MODULE – 2 ADVANCED & DIGITAL MANUFACTURING

Automated Manufacturing: Components & working principle of CNC, advantages and applications.
Additive Manufacturing: Working principle of Additive manufacturing, Advantages and Applications.
Industrial robots: Anatomy, joints and links, Cartesian and polar configuration, Applications of Robots in material handling, processing, assembly, and inspection.

AUTOMATED MANUFACTURING:

Automated manufacturing is the use of machinery and technology to perform tasks in a production process without direct human intervention. It involves the use of automated systems, such as robotics and computer-controlled equipment, to streamline and optimize manufacturing processes, increasing efficiency and precision.

COMPUTER NUMERICAL CONTROL (CNC)

Introduction to Numerical Control (NC)

- The machine is operated automatically by the means of directly inserted coded numerical instructions.
- NC is a concept of automated machine control.
- It is a programmable automation of machine tool.
- Manufacturing process is controlled by numbers, letters and symbols.

Definition of Computer Numerical Control (CNC):

"Computer Numerical Control or CNC is an advanced form of the NC system where the **machine control unit** is a dedicated **microcomputer** instead of a **hard-wired controller, as in conventional NC."**

OR

"Computer numerical control (CNC) is a method for **automating control of machine tools through the use of software embedded in a microcomputer attached to the tool**. It is commonly used in manufacturing for machining metal parts**."**

CNC Technology has powered the Machine Tool industry today. **It is used in majority of machine tools like machining centers, turning centers, grinders, lathes, drilling machines, etc.**

Computer Numerical Control has evolved during the rapid improvements of the computer technology. The advent of Microprocessors from the 1970s have helped in quick advancements in the Computer Technology and is in turn adapted in modern CNC Technology.
Today's CNC Controller has latest features like high speeds of operation, large memories, bus architectures, improved servos, etc.
CNC Technology has powered the Machine Tool industry today. It is used in majority of machine tools like machining centers, turning centers, grinders, lathes, drilling machines, etc.

COMPONENTS OF A CNC SYSTEM

A CNC System consists of the following elements:

1) Input Device
2) MCU or Machine Control Unit
3) Machine Tool
4) Driving System
5) Feedback devices
6) Display Unit

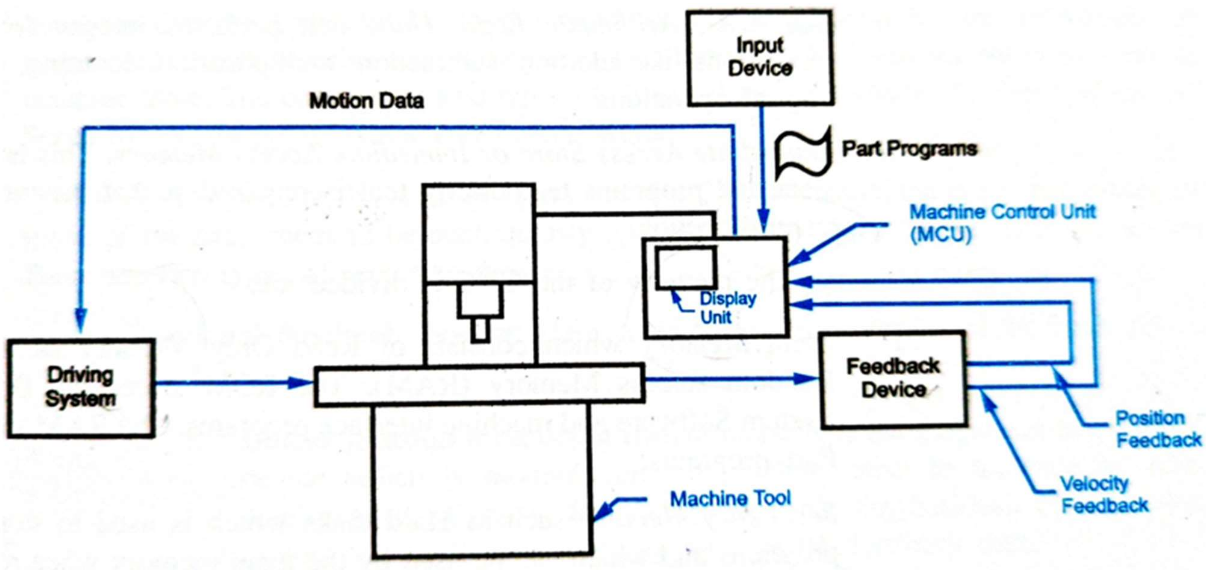


Fig. Elements of a CNC system

1. INPUT DEVICE:

The part program is entered into the CNC Control or the MCU through the input device. There are various input devices used on a CNC Machine such as

a) **USB (Universal Serial Bus) Flash drive:** Here the USB flash drives transfer data to the control. USB is very common nowadays and its use is increased in modern computers.
b) **Serial Communication:** A serial communication port connects a computer system and a CNC Machine tool through an interface called RS-232. Most machines have RS-232 port and an RS-232 cable connects the computer and the CNC Machine to transfer data from the computer to the CNC Machine.
c) **Ethernet Communication:** The Ethernet communication is a more reliable and efficient means of transferring part programs from Computer to the CNC Control.
d) **Conversational Programming:** This is another way to input part programs to the controller through a keyboard. Built-in intelligent software inside the controller enables the operator to enter step by step data.

