---

1. Machine Tool Operations

- **Definition:** Machine Tool is a power driven machine to perform machining. These machines are crucial for shaping parts and products by removing metal chips from a workpiece.
- **Key Functions:**
  - It rigidly supports the workpiece and cutting tool.
  - Provides relative motion between the workpiece and cutting tool.
  - Provides a range of speeds and feeds.
- **Historical Context:**
  - Before the 18th-century Industrial Revolution: Hand tools were used to cut and shape materials for producing goods like cooking utensils, wagons, ships, and furniture.
  - After the advent of the steam engine and new materials: Goods were produced by power-driven machines, which themselves could only be manufactured by machine tools.
  - 19th Century: Jigs and fixtures (for holding the work and guiding the tool) were indispensable innovations that made interchangeable parts a reality.

---

2. Conventional Machining

- **Definition:** Involves physical contact between a harder cutting tool and the workpiece, removing material in the form of chips.
- **Examples:** Turning, milling, drilling, grinding, shaping, and broaching.
- **Energy Source:** Primarily mechanical energy.
- **Suitability:** Suitable for materials that are relatively soft and can be economically machined with standard tools.
- **Limitations:** Can be challenging to machine hard materials, complex shapes, or those with intricate geometries.

---

3. Non-Conventional Machining (UCM)

- **Definition:** Utilizes various forms of energy (thermal, chemical, electrical, etc.) to remove material, often without direct contact between the tool and workpiece.
- **Examples:**
    - Electrochemical Machining (ECM): Uses electrochemical dissolution to remove material.
    - Electro-Discharge Machining (EDM): Uses electrical discharges to erode material.
    - Laser Beam Machining (LBM): Uses a focused laser beam to cut or ablate material.
    - Ultrasonic Machining (USM): Uses ultrasonic vibrations and an abrasive slurry to remove material.
    - Abrasive Jet Machining (AJM): Uses a high-velocity stream of abrasive particles to erode material.
- **Energy Source:** Thermal, chemical, and electrical energy.
- **Suitability:** Suitable for machining hard materials, complex shapes, and materials that are difficult to machine with conventional methods.
- **Advantages:** Can achieve higher precision, intricate geometries, and work with materials that are otherwise difficult to machine.
- **Limitations:** Generally more expensive than conventional methods and may require specialized equipment and skilled operators.

4.

Mechanism of Metal Cutting

- **Metal Cutting/Machining:** The removal of extra material from a metal surface by shearing or cutting action.
- **Shear Plane:** The cutting takes place along a plane, which is known as shear plane.

- **Primary Shear Zone:** A cutting zone where severe plastic deformation occurs due to compressive force applied by the sharp-edged cutting tool.
- **Chip Formation:** The extra material, due to this deformation, flows over the tool surface, known as chip.
- **Friction & Welding:** During the flow of the chip on the rake surface of the cutting tool, the temperature of the newly formed chip increases due to friction, causing it to get welded automatically on the rake surface.
- **Secondary Shear:** Due to compressive force applied by the newly formed chip (just after the welded chip), secondary shear of the welded chip occurs.
- **Generatrix:** The line generated by the cutting motion.
- **Directrix:** The line formed by the feed motion.

5.

Types of Chip Formation

Chips formed in various cutting conditions can be categorized as follows:

1. **Continuous Chip:**
   - **Formation Conditions:** Machining of ductile materials , small undercut thickness , high cutting speed , large rake angle of the tool , suitable cutting fluids.
2. **Discontinuous Chip:**
   - **Formation Conditions:** Machining of brittle work materials , low cutting speed , small rake angle , large uncut chip thickness.
3. **Continuous Chip with Built-up (BUP) Edge:**
   - **Formation Conditions:** Large friction or stronger adhesion between chips and tool face , low rake angle , large uncut chip thickness.

6.

Introduction to Lathe

- **Definition:** The oldest machine tool invented, starting with the Egyptian tree lathes.
- **Primary Operation (Turning):** The principal form of surface produced in a lathe is the cylindrical surface. This is achieved by rotating the workpiece while the single-point cutting tool removes material by traversing in a direction parallel to the axis of rotation and termed as turning.
- **Centre Lathe (Engine Lathe):** The most common of the lathes, deriving its name from the way a workpiece is clamped by centers (live and dead centers). Sometimes called an engine lathe because early lathes were driven by steam engines.

7.

Typical Parts of Lathe

- **Bed:** The backbone of the lathe upon which all other components are mounted. The top of the bed is formed by guideways, acting as a guide for accurate movement of the carriage and tailstock. Made up of cast iron because of good damping and frictional resistance.
- **Headstock (Live Centre):** A box-like casting mounted at the left end of the machine. It contains the feed gear box or cone pulley which enables the spindle to rotate at different speeds. The gear box distributes power to the lead screw for threading or to the feed rod for turning.
- **Tailstock (Dead Centre):** Mounted on the right side of the machine. It is the movable part of the lathe that carries the dead centre. It can be slid on the bed to support different lengths of workpiece. Can be moved laterally for taper turning. Can be used to carry tools like drill, reamer for making holes.
- **Carriage Assembly:**
    - **Cross Slide:** On the upper surface of the saddle. This moves the tool at a right angle to the spindle axis. It can be operated by a hand wheel or power feed through the apron mechanism.

