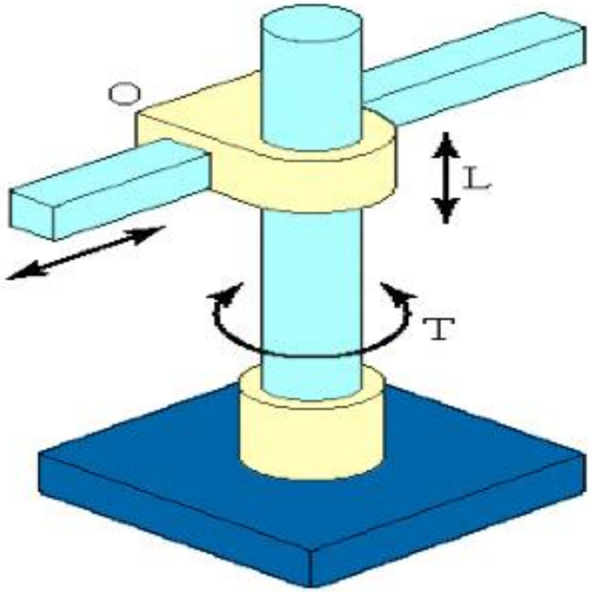
Cartesian coordinate robot – Other names for this configuration include rectilinear robot and x – y – z robot. As shown in Figure, it is composed of three sliding joints, two of which are orthogonal.





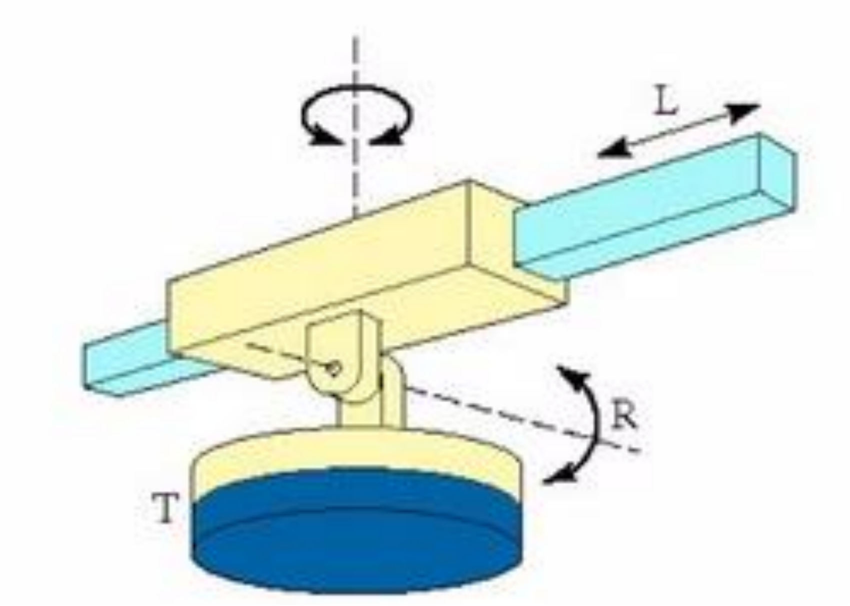
Body and Arm Configurations

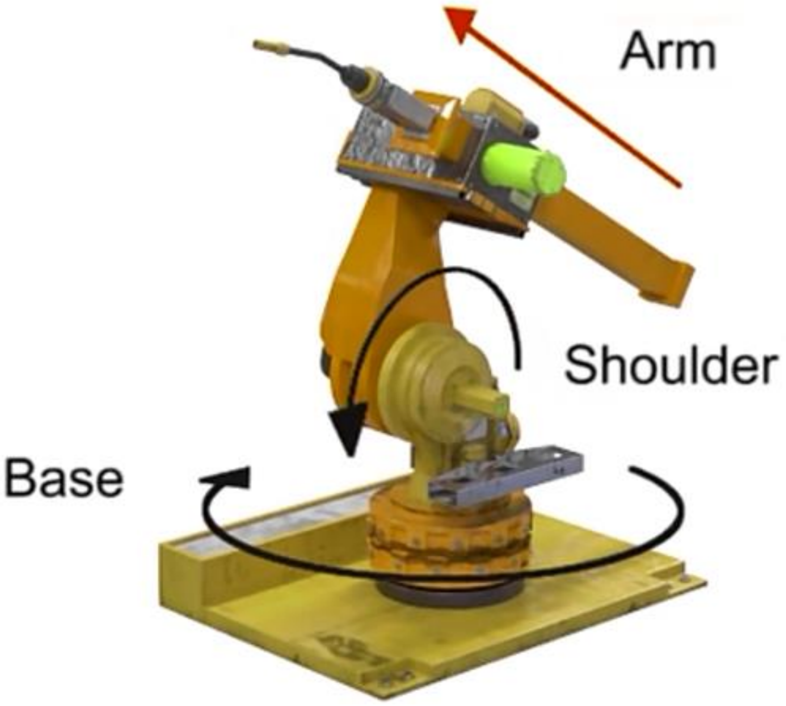
Cylindrical configuration – This robot configuration consists of a vertical column, relative to which an arm assembly is moved up or down. The arm can be moved in and out relative to the axis of the column. The column can be rotated about it's axis.



Body and Arm Configurations

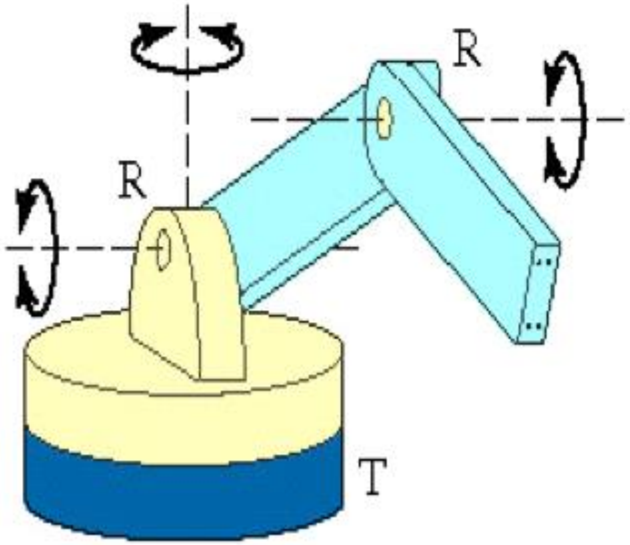
Polar configuration – This configuration consists of a sliding arm (L joint) actuated relative to the body, that can rotate about both a vertical axis (T joint) and a horizontal axis (R joint).





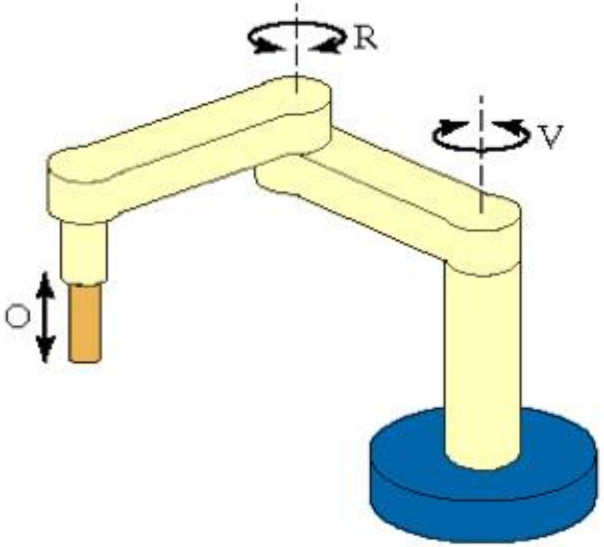
Body and Arm Configurations

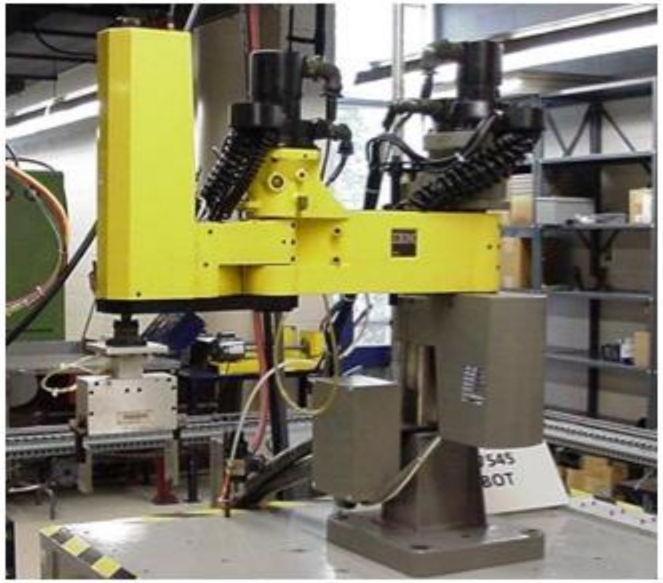
Jointed arm robot – This robot manipulator has the general configuration of a human arm. The jointed arm consists of a vertical column that swivels about the base using a T joint. At the top of the column is a shoulder joint (shown as an R joint in the figure), whose output link connects to an elbow joint (another R joint).



Body and Arm Configurations

SCARA – SCARA is an acronym for Selective Compliance Assembly Robot Arm. This configuration is similar to the jointed arm robot except that the shoulder and elbow rotational axes are vertical, which means that the arm is very rigid in the vertical direction, but compliant in the horizontal direction. This permits the robot to perform insertion tasks (for assembly) in a vertical direction, where some side to side alignment may be needed to mate the two parts properly.