2. MCU OR MACHINE CONTROL UNIT:

The Machine Control Unit or the MCU is the heart of the CNC System. It consists of the following components:

a) Central Processing Unit: The CPU is the brain of the MCU and it comprises of

i). **A control section** that retrieves data from the memory and generates signals which in turn activates all MCU components.

ii). **An ALU (Arithmetic Logic Unit)** that performs integer arithmetic operations like addition, subtraction, multiplication, counting, etc and logical operations

iii). **Immediate Access** Store or Immediate Access Memory: This holds the data and programs temporarily that is required at that instant by the control section.

b) CNC Memory: The memory of the CNC is divided into

i). **Main Memory** which consists of Read Only Memory (ROM) and Random Access Memory (RAM). The ROM stores the Operating System Software and machine interface programs. The RAM stores the Part programs.

ii). **Secondary Memory** such as Hard disks which is used to store large programs and which can be used by the main memory when required.

c) Input/output Interface:

- The Input/output interface or the I/O interface establishes communication between the machine operator, the components of the CNC system and other connected computers.
- The Operator control panel is the interface through which the machine operator communicates with the CNC system. A keyboard and a display screen are also included in the panel.

d) Machine tool controls:

- A Machine Tool consists of various axes such as X, Y, Z, A, B, C and a spindle which rotates at the designed RPM.
- The position and velocity control of each of the axis and the rotational speed control are accomplished by certain hardware components in the MCU.
- The MCU generates control signals that are transformed into a form suitable for the specific position control systems that is required to drive the various axes of the machine.

e) Sequence controls for auxiliary functions:

- Apart from the general functions like spindle speed, feed rate, etc, certain auxiliary functions like tool emergency stop, tool changing function, etc are carried out under part control program controls.

3. MACHINE TOOL:

- This can be any type of machine tool such as a Machining center, a turning center, a lathe, milling machine, etc.
- The essential parts of the machine tool include the machine table, machine slide, the driving lead screw, ball screw, rigid and heavy machine Structure, and automatic tool changing system, spindle and spindle drive system, chip removal System etc.

- The machine table is controlled in the X and Y axes, while the spindle runs along the Z axis.
- In other machine tools, there are additional axes such as A, B or C that allows rotary motions around the X, Y and Z axes.

4. DRIVING SYSTEM:

- A drive system essentially is made up of amplifier circuits, drive motors, and ball lead-screws. The control signals (position and speed) of each axis are fed by the Machine Control Unit (MCU) to the amplifier circuits.
- Then, the control signals are augmented to actuate drive motors which in turn rotate the ball lead-screws to position the machine table.
- The commonly used types of electrical motors include DC Servo Motor, AC Servo Motor, Stepping Motor and Linear Motor.

5. FEEDBACK DEVICES:

- For the accurate operation of a CNC Machine, the positional values and speed of the axes needs to be continuously updated.
- This is done by the feedback devices.

6. DISPLAY UNIT:

- The display unit is the device that ensures interaction between the machine operator and the machine.
- Display unit displays the current status of operation such as the spindle RPM, the running part program, the feed rate, position of the machine slide, etc.

ADVANTAGES OF CNC MACHINES

Computer Numerical Control (CNC) machines offer several advantages, including:

1) **Precision and accuracy**: CNC machines provide high levels of precision and accuracy in machining operations, leading to consistent and high-quality parts.
2) **Repeatability**: CNC machines can repeatedly produce identical parts with minimal variations, ensuring consistency in mass production
3) **Automation**: They can operate 24/7 without human intervention, increasing productivity and reducing labor costs.
4) **Flexibility**: Easily reprogrammable, CNC machines can switch between different tasks and part designs quickly, making them versatile for various applications.
5) **Complex Geometries**: They can create intricate and complex shapes and contours that are challenging to achieve manually.
6) **Improved Efficiency**: CNC machines work faster and more efficiently than manual machining, reducing production time and costs.