    - **Compound Rest:** 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:** Mounted on the compound rest and carries the cutting tool.
- **Feed Rod:** Long shaft used to drive the apron mechanism for cross and longitudinal power feed during turning. It is powered by a set of gears from the headstock.
- **Lead Screw:** 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.

---

8. Operations on Lathe

- **Plain Turning:**
    - **Definition:** The most commonly used operation in a lathe, where the workpiece rotates and the tool is fed parallel to the axis of rotation to generate a cylindrical surface.
    - **Stages:** Usually done in two stages:
        1. **Rough turning:** Involves the majority of material removal, typically at high speeds.
        2. **Smooth or Finish turning:** Done at lesser speeds and focuses on finishing the job to required dimensions.
- **Facing:**
    - **Definition:** An operation for generating flat surfaces in lathes.
    - **Feed Direction:** The feed is given in a direction perpendicular to the axis of revolution. The tool used should have a suitable approach angle to prevent interference with the workpiece.
- **Thread Cutting:**
    - **Definition:** A screw thread is a ridge of uniform cross-section that follows a helical or spiral path on the outside or inside of a cylindrical surface.
    - **Mechanism:** The cutting tool, whose shape depends on the thread type, is mounted on a holder and moved along the length of the workpiece by

the lead screw. This movement is achieved by engaging a split nut in the apron.

    - **Pitch Determination:** The axial movement of the tool in relation to the rotation of the workpiece determines the pitch. The lead screw drives the carriage, and when it rotates one revolution, the carriage travels a distance equal to the lead screw's pitch. If the lead screw's rotational speed equals the spindle's, the cut thread's pitch is exactly equal to the lead screw's pitch. The pitch of the resulting thread depends on the ratio of the rotational speeds of the lead screw and the spindle.
        1. Formula:
           Desired pitch of workpiecePitch of lead screw=rpm of lead screwrpm of workpiece
- **Taper Turning:**
    - **Definition:** Producing a conical surface from a cylindrical workpiece. The taper is usually represented by its half taper angle (α).
    - **Methods Available:**
        1. **Using Form Tools:** Normally used for production. The tool is plunged directly into the work. Useful for short tapers like chamfering.
        2. **Swiveling the Compound Rest:** Compound rest can be swiveled to the desired taper angle (graduated in degrees). Tool is made perpendicular to the workpiece, and feed is given manually.
            - **Features:** Short and steep tapers can be easily done.
            - **Limitations:** Limited movement of the compound rest , manual and non-uniform feeding, leading to low productivity and poor surface finish.
        3. **Offsetting the Tailstock:** Tailstock is offset from the center, inclining the job's axis of rotation by the half taper angle. Tool feed is parallel to the guideways.
            - **Suitability:** Small tapers over a long length.

            - **Disadvantage:** Centers are not properly bearing, causing non-uniform wear.
        4. **Using Taper Turning Attachment:** For turning tapers over a comprehensive range. A separate slideway is arranged at the rear of the cross slide, which can be set to any angle. A block sliding in this inclined track is connected to the cross slide, providing proportional cross movement to the tool. The tool tip follows the set taper direction.
            - **Commonality:** Most commonly used for a range of tapers.
- **Knurling:**
    - **Definition:** A metalworking operation in a lathe where a knurling tool (with serrations) is forced onto the workpiece, deforming its top layers.
    - **Purpose:** Forms a rough top surface that provides a proper gripping surface.
- **Parting:**
    - **Definition:** Similar to grooving, a flat-nosed tool plunge cuts the workpiece with a feed perpendicular to the axis of revolution.
    - **Purpose:** Generally carried out for cutting off the part from the parent material.

9.

Work Holding Device (Chucks)

- **Definition:** The most common form of work holding device used in a lathe. Chucks come in various forms with a varying number of jaws.
- **Three-Jaw Chuck (Self-Centering Chuck):**
    - **Advantage:** Quick centering of typical round or symmetrical jobs (e.g., hexagonal). All three jaws move radially inward or outward by the same amount.
- **Independent Jaw Chuck:**

    - **Characteristics:** Has four jaws that can be moved independently in their slots.
    - **Advantage:** Can effectively center any irregular surface.

10.

Machining Time

- **Estimation Requirement:** To estimate machining times, it's necessary to select proper process parameters (cutting speed, feed, depth of cut) based on workpiece and cutting tool material combinations.
- **Cutting Speed (V):** The surface speed of the workpiece.
    - **Formula:** $V=1000\pi DN$
        - V = cutting speed (surface), m/min
        - D = diameter of the workpiece, mm
        - N = rotational speed of the workpiece, rpm
    - **Diameter (D) Selection:** Can be initial or final diameter; practically, little change. Realistically, the average of the two diameters is better.
- **Time (t) for a single pass:**
    - **Formula:** $t=fNL+Lo$
        - L = length of the job, mm
        - Lo = 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
- **Number of Passes:** Depends on left-over stock (machining allowance) and desired surface finish/tolerance.
    - **Roughing Passes (Pr):** $Pr=drA-Af$
        - A = Total machining allowance, mm
        - Af = Finish machining allowance, mm
        - dr = Depth of cut in roughing, mm
    - **Finishing Passes (Pf):** $Pf=dfAf$

        - df = Depth of cut in finishing, mm

11.

