# ME7T4B - ROBOTICS

- Text books:
  1. Industrial Robotics by Mikell P.Groover, McGraw-Hill Int. Edition
  2. Robotics and Control / Mittal R K & Nagrath I J / TMH.

- Reference Books:
  1. Robotic Engineering by Richard D.Klafter, Prentice Hall
  2. Introduction to Robotics – Saeed B.Niku, Prentice Hall
  3. Introduction to Robotics – John J. Craig, Addison Wesley

# COURSE OUTCOMES

1. Demonstrate knowledge of industrial robots, characteristics, end effectors and actuators.
2. Apply spatial transformation to obtain forward and inverse kinematics
3. Solve robot dynamics problems, generate joint trajectory for path planning
4. Describe working principle of various sensors and program different operations
5. Appreciate applications of robots in industry.

UNIT I

- INTRODUCTION TO ROBOTICS: Automation and Robotics, major components of a robot, robotic like devices, Classification by coordinate system and by control method, Specifications of robots, Architecture, number of degrees of freedom, economic analysis, and overview of robot present and future applications.
- Robot end effectors: Introduction, end effectors, types of end effectors, grippers and tools, Requirements and challenges of end effectors.
- Actuators: Pneumatic, Hydraulic actuators, electric & stepper motors.

UNIT II

- TRANSFORMATIONS: Homogeneous coordinates, transformations as applicable to translation, rotation, problems.
- KINEMATICS: Introduction to Robot Kinematics-forward solution, Denavit-Hartenberg (D-H) Notation, Forward kinematics, Simple problems involving planar manipulators, Simple inverse kinematic problems.

UNIT III

- DIFFERENTIAL TRANSFORMATIONS: Differential transformations of manipulators, Jacobians, problems.

- DYNAMICS: Lagrange Euler and Newton Euler formulations, Problems.
- TRAJECTORY PLANNING: Path planning, avoidance of obstacles, path planning algorithms, trajectory planning with cubic polynomial, blending, higher order trajectories

UNIT IV

- ROBOTIC SENSORY DEVICES: Introduction, Non-optical position sensors– potentiometers, synchros, optical. position sensors – optical interrupters, optical encoders (absolute & incremental). Proximity sensors: Contact type, noncontact type – reflected light scanning laser sensors. Touch & slip sensors: Tactile sensors – proximity rod & photo detector sensors, Slip sensors- Forced oscillation slip sensor, interrupted type slip sensors.
- ROBOT PROGRAMMING: Robot programming, languages and software packages.

UNIT V

ROBOT APPLICATION IN MANUFACTURING: Material Transfer, Material handling, loading and unloading, Processing, spot and continuous arc welding & spray painting Assembly and Inspection.

# Introduction to Robotics

# AUTOMATION AND ROBOTICS

- The word automation comes from the Greek word “ automatos, ” meaning self-acting.
- The word automation was coined in the mid-1940s by the U.S. automobile industry to indicate the automatic handling of parts between production machines, together with their continuous processing at the machines.
- The advances in computers and control systems have extended the definition of automation.
- By the middle of the 20th century, automation had existed for many years on a small scale, using mechanical devices to automate the production of simply shaped items.
- However the concept only became truly practical with the addition of the computer, whose flexibility allowed it to drive almost any sort of task.

# AUTOMATION AND ROBOTICS

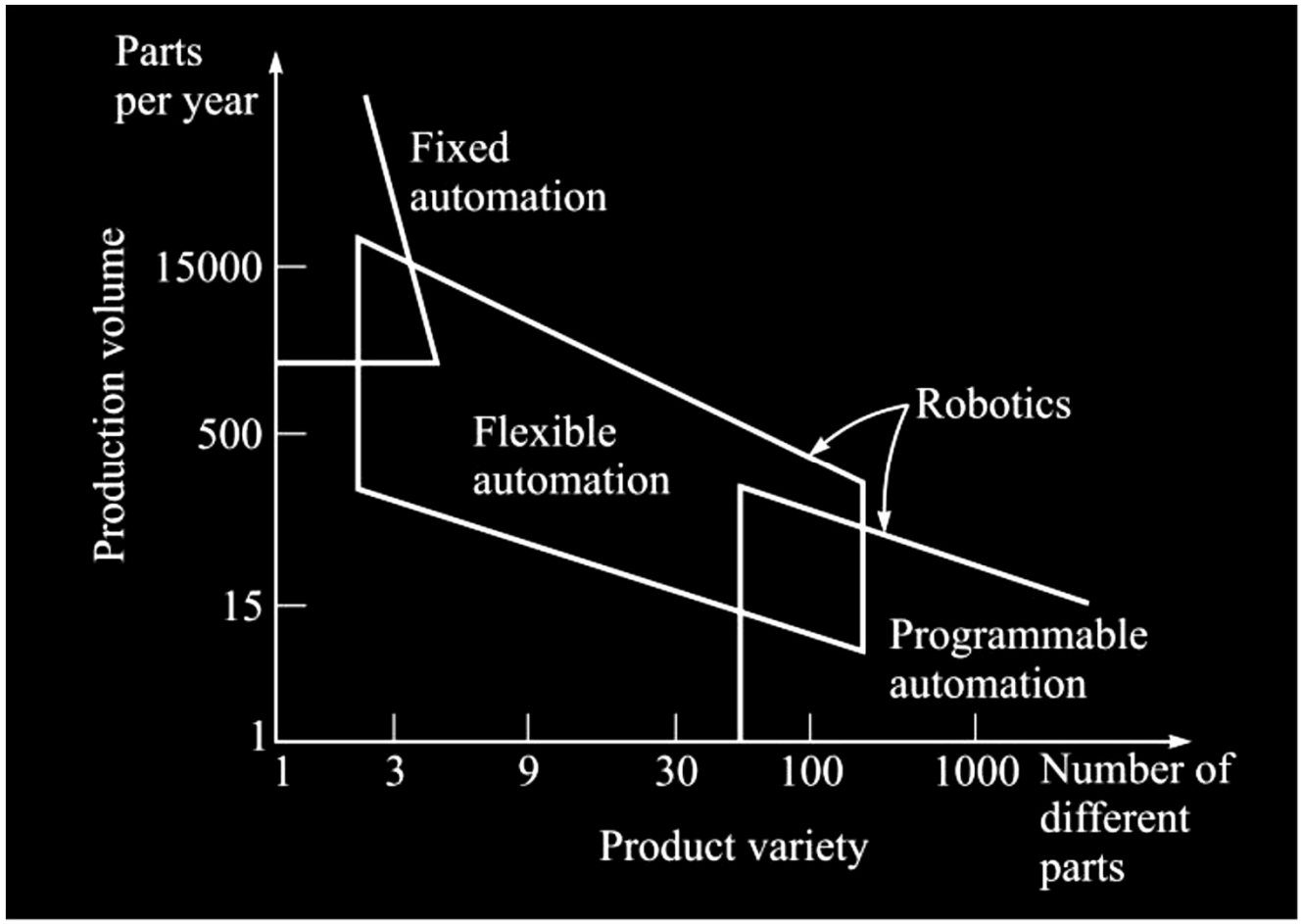
- Automation can generally be defined as the process of following a predetermined sequence of operations with little or no human labor, using specialized equipment and devices that perform and control manufacturing processes.
- Automation in its full sense, is achieved through the use of a variety of devices, sensors, actuators, techniques, and equipment that are capable of observing the manufacturing process, making decisions concerning the changes that need to be made in the operation, and controlling all aspects of it.
- Automation is the process in industry where various production operations are converted from a manual process, to an automated or mechanized process.
- Automation can be explained as a process to create, control and monitor the applications of technology. Automation is the process of handling the operation of equipment such as processors, machinery, stabilization of ships, aircraft, boilers and many applications with minimum human efforts.

# AUTOMATION AND ROBOTICS

- Automation and robotics are two closely related technologies. In an industrial context, automation is defined as a technology that is concerned with the use of mechanical, electronic and computer-based systems in the operation and control of production.
- There are three broad classes of industrial automation: fixed automation, programmable automation and flexible automation.
- Fixed automation refers to the use of special purpose equipment to automate a fixed sequence of processing or assembly operations.
- It is typically associated with high production rates and it is relatively difficult to accommodate changes in the product design.
- This is also called hard automation .
- For example, GE manufactures approximately 2 billion light bulbs per year and uses fairly specialized, high-speed automation equipment.

- Fixed automation makes sense only when product designs are stable and product life cycles are long.
- Machines used in hard-automation applications are usually built on the building block , or modular principle . They are generally called transfer machines , and consist of the following two major components: powerhead production units and transfer mechanisms.
- **Advantages**
  - Maximum Efficiency
  - Low unit cost
  - Automated Material Handling – fast and efficient movement of materials
  - Very little waste in production
- **Disadvantages**
  - Large initial Investment
  - Inflexible in accommodating the product variety

- In programmable automation, the equipment is designed to accommodate a specific class of product changes and the processing or assembly operations can be changed by modifying the control program.
- It is particularly suited to "batch production," or the manufacture of a product in medium lot sizes (generally at regular intervals).
- The example of this kind of automation is the CNC lathe that produces a specific product in a certain product class according to the "input program."
- In programmable automation, reconfiguring the system for a new product is time consuming because it involves reprogramming and set up for the machines, and new fixtures and tools. Examples include numerically controlled machines, industrial robots, etc.
- **Advantages**
  - Flexibility to deal with variations and changes in product.
  - Low unit cost for large batches.
- **Disadvantages**
  - New product requires long set up time and High unit cost relative to fixed automation.




Relationship fixed automation, programmable automation and flexible automation as a function of production volume and product variety.

- In flexible automation, the equipment is designed to manufacture a variety of products or parts and very little time is spent on changing from one product to another. Thus, a flexible manufacturing system can be used to manufacture various combinations of products according to any specified schedule.
- With a flexible automation system, it is possible to quickly incorporate changes in the product (which may be redesigned in reaction to changing market conditions and to consumer feedback) or to quickly introduce a new product line.
- For example, Honda is widely credited with using flexible automation technology to introduce 113 changes to its line of motorcycle products in the 1970s.
- Flexible automation gives the manufacturer the ability to produce multiple products cheaply in combination than separately.
- **Advantages**
  - Flexibility to deal with product design variations.
  - Customized products.
- **Disadvantages**
  - Large initial investment and High unit cost relative to fixed or programmable automation.

# REASONS FOR AUTOMATION

- Shortage of labor and High cost of labor
- Increased productivity: Higher production output per hour of labor input is possible with automation than with manual operations. Productivity is the single most important factor in determining a nation's standard of living. If the value of output per hour goes up, the overall income levels go up.
- Competition: The ultimate goal of a company is to increase profits. However, there are other goals that are harder to measure. Automation may result in lower prices, superior products, better labor relations, and a better company image.
- Safety: Automation allows the employee to assume a supervisory role instead of being directly involved in the manufacturing task. For example, die casting is hot and dangerous and the work pieces are often very heavy. Welding, spray painting, and other operations can be a health hazard. Machines can do these jobs more precisely and achieve better quality products.

# REASONS FOR AUTOMATION

- Reducing manufacturing lead-time: Automation allows the manufacturer to respond quickly to the consumers needs. Second, flexible automation also allows companies to handle frequent design modifications.
- Lower costs: In addition to cutting labor costs, automation may decrease the scrap rate and thus reduce the cost of raw materials. It also enables just-in-time manufacturing which in turn allows the manufacturer to reduce the in-process inventory. It is possible to improve the quality of the product at lower cost.

# ROBOTICS

- Robots alone are hardly ever useful. They are used together with other devices, peripherals, and manufacturing machines.
- They are generally integrated into a system, which as a whole is designed to perform a task or to do an operation.
- Robots are very powerful elements of today's industry. They are capable of performing many different tasks and operations precisely and do not require common safety and comfort elements that humans needs. However, it takes much effort and many resources to make a robot function properly.
- As with humans, robots can do certain things, but not other things. As long as they are designed properly for the intended purpose, they are very useful and will continue to be used.
- Robotics is the art, knowledge base, and the know-how of designing, applying, and using robots in human endeavours. Robotic systems consist of not just robots, but also other devices and systems that are used together with the robots to perform the necessary tasks.

# DEFINITION OF A ROBOT

- A robot is a computer-controlled machine that is programmed to move, manipulate objects, and accomplish work while interacting with its environment.
- According to the Robot Institute of America (1979), a robot is defined as "a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks."
- Industrial robot is defined as "a number of rigid links connected by joints of different types that are controlled and monitored by computer."
- One feature of a robot is the ability to operate automatically, on its own. This means that there must be in-built intelligence, or a programmable memory, or simply an arrangement of adjustable mechanisms that command manipulation.

# LAWS OF ROBOTICS

- Isaac Asimov proposed three laws of robotics and he later added a "zeroth law."
- Law One : A robot may not injure a human being, or, through inaction, allow a human being to come to harm, unless this would violate a higher order law.
- Law Two : A robot must obey orders given to it by human beings, except where such orders would conflict with a higher order law.
- Law Three : A robot must protect its own existence as long as such protection does not conflict with a higher order law.
- Law Zero : A robot may not injure humanity, or, through inaction, allow humanity to come to harm.

# ADVANTAGES AND DISADVANTAGES OF ROBOTS

- If introduced correctly, industrial robots can improve the quality of life by freeing workers from dirty, boring, dangerous, and heavy labor. It can be said, therefore, that robots give the possibility to humans to occupy with jobs, that they can execute better.
- It is true that robots can cause unemployment by replacing human workers but robots also create jobs such as robot technicians, salesmen, engineers, programmers, and supervisors.
- The advantages of robots are:
  - Increase in productivity, safety, efficiency, quality, and consistency of products with the use of robots.
  - Robots can work in hazardous environments without the need for life support, comfort, or concern about safety.
  - Robots need no environmental comfort such as lighting, air conditioning, ventilation, and noise protection.

# ADVANTAGES AND DISADVANTAGES OF ROBOTS

- The advantages of robots are:
  - Robots can work continuously without experiencing fatigue or boredom, do not have hangovers, and need no medical insurance or vacation.
  - Robots have repeatable precision at all times, unless something happens to them or unless they wear out.
  - Robots can be much more accurate than humans.
- The disadvantages of robots are:
  - Robots replace human workers creating economic problems, such as lost salaries, and social problems such as dissatisfaction and resentment among workers.
  - Robots lack capability to respond in emergencies, unless the situation is predicted and the response is included in the system. Safety measures are needed to
  - ensure that they do not injure operators and machines working with them.
  - Robots are costly due to initial cost of equipment, installation costs, need for training, and need for programming.