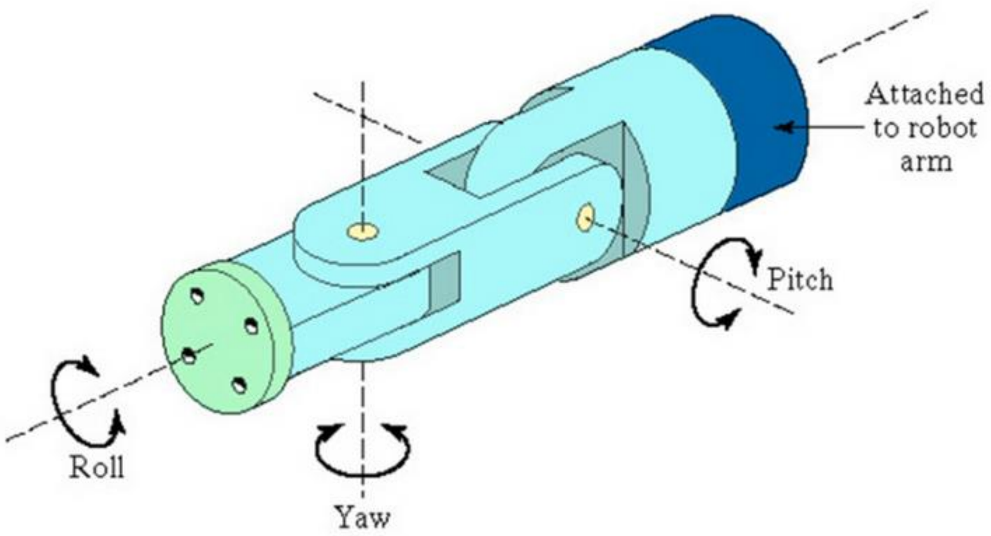


Wrist Configurations

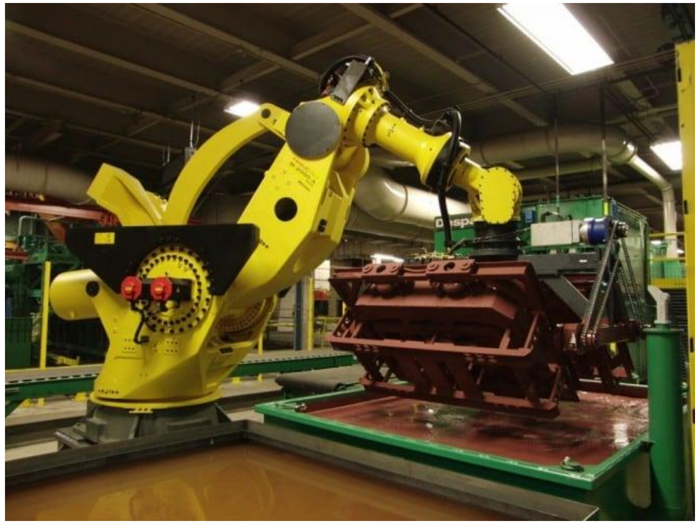
- The robot's wrist is used to establish the orientation of the end effector.

- The three joints are defined as:

1) **Roll**, using a T joint to accomplish rotation about the robot's arm axis
2) **Pitch**, which involves up and down rotation, typically using a R joint
3) **Yaw**, which involves right and left rotation, also accomplished by means of a R - joint.



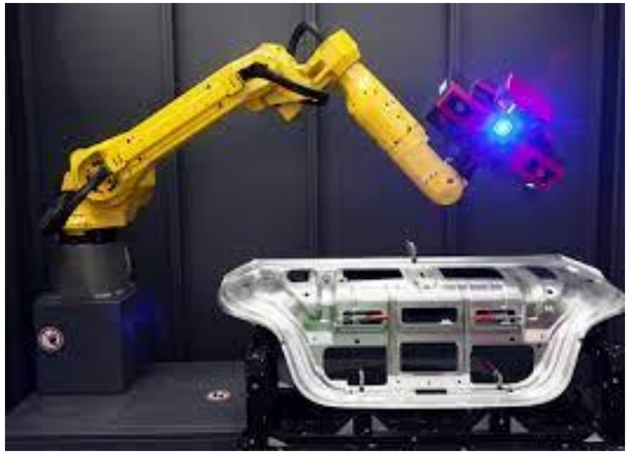
Applications



- Material handling applications –
  1) Material transfer
  2) Machine loading and/or unloading

- Processing Operations – Spot welding, Continuous arc welding, Spray painting etc.

- Assembly and Inspection

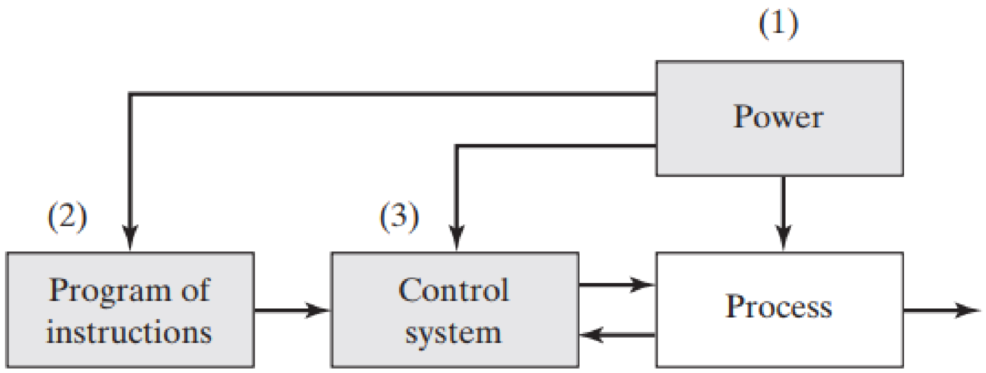


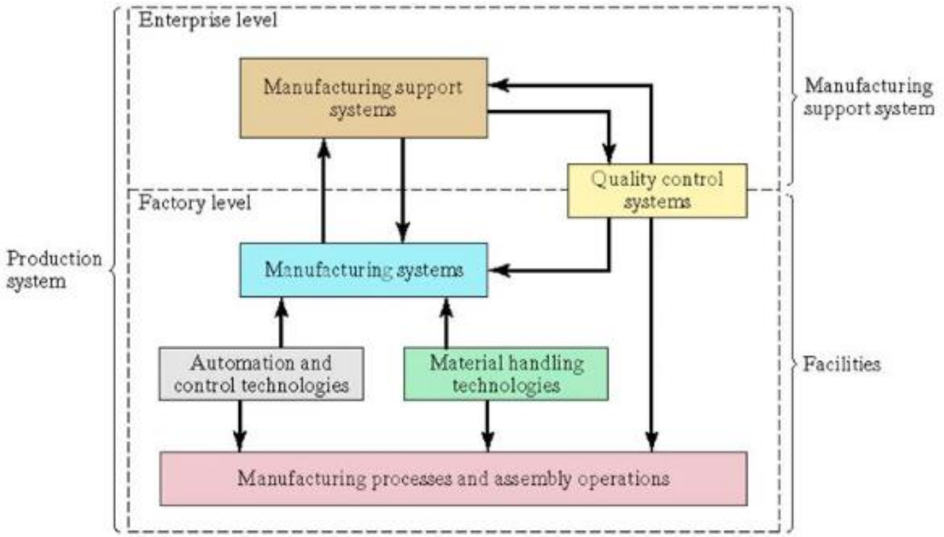
INTRODUCTION TO AUTOMATION

- **Automation is the technology by which a process or procedure is accomplished without human assistance.**

- It is implemented using a **program of instructions** combined with a **control system** that executes the instructions. To automate a process, **power** is required, both to drive the process itself and to operate the program and control system.

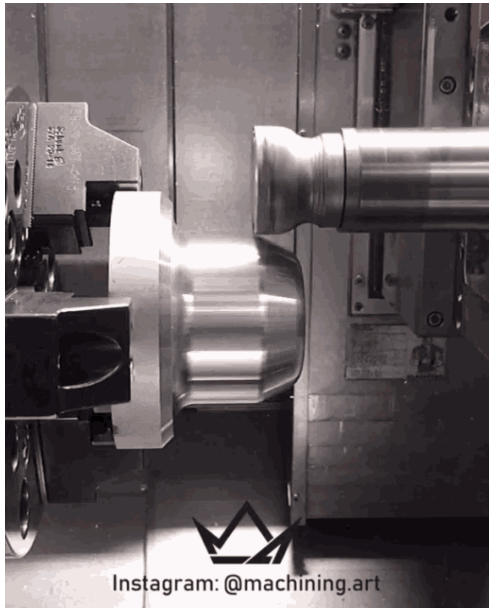
- Although automation can be applied in a wide variety of areas, it is most closely associated with the **manufacturing industries**.





EXAMPLES OF AUTOMATED MANUFACTURING SYSTEMS

- Automated machine tools that process parts
- Transfer lines that perform a series of machining operations
- Automated assembly systems
- Manufacturing systems that use industrial robots to perform processing or assembly operations
- Automatic material handling and storage systems to integrate manufacturing operations
- Automatic inspection systems for quality control



TYPES OF AUTOMATED MANUFACTURING SYSTEMS

Fixed Automation

- **Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration.**

- Each of the operations in the sequence is usually simple, involving perhaps a plain linear or rotational motion or an uncomplicated combination of the two.

- Typical features: **high initial investment, high production rates, relatively inflexible in accommodating product variety.**

- **Examples – machining transfer lines and automated assembly machines.**

TYPES OF AUTOMATED MANUFACTURING SYSTEMS

Programmable Automation

- **In *programmable automation*, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations.**

- The operation sequence is controlled by a program, which is a set of instructions coded so that they can be read and interpreted by the system.

- New programs can be prepared and entered into the equipment to produce new products.