Drilling

- **Definition:** The operation of making primarily a hole in a workpiece using a drill bit.
- **Mechanism:** The stationary work is held in a fixture, and the rotating tool is fed vertically to make a circular hole.
- **Tool:** The cutting tool used for making holes in solid material is called the twist drill.
    - **Parts:** Consists of two parts: the body (containing cutting edges) and the shank (for holding).
    - **Flutes:** Has two cutting edges and two opposite spiral flutes cut into its surface.
        - **Functions of Flutes:** Provide clearance to the chips produced at the cutting edges and allow cutting fluid to reach the cutting edges.

12.

Drilling Machines (Types)

- **Radial Drilling Machine:**
    - **Characteristics:** The drill head can move along the radial arm to any position, while the radial arm itself can rotate on the column.
    - **Use:** More convenient for large workpieces that cannot be moved easily due to their weight; the drill head is moved to the actual location.
- **Gang Drilling Machine:**

    - **Characteristics:** Have a number of spindles (often four) laid out in parallel. Each spindle can hold different drills or hole-making tools in sequence.
    - **Use:** Used for volume production with workpieces located in a jig.

13.

Reaming

- **Definition:** 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.
- **Tool:** Carried out using a multi-tooth revolving tool called a reamer, which consists of a set of parallel straight or helical cutting edges.
- **Speed:** While reaming, the speed of the spindle is reduced to nearly half of that of drilling.

14.

Boring

- **Definition:** An operation of enlarging a hole.
- **Tool:** The single-point cutting tool used is mounted in the boring bar of suitable diameter.
- **Advantages (Sizing & Correction):** Boring brings the hole to the proper size and finish; it can work to any diameter. It also corrects hole location and out-of-roundness, as the tool can be adjusted to remove more metal from one side.

15.

Tapping

- **Definition:** A faster way of producing internal threads in a previously drilled hole.

- **Tool:** A tap is a multi-fluted cutting tool with cutting edges resembling the shape of threads.
- **Process:** A tap of the required size is used after pre-drilling operations. Tapping drill sizes for ISO metric threads are standard.
- **Considerations:** Care must be taken to start the tap in proper alignment with the hole. Sometimes, reversing the tap slightly to break chips is necessary.

16.

Counterboring

- **Definition:** The hole is enlarged with a flat bottom to provide proper seating for a bolt head or a nut, which will be flush from the outer surface.
- **Tool:** Can be done by a tool with cutting edges along the side and end, and a pilot portion to ensure concentricity with the already machined hole.
- **Speeds/Feeds:** Generally slightly smaller than those used for corresponding drilling operations.

17.

Countersinking

- **Definition:** Similar to counterboring, but the additional machining done on a hole is conical to accommodate the countersunk machine screw head.
- **Depth:** The depth of countersinking should be large enough to accommodate the screw head fully flush with the surface.

18.

Milling

- **Definition:** The workpiece is fed into a rotating milling cutter, which is a multi-point tool (unlike a lathe's single-point tool).

19.

Milling (Classifications)

- **Categories:**
  1. **Peripheral Milling:** The surface generated is parallel with the axis of rotation of the cutter. Carried out in Horizontal milling machines.
  2. **Face Milling:** The surface generated is at a right angle to the cutter axis. Carried out in Vertical milling machines.

20.

Up and Down Milling

- **Types (based on cutter/feed direction):**
  1. **Up Milling (Conventional Milling):** The cutting tool rotates in the opposite direction to the table movement. Tends to lift the workpiece from the table.
  2. **Down Milling (Climb Milling):** The cutting tool rotates in the same direction as the table movement. The cutting force acts downwards, keeping the workpiece firmly in the work holding device.

21.

Milling Machine Comparison: Horizontal vs. Vertical

SI 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	Operations such as plan milling, gear cutting, form milling, straddle, gang milling, etc., can be performed.	Operations such as slot milling, T-slots, flat milling, and also different drilling operations can be performed.

22.