# CHARACTERISTICS OF AN INDUSTRIAL ROBOT

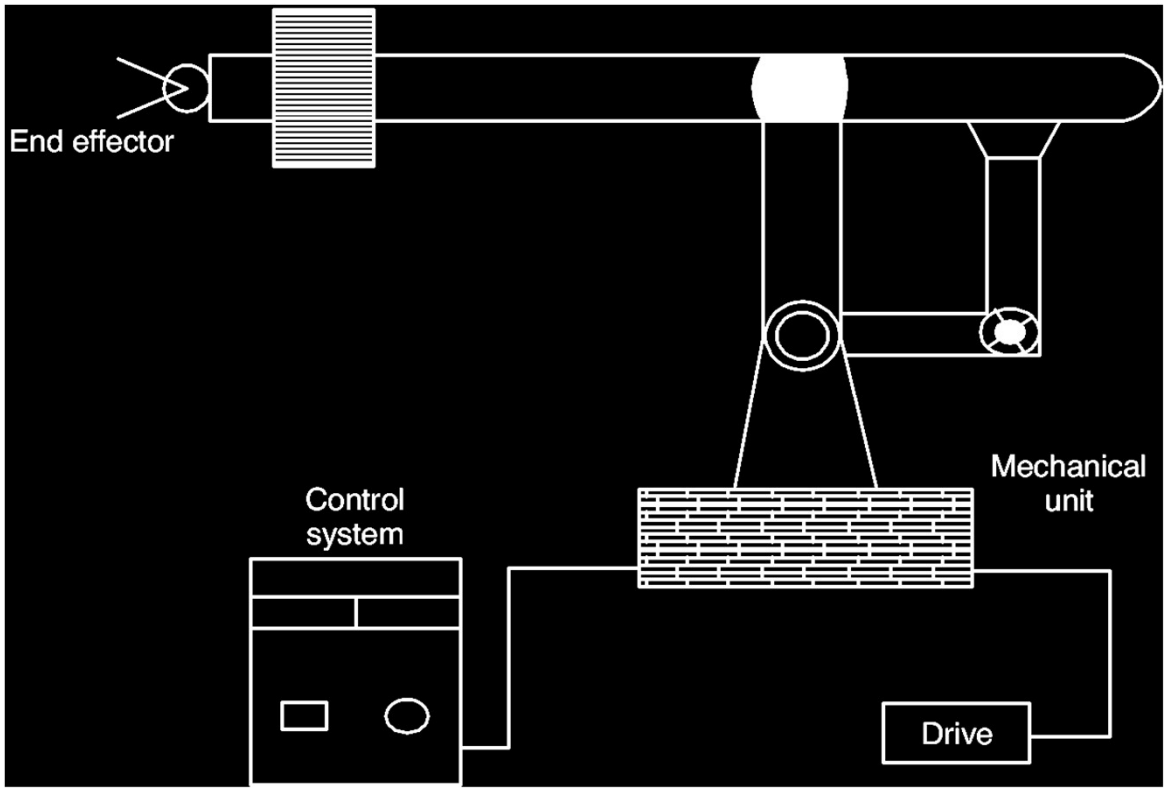
- An industrial robot has a hand, wrist, arm, base, lifting power, repeatability, manual control, automatic control, memory, programs, safety interlock, speed of operation, computer interface, reliability, and easy maintenance.
- The hand of a robot is known as a gripper or end effector or end-of-arm tooling. It is the driven mechanical device(s) attached to the end of the manipulator.
- The wrist of the robot is used to aim the hand at any part of the work piece. The wrist may have three motions: pitch (up-and-down motion), yaw (side-to-side motion), and roll (rotating motion).
- The arm is used to move the hand within reach of a part or work piece. It can pivot at its elbow and at its shoulder joint.
- The waist, or base, of the robot supports the arm and is called the shoulder. The arm can rotate about the shoulder.
- Repeatability is the replication of motion within some specified precision or tolerance.

# CHARACTERISTICS OF AN INDUSTRIAL ROBOT

- An RCC or remote center compliance device helps pull the hand or tool into the required position by acting as a multi-axis float.
- A manual control device is used to teach the robot how to do a new task.
- An automatic control system is used to carry out the instructions stored in the robot's memory.
- The robot's memory holds a library of programs to use in executing different tasks.
- Safety interlocks prevent the robot from inserting a hand into a machine and causing damage to the robot and machine.
- The robot's speed of operation in performing a task should be at least equal to that of the human worker it is replacing.
- The robot's computer interface enables the robot to use the computer's larger memory to hold more task programs and to synchronize its actions with a complete production line of robots and other machines.

# COMPONENTS OF AN INDUSTRIAL ROBOT

- Industrial robot systems consist of four major subsystems as shown in Figure
  - Mechanical unit
  - Drive
  - Control system
  - Tooling



# COMPONENTS OF AN INDUSTRIAL ROBOT

- Mechanical unit
  - Mechanical Unit. The mechanical unit refers to the robot's manipulative arm and its base. Tooling such as end effectors, tool changers, and grippers are attached to the wrist-tooling interface.
  - The mechanical unit consists of a fabricated structural frame with provisions for supporting mechanical linkage and joints, guides, actuators, control valves, limiting devices, and sensors.
  - The physical dimensions, design, and loading capability of the robot depends upon the application requirements.
- Drive.
  - An important component of the robot is the drive system. The drive system supplies the power, which enables the robot to move.
  - Drive for a robot may be hydraulic, pneumatic, or electric.
  - Hydraulic drives have been used for heavier lift systems.
  - Pneumatic drives have been used for high speed, non-servo robots and are often used for powering tooling such as grippers.

# COMPONENTS OF AN INDUSTRIAL ROBOT

- Drive.
  - Electric drive systems can provide both lift and/or precision, depending on the motor and servo system selection and design.
  - An AC or DC powered motor may be used depending on the system design and applications.
- Control System.
  - Controller is the brain of the robot. Controller is a communication and information-processing device that initiates, terminates, and coordinates the motions and sequences of a robot.
  - Most industrial robots incorporate computer or microprocessor based controllers.
  - These perform computational functions and interface with sensors, grippers, tooling, and other peripheral equipment.
  - Controller programming may be done on-line or from off-line control stations. Programs may be on cassettes, floppy disks, internal drives, or in memory; and may be loaded or downloaded by cassettes, disks, or telephone modem.
  - Some robot controllers have sufficient computational ability, memory capacity, and input/output capability to serve as system controllers for other equipment and processes

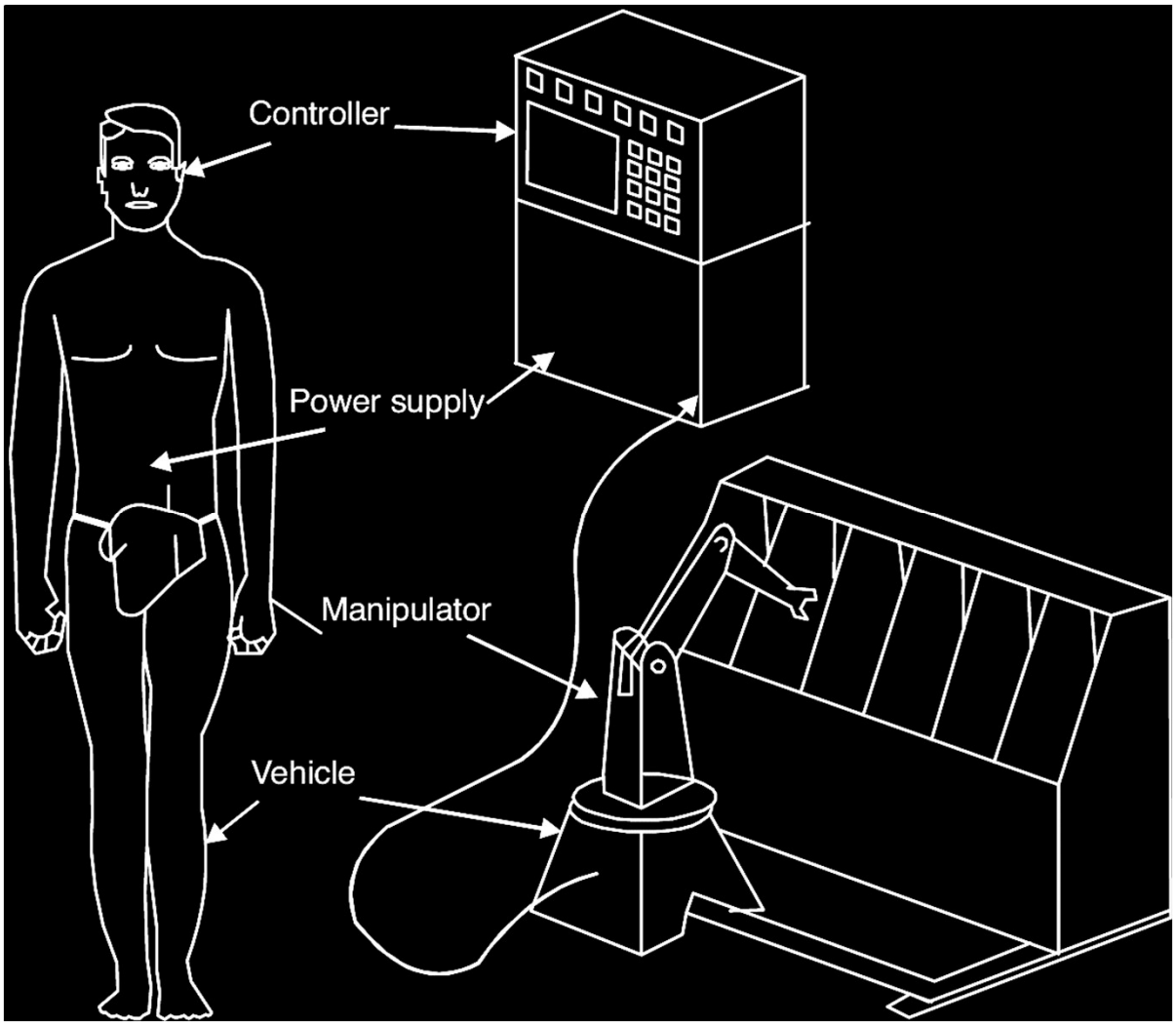
# COMPONENTS OF AN INDUSTRIAL ROBOT

- Tooling..
  - Tooling is manipulated by the robot to perform the functions required for the application.
  - Depending on the application, the robot may have one functional capability, such as making spot welds or spray painting.
  - These capabilities may be integrated with the robot's mechanical system or may be attached at the robot's wrist-end effector interface.
  - Alternatively, the robot may use multiple tools that may be changed manually (as part of set-up for a new program) or automatically during a work cycle.
  - Tooling and objects that may be carried by a robot's gripper can significantly increase the envelope in which objects or humans may be struck.
  - Tooling manipulated by the industrial robot and carried objects can cause more significant hazards than motion of the bare robotic system.
  - The hazards added by the tooling should be addressed as part of the risk assessment.

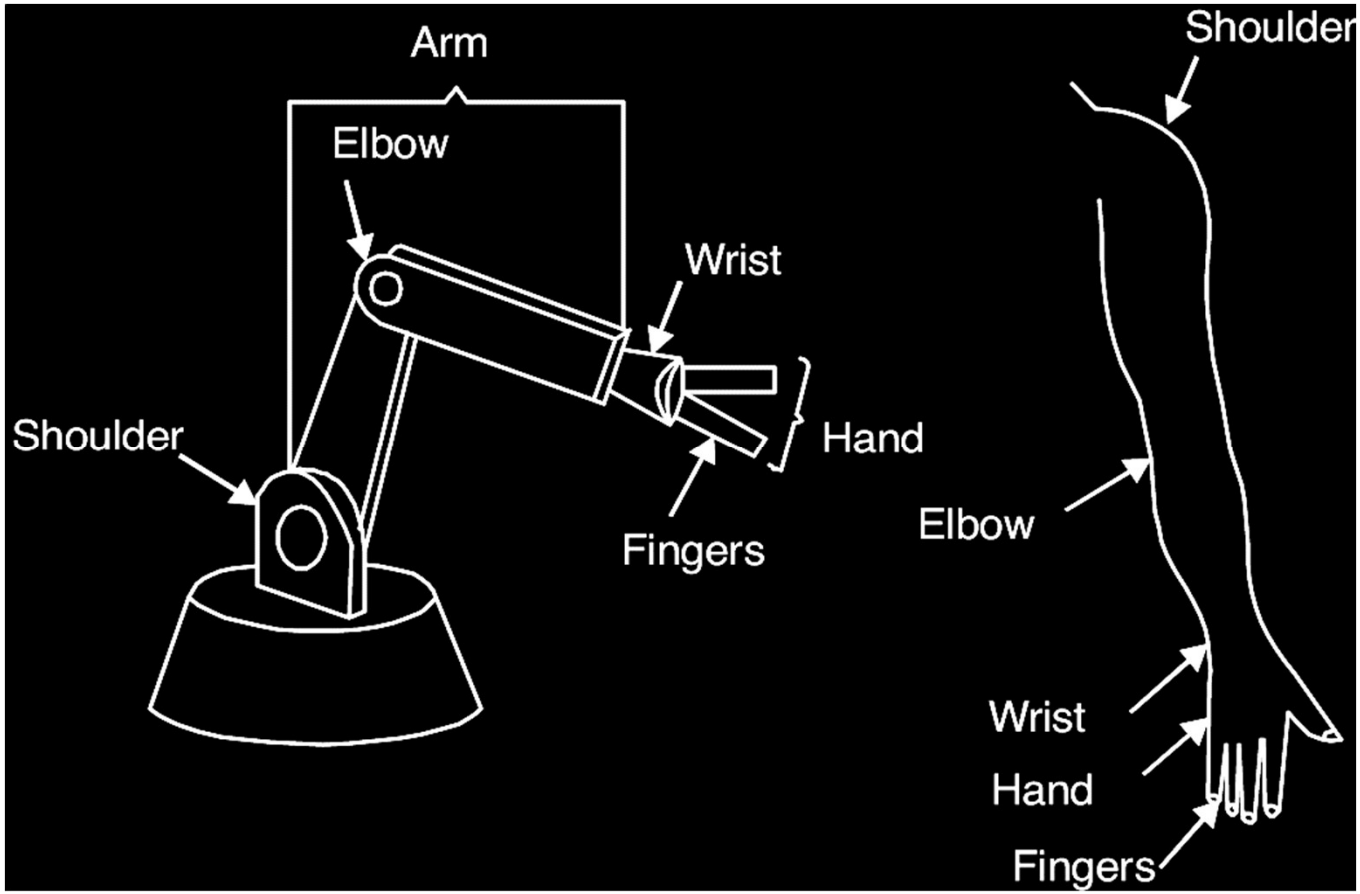
# COMPONENTS OF AN INDUSTRIAL ROBOT

- Sensors.
  - Sensors are used to collect information about the internal state of the robot or to communicate with the outside environment.
  - As in humans, the robot controller needs to know where each link of the robot is, in order to know the robot's configuration.
  - The state of the human body is determined because feedback sensors in human's central nervous system embedded in their muscle tendons send information to the brain. The brain uses this information to determine the length of their muscles, and thus, the state of their arms, legs, etc. The same is true for robots;
  - sensors integrated into the robot send information about each joint or link to the controller, which determines the configuration of the robot.
  - Robots are often equipped with external sensory devices such as a vision system, touch and tactile sensors, speech synthesizers, etc., which enable the robot to communicate with the outside world.