- Typical features**: high investment in general purpose equipment; lower production rates than fixed automation; flexibility to deal with variations and changes in product configuration; most suitable for batch production**

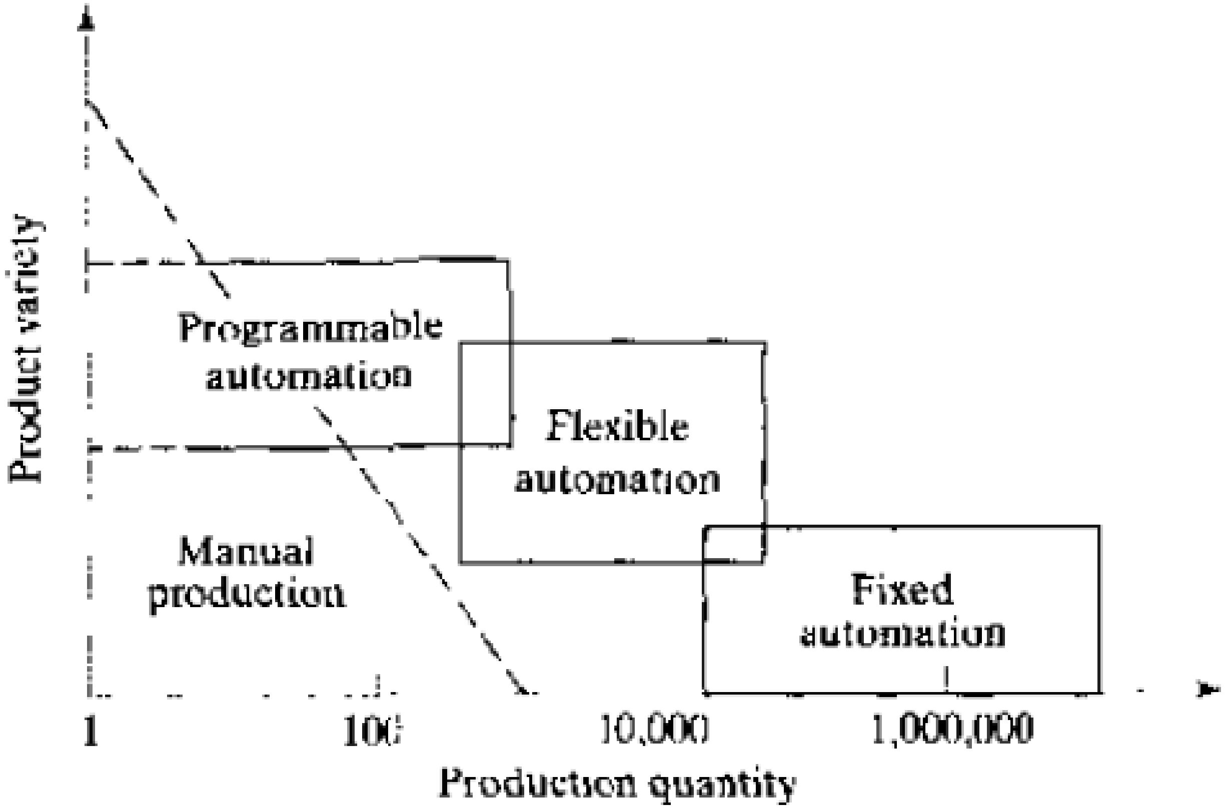
- **Examples – CNC machine tools, industrial robots etc.**

TYPES OF AUTOMATED MANUFACTURING SYSTEMS

Flexible Automation

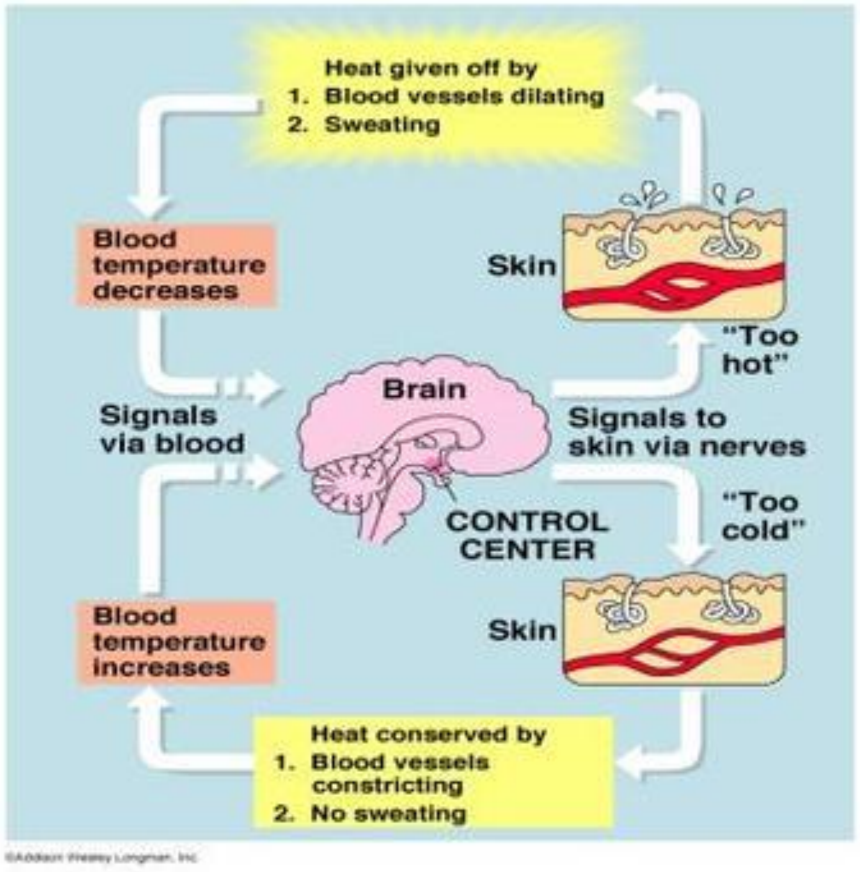
- Flexible automation is an extension of programmable automation.
- **A flexible automated system is capable of producing a variety of parts with virtually no time lost for changeovers from one part style to the next.**
- There is no lost production time while reprogramming the system and altering the physical setup. Consequently the system can produce various combinations of parts or products instead of requiring that they be made in batches.
- What makes flexible automation possible is that the differences between parts processed by the system are not significant.
- Typical features: **high investment for a custom engineered system; continuous production of variable mixtures of products; medium production rates; flexibility to deal with product design variations**

TYPES OF AUTOMATED MANUFACTURING SYSTEMS



INTRODUCTION TO CONTROL SYSTEMS

- ***The control system is that means by which any quantity of interest in a machine, mechanism or other equipment is maintained or altered in accordance with a desired manner.***



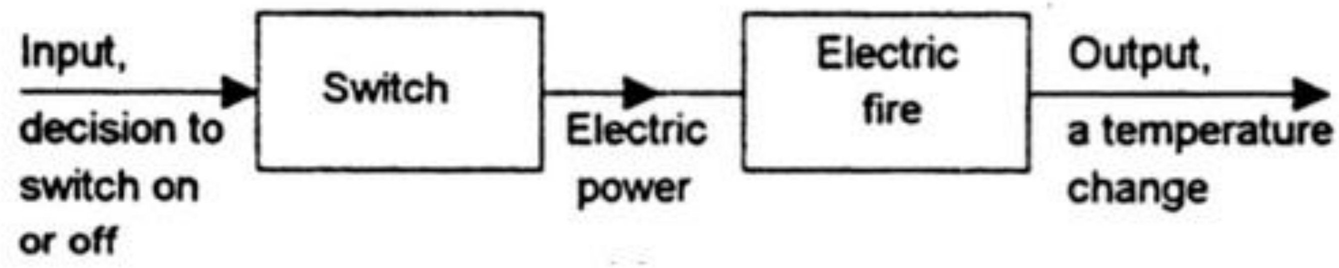
Your body temperature remains almost constant regardless of whether you are in a cold or hot environment. To maintain this constancy your body has a temperature control system. If your temperature begins to increase above the normal you sweat, if it decreases you shiver. Both these are mechanisms which are used to restore the body temperature back to its normal value. The control system is maintaining constancy of body temperature.

OPEN AND CLOSED LOOP CONTROL SYSTEMS

- There are two basic forms of control system, one being called ***open loop and the other closed loop***.

- Consider an electric fire which has a selection switch which allows a 1 kW or a 2kW element to heat a room, he or she might just switch on the 1 kW element if the room is not required to be at too high a temperature.

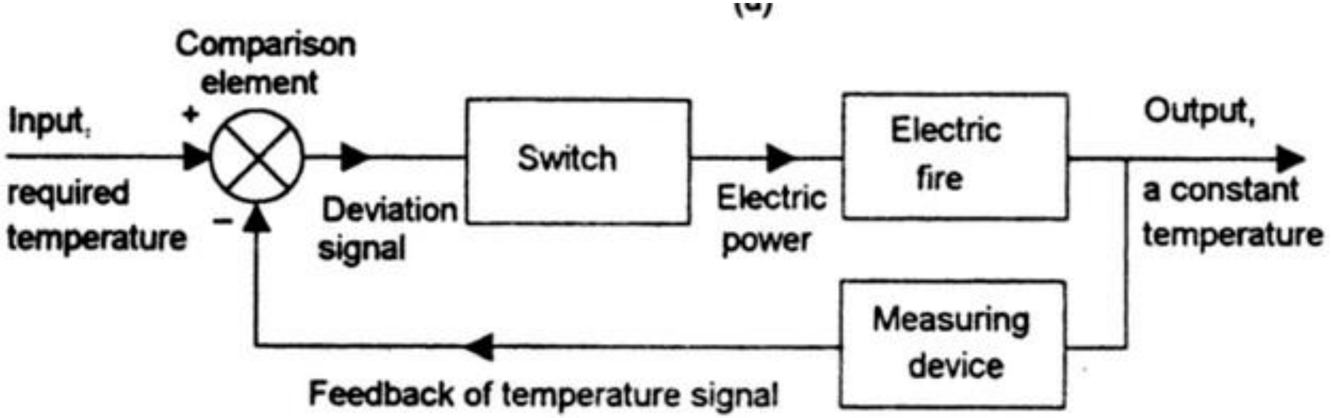
- The room will heat up and reach a temperature which is only determined by the fact the 1 kW element was switched on and not the 2 kW element. If there are changes in conditions, perhaps someone opening a window, there is no way the heat output is adjusted to compensate. This is an example of open loop control in that there is no information fed back to the element to adjust it and maintain constant temperature.