Milling Operations (Specific Types)

- **Slab Milling:**
  - **Definition:** The basic form of peripheral milling where the cutter width extends beyond the workpiece on both sides.
- **Slotting:**
  - **Definition:** The width of the cutter is less than the workpiece width, creating a slot (can mill narrow slots if cutter is thin).
- **Side and Straddle Milling:**

    - **Side Milling:** Cutter machines the side of the workpiece.
    - **Straddle Milling:** Same as side milling, but cutting takes place on both sides of the work.
- **Form Milling:**
    - **Definition:** The milling teeth have a special profile that determines the shape of the slot cut in the work.
- **Angular Milling:**
    - **Definition:** Operation of producing an angular surface on the workpiece. A single or double cutter can be used to produce shapes like V-grooves in V-blocks.
- **End Milling:**
    - **Definition:** Operation performed for producing flat surfaces, slots, grooves, or finishing edges of the workpiece using an end mill or end milling cutter. The cutter has teeth on the end as well as the periphery.
    - **Profile Milling:** A form of end milling done on the perimeter of a workpiece. Can produce nearly any shape with interior radii at least as large as the cutter.
- **Pocket Milling:**
    - **Definition:** Another form of end milling used to mill shallow pockets into flat parts.
- **Surface Contouring:**
    - **Definition:** A ball-nose cutter is fed back and forth across the work along a curvilinear path at close intervals to create a three-dimensional surface form.
    - **Application:** Can be used to produce tooling such as injection molds and forming dies.

- **Definition:** A manufacturing system consists of all the resources required to transform the material from its raw form to finished form.
- **Resources:** May include man, materials, money, machine, management, energy, etc..
- **Components Categorization:**
    1. Production machines, tools, jigs, fixtures, etc..
    2. Material handling systems.
    3. Computer systems.
    4. Human resources.

24.

Numerical Control (NC)

- **Definition:** A form of programmable automation where the machining process is controlled by numbers, letters, and symbols.
- **Principal Application:** Machining operations.
- **Basic Components of an Operational NC System:**
    - **Program of Instruction:** Consists of details of sequence of operations in symbolic, numeric, or alpha numeric form on some medium like tape, which can be interpreted by the controller unit. In machine tool applications, it's called a part program. Individual commands refer to tool positions relative to the worktable, plus instructions like spindle speed, feed rate, tool selection.
    - **Controller Unit:** Consists of the electronics and hardware that read and interpret the program of instructions and convert it into mechanical actions of the machine tool. Typical elements include tape reader, data buffer, signal output/feedback channels, and sequence control.
    - **Machine Tool:** The part of the NC system which performs useful work. Includes cutting tools, work fixtures, and auxiliary equipment.
- **Limitations/Drawbacks of Conventional NC System:**

    - Part programming mistakes in punched tape are common.
    - Short life of punch tape due to wear and tear.
    - Less reliable tape reader component.
    - Less flexible hard wired controller unit.
    - Non-optimal speed and feed.

25.

Computer Numerical Control (CNC)

- **Difference from Conventional NC:** In conventional NC, the punched tape is cycled for each work part. In CNC, the entire program is entered once and stored in computer memory. The machining cycle for each part is controlled by the program in memory, not from the tape itself.
- **Features Associated with CNC System:**
    - Storage of more than one program.
    - Program editing at the machine tool site.
    - Fixed cycles and programming subroutines.
    - Interpolation.
    - Positioning features for setup.
    - Cutter length compensation.
    - Diagnostics.
    - Communication interface.
- **Advantages of CNC System:**
    - Increased Precision and Accuracy: Digital computer programs result in higher accuracy and repeatability, tighter tolerances, fewer errors.
    - Enhanced Flexibility and Adaptability: Programs can be modified easily without altering physical tapes.
    - Higher Automation and Efficiency: Automates machining, reduces manual intervention, minimizes human error, leading to faster cycles and increased throughput.

- Reduced Labor Costs: Less operator intervention due to automation.
- Improved Consistency and Quality: Consistently produces parts to same specifications.
- Faster Production of Complex Designs: Handles complex designs with ease due to advanced programming.
- Streamlined Production Processes: Stores and reuses programs for rapid setup and changeovers.
- Effective Prototyping: Flexibility and quick adaptation to design changes.

26.

CNC-PROGRAMMING METHODS

1. **Manual Part Programming:** Oldest and still popular. Programmer manually calculates all tool paths from a part drawing, records on manuscript, then punched tape is prepared.
2. **Computer Assisted Part Programming:** Computer performs tedious work like calculating tool offsets, partial arcs, and part geometry. Programmer uses a high-level language to describe part geometry and cutter path; computer generates and post-processes tool path data. Substantial savings for complex parts.
3. **Computer Aided Drafting/Computer Aided Manufacturing (CAD/CAM):** Sophisticated and growing in popularity. CAD/CAM software allows manipulating CAD data for CAM software to understand. CAM software performs calculations and generates CNC tool path data.
4. **Conversational and Shop Floor Programming:** Interactive method for generating CNC code. Programmer/operator answers questions and provides data prompted by software, which translates into a CNC program. Often resides on the machine tool controller (shop floor programming). Generally restricted to relatively simple geometry.

5. **Parametric Programming:** Enhancement to other methods. Enables programmer to describe part geometry using variables. Entering specific values for variables generates an actual tool path CNC program.

27.

CNC Machining Centres

- **Definition:** A computer-controlled machine capable of performing a variety of cutting operations on different surfaces and directions on a workpiece.
- **Broad Categories:**
    1. **Vertical Axis Machining Centre (VMC):**
        - More versatile for generating complex surfaces.
        - Most come with 3 axes; additional axes (e.g., swiveling spindle head about X or Y axis) added for complex geometries like sculptured surfaces.
    2. **Horizontal Axis Machining Centre (HMC):**
        - Sturdier than VMCs, used for heavier workpieces with large metal removal rates.
        - Cutting tools normally big, so tool magazines are heavier and typically have higher capacity.