# Comparison of Parts of Robot and Human Being.

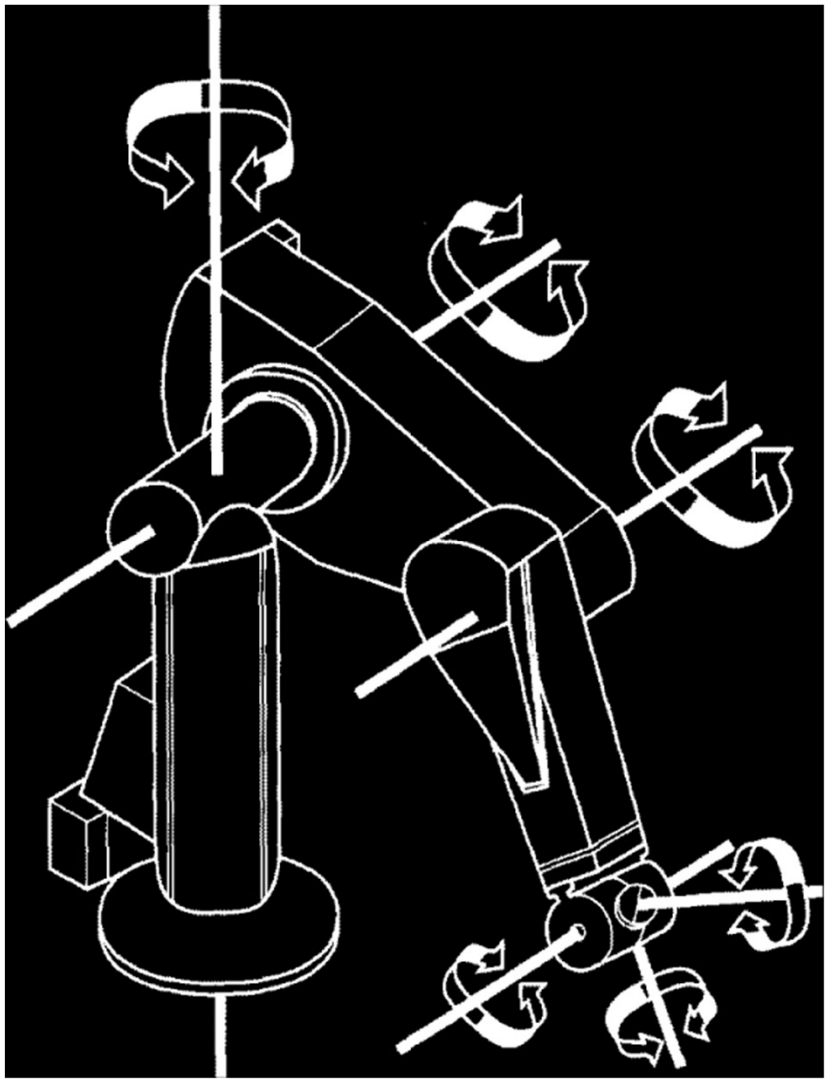


# Comparison of Human and Robot Manipulator



# ROBOT TERMINOLOGY

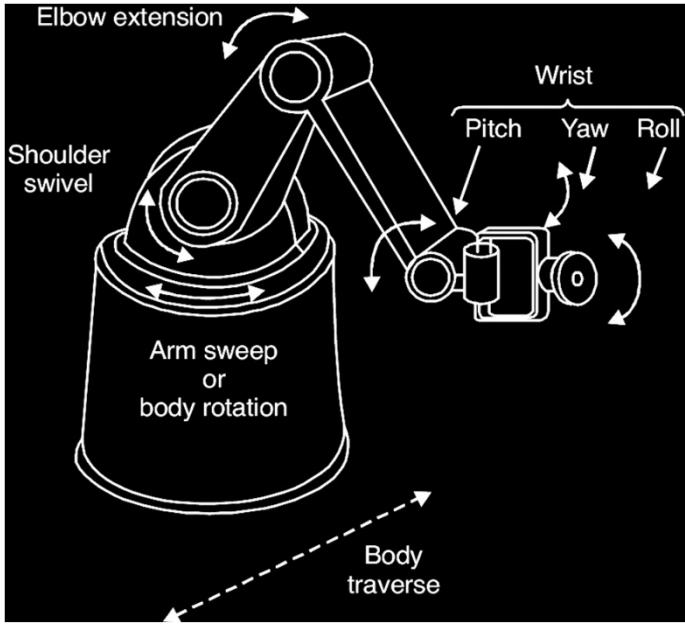
- Links and Joints: Links are the solid structural members of a robot, and joints are the movable couplings between them.
- Degree of Freedom (dof): Degree of freedom is the number of independent movements a robot can realize with respect to its base.
- The number of axes is normally the same as the number of degrees of freedom of the robot.
- Each joint on the robot introduces a degree of freedom. Each degree of freedom can be a slider, rotary, or other type of actuator.
- Robots typically have five or six degrees of freedom as shown in Figure



# ROBOT TERMINOLOGY

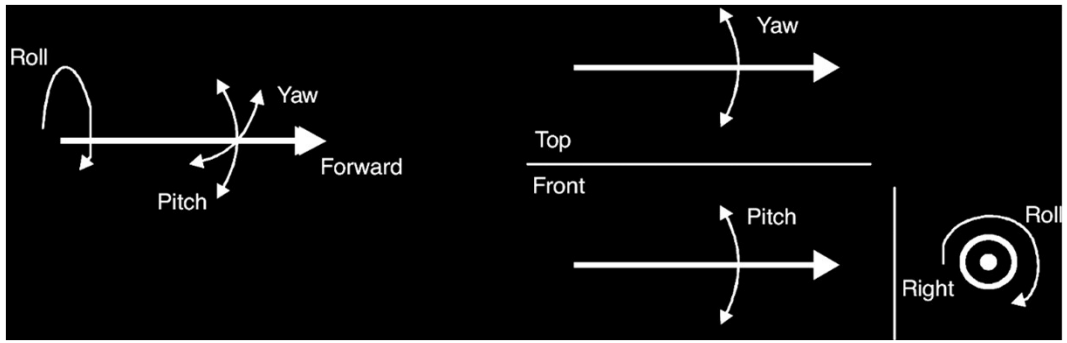
- Three of the degrees of freedom allow positioning in 3D space, while the other two or three are used for orientation of the end effector.
- Six degrees of freedom are enough to allow the robot to reach all positions and orientations in 3D space.
- Six degrees of freedom are commonly available with articulated arm and gantry robots.

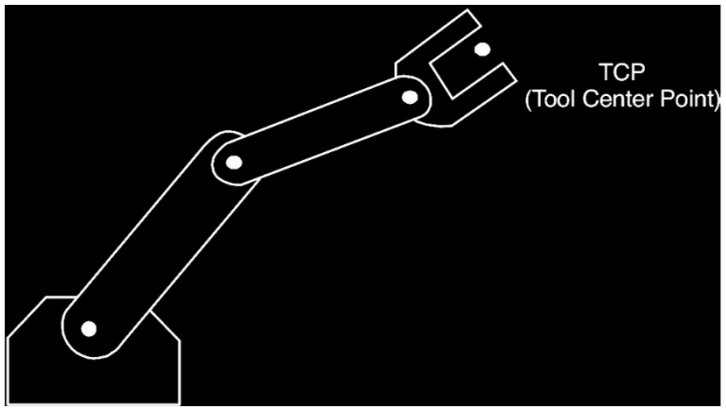
- Four degrees of freedom are typical with the selective compliance assembly robot arm (SCARA) configuration.
- Seven or more axes are used for some special applications.
- Figure shows an industrial robot with three basic degrees of freedom plus three degrees of freedom in the wrist and a seventh in its ability to move back and forth along the floor.



# ROBOT TERMINOLOGY

- Orientation Axis: Basically, if the tool is held at a fixed position, the orientation determines which direction it can be pointed in. Roll, pitch, and yaw are the common orientation axes used.

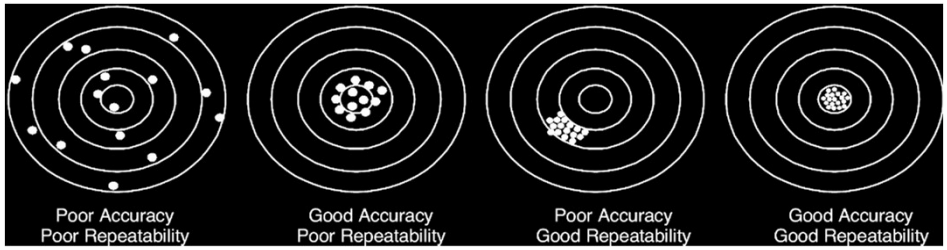



- Position Axis: The tool, regardless of orientation, can be moved to a number of positions in space.
- Tool Center Point (TCP): The tool center point is located either on the robot, or the tool as shown in Figure . Typically, the TCP is used when referring to the robots position, as well as the focal point of the tool (e.g., the TCP could be at the tip of a welding torch). The TCP can be specified in Cartesian, cylindrical, spherical, etc., co-ordinates depending on the robot. As tools are changed, one often reprograms the robot for the TCP.

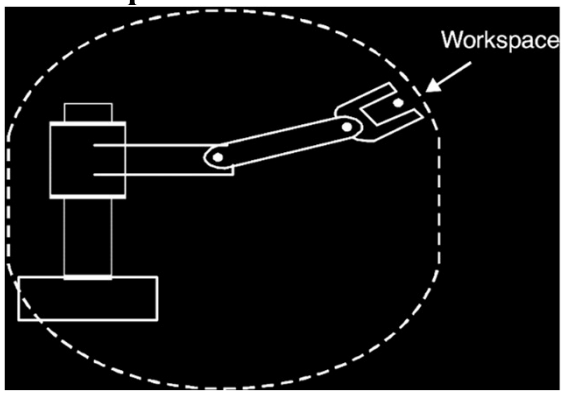
# ROBOT TERMINOLOGY

- Accuracy: Accuracy specification describes how close the arm will be when it moves to the desired point.
- Precision (validity): Precision is defined as how accurately a specified point can be reached. This is a function of the resolution of the actuators, as well as its feedback devices.
- Repeatability (variability): Repeatability is how accurately the same position can be reached if the motion is repeated many times (Refer to Figure). Suppose that a robot is driven to the same point 100 times. Because many factors may affect the accuracy of the position, the robot may not reach the same point every time, but will be within a certain radius from the desired point. The radius of a circle that is formed by this repeated motion is called repeatability.
- Repeatability is much more important than precision. If a robot is not precise, it will generally show a consistent error, which can be predicted and thus, corrected through programming.



# ROBOT TERMINOLOGY

- Work envelope/Workspace: A robot can only work in the area in which it can move. This area is called the work envelope.
- The work envelope is determined by how far the robot's arm can reach and how flexible the robot is.
- It is one of the most important characteristics to be considered in selecting a suitable robot.
- Various robot configurations have different work envelopes.
- For a Cartesian configuration, the reach is a rectangular-type space.
- For a cylindrical configuration, the reach is a hollow cylindrical space.
- For a polar configuration, the reach is part of a hollow spherical shape.
- Robot reach for a jointed-arm configuration does not have a specific shape. Figure  shows the work envelope of a robot.



# ROBOT TERMINOLOGY

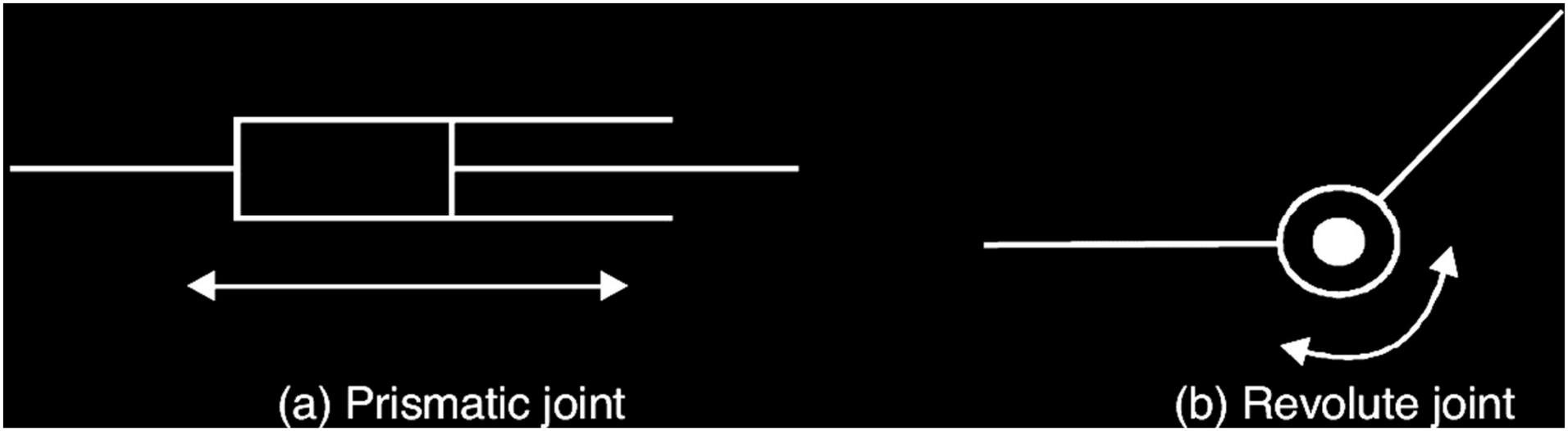
- Stability. Stability refers to robot motion with the least amount of oscillation. A good robot is one that is fast enough but at the same time has good stability.
- Speed. Speed refers either to the maximum velocity that is achievable by the Tool Center Point (TCP), or by individual joints. it should be done with great care.
- Payload. Payload is the weight a robot can carry and still remain within its specifications. For example, a robot's maximum load capacity may be much larger than its specified payload, but at the maximum level, it may become less accurate, may not follow its intended path accurately, or may have excessive deflections. The payload of robots compared with their own weight is usually very small.
- Reach. Reach is the maximum distance a robot can reach within its work envelope.
- Settling Time. During a movement, the robot moves fast, but as the robot approaches the final position it slows down, and slowly approaches at final position. The settling time is the time required for the robot to be within a given distance from the final position.