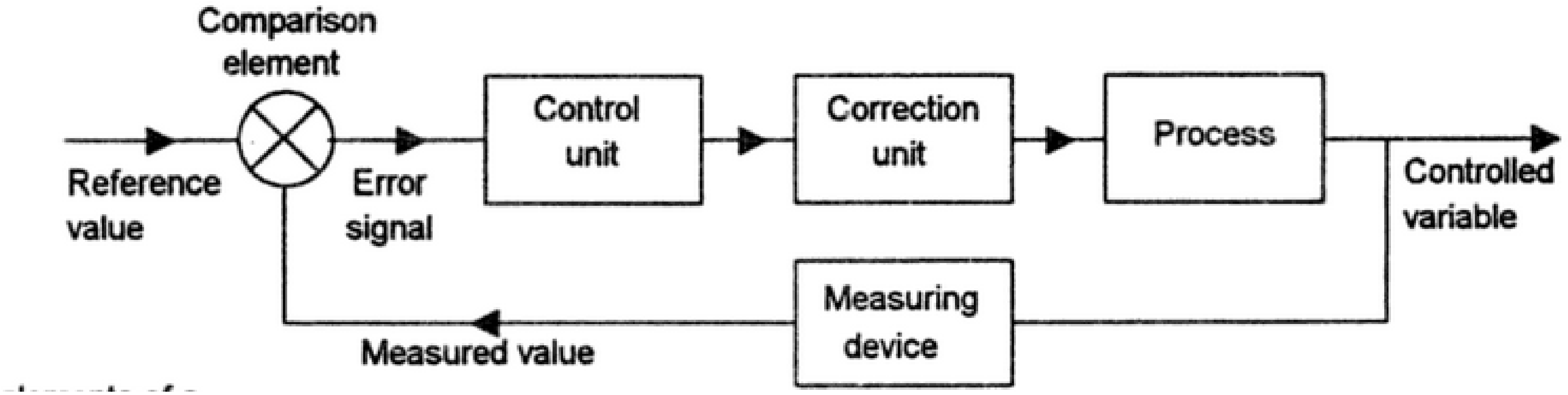
OPEN AND CLOSED LOOP CONTROL SYSTEMS

- The heating system with the heating element could be made a closed loop system if the person has a thermometer and switches the 1 kW and 2kW elements on or off, according to the difference between the actual temperature and the required temperature, to maintain the temperature of the room constant.

- In this situation, there is feedback, the input to the system being adjusted according to whether its output is the required temperature. This means that the input to the switch depends on the deviation of the actual temperature from the required temperature., the difference between them determined by a comparison element – the person in this case.



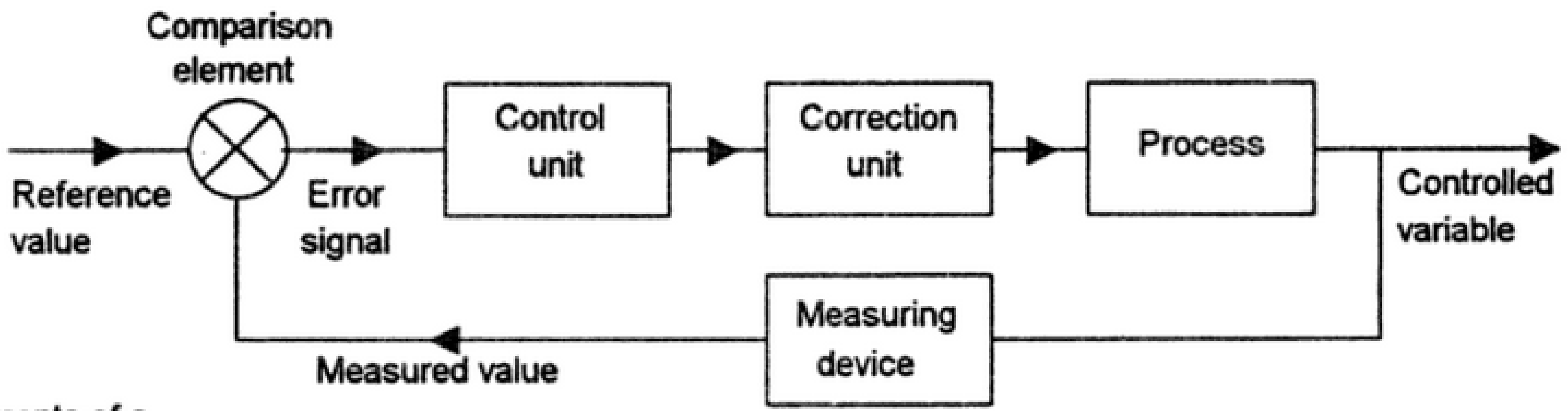
BASIC ELEMENTS OF A CONTROL SYSTEM



- ***Comparison element –*** This compares the required or reference value of the variable condition being controlled with the measured value of what is being achieved and produces an error signal.

Error signal = reference value signal – measured value signal

BASIC ELEMENTS OF A CONTROL SYSTEM

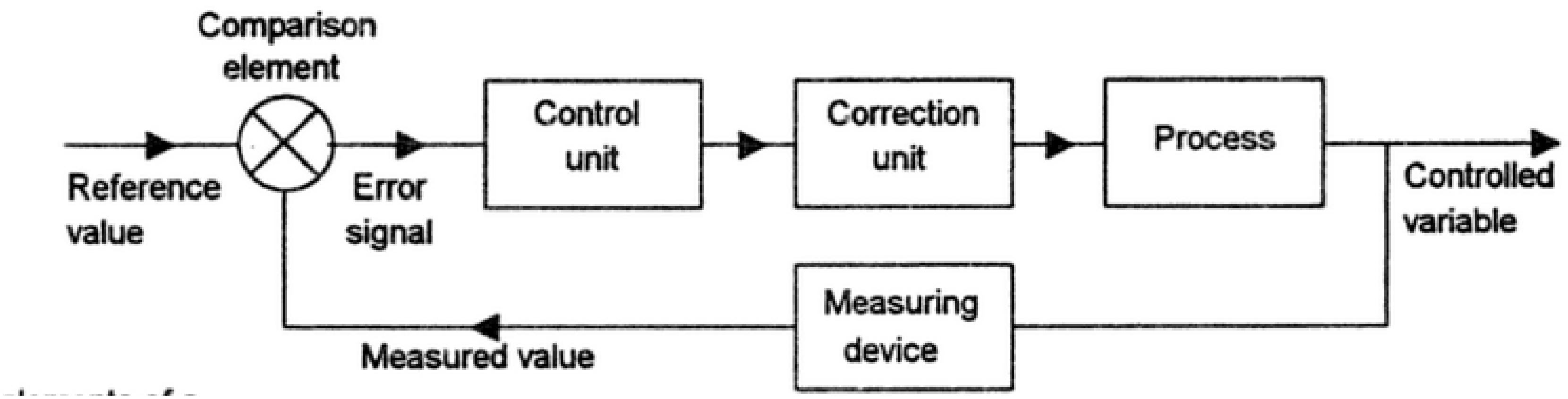


- ***Feedback loop –*** A feed back loop is a means whereby a signal related to the actual condition being achieved is fed back to modify the input signal to a process.

- ***Control unit –*** This decides what action to take when it receives an error signal.

- ***Correction unit –*** The correction unit produces a change in the process to correct or change the controlled condition.

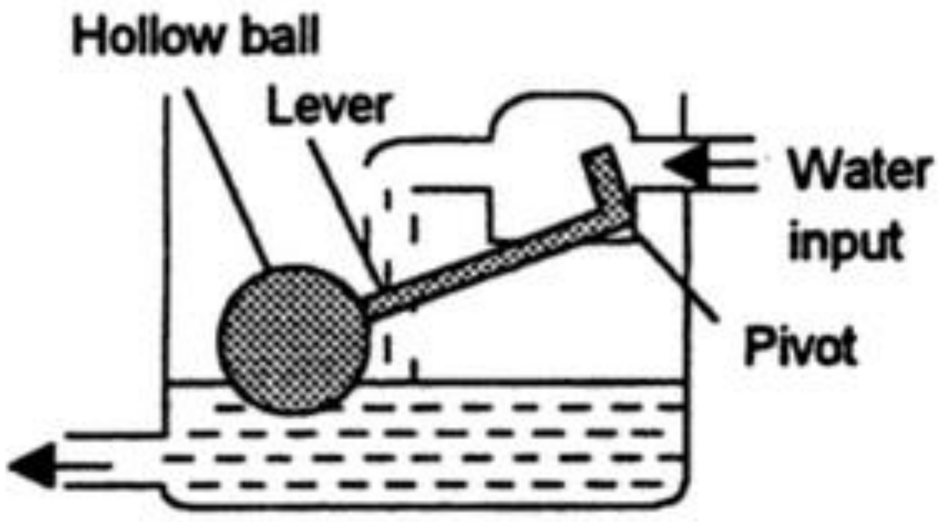
BASIC ELEMENTS OF A CONTROL SYSTEM



- ***Process unit –*** The process which is being controlled.

- ***Measurement unit –*** The measurement element produces a signal related to the variable condition of the process that is being controlled.