28.

CNC Turning Centre

- **Components:** CNC lathes, also called turning centers, are important machine tools for cylindrical components.
- **Design:** Major change is the early adoption of the **slant bed** for better machining plane view and easier placement of devices in the machining zone.
- **Tooling:** Most turning centers are provided with a tool turret, typically with a capacity of 8 to 12 tools of various types.

29.

Additive Manufacturing

- **Definition:** Fabricates parts by building them up layer-by-layer, as opposed to cutting material away or molding it.
- **Digital to Physical:** Views a 3D software design (digital model) into a physical one.
- **Opportunities:** Doesn't replace other methods but creates new opportunities; some objects are almost impossible to make otherwise.
- **Domains:** Used in healthcare, construction, defense, retail, pharma, automotive, aerospace, making parts in nearly any area, including human tissue and food, smart manufacturing. Subject of intensive R&D.
- **Processes/Technologies:** Total of seven different additive manufacturing processes established, leading to ten different types of 3D printing technology.

30.

Material Extrusion – Fused Deposition Modelling (FDM)

- **Process:** A filament of solid thermoplastic material is pushed through a heated nozzle, melting it. The printer deposits the material on a build platform along a predetermined path, where it cools and solidifies.
- **Stages:**
    1. **Part Preparation:** Import design file, choose build options (layer height, orientation, infill percentage). Software computes sections and slices the part into layers, then creates extruder paths and building instructions.
    2. **FDM Machine Setup:** Printer loaded with thermoplastic filament for model and support extruders. Build platform is usually heated to control material cooling. Extruders heat, and nozzle pushes/melts filament.
    3. **FDM Printing:** Extrusion head gantry and build platform are on a three-axis system, allowing nozzle movement in three directions. Extruder

deposits material layer by layer in predefined areas to cool and solidify. Cooling fans may assist.

4. **FDM Part Removal:** Final stage involves removing parts from the build platform and cleaning them by removing supports.

31.

Unconventional Machining Processes (UCM)

- **Definition:** UCM process is completely non-mechanical.
- **Mechanism:** No chip formation. Material removal occurs via melting and evaporation of unwanted metal or removal as powder due to brittle fracture.
- **Use:** Used for machining difficult profiles and very hard materials.

32.

Main Characteristics of UCM

- No chip formation.
- No residual stress set-up in work materials.
- No mechanical contact of tool and work materials.
- Tool wear is lesser compared to conventional processes.
- Tool need not be harder than work material.
- Better surface finish and close tolerance may be achieved.
- Intricate shape, very hard, and fragile materials can be machined.

33.

Abrasive Jet Machining (AJM)

- **Principle of Operation:** Material removal occurs due to tiny brittle fracture of the metallic layer with high-velocity impact of abrasive particles.
- **Suitability:** More suitable for brittle materials.

- **Carrier Medium:** High-velocity jet of dry air, CO_2, or nitrogen gas containing abrasive particles.
- **Abrasives:** Al_2O_3, SiC, boron carbide, and diamond.
- **Particle Sizes & Velocity:** Abrasives typically range from 10 to 50 μm; jet velocity ranges from 150 to 300 m/s.
- **Nozzle Tip Distance (NTD):** Kept about 1 mm.

34.

AJM Process Parameters (Effect on Material Removal Rate - MRR)

- **Mass Flow Rate:** MRR increases with mass flow rate, then decreases after a certain limit.
- **Velocity of Abrasive Particles:** MRR always increases with increasing velocity.
- **Mass Fraction of Abrasive in Jet:** MRR increases but after a certain limit starts to decrease.
- **Nozzle Tip Distance (NTD):** For a certain range, MRR is constant, but decreases below or above this range. NTD ranges from 0.25 to 75 mm.
- **Nozzle Materials:** Tungsten carbide or sapphire. Orifice area: 0.05 to 0.2 mm^2.
- **Gas Pressure:** MRR always increases with increasing gas pressure. Gas pressure ranges from 2 to 10 atm.

35.

AJM Applications

- Machining, cleaning, etching, marking, deburring for brittle materials like glass, ceramics, refractories, germanium, silicon, quartz, mica.
- Fine drilling in printed circuit boards (PCB) and micro welding.
- Aperture drilling for electronic microscopes.
- Machining of semiconductors.
- Machining of hard and fragile materials.
- Frosting and abrading of glass.

36.

AJM Advantages

- Low capital investment.
- Brittle materials of this section can be easily machined.
- Cavities and holes of any shape can be drilled in material of any hardness.
- Amount of heat generation is low.
- No direct tool and workpiece contact, so tool damage rate is very low.

37.

AJM Limitations

- Not suitable for machining ductile material due to embedding of abrasive particles.
- Very low metal removal rate.
- Poor machining accuracy.
- Requires cleaning after operation to remove abrasive particles.
- Abrasive powder cannot be reused.