# ROBOTIC JOINTS

- A robot joint is a mechanism that permits relative movement between parts of a robot arm. The joints of a robot are designed to enable the robot to move its end effector along a path from one position to another as desired.
- The basic movements required for a desired motion of most industrial robots are:
  - Rotational movement: This enables the robot to place its arm in any direction on a horizontal plane.
  - Radial movement: This enables the robot to move its end-effector radially to reach distant points.
  - Vertical movement: This enables the robot to take its end-effector to different heights.
- Degrees of freedom, independently or in combination with others, define the complete motion of the end effector.
- These motions are accomplished by movements of individual joints of the robot arm. The joint movements are basically the same as relative motion of adjoining links.
- Depending on the nature of this relative motion, the joints are classified as Prismatic joints and Revolute joints

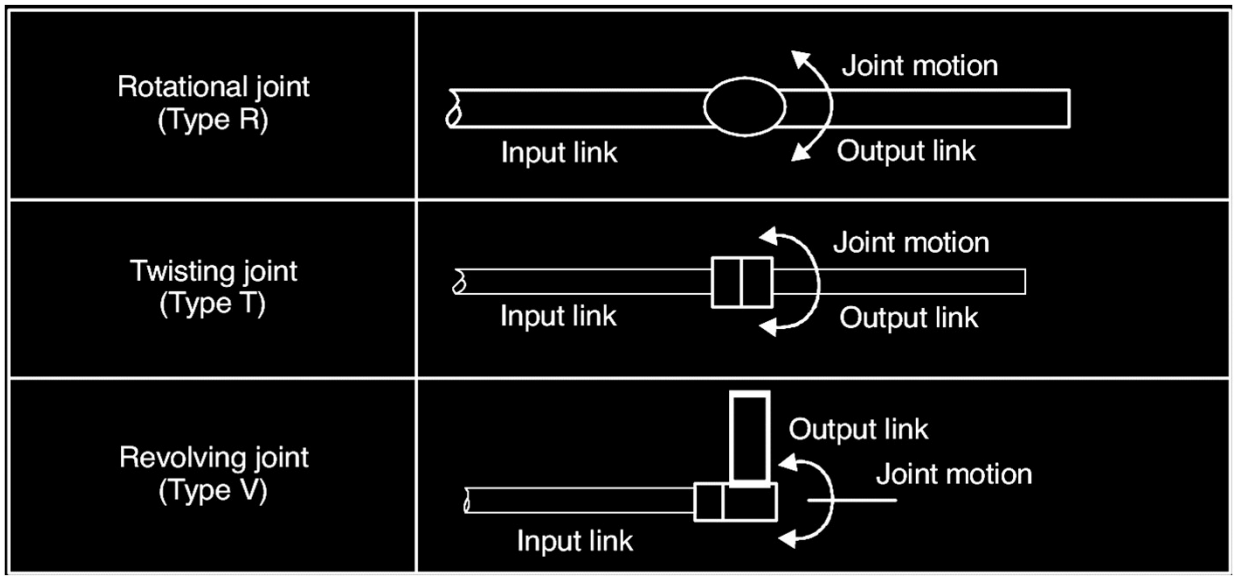
# ROBOTIC JOINTS

- Prismatic joints are also known as sliding as well as linear joints. They are called prismatic because the cross section of the joint is considered as a generalized prism. They permit links to make a linear displacement along a fixed axis.
- In other words, one link slides on the other along a straight line.
- These joints are used in gantry, cylindrical, or similar joint configurations.
- Revolute joints, the second type of joint is a revolute joint where a pair of links rotates about a fixed axis.



# ROBOTIC JOINTS

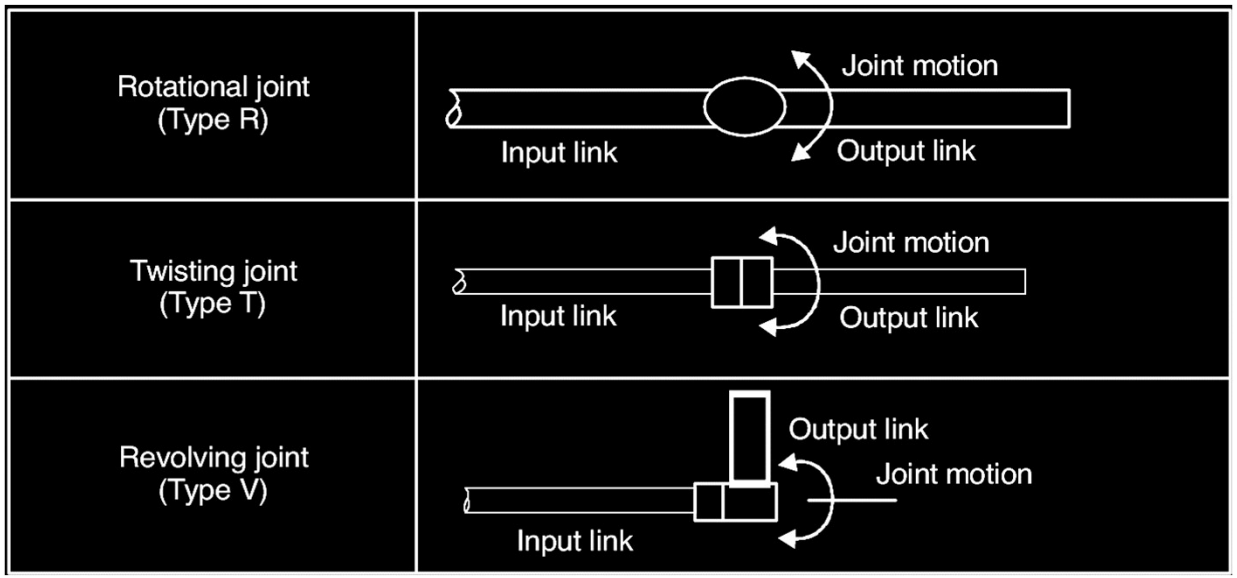
- The variations of revolute joints shown in Figure include: Rotational joint (R), Twisting joint (T) and Revolving joint (V)




- A rotational joint (R) is identified by its motion, rotation about an axis perpendicular to the adjoining links.
- Here, the lengths of adjoining links do not change but the relative position of the links with respect to one another changes as the rotation takes place.

# ROBOTIC JOINTS

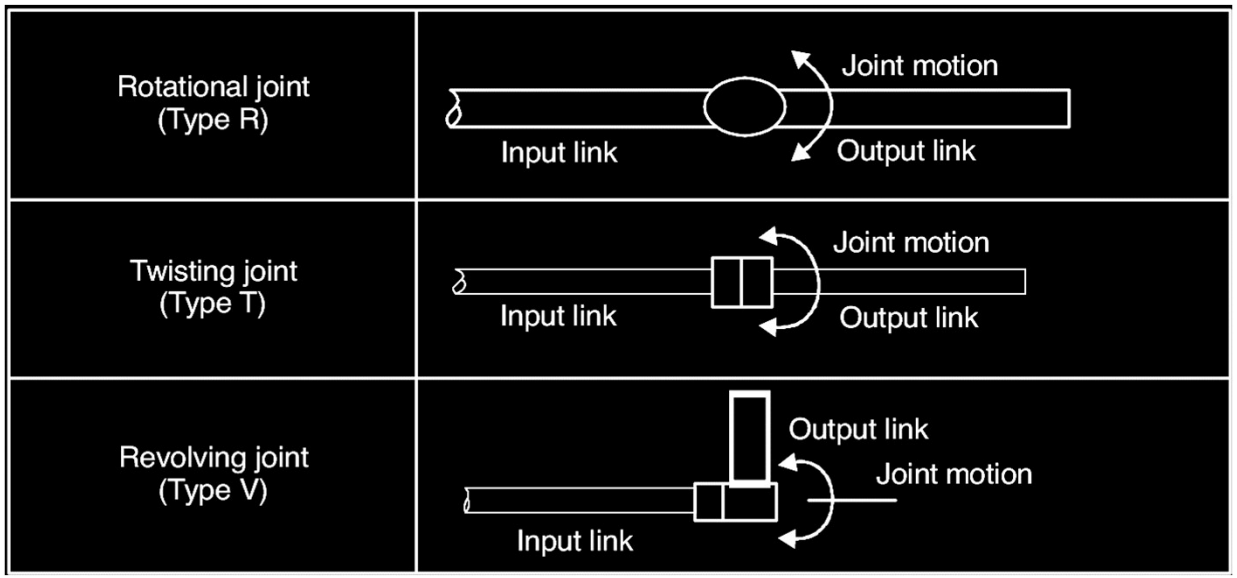
- The variations of revolute joints shown in Figure include: Rotational joint (R), Twisting joint (T) and Revolving joint (V)




- A twisting joint (T) is also a rotational joint, where the rotation takes place about an axis that is parallel to both adjoining links.

# ROBOTIC JOINTS

- The variations of revolute joints shown in Figure include: Rotational joint (R), Twisting joint (T) and Revolving joint (V)



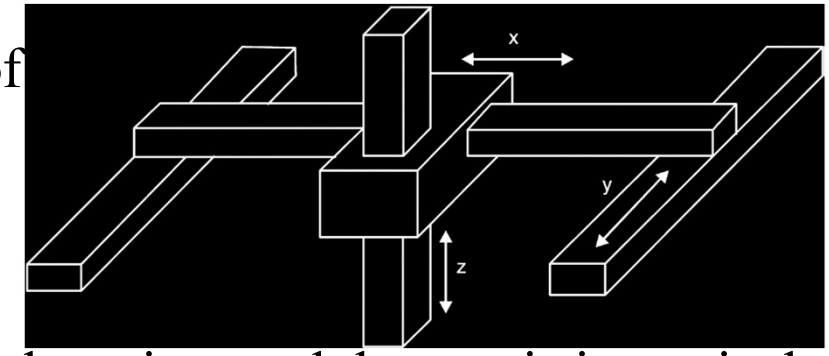

- A revolving joint (V) is another rotational joint, where the rotation takes place about an axis that is parallel to one of the adjoining links.
- Usually, the links are aligned perpendicular to one another at this kind of joint.
- The rotation involves revolution of one link about another.

# CLASSIFICATION OF ROBOTS

- Robots can be classified by four fundamental elements of operation:
  - Coordinate systems
  - Power source
  - Method of control
  - Programming method
- ROBOT CLASSIFICATION ON THE BASIS OF CO-ORDINATE SYSTEMS
- Structurally, robots are classified according to the wrist's co-ordinate system as follows:
  1. Cartesian/Rectilinear Robot
  2. Cylindrical Robot
  3. Spherical (Polar) Robot
  4. Articulated Robot
  5. SCARA Robot

# CLASSIFICATION OF ROBOTS

1. Cartesian/Rectilinear Robot: The axis or dimensions of these robots are 3intersecting straight lines (x-y-z) as shown in Figure




- The Cartesian co-ordinate robot is one that consists of a column and an arm.
- It is sometimes called an x-y-z robot, indicating the axis of motion.
- The x-axis is lateral motion, the y-axis is longitudinal motion, and the z-axis is vertical motion. Thus, the arm can move up and down on the z-axis; the arm can slide along its base on the x-axis; and then it can telescope to move to and from the work area on the y-axis.
- The features of a Cartesian robot (electronic equipment, control program) are same as those of CNC machine tools.
- Cartesian robots are not preferred in the industry because they do not have mechanical flexibility (i.e., they cannot reach objects that lie on the floor or that are not visible from their base). Also, speed of operation on a horizontal plane is usually less than the corresponding speed of robots with a revolute base.

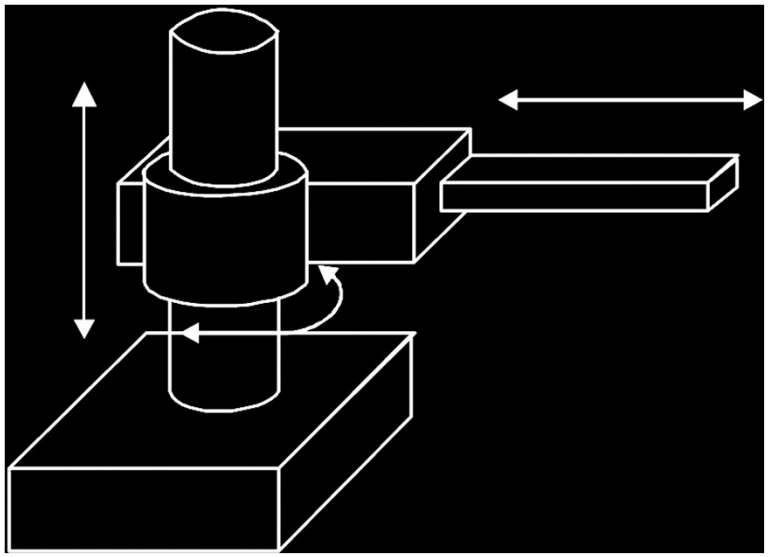
# CLASSIFICATION OF ROBOTS

Cartesian/Rectilinear Robot Applications

- These types of robots are used for:
  - Pick and place work
  - Application of sealant
  - Assembly operations
  - Handling machine tools
  - Arc welding
- Advantages
  - Ability to do straight line insertions into furnaces
  - Easy computation and programming
  - Most rigid structure for given length
- Disadvantages
  - Requires large operating volume
  - Exposed guiding surfaces require covering in corrosive or dusty environments
  - Can only reach front of itself

# CLASSIFICATION OF ROBOTS

2. Cylindrical Robot: Cylindrical robots have one angular dimension and 2 linear dimensions as shown in Figure



- The rigid structure of this system offers them the capability to lift heavy loads through a large working envelope.
- The main body of such a robot consists of a horizontal arm mounted on a vertical column. The column is mounted on a rotating base.
- The horizontal arm moves forward and backward on the direction of the longitudinal axis and it also moves up and down on the column.
- Column and arm are rotating on the base around the vertical axis.
- Resolution of a cylindrical robot is not constant, but depends on the distance between the column and the tool along the horizontal arm.
- These types of robots are used for:
  - Assembly operations
  - Handling machine tools
  - Spot-welding
  - Handling die-casting machines

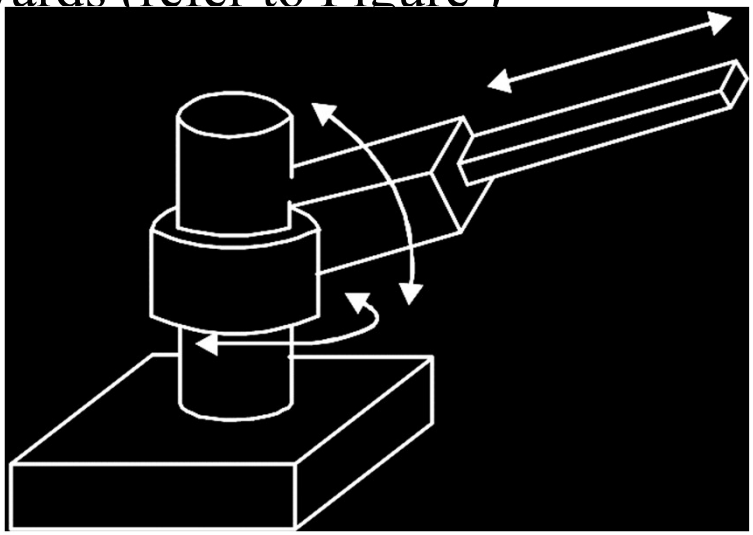
# CLASSIFICATION OF ROBOTS

Cylindrical Robot:

- Advantages
  - Can reach all around itself
  - Rotational axis easy to seal
  - Relatively easy programming
  - Rigid enough to handle heavy loads through large
  - working space
  - Good access into cavities and machine openings
- Disadvantages
  - Can’t reach above itself
  - Won’t reach around obstacles
  - Exposed drives are difficult to cover from dust and liquids
  - Linear axes is hard to seal

# CLASSIFICATION OF ROBOTS

3. Spherical (Polar) Robot: Robots of this type consist of a rotating base, a lifting part, and a telescopic arm, which moves inwards and outwards (refer to Figure )

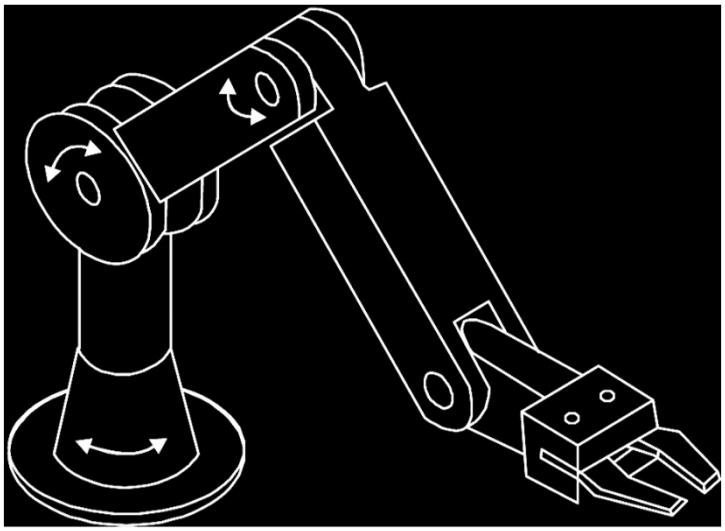


- The 2 dimensions of spherical robots are angles and the third is a linear distance from the point of origin.
- These robots operate according to spherical coordinates and offer greater flexibility.
- This design is used where a small number of vertical actions are adequate.
- These types of robots are used for:
  - Handlings at die casting or fettling machines
  - Handling machine tools
  - Arc/spot welding
- Advantages
  - Large working envelope
  - Two rotary drives are easily sealed against liquids/dust
- Disadvantages
  - Complex co-ordinates more difficult to visualize, control, and program
  - Exposed linear drive
  - Low accuracy

# CLASSIFICATION OF ROBOTS

4. Articulated Robot: Articulated robots consist of three constant parts (links) that are joined with revolute joints and are placed on a rotating base as shown in Figure.

- The kinematics layout is similar to a human arm.
- The tool (gripper) is similar to a palm and is adjusted to the lower part of the arm through the wrist.
- The elbow connects the lower and upper part of the arm and the shoulder connects the upper part of the arm with the base.
- Many times the shoulder joint has a rotational motion in the horizontal plane.



- The articulated robot has all three axes revolute, so the position resolution is completely dependent on the arm's position.
- The total accuracy of an articulated robot is small, because joint errors are accumulated at the end of the arm, which is at the wrist position.

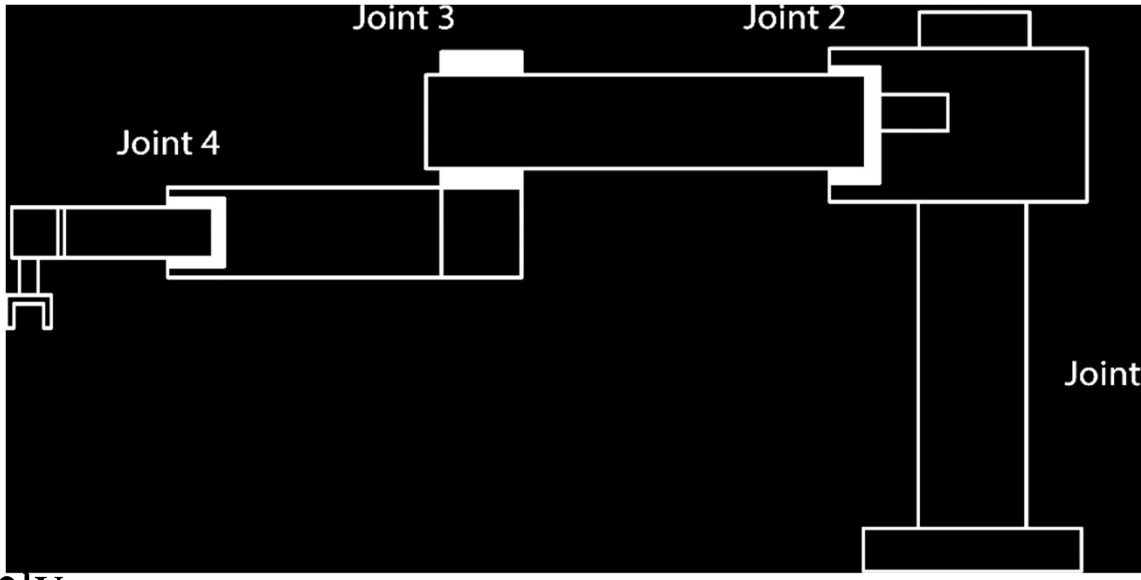
# CLASSIFICATION OF ROBOTS

Articulated Robot Applications

- These types of robots are used for:
  - Assembly operations
  - Die casting
  - Fettling machines
  - Gas welding
  - Arc welding
  - Spray-painting
- Advantages
  - High mechanical flexibility
  - They can move with high speed at three degrees of freedom
  - All joints can be sealed from the environment
- Disadvantages
  - Extremely difficult to visualize, control, and program
  - Restricted volume coverage
  - Low accuracy

# CLASSIFICATION OF ROBOTS

5. SCARA Robot: One style of robot that has recently become quite popular is a combination of the articulated arm and the cylindrical robot. This robot has more than three axes and is called a SCARA robot (refer to Figure )




- It is used widely in electronic assembly.
- The rotary axes are mounted vertically rather than horizontally.
- This configuration minimizes the robot's deflection when it carries an object while moving at a programmed speed.
- The acronym SCARA stands for Selective Compliance Assembly Robot Arm, a particular design developed in the late 1970s.

# CLASSIFICATION OF ROBOTS

SCARA robots are commonly used for:

- Pick and place work
- Assembly operations
- Application of sealant
- Handling machine tools

➢ Advantages

- High speed
- Excellent repeatability
- Good payload capacity
- Large work area for floor space
- Moderately easy to program

➢ Disadvantages

- Limited applications
- Two ways to reach point
- Difficult to program off-line
- Highly complex arm

# ROBOT CLASSIFICATION ON THE BASIS OF POWER SOURCE

- Actuators drive the mechanical linkages and joints of a manipulator, which can be various types of motors and valves.
- The energy for these actuators is provided by some power source such as hydraulic, pneumatic, or electric.
- There are three major types of drive systems for industrial robots:
  - Hydraulic drive system
  - Pneumatic drive system
  - Electric drive system

## 1. Hydraulic Drive System

- The most popular form of the drive system is the hydraulic drive system because hydraulic cylinders and motors are compact and allow for high levels of force and power, together with accurate control.
- These systems are driven by a fluid that is pumped through motors, cylinders, or other hydraulic actuator mechanisms.
- A hydraulic actuator converts forces from high pressure hydraulic fluid into the mechanical shaft rotation or linear motion.

- Hydraulic Drive System

Hydraulic robots are preferred in environments in which the use of electric drive robots may cause fire hazards, for example, in spray painting.

- Advantages
  - A hydraulic device can produce an enormous range of forces without the need for gears, simply by controlling the flow of fluid
  - Preferred for moving heavy parts
  - Preferred to be used in explosive environments
  - Self-lubrication and self-cooling
  - Smooth operation at low speeds
  - There is need for return line
- Disadvantages
  - Occupy large space area
  - There is a danger of oil leak to the shop floor

2. Pneumatic Drive System

- Pneumatic drive systems are found in approximately 30 percent of today's robots.
- These systems use compressed air to power the robots. Because machine shops typically have compressed air lines in their working areas, the pneumatically driven robots are very popular.
- These robots generally have fewer axis of movement and can carry out simple pick-and-place material-handling operations, such as picking up an object at one location and placing it at another location.
- These operations are generally simple and have short cycle times.
- The pneumatic power can be used for sliding or rotational joints.
- **Advantages**
  - Less expensive than electric or hydraulic robots
  - Suitable for relatively less degrees of freedom design
  - Do not pollute work area with oils
  - No return line required
  - Pneumatic devices are faster to respond as compared to a hydraulic system as air is lighter than fluid

2.Pneumatic Drive System

- Disadvantages
  - Compressibility of air limits control and accuracy aspects
  - Noise pollution from exhausts
  - Leakage of air can be of concern

3. Electric Drive System

- Electrical drive systems are used in about 20 percent of today's robots.
- These systems are servomotors, stepping motors, and pulse motors.
- These motors convert electrical energy into mechanical energy to power the robot.
- Compared with a hydraulic system, an electric system provides a robot with less speed and strength.
- Electric drive systems are adopted for smaller robots.
- Electrically driven robots are the most commonly available and used industrial robots.
- There are three major types of electric drive that have been used for robots:

3. Electric Drive System

- Stepper Motors: These are used mainly for simple pick and place mechanisms where cost is more important than power or controllability.
- DC Servos: For the early electric robots, the DC servo drive was used extensively. It gave good power output with a high degree of control of both speed and position.
- AC Servos: In recent years, the AC servo has taken over from the DC servo as the standard drive. These modern motors give higher power output and are almost silent in operation.
- As they have no brushes, they are very reliable and require almost no maintenance in operation.
- Advantages
  - Good for small and medium size robots
  - Better positioning accuracy and repeatability
  - Less maintenance and reliability problems

3. Electric Drive System

- Disadvantages
  - Provides less speed and strength than hydraulic robots
  - Not all electric motors are suited for use as actuators in robots
  - Require more sophisticated electronic controls and can fail in high temperature, wet, or dusty environments

## 3. ROBOT CLASSIFICATION ON THE BASIS OF METHOD OF CONTROL

- The motions of a robot are controlled by a combination of software and hardware that is programmed by the user.
- Robots are classified by control method into servo and non-servo robots.

### 1. Non-Servo Controlled Robots

- Non-servo control is a purely mechanical system of stops and limit switches, which are pre-programmed for specific repetitive movements.
- This can provide accurate control for simple motions at low cost.
- The motions of non-servo controlled robots are controlled only at their endpoints, not throughout their paths.
- Non-servo robots are often referred as “endpoint,” “pick and place,” or “limited sequence” robots.
- These robots are used primarily for materials transfer.

- Characteristics of non-servo robots include:
  - Relatively high speed possible due to smaller size of the manipulator
  - These robots are low cost and simple to operate, program, and maintain
  - These robots have limited flexibility in terms of program capacity and positioning capability

## 2. Servo Controlled Robots

- Servo control system is capable of controlling the velocity, acceleration, and path of motion, from the beginning to the end of the path.
- It uses complex control programs. These systems use programmable logic controllers (PLCs) and sensors to control the motions of robots.
- They are more flexible than non-servo systems, and they can control complicated motions smoothly.
- Sensors are used in servo-control systems to track the position of each of the axis of motion of the manipulator.
- Servo controlled robots are classified according to the method that the controller uses to guide the end-effector. These are: Point-to-point (PTP) control robot , Continuous-path (CP) control robot and Controlled-path robot

## (a) Point-to-Point Control Robot (PTP)

- A point-to-point robot is capable of moving from one discrete point to another within its working envelope.
- During point-to-point operation the robot moves to a position, which is numerically defined, and it stops there.
- The end effector performs the desired task, while the robot is halted. When task is completed, the robot moves to the next point and the cycle is repeated.
- Such robots are usually taught a series of points with a teach pendant. The points are then stored and played back.
- Applications: Point-to-point robots are severely limited in their range of applications. Common applications include:
  - Component insertion
  - Spot-welding
  - Hole drilling
  - Machine loading and unloading
  - Assembly operations

## (a) Point-to-Point Control Robot (PTP)

- An example of a typical point-to-point system is found in a spot welding robot. In this case, the robot moves until the point to be welded is positioned between the two electrodes of the welding pistol, and welding is performed. Then, the robot moves to another point, which is again welded. This procedure is repeated until all necessary points are welded.

## (b) Continuous-path (CP) Control Robot

- In a continuous-path robot, the tool performs its task, while the robot (its axes) is in motion, like in the case of arc welding, where the welding pistol is driven along the programmed path.
- All axes of continuous path robots move simultaneously, each with a different speed. The computer co-ordinates the speeds so that the required path is followed.
- The robot's path is controlled by storing a large number of spatial points in the robot's memory during the teach sequence.
- During teaching, and while the robot is being moved, the co-ordinate points in space of each axis are continually monitored and placed into the control system's computer memory.
- These are the most advanced robots and require the most sophisticated computer controllers and software development.
- Applications: Typical applications include:
  - Spray painting
  - Finishing
  - Gluing
  - Arc welding operations
  - Cleaning of metal articles
  - Complex assembly processes

## (c) Controlled-path Robot

- In controlled-path robots, the robot is moved along a computer-generated, predictable path as the robot travels from point to point.
- The computer-generated path may be a straight line with end-effector orientation or it may involve curved paths through successive points and/or gradual orientation changes.
- Good accuracy can be obtained at any point along the specified path.
- Only the start and finish points and the path definition function must be stored in the robot's control memory.
- The robot movements are more precise than with point-to-point programming are less likely to present a hazard to personnel and equipment.

# ROBOT SELECTION

Once the application is selected, a suitable robot should be chosen from the many commercial robots available in the market. The characteristics of robots generally considered in a selection process include:

- Size of class
- Degrees of freedom
- Velocity
- Drive type
- Control mode
- Repeatability
- Lift capacity
- Right-left, Up-down, and In-out traverse
- Yaw, pitch, and roll
- Weight of the robot

# ECONOMIC ANALYSIS FOR ROBOTICS

# INTRODUCTION

- The economy is an important issue while setting up a new automated firm.
- An economic analysis of the proposed engineering project must be done.
- On the basis of this analysis, the management usually decides the feasibility of the project.
- The economic analysis of the proposed robot project requires certain basic information about the project.
- This information includes the following:
  - Type of robot installation.
  - Cost of robot installation.
  - Production cycle time.
  - Savings and benefits resulting from the project.