BASIC ELEMENTS OF A CONTROL SYSTEM

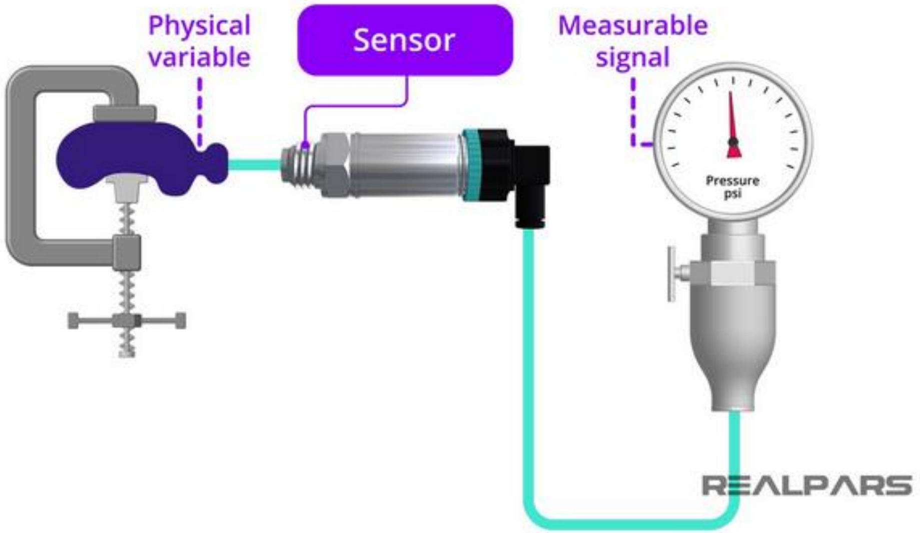


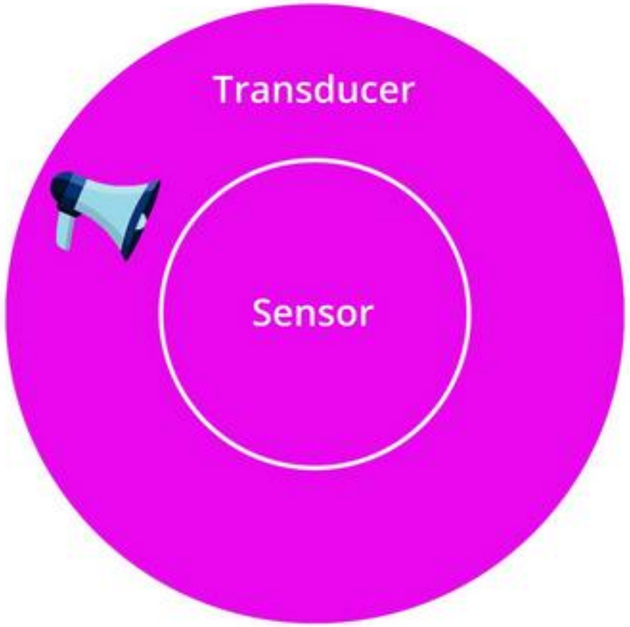
AUTOMATIC WATER LEVEL CONTROL

Identify controlled variable, reference value, comparison element, error signal, control unit, Correction unit, process and measuring unit????

SENSORS AND TRANSDUCERS

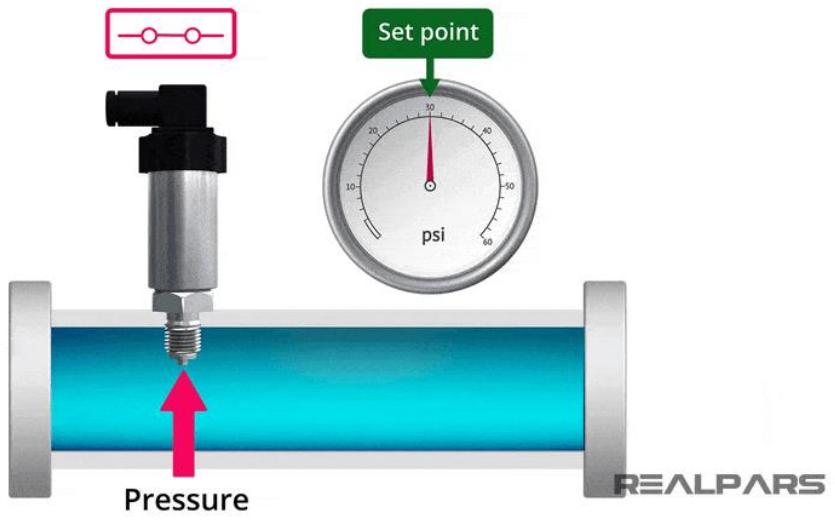
- The term ***sensor*** is used for an element which produces a signal relating to the quantity being measured.
- The term ***transducer*** is defined as an element that when subject to some physical change experience a related change.

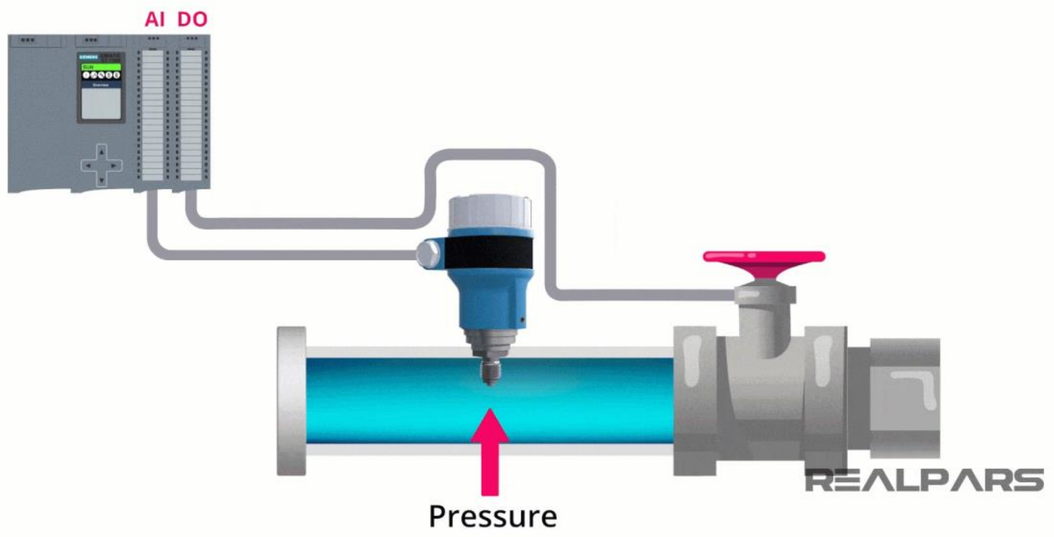




All sensors are transducers, but not all transducers are sensors.

SENSORS AND TRANSDUCERS



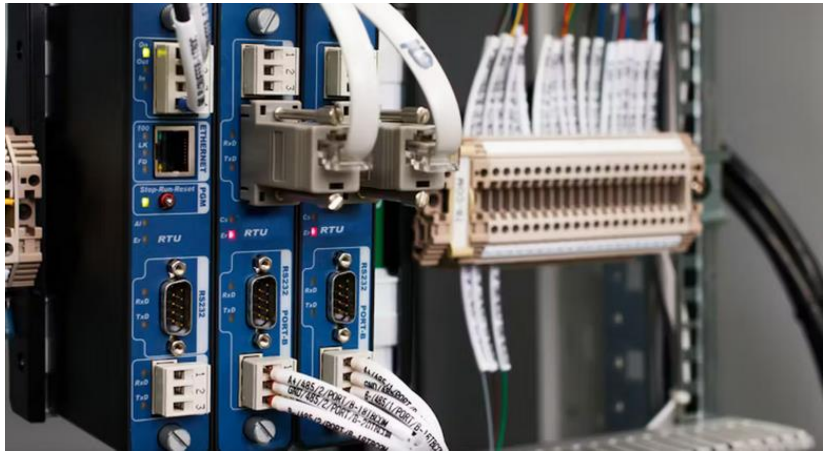


MICROPROCESSOR BASED CONTROLLERS

- Microprocessors are used in general to carry out control functions.

- In many simple systems there might be just an embedded microcontroller, this being a microprocessor with memory all integrated on one chip, which has been specifically programmed for the task concerned.

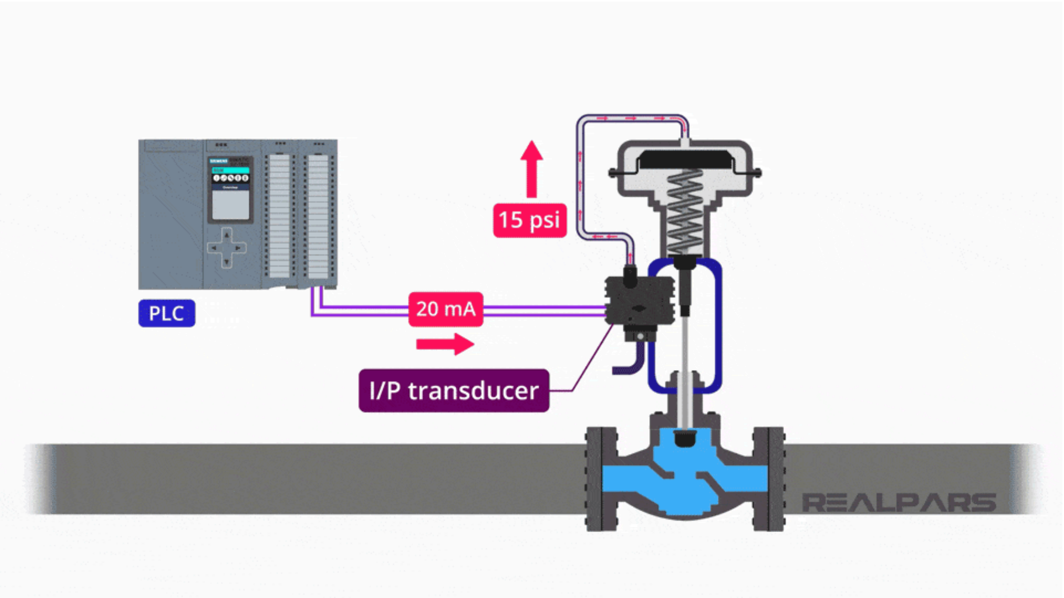
- A more adaptable form is the programmable logic controller. This is a microprocessor based controller which uses programmable memory to store instructions and to implement functions such as logic, sequence, timing counting, and arithmetic to control events and can be readily programmed for different tasks.