DISADVANTAGES OF CNC MACHINES

CNC (Computer Numerical Control) machines come with some disadvantages, including:

1) **High Initial Cost**: The purchase and installation of CNC machines can be expensive, which can be a barrier for smaller businesses.
2) **Skilled Operator Requirement**: While less specialized than traditional machining, CNC machines still require skilled operators to program and maintain them, which may lead to higher labor costs.

3) **Maintenance Costs**: CNC machines need regular maintenance and occasional repairs, which can be costly.
4) **Limited Adaptability**: CNC machines may not easily adapt to changes in production requirements, and reprogramming can be time-consuming.
5) **Energy Consumption**: CNC machines can consume significant amounts of electricity, which can impact operational costs.
6) **Risk of Downtime**: Technical issues, tool wear, or programming errors can lead to downtime, affecting production schedules.

APPLICATIONS OF CNC MACHINES

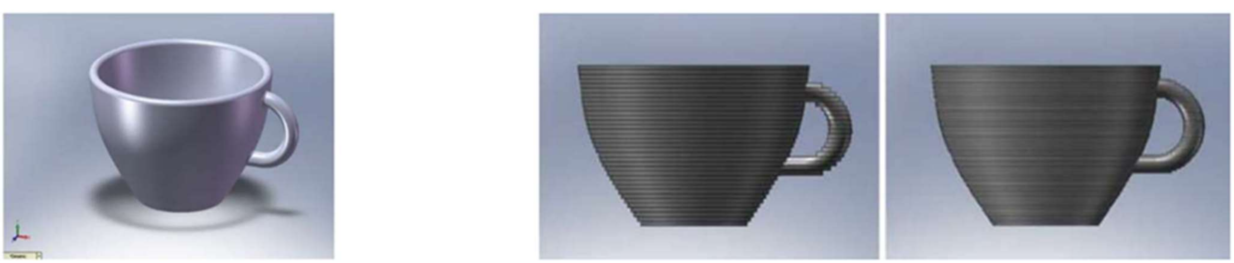
Computer Numerical Control (CNC) machines are widely used in manufacturing and various industries. Some of their key applications include:

1) **Precision Machining:** CNC machines are used for precise and consistent shaping, cutting, and drilling of materials like metal, plastic, and wood, making them essential in industries like aerospace and automotive.
2) **Prototyping and Rapid Manufacturing:** CNC machines enable the quick and accurate production of prototypes and small-batch manufacturing, reducing lead times in product development.
3) **Mass Production:** They are essential for high-volume manufacturing, allowing for efficient and repeatable production of identical parts.
4) **Woodworking:** CNC routers are commonly used in woodworking for intricate and detailed designs, carving, and shaping wood materials.
5) **Metal Fabrication:** CNC machines are used to cut, bend, and shape metal sheets and bars in metal fabrication processes.
6) **Engraving and Marking**: CNC machines are used to engrave serial numbers, logos, and intricate designs onto various materials.

ADDITIVE MANUFACTURING

Definition:

"Additive manufacturing, also known as 3D printing, is a process that builds objects layer by layer, adding material one layer at a time to create a three-dimensional product."



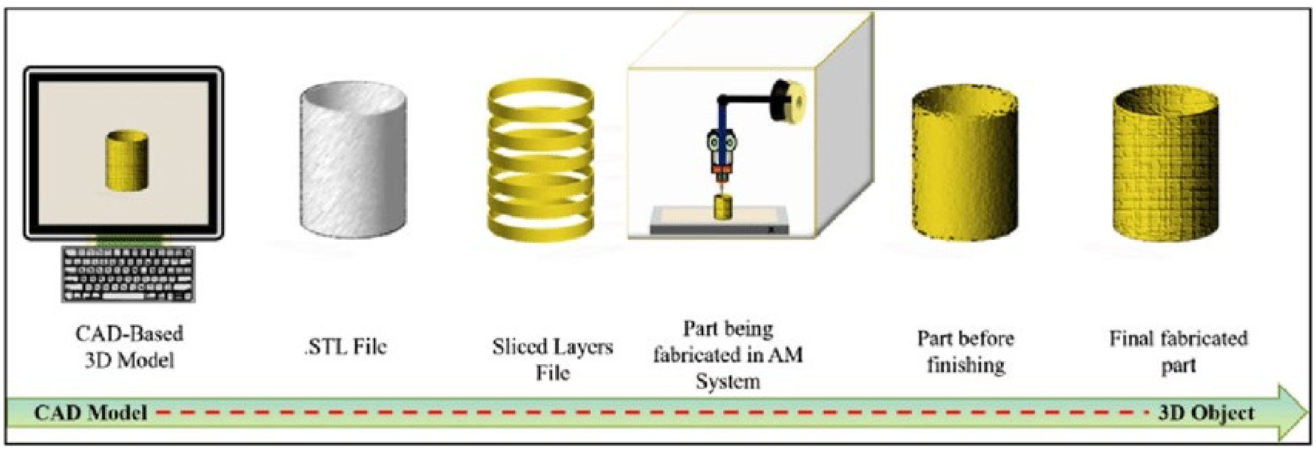
CAD image of a teacup with further images showing the effects of building using different layer thicknesses

WORKING PRINCIPLE OF ADDITIVE MANUFACTURING

The basic working principle of additive manufacturing can be summarized as follows:

1) **Digital Design**: The process begins with the creation of a 3D digital model of the object to be manufactured. This model is typically designed using computer-aided design (CAD) software.