# TYPE OF ROBOT INSTALLATION

- There are two basic categories of robot installation:
  - New application: Here we have to begin from the scratch. So we are in a need for new facilities, and the robot installation is the only facility to satisfy that need. In this case, the best alternative is selected after comparing various alternatives and the selected alternative should meet the investment criteria of the firm.
  - Existing application: Here, the robot is employed as a substitute for the human labour. In this scenario, the economic justification of the robot installation depends on how inefficient and costly the manual method is, rather than the absolute merits of the method.
  - In either of these situations, certain basic cost information is needed in order to perform the economic analysis.

# COST DATA REQUIRED FOR THE ANALYSIS

- The cost data required for the economic analysis involves the following:
  - Investment costs
  - Operating costs

**Investment costs**

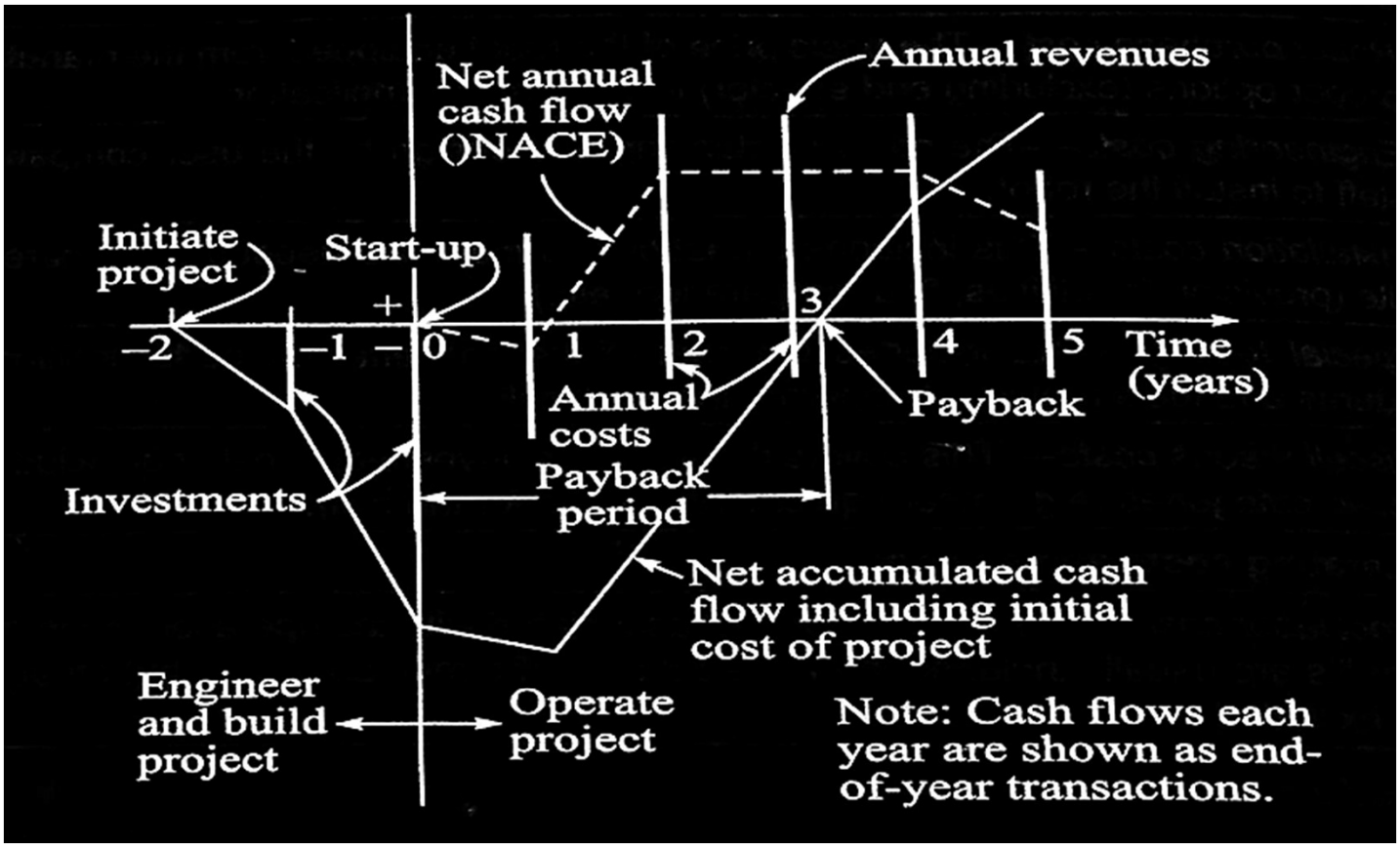
- ✓Robot purchase cost
- ✓Engineering cost
- ✓Installation cost
- ✓Special tooling cost
- ✓Miscellaneous cost

**Operating costs**

- ✓Direct labour cost
- ✓Indirect labour cost
- ✓Maintenance cost
- ✓Utilities cost
- ✓Training cost

# LIFE CYCLE OF CASH FLOW

**Net Annual Cash flow (NACF) = Revenues – Operating cost**



# METHODS OF ECONOMIC ANALYSIS

- The methods of economic analysis are listed below:
  - Payback (or payback period) Method
  - Equivalent Uniform Annual Cost (EUAC) Method
  - Return on Investment (ROI) Method

# PAYBACK PERIOD METHOD

- Payback period means the period of time that a project requires to recover the money invested On it.
- The payback period of a project is expressed in years and is computed using the following formula:

$$n = \frac{IC}{NACF}$$

Where n = Payback period

IC = Investment cost

NACF = Net Annual Cash Flow

**Assumptions:**

✓ NACF is + ve. [Revenues > Operating Cost]

✓ All cash flows occur at the end of the year.

✓ All the investments are done at beginning of the year.

✓ NACF is calculated at the end of the year.

- Most of the companies require a payback period of not more than two to three years.

# EUAC METHOD

- The equivalent uniform annual cost (EUAC) is the annual cost of owning an asset over its entire life. Equivalent uniform annual cost is often used by firms for capital budgeting decisions.
- Equivalent uniform annual cost is calculated as: $\frac{Asset\ Price \times Discount\ Rate}{1-(1+Discoun\ \ Rate)^{-Numb\ \ \ of\ Periods}}$
- This method converts all of the present, future investments and the cash flows into their equivalent uniform cash flows over the anticipated life of the project.
- This is accomplished by using various interest factors associated with engineering economic calculations.
- When the company is to be started it must select the minimum attractive rate of return (MARR). This is used to decide whether funding is to be made or not.
- If the sum of EUAC > 0 then the company is attractive. If the sum of EUAC < 0 then the company is non attractive.

# ROI METHOD

- This method determines the rate of returns on the proposed work based on estimated cost and revenues.
- To calculate ROI, the benefit (or return) of an investment is divided by the cost of the investment, and the result is expressed as a percentage or a ratio.
- The return on investment formula:

$$\text{ROI} = \frac{\text{Gain from the Investment} - \text{Cost of Investment}}{\text{Cost of Investment}}$$

- This rate of return is compared with company's MARR to determine whether the investment is justified or not.

- Robot Application

  Machine loading
  Pick and place operations
  Welding
  Painting
  Sampling
  Assembly operation
  Manufacturing
  Surveillance
  Medical applications
  Assisting disabled individuals
  Hazardous environments
  Underwater, space, and remote locations

# Robot Applications

- Industrial Applications
  - Industrial robots are used to assemble the vehicle parts. As the assembly of the machine parts is a repetitive task to be performed, the robots are conveniently used instead of using mankind (which is more costly and less précised compared to robots.).
  - The auto industry is the largest users of robots, which automate the production of various components and then help, assemble them on the finished vehicle.
  - Car production is the primary example of the employment of large and complex robots for producing products.
  - Robots are used in that process for the painting, welding and assembly of the cars. Robots are good for such tasks because the tasks can be accurately defined and must be performed the same every time, with little need for feedback to control the exact process being performed.

## ➢Material Transfer , Machine Loading And Unloading

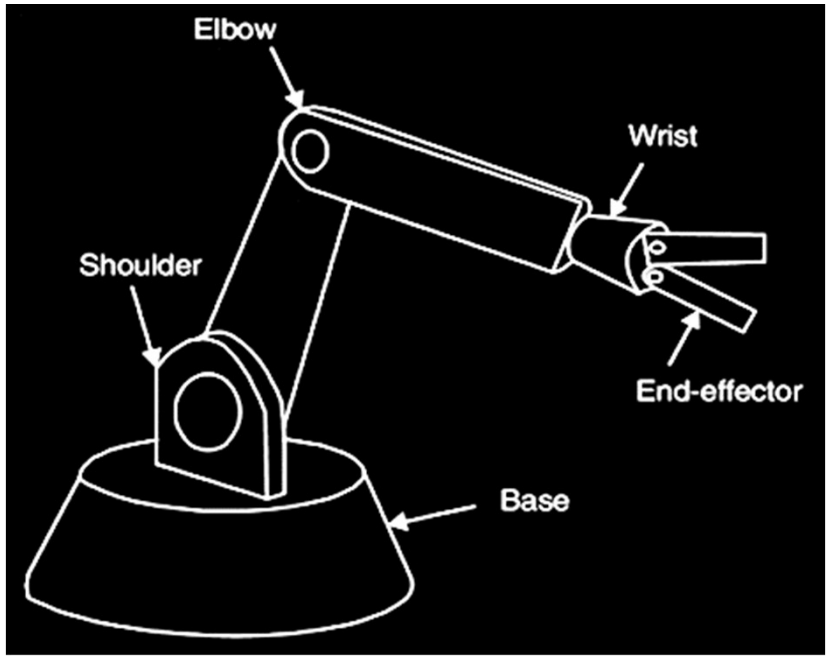
- There are many robot applications in which the robot is required to move a work part or other material from one location to another.
- The most basic of these applications is where the robot picks the part up from one position and transfers it to another position.
- In other applications, the robot is used to load and/or unload a production machine of some type.
- Material transfer applications are defined as operations in which the primary objective is to move a part from one location to another location. They are usually considered to be among the most straightforward of robot applications to implement. The applications usually require a relatively unsophisticated robot, and interlocking requirements with other equipment are typically uncomplicated. These are the pick ad place operations. The machine loading and unloading applications are material handling operations in which the robot is used to service a production machine by transferring parts to and/or from the machine.
- The other industrial applications of robotics include processing operations such as spot welding, continuous arc welding; spray coating, also in assembly of machine parts and their inspection.

- Medical Applications
  - Medical robotics is a growing field and regulatory approval has been granted for the use of robots in minimally invasive procedures.
  - Robots are being used in performing highly delicate, accurate surgery, or to allow a surgeon who is located remotely from their patient to perform a procedure using a robot controlled remotely.
  - More recently, robots can be used autonomously in surgery.
- Future Applications
  - Intelligence: The future robot will be about the task it performs based on high-level programming commands and feed back data from its environment.
  - Sensor capabilities: robot capabilities including will have vision, tactile sensing, and others. Progress is being made in the field of feedback and tactile sensors, which allow a robot to sense their actions and adjust their behavior accordingly. This is vital to enable robots to perform complex physical tasks that require some active control in response to the situation. Robotic manipulators can be very precise, but only when a task can be fully described

# END EFFECTORS

- In robotics, an "end effector" is a device or tool connected to the end of a robot arm to enable the robot to accomplish a specific task.
- Basically, it is a tool to grip, hold, and transport object and position them in a desired location. End effectors are the devices through which a robot interacts with the world around it, grasping and manipulating parts, inspecting surfaces, and working on them. As such, end effectors are among the most important elements of a robotic system.

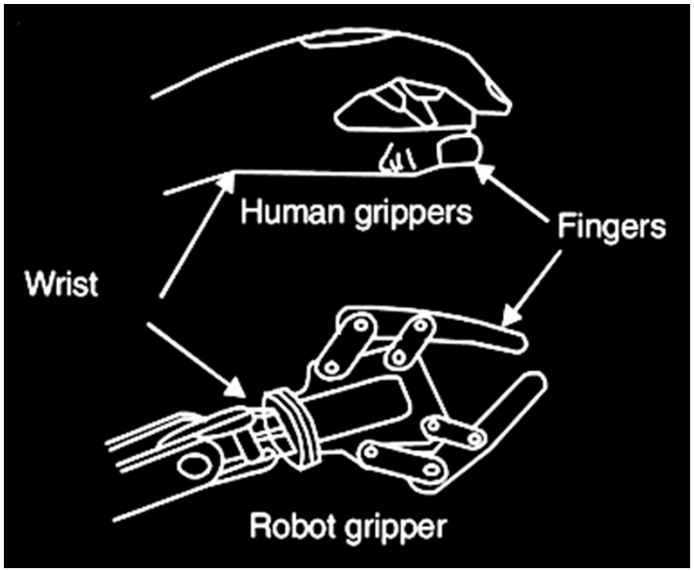
- Robot end effectors are also known as robot's hand, robotic peripherals, robotic accessories, robot tools or robotic tools, end-of-arm tooling (EOA), or end-of-arm devices.
- An end effector attached to the robot arm is shown in the figure.
- The two categories of end effectors are grippers and tools.



# GRIPPERS

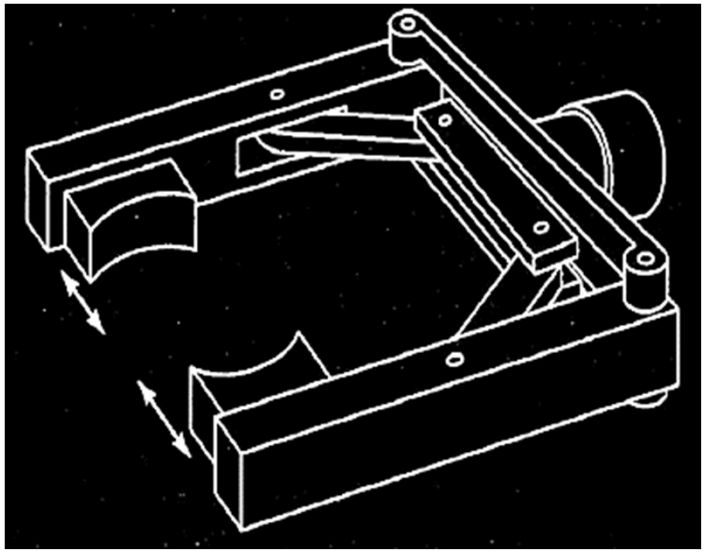
- Grippers are end effectors used to grasp and manipulate objects during the work cycle. The objects are usually work parts that are moved from one location to another in the cell.
- Grippers take advantage of point-to-point control and are used in applications for machine loading and unloading, material handling, and assembling.