38.

Electron Beam Machining (EBM)

- **Nature:** Thermal process of material removal.
- **Principle:** High-speed electrons impinge on the work surface, transferring kinetic energy to produce intense heating, leading to melting or vaporization.
- **Beam Characteristics:** Very high velocity, can be focused on a point of 10–200 μm diameter. Power density up to 6,500 billion W/mm².
- **Mechanism:**
    - Electrons emitted from the cathode (hot tungsten filament).
    - Beam shaped by the grid cup.

    - Electrons accelerated by large potential difference between cathode and anode.
    - Beam focused by electromagnetic lenses.
    - Deflecting coils control beam movement.
- **Hole Drilling:** Hole diameters depend on beam diameter and energy density. For larger holes than beam diameter, beam is deflected in a circular path.
- **Hole Characteristics:** Most holes have a small crater on the beam incident side. Drilled holes may have a slight taper (2°–4°) for sheet thickness > 0.1 mm.
- **Environment:** Machining requires vacuum of 10^{-5} mmHg.

39.

EBM Advantages

- No burr produced.
- No heat affected area.
- No machining stress set up.
- One of the fastest methods of metal removal on tough alloys.
- Useful in cutting slots, deep holes of small diameter in hardened steel or difficult-to-cut alloys.
- Excellent repeatability.
- Very close tolerances (0.02 mm) obtainable.
- Finish obtainable is 0.1–4 μm.

40.

EBM Disadvantages

- High initial cost of machine set up and tooling.
- Requires complex electrodes and flushing arrangement.
- Requires high power consumption.
- Machining requires vacuum of 10^{-5} mmHg.

41.

EBM Applications

- Very effective for machining materials of low heat conductivity and high melting point.
- Used for micro machining operations on workpieces of thin section.
- Used for micro drilling operations (up to 0.002 mm) for thin orifices dies for wire drawing, parts of electron microscopes, fiber spinner, injector nozzles for diesel engines.

42.

Heat Treatment

- **Definition:** A process to control the mechanical properties of engineering materials by heating, cooling, and alloying the metal as per requirement.
- **Purpose:** Deals with change in properties by alloying different elements to the metal at various temperatures.
- **Properties Controlled:** Hardness, toughness, ductility, machinability, and grain refinement are controlled by heat treatment.
- **Focus:** Primarily deals with steel and its properties.
- **Basic Processes:** Hardening, normalizing, annealing, tempering.

43.

Normalizing

- **Process:** Heating steel about 30–50°C above its higher critical point for a duration of 15 minutes, then cooling in still air.
- **Purposes:**
    - To reduce grain size of steel.
    - To remove internal stress caused by working.
    - To improve some of the mechanical properties.

- **Products:**
    - For hypoeutectoid steel: Ferrite and pearlite.
    - For hypereutectoid steel: Pearlite and cementite.
    - Normalized structure: Consists of sorbite and ferrite.
- **Properties of Normalized Steel:** Higher yield point, ultimate tensile strength, impact strength, and lower ductility.
- **Advantages:** Beneficial for low and medium carbon steel. For alloy steel, it is possible with 2 hours of cooling in a furnace.

44.

Annealing

- **General Purposes:**
    1. To soften the metal for easy machining.
    2. To remove internal stress caused by working.
    3. To increase ductility.
    4. To refine grain size.
    5. To modify electrical and magnetic properties.
- **Comparison to Normalized Steel:** Normalized steel is less ductile and has more yield point and tensile strength than annealed steel.
- **Types of Annealing:**
    1. **Process Annealing:**
        - **Process:** Heating metal below or very close to the lower critical temperature (i.e., 650°C for steel) and slow cooling to form a new grain structure.
        - **Purposes:** To increase ductility of cold-worked metal and to remove internal stress.
        - **Use:** Frequently used in wire drawing to increase plasticity.
    2. **Full Annealing:**
        - **Purposes:** To soften the steel and to refine grain structure.

        - **Process:** Heated 20–30°C above the upper critical limit for 0.9% C-steel, or by the same amount below the critical point for high carbon steel. Carbon steel is cooled 100–200°C per hour. Steel should not hold less than 4–8 min for heating. Workpiece is closed in a metal box to prevent carburization and oxidization.
        - **Microstructure:** Austenite changes to pearlite and a mixture of pearlite and ferrite.

45.

Hardening

- **Purposes:**
    - To harden the steel to resist wear.
    - To enable it to cut other metal.
- **Process:** The metal is heated 30–50°C above the upper critical temperature for hypoeutectoid steel, and the same amount above the lower critical temperature for hypereutectoid steel. It is left for soaking for a considered time.
- **Quenching:** High carbon steel heated to 1,100–1,300°C is quenched in a current of air. Quenching at 150–200°C per second in solutions (3–10% caustic soda and 5–15% salt) is more rapid than in water at 20°C, and 32–42°C for oil quenching.

46.