2) **Slicing**: The 3D digital model is divided into thin horizontal cross-sectional layers using slicing software (STL File). These layers are like virtual slices of the object.
3) **Printing**: The actual 3D printing process begins by selecting a suitable additive manufacturing technology, such as fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), or other methods.
4) **Layer-by-Layer Deposition**: The 3D printer follows the instructions from the sliced model, starting with the first layer. It adds material (plastic, metal, resin, or other materials) to create that layer. This can involve melting, curing, or fusing the material, depending on the specific technology being used.
5) **Repeating the Process**: The printer continues to add one layer at a time, stacking them on top of each other until the entire object is complete. Some 3D printers have support structures or infill to provide stability during the printing process.
6) **Post-Processing (optional):** Depending on the material and technology used, post-processing steps like curing, sanding, painting, or assembly might be necessary to finish the printed object.



ADVANTAGES OF ADDITIVE MANUFACTURING (AM)

Additive Manufacturing (AM), offers several advantages, including:

1) **Design Freedom**: AM allows for complex and customized designs that are difficult or impossible to achieve with traditional manufacturing methods.
2) **Rapid Prototyping**: It enables quick and cost-effective prototyping, reducing lead times in product development.
3) **Material Efficiency:** AM minimizes waste as it only uses the necessary material, reducing material and energy consumption.
4) **Reduced Tooling Costs**: Unlike traditional manufacturing, AM doesn't require expensive molds or tooling, saving on setup costs.
5) **Lightweight and Complex Structures**: AM can create lightweight yet strong components with intricate geometries, ideal for aerospace and automotive industries.
6) **Customization**: It allows for mass customization, tailoring products to individual needs or small-batch production.
7) **Repair and Spare Parts**: It can be used to quickly produce replacement parts, extending the lifespan of older machinery.

DISADVANTAGES OF ADDITIVE MANUFACTURING (AM)

Additive Manufacturing (AM) has several disadvantages, including:

1) **Limited Material Choices**: AM may have limitations in available materials compared to traditional manufacturing processes, which can restrict its use for certain applications.
2) **Surface Finish and Resolution**: The surface finish of AM parts may be rougher, requiring additional post-processing steps to achieve the desired quality.
3) **Speed and Scalability**: AM can be relatively slow for large-scale production, making it less suitable for high-volume manufacturing.
4) **Cost:** Initial equipment costs for high-quality AM machines can be expensive, and materials can also be costly, especially for specialized applications.
5) **Design Constraints**: Some complex designs may not be feasible with AM, and part orientation and support structures can be challenging to manage.
6) **Limited Size**: Many AM machines have size limitations, making it challenging to produce large parts.

APPLICATIONS OF ADDITIVE MANUFACTURING (AM)

Additive Manufacturing (AM) has a wide range of applications across various industries, including:

1) **Aerospace**: AM is used to create lightweight, complex components for aircraft and spacecraft, reducing fuel consumption and improving performance.
2) **Healthcare**: It's employed to produce customized implants, prosthetics, dental models, and patient-specific surgical guides.
3) **Automotive**: AM is used for rapid prototyping, producing lightweight parts, and creating intricate designs in automotive components.
4) **Architecture and Construction**: Large-scale AM is used to build architectural structures, such as buildings and bridges, using materials like concrete or polymers.
5) **Electronics**: It's used to create intricate, customized electronic components and enclosures.
6) **Defense and Military**: AM is used for rapid production of spare parts, lightweight armor, and specialized equipment.
7) **Food Industry**: Emerging applications in the food industry include 3D printing of edible items, like chocolates and intricate cake decorations.
8) **Art and Design**: Artists and designers use AM to create intricate sculptures, jewelry, and artistic pieces.