- Grippers can be categorized as follows:
  - **Mechanical grippers**
    - ✓Single grippers
    - ✓Double grippers
  - **Other types of grippers**
    - ✓Vacuum grippers
    - ✓Magnetic grippers
    - ✓Adhesive grippers
    - ✓Hooks, scoops, and other miscellaneous devices



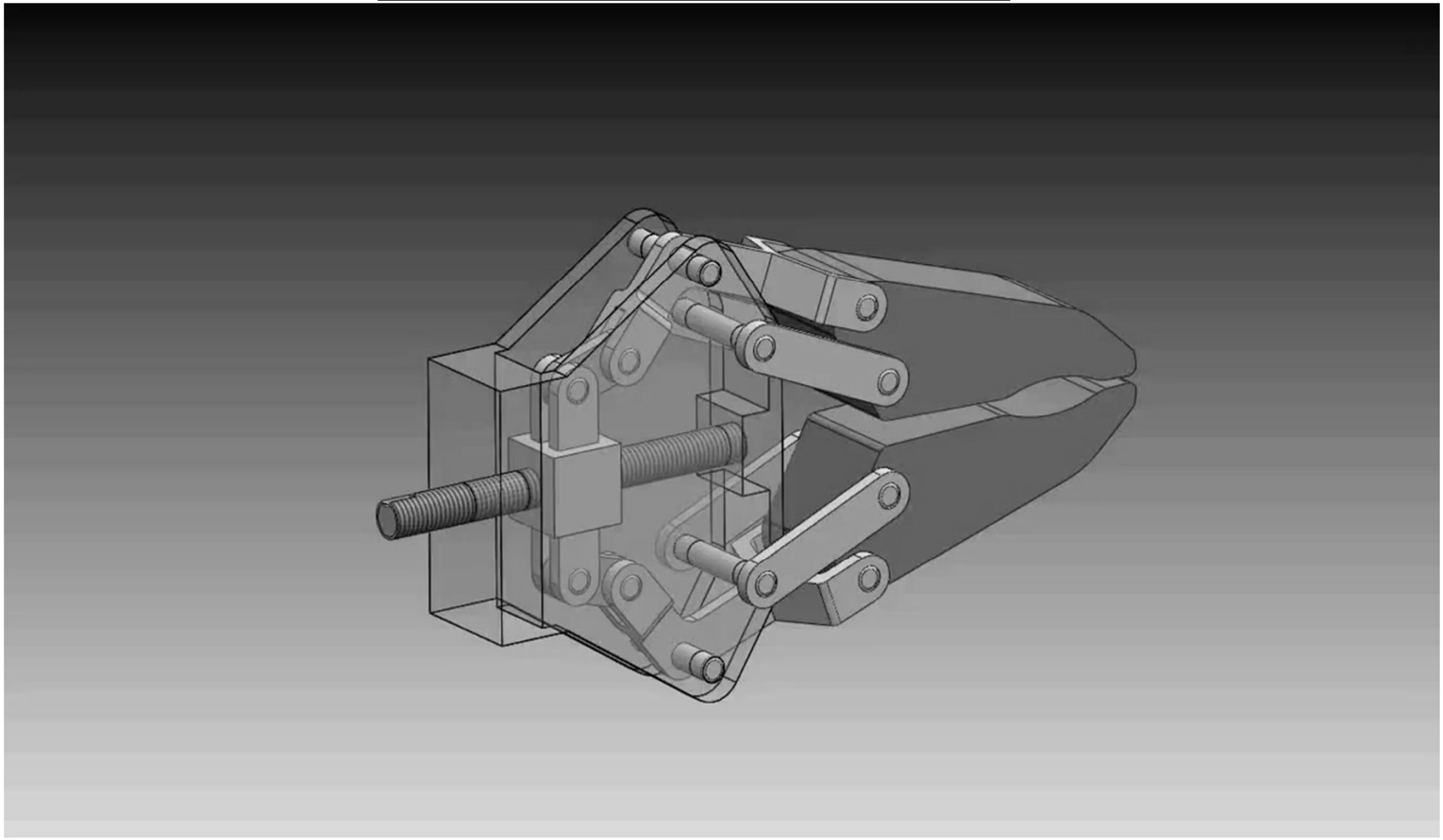
# MECHANICAL GRIPPERS

- A mechanical gripper is an end effector which consists of two or more mechanical fingers that can be actuated by the robot controller to grasp the workpart.
- A robot's hand can have a maximum of three fingers and these fingers, sometimes, are also called as jaws.
- Mechanical grippers can further be classified as follows:
  - Single grippers
  - Double grippers



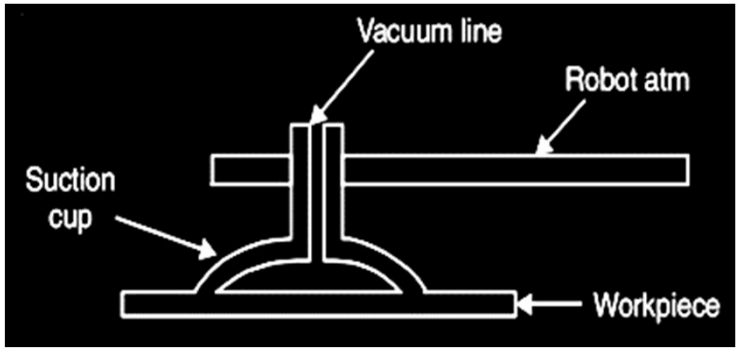
- Single grippers: These grippers have only one gripping device attached to the robot's wrist and are used mainly for pick and place applications.
- Double grippers: These grippers have two gripping devices attached to the robot's wrist and are used to handle two separate objects. These grippers are mainly used in machine loading & unloading applications as both of the grippers can be actuated independently.

# MECHANICAL GRIPPERS

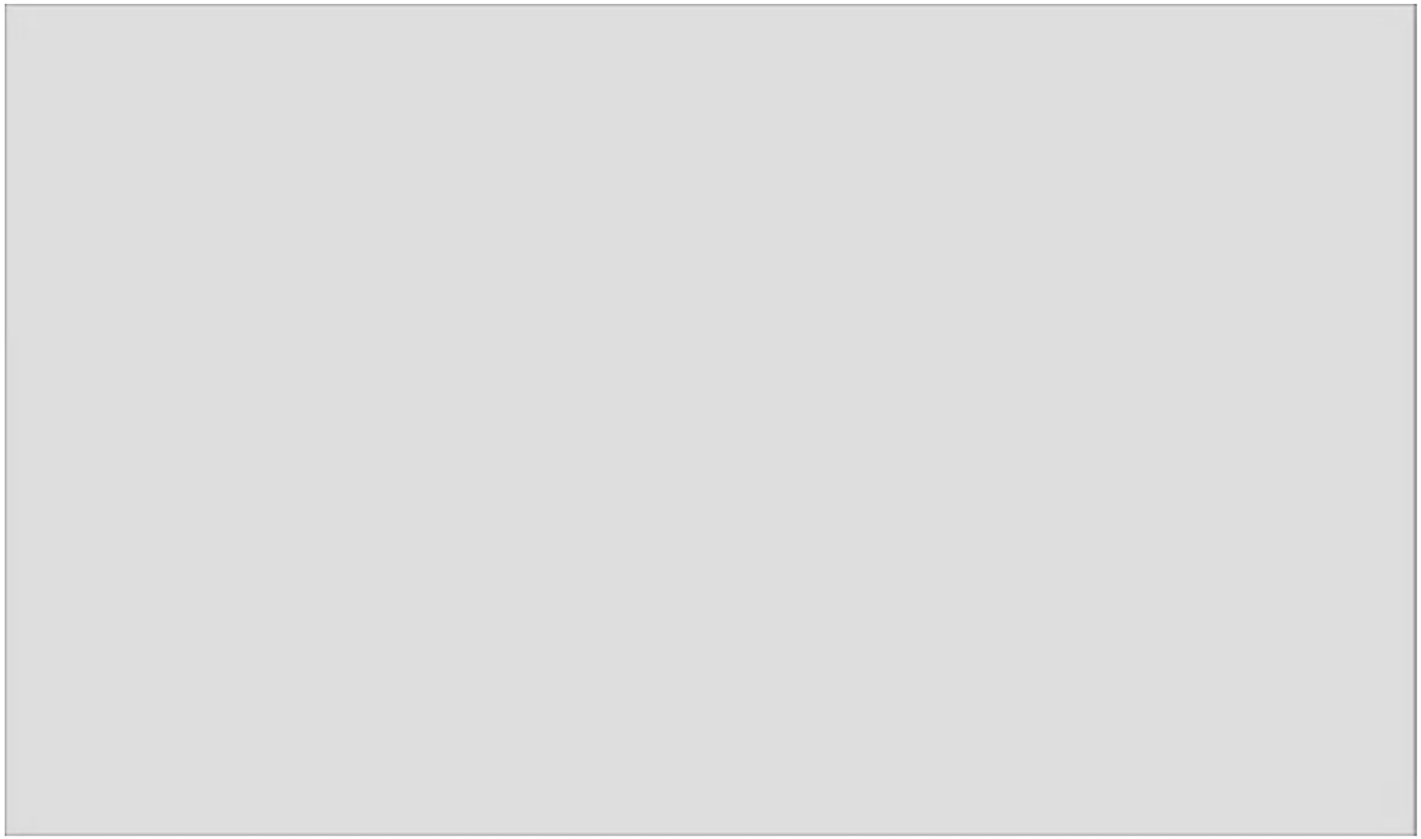


# VACUUM GRIPPERS

- Vacuum grippers are used in the robots for grasping the non-ferrous objects.
- It uses vacuum cups as the gripping device, which is also commonly known as suction cups. This type of grippers will provide good handling if the objects are smooth, flat, and clean. It has only one surface for gripping the objects. Most importantly, it is not best suitable for handling the objects with holes.
- Generally, the vacuum cups (suction cups) are in the round shape. These cups are developed by means of rubber or other elastic materials. Sometimes, they are also made up of soft plastics. Moreover, the vacuum cups are prepared of hard materials for handling the soft material objects.
- These devices are mainly used for holding objects like glass, ceramic tiles, etc. to avoid the marks on the object's surface as the use of mechanical grippers may produce scratches which ruin the aesthetic look of the object.



# VACUUM GRIPPERS



# VACUUM GRIPPERS

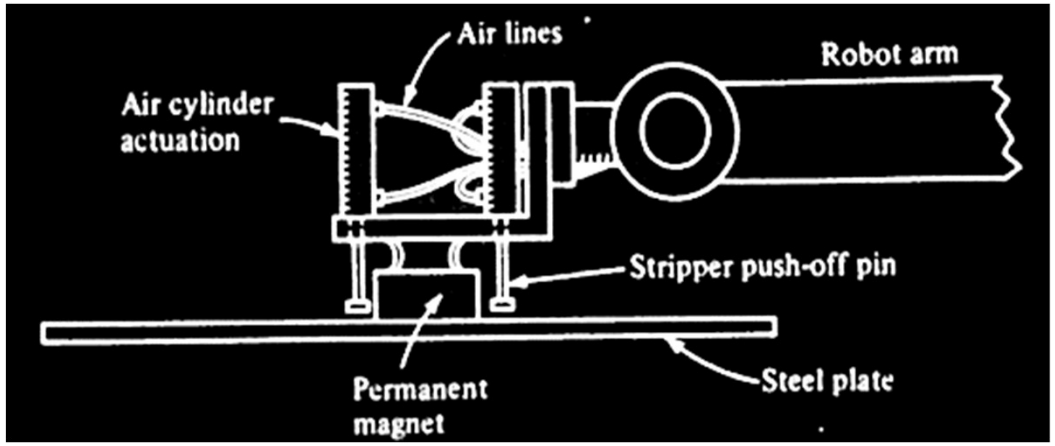
- **Advantages**
  - The gripper is light weight.
  - No danger of scratches or crushing of fragile objects.
  - Distribution of uniform pressure on the objects during operation.
  - It works and does not let the workpiece fall down during the power failure.
  - It requires only one surface of the object to grasp.
  - Many different materials can be used in grasping operation.
- **Disadvantages**
  - It works only on flat, clean and smooth surfaces.
  - The maximum force is limited by size of suction cups.
  - Time may be needed form vacuum creation.
  - It is not suitable for the curved surfaces or the surfaces with holes & cavities.
  - Sometimes, positioning may be inaccurate.

# MAGNETIC GRIPPERS

- Magnetic grippers are most commonly used in a robot as an end effector for grasping the ferrous materials.
- It is another type of handling the work parts other than the mechanical grippers and vacuum grippers.
- The magnetic grippers can be categorized as follows:
  - Magnetic grippers with electromagnets, and
  - Magnetic grippers with permanent magnets.
- **Electromagnetic gripper:**
  - It includes a controller unit and a DC power for handling the materials.
  - This type of grippers is easy to control, and very effective in releasing the part at the end of the operation than the permanent magnets.
  - If the work part gripped is to be released, the polarity level is minimized by the controller unit before the electromagnet is turned off.
  - This process will certainly help in removing the magnetism on the work parts. As a result, a best way of releasing the materials is possible in this gripper.

# MAGNETIC GRIPPERS

- Permanent magnets gripper: It does not require any sort of external power as like the electromagnets for handling the materials.
- After this gripper grasps a work part, an additional device called as stripper push-off pin will be required to separate the work part from the magnet. This device is incorporated at the sides of the gripper.
- The advantage of this permanent magnet gripper is that it can be used in hazardous applications like explosion-proof apparatus because of no electrical circuit. Moreover, there is no possibility of spark production as well.