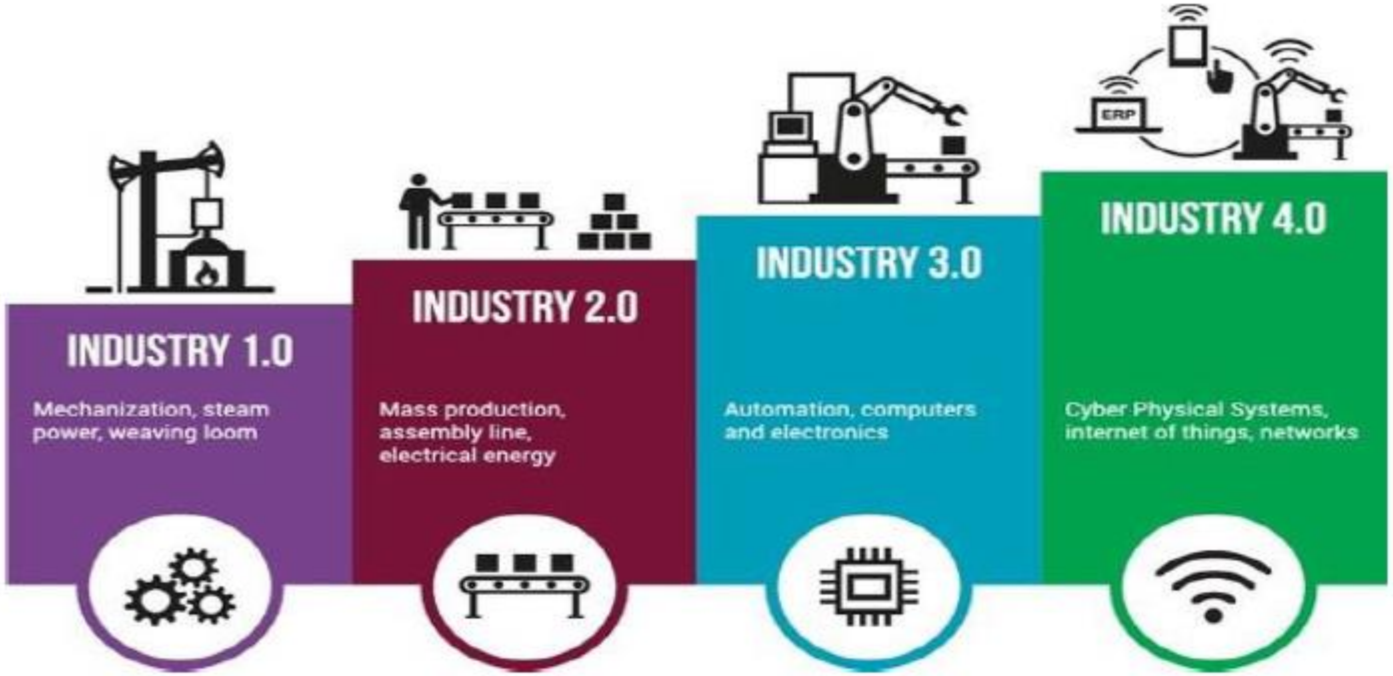
ACTUATION SYSTEMS

- ***Actuation systems are elements of control systems which are responsible for transforming the output of a microprocessor or control system into a controlling action on a machine or device.***

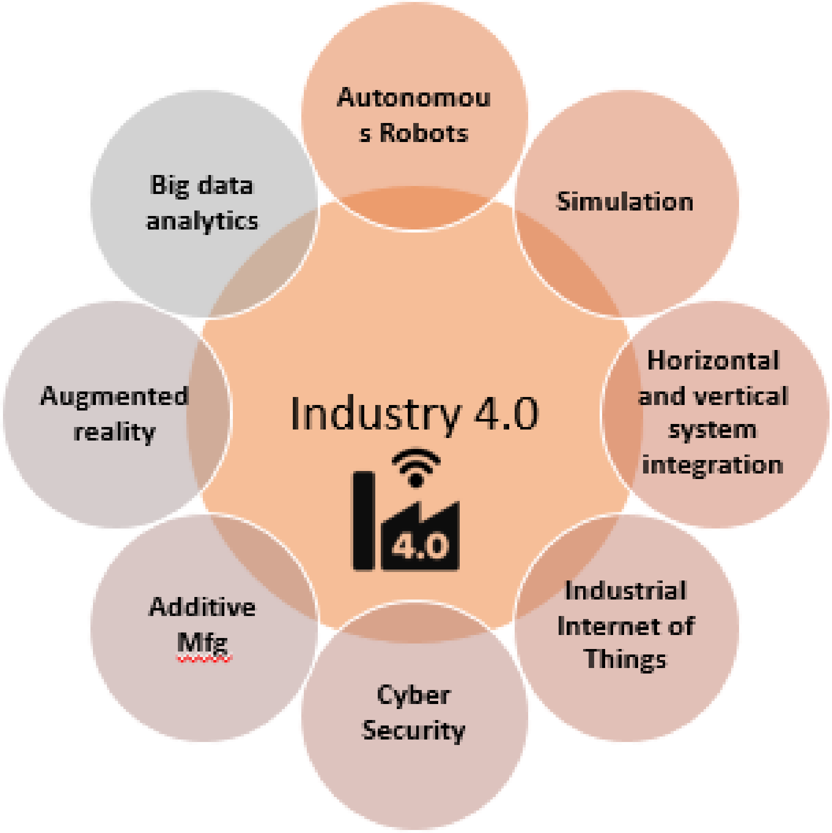
- Examples – an electrical output from the controller may have to be transformed into a linear motion to move a load, an electrical output from the controller may have to be transformed into a action which controls the amount of liquid passing along a pipe etc.



- *Industry 4.0 has been defined as **“a name for the current trend of automation and data exchange in manufacturing technologies, including cyber-physical systems, the Internet of things, cloud computing and cognitive computing and creating the smart factory”.***



BUILDING BLOCKS OF INDUSTRY 4.0

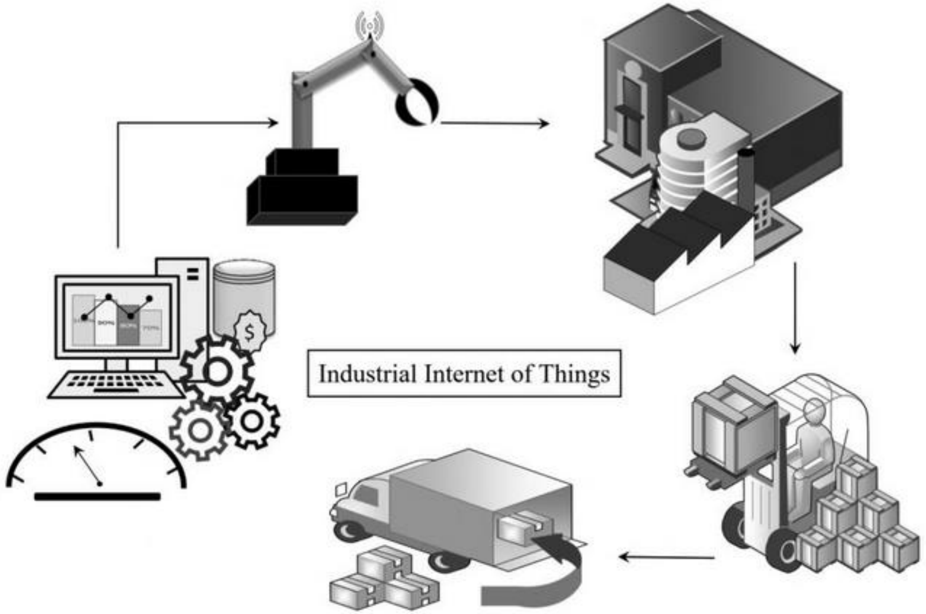


Industrial Internet of Things (IIoT)

- IIoT can be described as an interconnection of a large number of industrial processes and systems, which communicate and coordinate among themselves.

- The real time data collected from sensor nodes are stored, processed, and analysed to improve the performance and efficiency of the overall system.

- As shown in the figure, the sensor nodes deployed at various industrial locations sense and transmit data to the server. The real time processing and complex analysis of the data help to optimize various industrial processes such as **predictive maintenance of machines, inventory management and packaging of finished products.**

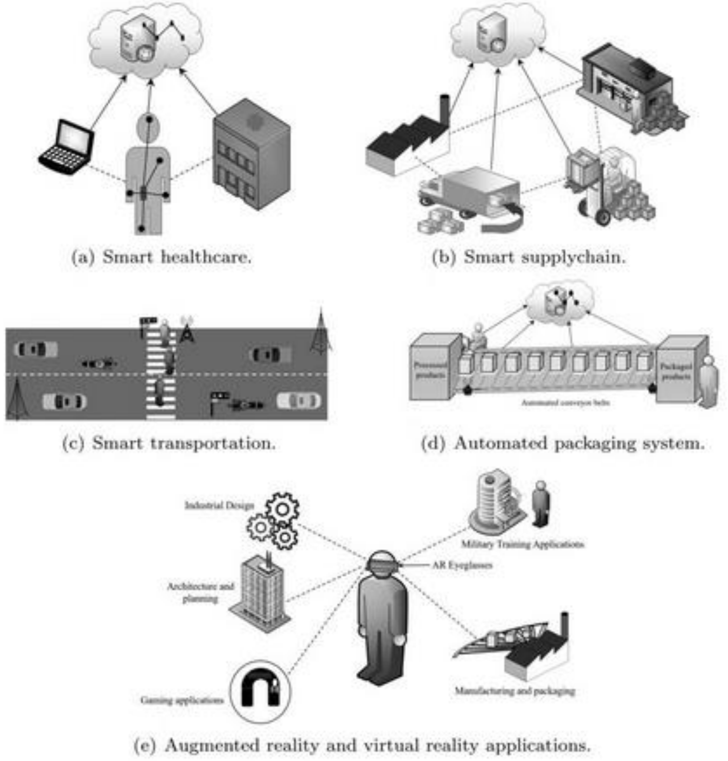


Applications of Industrial Internet of Things (IIoT)

1) ***Smart healthcare*** – Sensor nodes sense and transmit the physiological data of the patient to the local processing unit. Further, the LPU transmits the data to the local server. Medical experts can remotely observe the health conditions of the patient.

2) ***Smart supply chain*** - Proper maintenance of the raw materials, available inventory stock, details of each steps involved in the production process, proper flow of information among various stages , maintaining the time window for delivery of goods, and returning the faulty goods.