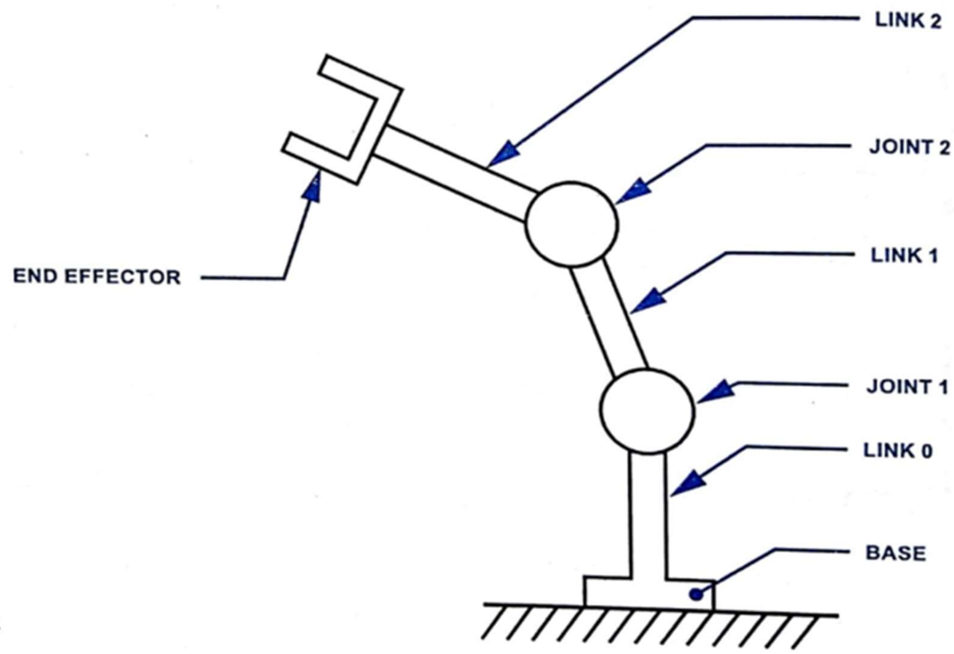
INTRODUCTION TO INDUSTRIAL ROBOTS:

- ***Robot definition:*** “A Robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions of performance of a variety of tasks”.

- ***Robotics definition:*** Robotics can be defined “as a field of technology that deals with the conception, design, construction, operation and application of robots”.

- Robots possess **anthropomorphic** characteristics (meaning human-like characteristics) such as mechanical arm (resembling human arm) to perform variety of tasks, capability to respond to sensory inputs, communication, interaction and taking decisions.

ROBOT ANATOMY



Simple Robot Construction

1) **Manipulator:** manipulator is an arm-like mechanism which is designed to manipulate or move materials, parts or tools without direct human contact.
2) **Joint:** A joint is the one that *integrates two or more links* to provide controlled relative movement between input link and the output link.
3) **Link:** The link is a rigid member that connects the joints. Link can be an input link and an output link. *The movement of the input link causes various motions of the output link*.
4) **Degrees of freedom (D.O.F)**: The degrees of freedom describe a *robot's freedom of motion in the three-dimensional space*.
5) **End effectors**: End effectors or end-of-arm tool is the device at the end of the *robotic arm which is shaped like a hand or as a special tool depending upon the application.*
6) **Base**: The support for the robot arm is called as the base.

TYPES OF END EFFECTOR

There are broadly two types of end-effectors:

1) Grippers
2) Tools

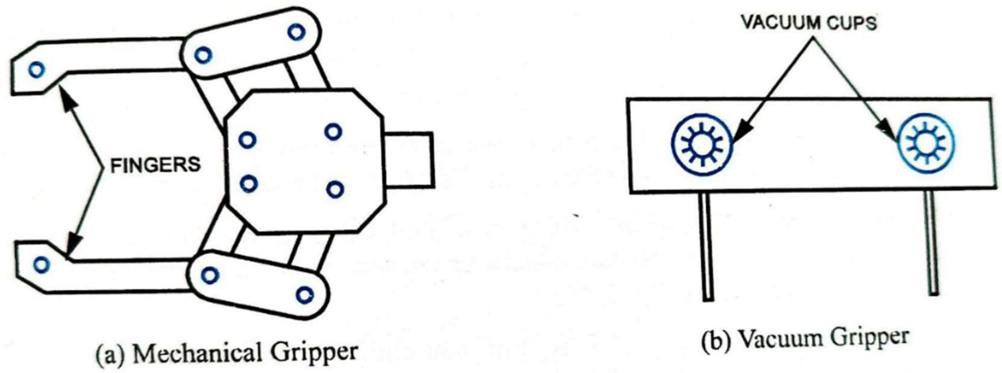


Fig. Types of End Effector

1) **Grippers**: Gripper is a component of a robot that is used to grasp the object/s to be manipulated. Grippers are either actuated pneumatically or by using servomotors. The design of a gripper depends on the shape, size and weight of the part to be gripped.