Tempering

- **Process:** Reheating of hardened steel below its critical range, and cooled at a decreased rate (approximately 4–5 min for each mm of the section).
- **Effect:** There is a partial transformation of martensite to secondary constituent troostite and sorbite.
- **Purposes:**

1. To reduce some amount of hardness produced during hardening and increase the ductility.
2. To remove strain produced during heating.

- **Types:**
    1. **Low Temperature Tempering:** Steel is heated to 150–250°C and cooled down. Used to remove internal stress, reduce hardness, and increase ductility without changing the steel structure.
    2. **Medium Temperature Tempering:** Steel is heated to 350–450°C and cooled down. Martensite is changed to secondary troostite. Results in reduction in strength and hardness, and increase in ductility. Used for parts used in impact loading (chisel, hammer, spring, spring plates).
    3. **High Temperature Tempering:** Steel is heated to 500–600°C and cooled down. Martensite is changed to sorbite. Internal stress is relieved completely. Used for parts subjected to high impact and stress (gear wheels, shafts, connecting rod).

47.

Martempering

- **Definition:** Martempering or marquenching permits the transformation of austenite to martensite to take place at the same time throughout the structure of the metal part.
- **Process:** Uses interrupted quench. Cooling is stopped at a point above the martensite transformation region to allow sufficient time for the center to cool to the same temperature as the surface. Then cooling continues through the martensite region, followed by usual tempering.

48.

Carburizing

- **Definition:** A heat treatment process where iron or steel absorbs carbon liberated when heated in a carbon-rich atmosphere (e.g., charcoal, carbon monoxide) to make the metal harder.
- **Effect of Time/Temperature:** Longer carburizing times and higher temperatures lead to greater carbon diffusion and increased depth.
- **Microstructure after Quenching:** Higher carbon content on the outer surface becomes hard (martensite), while the core remains soft and tough (ferritic and/or pearlite microstructure).
- **Applications/Characteristics:** Applied to low-carbon workpieces. Produces a hard workpiece surface; cores largely retain their toughness and ductility. Case hardness depths up to 6.4 mm.
- **Gas Carburizing:** Improves case depth hardness by diffusing carbon into the surface layer to improve wear and fatigue resistance.
- **Pack Carburizing:** Carbon monoxide from a solid compound decomposes at the metal surface into nascent carbon and carbon dioxide.

49.

Cyaniding

- **Process:** Steel parts are surface hardened by heating in contact with a cyanide salt, followed by quenching.
- **Case:** Only a thin case is obtained.
- **Advantages:** Rapid and economical method of case hardening, used for relatively unimportant parts.
- **Conditions:** Immersion in molten sodium or potassium cyanide bath (760–899°C) for 30 to 60 min. Parts are quenched in water immediately after removal.
- **Case Formation:** Due principally to the formation of carbides and nitrides on the steel surface.
- **Safety:** Cyanide vapours are extremely poisonous; requires a closed pot and ventilating hood.

50.

Nitriding

- **Advantage:** A harder case is obtained than by carburizing.
- **Applications:** Many engine parts like cylinder barrels and gears.
- **Suitability:** Generally applied to special steel alloys, with aluminum as an essential constituent.
- **Process:** Involves exposing parts to ammonia gas or other nitrogenous materials for 20–100 h at 500–650°C. Container must be airtight for good circulation and even temperature.
- **Case Depth:** About 0.2–0.4 mm if heated for 50 h.
- **Core Effect:** Does not affect the physical state of the core if the preceding tempering temperature was 500°C or over.

51.

Induction Hardening

- **Process:** Involves rapid and local heating applied to the steel component via high frequency electric fields (induction coils), followed by quenching with water.
- **Result:** Localized hardened layer at the surface.
- **Coils:** Different shaped induction coils are available and can be custom-made.
- **Advantages:** Offers a cost-effective, low-distortion surface hardening treatment to steels, particularly large components requiring increased surface hardness while maintaining core properties.

52.

Introduction to Control Systems

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

- **Example:** Human body temperature control system (sweating if increases, shivering if decreases) to maintain constancy.

53.

Open and Closed Loop Control Systems

- **Two Basic Forms:** Open loop and closed loop.
- **Open Loop Control (Example: Electric Fire):**
  - **Mechanism:** User switches on a 1kW element for a desired temperature. The room temperature is determined only by the element selected.
  - **Lack of Feedback:** If conditions change (e.g., window opens), there is no adjustment to heat output to compensate. This is open loop control as no information is fed back to maintain constant temperature.
- **Closed Loop Control (Example: Electric Fire with Person):**
  - **Mechanism:** The system becomes closed loop if a person uses a thermometer and switches elements on/off based on the difference between actual and required temperature, maintaining constant temperature.
  - **Feedback:** The input to the switch depends on the deviation of the actual temperature from the required temperature, with the person acting as the comparison element.

54.

Basic Elements of a Control System

- **Comparison Element:** Compares the required or reference value of the variable with the measured value and produces an error signal.
  - **Error Signal:** = reference value signal – measured value signal.
- **Feedback Loop:** 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:** Decides what action to take when it receives an error signal.
- **Correction Unit:** Produces a change in the process to correct or change the controlled condition.
- **Process Unit:** The process which is being controlled.
- **Measurement Unit:** Produces a signal related to the variable condition of the process that is being controlled.