3) ***Smart transportation*** – The sensor nodes placed on the vehicles and road side units (RSU) sense and transmit data to the local server. Various real time info such as safe speed, safe distance with the neighboring vehicles, and weather conditions are conveyed to the drivers. (ITS and ADAS)

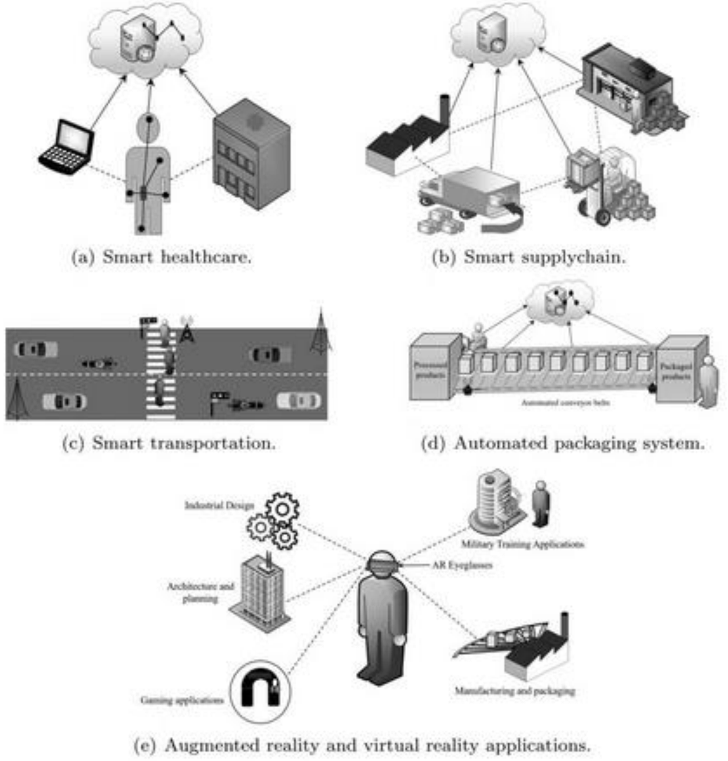

(a) Smart healthcare. (b) Smart supplychain.
(c) Smart transportation. (d) Automated packaging system.
(e) Augmented reality and virtual reality applications.

Applications of Industrial Internet of Things (IIoT)

4) Smart manufacturing system – These improve the efficiency of production and product quality, reduce the per unit cost of production and enhance the life time of machines and developed products.

e.g., Automatic packaging of a production in a manufacturing plant with minimum human intervention.

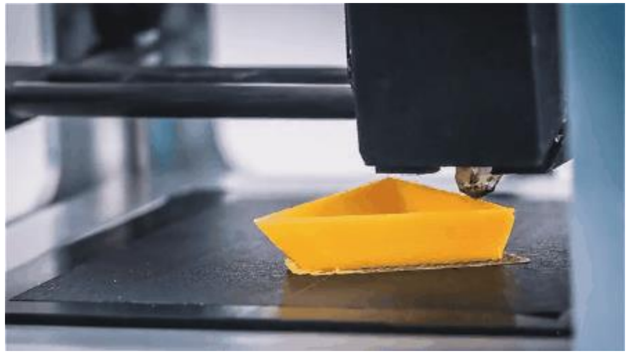
5) AR and VR applications – Augmented reality and virtual reality have widespread applications in the optimization stages of manufacturing industries, inventory management in warehouses, training of personnel in military, healthcare, and assembly line operations.



Additive manufacturing

- ***‘Additive manufacturing fabricates parts by building them up layer-by-layer, as opposed to cutting material away or molding it’.***

- Additive manufacturing can also be viewed as a way to turn a digital model (of the object to be constructed) into a physical one since it starts as a (3D) software design.



- Additive manufacturing doesn’t replace other manufacturing methods (at least not for many years to come) but leads to a wealth of new opportunities. Moreover, some objects would be almost impossible to make without additive manufacturing.

- ***Additive manufacturing and 3D printing are used in multiple domains (healthcare, the construction industry, defense, retail, pharma, automotive industry, aerospace, making parts in close to any area you can imagine, including human tissue and food, smart manufacturing). They are also the subject of intensive research and development (methods, materials, new techniques, application areas, etc.).***

Different 3D Printing Processes

- A total of seven different types of additive manufacturing processes have been established and identified. These seven 3D printing processes brought forth ten different types of 3D printing technology that 3D printers use today.

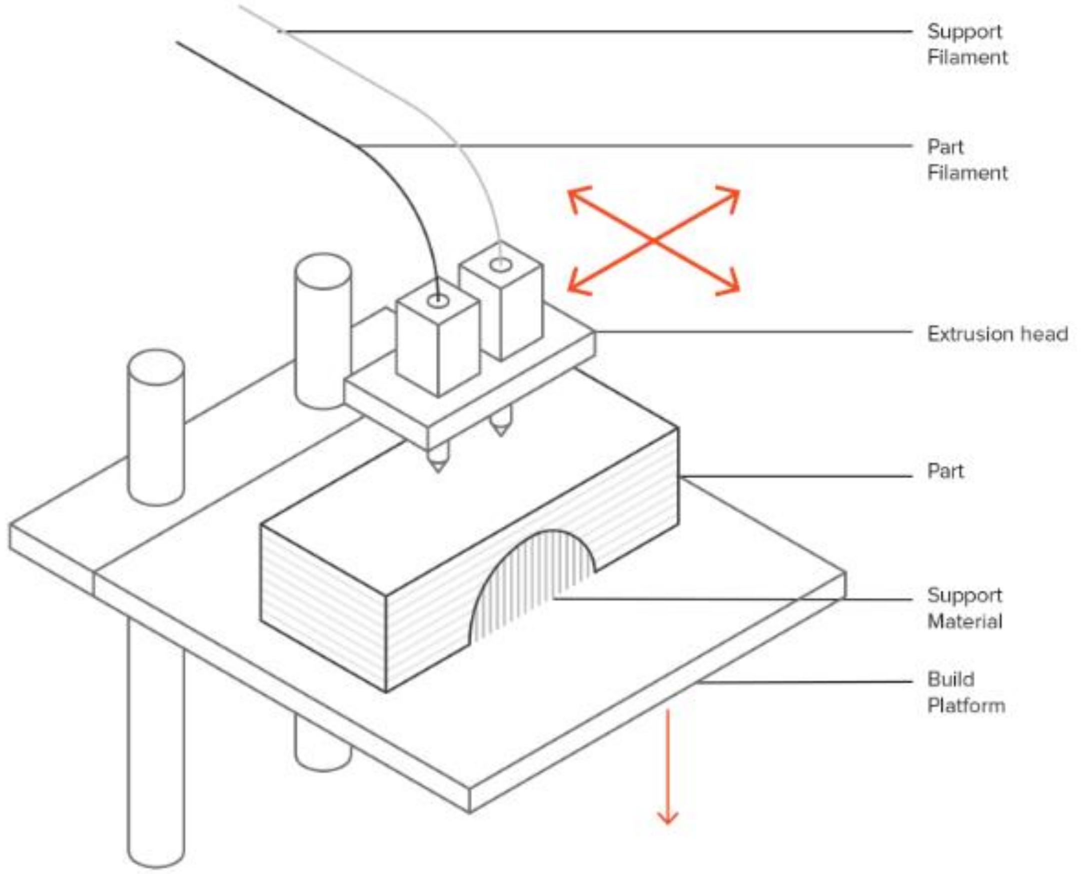
- 3DPrinting Process: Material Extrusion
  - Fused Deposition Modeling (FDM)
- 3D Printing Process: Vat Polymerization
  - Stereolithography (SLA)
  - Digital Light Processing (DLP)
- 3D Printing Process: Powder Bed Fusion
  - 3D Printing Process: Powder Bed Fusion (Polymers)
    - Selective Laser Sintering (SLS)
  - 3D Printing Process: Powder Bed Fusion (Metals)
    - Direct Metal Laser Sintering (DMLS)/Selective Laser Melting (SLM)
  - Electron Beam Melting (EBM)
- 3D Printing Process: Material Jetting
  - Material Jetting (MJ)
  - Drop on Demand (DOD)
- 3D Printing Process: Binder Jetting
  - Sand Binder Jetting
  - Metal Binder Jetting
- Sheet Lamination
- Directed Energy Deposition

Material Extrusion – Fused Deposition Modelling

- Material extrusion is a 3D printing process where a filament of solid thermoplastic material is pushed through a heated nozzle, melting it in the process.
- The printer deposits the material on a build platform along a predetermined path, where the filament cools and solidifies to form a solid object.

  - **Types of 3D printing technology**: Fused deposition modeling (FDM), sometimes called fused filament fabrication (FFF)
  - **Materials**: Thermoplastic filament (PLA, ABS, PET, TPU)
  - **Dimensional accuracy**: ±0.5% (lower limit ±0.5 mm)
  - **Common applications**: Electrical housings; Form and fit testings; Jigs and fixtures; Investment casting patterns
  - **Strengths**: Best surface finish; Full color and multi-material available
  - **Weaknesses**: Brittle, not sustainable for mechanical parts; Higher cost than SLA/DLP for visual purposes

Material Extrusion – Fused Deposition Modelling



Material Extrusion – Fused Deposition Modelling

1) Part preparation

- The initial stage is to import the design file and choose options for the build, such as layer height, orientation and infill percentage.

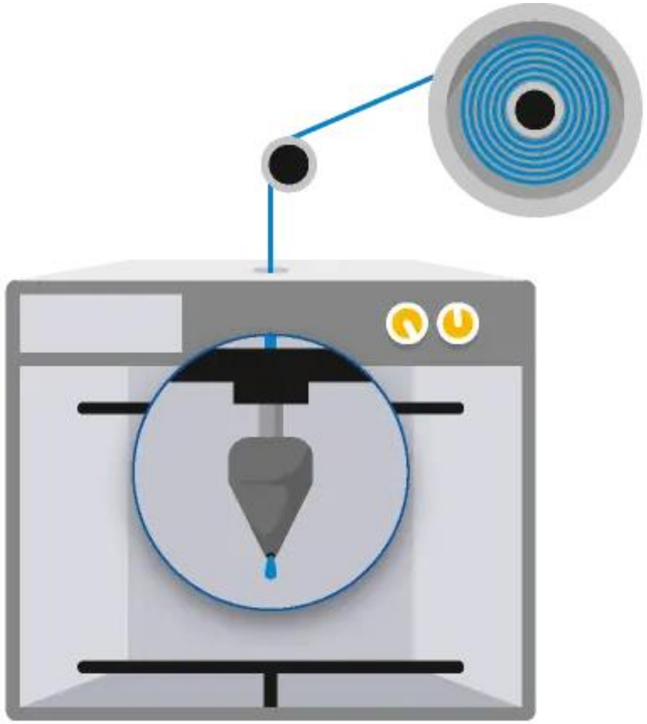
- The software then computes sections and slices the part into several layers. The program then creates extruder paths and building instructions based on the sectioning data to drive the extrusion heads.