There are various types of grippers available:

a) Mechanical Grippers
b) Vacuum Grippers
c) Magnetic Grippers
d) Adhesion Grippers
e) Simple Mechanical Grippers

2) **Tools**: Tools for processing operations such as spot welding, spray painting, drilling, milling, etc; can be used as end-effectors to move relative to the workpiece and perform the required operations. Example: A spray painting gun can be an end-effector that is used by the robot to perform spray painting on the work surface. Other examples of tools include spot welding gun, plasma torch, a rotating spindle on which various tools such as drill bits, milling cutters, etc; can be mounted and so on.

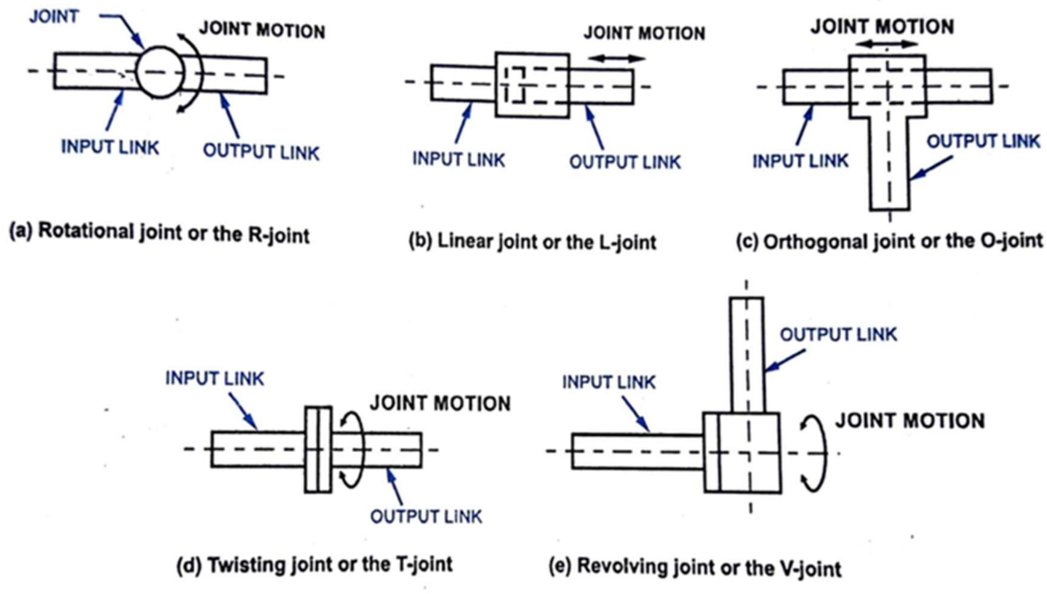
JOINTS AND LINKS

- The members of a robotic manipulator are called as **links**. The links are connected together by **joints.**
- The relative motion between the links are mainly due to joints.

  There are various types of joints that are used in the construction of a robot. These joints are called the robot joints.

<u>There are majorly five types of robot joints:</u>

1. Rotational joint or the R-joint
2. Linear joint or the L-Joint
3. Orthogonal joint or the O-joint
4. Twisting joint or the T-joint
5. Revolving joint or the V-joint



Types of Robot joints

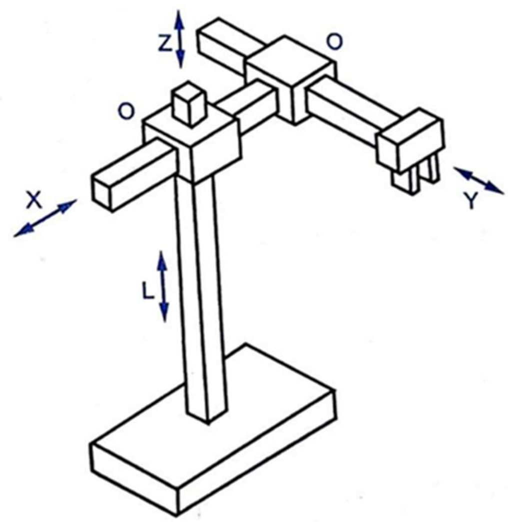
1. **Rotational joint or the R-joint:** This type of joint allows rotary relative motion where the axis of the rotation is perpendicular to the axes of the input link and the output link. This is shown in Fig (a)
2. **Linear joint or the L-Joint:** This type of joint allows a translational sliding motion between the input and the output links with the axes of the links parallel as shown in the Fig (b).
3. **Orthogonal joint or the O-joint:** This type of joint allows a translational sliding motion between the input link and the output link with the axis of the output link perpendicular to the input link as shown in Fig. (c).
4. **Twisting joint or the T-joint:** This type of joint allows rotary motion where the axis of rotation is parallel to the axes of the input and output links as shown in the Fig (d).
5. **Revolving joint or the V-joint:** In this type of joint, the input link axis is parallel to the rotational axis of the joint whereas the output link axis is perpendicular to the rotational axis of the joint as shown in the Fig (e).