55.

Sensors and Transducers

- **Sensor:** An element that produces a signal relating to the quantity being measured.
- **Transducer:** An element that, when subject to some physical change, experiences a related change.
- **Relationship:** All sensors are transducers, but not all transducers are sensors.

56.

Microprocessor Based Controllers

- **Microprocessors:** Used in general to carry out control functions.
- **Embedded Microcontroller:** A microprocessor with memory all integrated on one chip, specifically programmed for the task.
- **Programmable Logic Controller (PLC):** A more adaptable microprocessor-based controller that uses programmable memory to store instructions and implement functions (logic, sequence, timing, counting, arithmetic) to control events, readily programmed for different tasks.

57.

Actuation Systems

- **Definition:** Elements of control systems 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 be transformed into a linear motion to move a load, or control the amount of liquid passing along a pipe.

58.

Introduction to Industrial Robotics

- **Definition:** An industrial robot is a general purpose, programmable machine possessing certain anthropomorphic characteristics.
- **Anthropomorphic Characteristic:** The most obvious is its mechanical arm, used to perform various industrial tasks.
- **Capabilities:** Robot's capability to respond to sensory inputs, communicate with other machines, and make decisions. These permit robots to perform a variety of useful tasks.

59.

Reasons for Commercial and Technological Importance of Industrial Robots

- **Hazardous Environments:** Can be substituted for humans in hazardous or uncomfortable work environments.
- **Consistency & Repeatability:** Performs work cycle with consistency and repeatability unattainable by humans.
- **Reprogrammability:** Can be reprogrammed and equipped with necessary tooling for different tasks when current production run is completed.
- **Computer Integration:** Controlled by computers and can be connected to other computer systems to achieve Computer Integrated Manufacturing.

60.

Robot Anatomy

- **Manipulator:** Constructed of a series of joints and links.
- **Concern:** Robot anatomy is concerned with the types and sizes of these joints and links and other aspects of the manipulator's physical construction.

61.

Joints and Links

- **Joint:** Similar to a joint in the human body, provides relative motion between two parts.
- **Links:** Rigid components of the robot manipulator, connected to each joint (an input link and an output link).
- **Purpose of Joint:** To provide controlled relative movement between the input link and the output link.
- **Base Connection:** Base and its connection to the first joint is referred to as link 0 (input link to joint 1). The output link of joint 1 is link 1, and so forth.

62.

Types of Joints

Nearly all industrial robots have mechanical joints that can be classified into five types:

- **Translational Motion (2 types):**
  - **Linear joint (L):** Provides linear sliding motion along an axis.
  - **Orthogonal joint (O):** Provides linear sliding motion along an axis perpendicular to the previous axis.
- **Rotary Motion (3 types):**
  - **Rotational joint (R):** Provides rotary motion about an axis perpendicular to the connected links.

    - **Twisting joint (T):** Provides rotary motion about an axis parallel to the connected links.
    - **Revolving joint (V):** Provides rotary motion about an axis parallel to the connected links, but the axis itself revolves.

63.

Robot Configurations
A robot manipulator can be divided into two sections:

1. **Body and Arm Assembly:** Used to **position** the end effector.
2. **Wrist Assembly:** Used to **orient** the end effector.

- **End Effector:** A device at the manipulator's wrist related to the task. Usually a gripper (for holding parts) or a tool (for performing a process).

64.

Body and Arm Configurations

- **Cartesian Coordinate Robot (Rectilinear robot and x-y-z robot):**
    - **Configuration:** Composed of three sliding joints (L or O types), two of which are orthogonal.
- **Cylindrical Configuration:**
    - **Configuration:** Consists of a vertical column, relative to which an arm assembly moves up or down. The arm can also move in and out relative to the column's axis. The column can rotate about its axis.
- **Polar Configuration:**
    - **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).
- **Jointed Arm Robot:**

    - **Configuration:** Has the general configuration of a human arm. Consists of a vertical column that swivels about the base (T joint), a shoulder joint (R joint), and an elbow joint (another R joint).
- **SCARA (Selective Compliance Assembly Robot Arm):**
    - **Configuration:** Similar to the jointed arm robot, but the shoulder and elbow rotational axes are vertical.
    - **Characteristics:** Very rigid in the vertical direction, but compliant in the horizontal direction.
    - **Purpose:** Permits the robot to perform insertion tasks (for assembly) in a vertical direction, where some side-to-side alignment may be needed.

65.

Wrist Configurations

- **Purpose:** The robot's wrist is used to establish the orientation of the end effector.
- **Three Joints Defined:**
    1. **Roll:** Uses a T joint to accomplish rotation about the robot's arm axis.
    2. **Pitch:** Involves up and down rotation, typically using an R joint.
    3. **Yaw:** Involves right and left rotation, also accomplished by means of an R-joint.

66.

Applications (Robotics)

- **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**.