Material Extrusion – Fused Deposition Modelling

2) FDM Machine setup

- The printer is loaded with a thermoplastic filament spool for both model and support extruders. Generally, the build platform is heated and maintained at a higher temperature to control the cooling of the extruded material.

- Extruders are heated, and when the nozzle reaches the required temperature, the head will start pushing and melting the filament into a small ribbon roughly the size of a human hair.

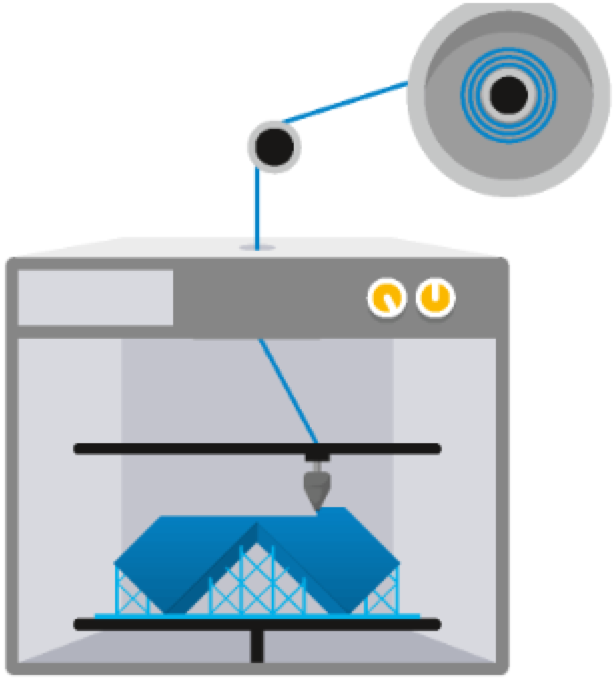


Material Extrusion – Fused Deposition Modelling

3) FDM printing

- The extrusion head gantry and the build platform are on a three-axis system, which allows the nozzle tip to move in three directions in space.

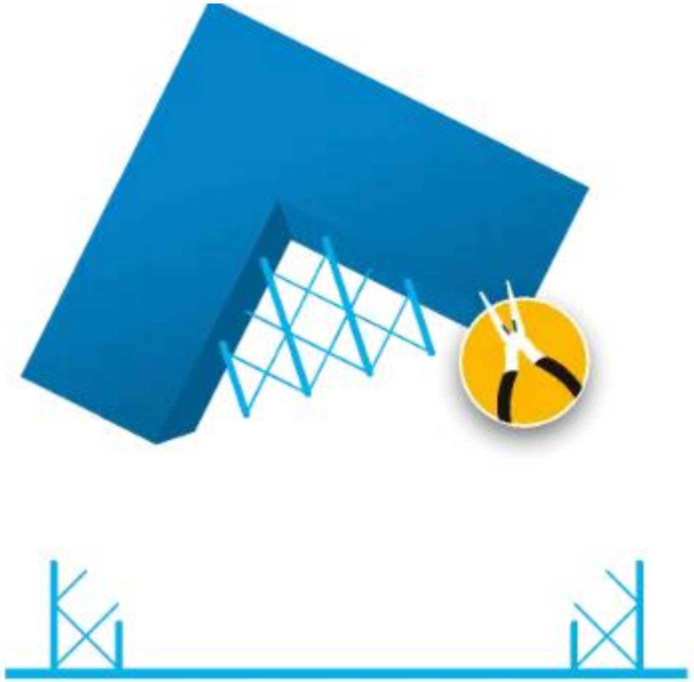
- The extruder will start depositing the material layer by layer in predefined areas to cool and solidify. Sometimes the material cooling is assisted using cooling fans mounted to the extrusion head.



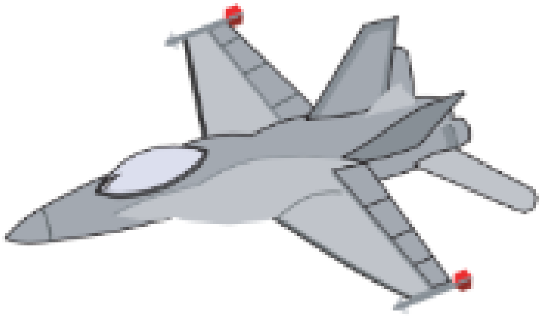
Material Extrusion – Fused Deposition Modelling

4) FDM part removal

- Like any other 3D printing process, the next stage involves removing parts from the build platform and cleaning them by removing all supports.



RAPID PROTOTYPING

A prototype is the first or original example of something that has been or will be copied or developed; it is a model or preliminary version; e.g.: A prototype supersonic aircraft.	

RAPID PROTOTYPING

The general definition of the prototype contains three aspects of interests:

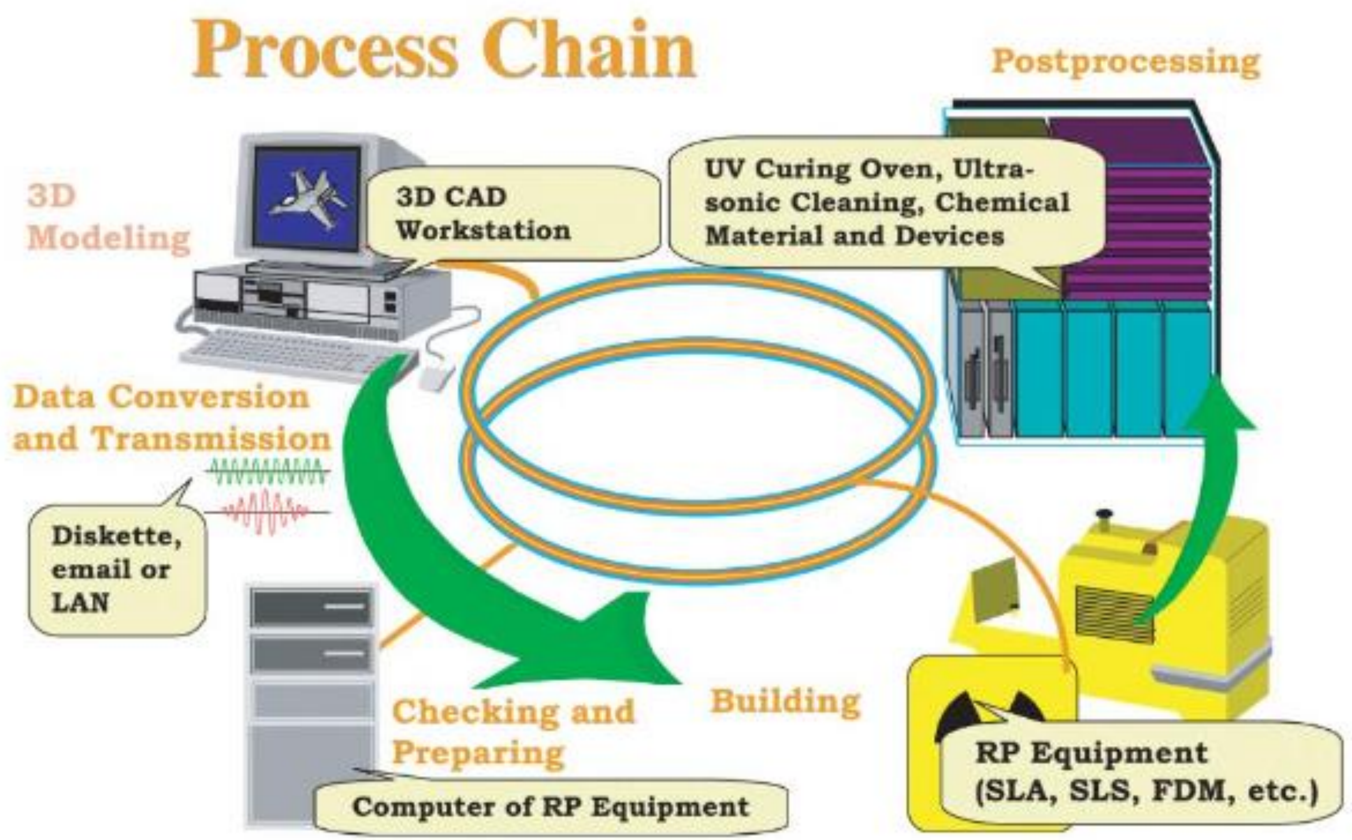
(1) the implementation of the prototype; from the entire product (or system) itself to its subassemblies and components,
(2) the form of the prototype; from a virtual prototype to a physical prototype and
(3) the degree of the approximation of the prototype; from very rough representation to exact replication of the product.

RAPID PROTOTYPING

Prototypes play several roles in the product development process. They include the following:

(1) experimentation and learning,
(2) testing and proofing,
(3) communication and interaction,
(4) synthesis and integration and
(5) scheduling and markers.

RAPID PROTOTYPING



Rapid Prototype

Finishing Process	
• Machining: milling, lathe, boring, grinding, etc.	
• Sand blasting	• Coating
• Polishing	• Painting (varnishing)

Applications		
Design	***Engineering, Analysis and Planning***	***Manufacturing and Tooling***
• CAD-model verification (design specification) • Visualizing objects • Proof of concept • Marketing and presentation model	• Form and fit-models • Flow analysis • Analysis of stress distribution • Pre-series parts • Diagnostic and pre-surgical operation planning • Design and fabrication of custom protheses and implants	• Tooling mold parts - direct soft tools - indirect soft tools - direct hard tools - indirect hard tools • Casting - sand-casting - investment casting - evaporative pattern casting - die casting • EDM electrodes • Master models

Industries		
• Aerospace	• Automotive	• Biomedical
• Jewelry	• Coin	• Tableware
• Consumer electronics	• Home appliances	• Others