ROBOT CONFIGURATION

- Robot configuration *specifies the possible movements provided by different robots*.
- The majority of present commercially available robots poses one of these four basic configurations.
  1) Cartesian Co-ordinate Robot
  2) Polar Configuration (Spherical Configuration)
  3) Cylindrical Configuration
  4) Jointed-arm Configuration Robot

1. CARTESIAN CO-ORDINATE ROBOT

A cartesian co-ordinate robot shown in figure below



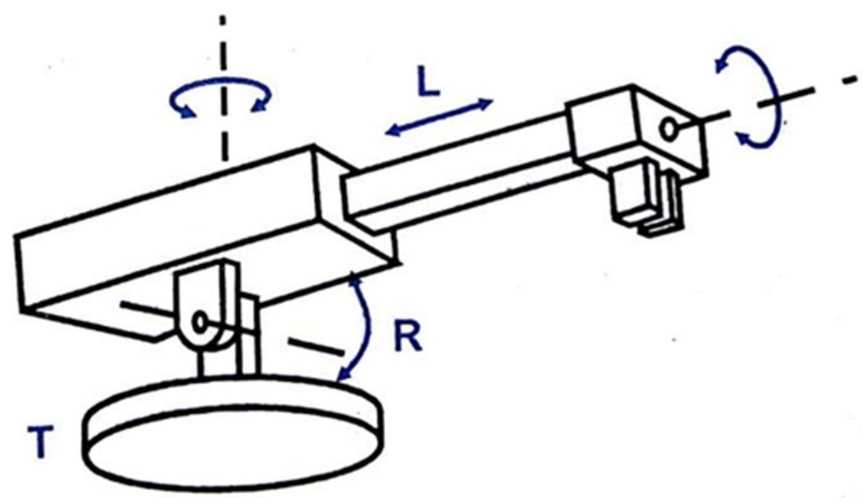
Cartesian Co-ordinate Robot

- It is also called as a rectilinear robot or a **XYZ Robot.**
- It consists of **Three Sliding** joints along the X, Y and Z direction in three dimensional spaces.
- There are two orthogonal Joints **(O-joints)**. Since movement can stop and start and start simultaneously along X, Y and Z axes the motion of the tool tip is smoother.

Application:

- These configurations of robots are used for material handling, material transfers, material loading and unloading, pick and place tasks.

2. POLAR CONFIGURATION (SPHERICAL CONFIGURATION)



Polar Configuration Robot

- The Polar configuration robots also called as the spherical configuration robots.
- It consists a sliding arm **(L-joint)** that is actuated relative to the body and a rotational base along with a pivot, which can rotate about a horizontal axis **(R joint**) and the vertical axis **(T Joint)** This is shown in the Fig.

Application:

- These configurations of robots are used in critical and hazardous operations of manufacturing process lines such as Welding, Die casting, forging, injection moulding, Dip coating, cleaning of parts etc., as they create large work space.

APPLICATION OF ROBOTS

I. **Material / Part Handling applications**
   a) Transfer materials – (Pick-and-place application, Palletizing application, etc.,)
   b) Machine loading/unloading

II. **Processing operations**
   a) Spot Welding
   b) Arc Welding
   c) Spray Coating

III. **Assembly and Inspection**
   a) Assembly
   b) Inspection

I. MATERIAL / PART HANDLING APPLICATIONS

Most of the applications of the Robot falls under this category. Here the Robots are used to

a) **Transfer materials** from one location to another location. Typical applications are as given below:
   i. **Pick-and-place application:** The most common and simplest application here is the pick- and-place application where objects are picked from one location and placed to another location.
   ii. **Palletizing application**: Another application that is slightly complex is the "Palletizing application" where the robot stacks products or carton boxes onto a pallet at various positions on the pallet to the required height
   iii. **Depalletizing application**: Here the robot picks parts from an orderly stacked pallet to another location.
   iv. **Stacking application:** Here, the robots are used to stack parts one upon another. After each placement, the vertical position is re-calculated and the new stacking height is determined.
   v. **Insertion operation:** Here, the robots are used to insert parts into the compartments or spaces provided in a carton.

b) **Machine loading/unloading:** In the machine loading/unloading application, a robot is used to move the work parts to or/and from the production machine.

Following are the industrial applications of robots used for machine loading/unloading:

1. **Die casting:** Here the robot is used to safely unload the parts from a die-casting machine with the safety gates closed.
2. **Forging:** Forging is one of the toughest environments considering the extreme heat, pollution and noise. The use of a robot immensely helps to face the environment of forging. Here the robot loads the red hot billet on to the die of the forging hammer, holds it during the blows and unloads to a safe place away from the hammer.
3. **Plastic injection moulding**: Here a robot unloads parts from the injection moulding machine, cuts the runner and drops runner to scrap area.
4. **Sheet metal press operation (Press working)**: Here a robot loads a blank into the press, and then after the press stamping operation is performed the robot unloads the scrap and throws it into the scrap area. The stamped parts from the blank falls in the container placed at the back of the machine.
5. **Machining operations:** Here the robot loads the raw blanks on to the machine tool and unloads the finished parts.
6. **Heat treating:** Here the robot loads/unloads parts to/from a furnace.

II. PROCESSING OPERATIONS

Robots are used to carry out the processing operations such as spray painting, spot welding, etc. by using a tool at its end-effectors.

a) **Spot Welding**: The end effectors of the robot here is the spot welding gun that applies the approximate pressure and current to the sheet parts to be welded. The spot-welding robots have enough number of axes of motion to approach points in the work envelope at any angle. This was difficult to realize in a manned environment in the absence of robots. Spot welding is used largely in the automobile industry to weld automobile bodies such as car panels.

b) **Arc Welding:** The welding here is continuous unlike spot welding. When arc welding is manually carried out, the conditions are difficult for the operators since they require Personal Protective Equipment like welding shield with special glass to avoid UV rays are under the danger of operating at high temperatures involving high amount of heat and moreover they must be accurate in following the welding path. These problems are now overcome with the use of arc welding robots.

c) **Spray Coating**: Spray coating is a process where parts are coated by a spray gun spraying the fluid on to the surface of the part. The fluid passes through the nozzle of the spray gun and is dispersed at high velocity to the surface to be coated. Common examples are powder coating and spray painting.

III. ASSEMBLY AND INSPECTION

a) **Assembly:** The combination of two or more parts to form a new object is called as an assembly. The parts that join to form a new entity are securely held together either by fastening or joining processes. Assembly automation using robots will ensure higher productivity, consistency in quality and cost savings when compared to manual assembly. Robots have saved the assembly workers from the tedious, dull and repetitive jobs which were quite labour-intensive.

b) **Inspection:** Inspection is a means to separate poor quality products from the good ones to ensure the required quality. Inspection, when manually carried out is a labour-intensive job that is also time consuming and costly. More inspection means increased manufacturing lead time and increased product cost without adding any real value to the products. So, the use of robots for inspection activities is slowly on the rise in industries.

Following are some of the inspection task cases performed by robots:

i. ***The robot arm manipulates an inspection probe*** that moves relative to the product to be inspected. The end-effectors here are the inspection probe. Here care must be taken to present the part at the inspection workstation at the right position and the right orientation so that the part is inspected accurately.

ii. *Robots can inspect whether the part is present on an assembly or not*. Inspection systems for instance look at an engine to find out if it is completely assembled or not.

iii. *The robot picks part at the cell entry point, loads to the inspection machine and after inspection unloads the part and then places to the cell exit poi*nt. Few cases may also involve robot taking additional responsibility of segregating parts based on inspection result.

iv. *Robots are used to detect flaws by comparing the good part with the bad part*. This requires the end users to define what a good part is and what a bad part is.

ADVANTAGES OF ROBOTS

1) Robots can be substituted for humans to work in hazardous work environments.
2) Robots can produce greater quantity in a short span of time with consistency and accuracy that cannot be matched by humans.
3) Robots can work at constant speeds without any break which is not possible by humans.
4) Robots are capable of lifting heavy loads without getting tired or injured.
5) Robots can be re-programmed with changed tooling to take up a different task after the end of a batch or a production run. In such cases, robots are better than fixed automation.
6) Accidents at the workplace is avoided since robots perform the risky jobs which were otherwise done by humans.
7) Since Robots are controlled by computers, they can be integrated to other computer systems to realize Computer Integrated Manufacturing (CIM)
8) The usage of robots produces lesser or no defective parts and hence saves time of rework and money to the organization.

DISADVANTAGES OF ROBOTS

1) Organizations have to make huge investments to introduce robots at their workplaces.
2) Since parts of a robot are made very precisely, their replacement is very difficult and to maintain, it costs huge amount of money.
3) To program and setup, the robotic systems and robots, and to avoid unnecessary future problems and mishaps, it requires highly skilled technical engineers and programmers which again is a significant cost for the organization.
4) Unless the level of the artificial intelligence is highly sophisticated, robots may not be able to respond properly during times of emergency, during times of accidents or when an unexpected variance occurs.

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