# MAGNETIC GRIPPERS



# MAGNETIC GRIPPERS

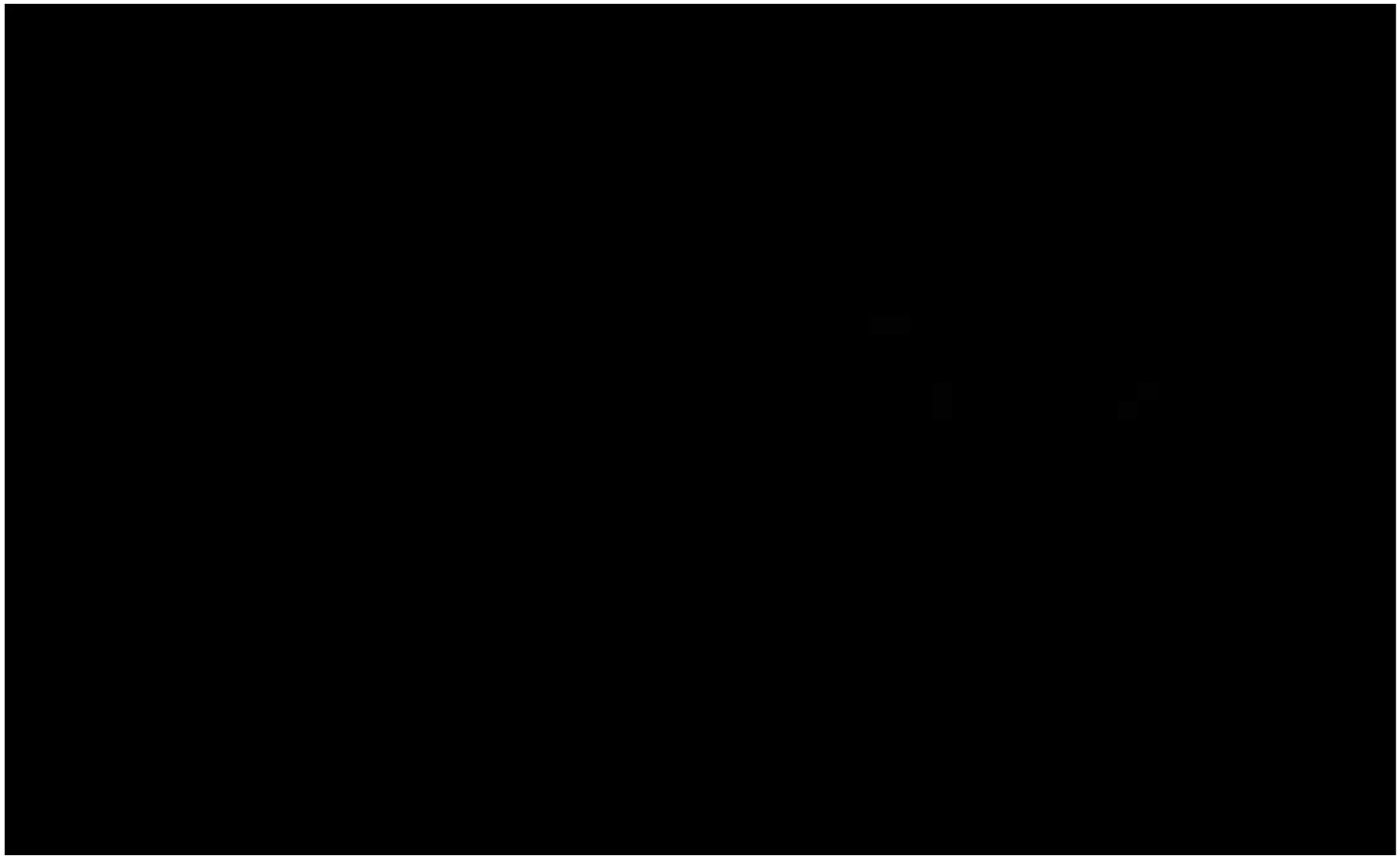
- **Advantages**
  - It can handle objects with holes.
  - It requires only one surface to grasp the object.
  - Pickup times are very fast.
  - It can tolerate the variations in object size.
  - It does not require separate designs for handling different size of materials.
- **Disadvantages**
  - Residual magnetism remaining in the object may cause problems.
  - Possible side slippage if moved quickly.
  - While picking up the sheet from the stack, it is possible that more than a single sheet is lifted (if the magnetic attraction tends to penetrate beyond the top sheet in the stack).
  - Sometimes, oil on the surface can reduce the strength of the gripper.
  - The machining chips may stick to the gripper during operation.

# ADHESIVE GRIPPERS

- In this gripper, the adhesive body is used to grasp the fabric objects. It is also very much suitable for carrying the light-weight materials. As like magnetic and vacuum grippers, it uses only one surface for gripping the objects.
- One disadvantage in this gripper design is that it will lose its strong adhesive substances when it is used continuously. As a result, the consistency of the gripper is reduced and leads to the improper grasping of objects.
- This disadvantage can be solved by constantly applying the adhesive substances on the gripper. It can be done by using a continuous ribbon connected to a feeding system, which is placed in the robot wrist. This process looks very much related to the operation of a typewriter ribbon system.



# ADHESIVE GRIPPERS



# HOOKS, SCOOPS, & INFLATABLE DEVICES

- **Hooks:** A hook gripper is incorporated in an operation for picking up the containers of parts. A hook that grips an object will require a handle for permitting the gripper to grasp it. Moreover, this type of grippers can be used in the part loading and unloading process in which the work parts hang from the overhead conveyors.
- **Scoops:** Scoop is used as an end effector for grasping the material in the form of powder or liquid. It handles some objects like molten metal, food, chemicals, and granular. There are two problems in this gripper such as:
  - The control of the material is very difficult.
  - It may also spill out the materials, while performing the process.
- **Inflatable bladder type grippers:** The inflatable bladder type gripper is made of rubber or some sort of elastic materials. It can be used to pick up the fragile objects by expanding the inflatable bladder. The mechanical gripper applies concentrated power for grasping a material, while this type of gripper applies a constant handling pressure in opposition to the object surface.

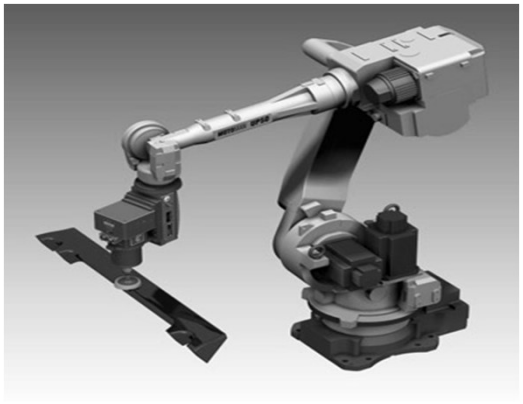
# GRIPPERS



# TOOLS AS END EFFECTORS

- A tool is mounted on the robot's wrist for carrying out several operations on the work parts instead of grasping it. A tool itself acts as an end effector when it is attached directly to the robot's wrist.
- In some applications, there will be a need for multi-tool task, and changing the tool all the time from the robot wrist will be highly difficult. As a result, a gripper is used in this process to grasp and manipulate the tool. It certainly helps the robot to handle several tools in an operation, and thus makes the multi-tooling function possible. Moreover, the time taken to change the tool is very low.







# TOOLS AS END EFFECTORS

- Some examples of tools used as end effectors in robot applications include:
  - Spot welding tools
  - Spray painting nozzle
  - Arc welding torch
  - Rotating spindle for operations such as:
    - ✓Drilling
    - ✓Routing
    - ✓Wire brushing
    - ✓Grinding
  - Liquid cement applicators
  - Water jet cutting tool
  - Heating torches

# ACTUATORS

- Actuators are the devices which provide the actual motive force for the robot joints.
- Actuators are the muscles of robots. If you imagine that the links and the joints are the skeleton of the robot, the actuators act as muscles, which moves or rotate the links to change the configuration of robots. The actuators must have enough power to accelerate and decelerate the links and to carry the loads, yet be light, economical, accurate, responsive, reliable and easy to maintain.
- Actuators in robotic system basically consists of :
  - A power supply.
  - A power amplifier.
  - A servomotor.
  - A transmission system.

# Actuator system

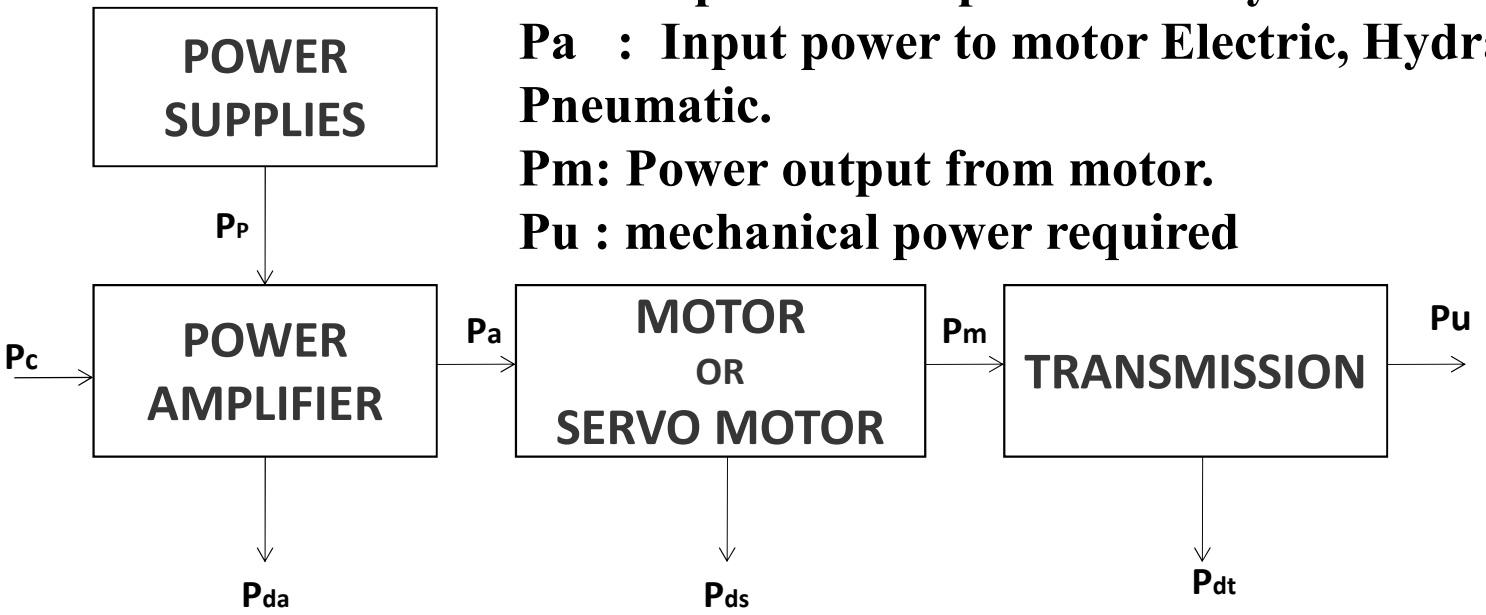
**Pp : Primary source of power (Electric, Press. fluid, compress. Air)**

**Pc : Input control power usually electric .**

**Pa : Input power to motor Electric, Hydraulic, or Pneumatic.**

**Pm: Power output from motor.**

**Pu : mechanical power required**



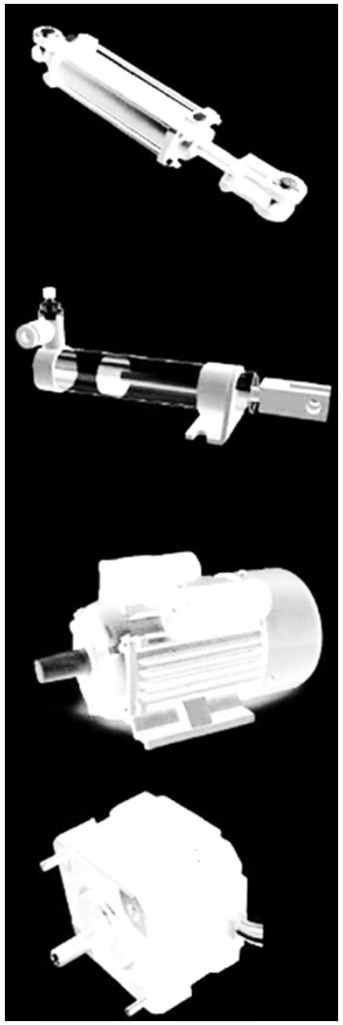

**$P_{ds}$, $P_{dt}$ , $P_{da}$ : Powers lost in dissipation for the conversion performed by the Amplifier, Motor, Transmission**

# CHARACTERISTICS OF AN ACTUATOR

- Load (e.g. torque to overcome own inertia)
- Speed (fast enough but not too fast)
- Accuracy (will it move to where you want?)
- Resolution (can you specify exactly where?)
- Repeatability (will it do this every time?)
- Reliability (mean time between failures)
- Power consumption (how to feed it)
- Energy supply & its weight.

# TYPES OF ACTUATORS

- Based on the source of Input Power actuators are classified in to three groups :
  1. Pneumatic Actuators.
     - These utilize pneumatic energy provided by the compressor and transforms it into mechanical energy by means of pistons or turbines.
  2. Hydraulic Actuators.
     - These Transform the energy stored in reservoir into mechanical energy by means of suitable pumps.
  3. Electric Actuators.
     - Electric actuators are simply electro-mechanical devices which allow movement through the use of an electrically controlled systems of gears

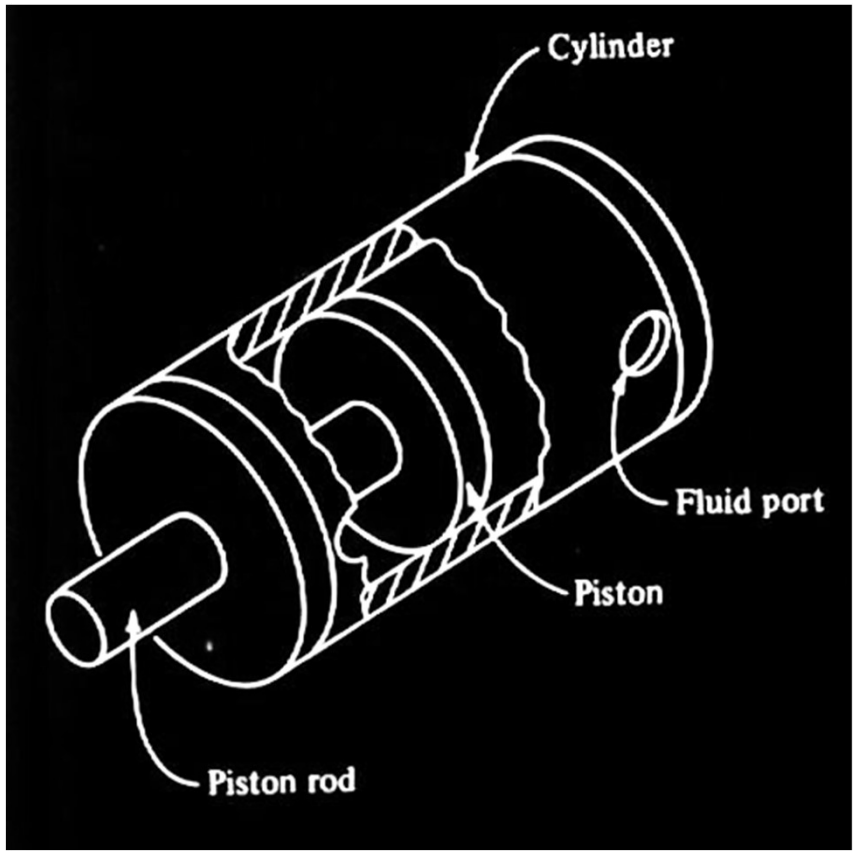


# *Pneumatic* and *Hydraulic* Actuators

- Both these actuators are powered by moving fluids.
- In the first case, the fluid is compressed air *and*
- In the second case, the fluid is pressurized oil.
- Pneumatic systems typically operate at about **100lb/in2**
- Hydraulic systems at **1000 to 3000 lb/in2**.
- Both Hydraulic and Pneumatic actuators are classified as
  - linear Actuators (Cylinders).
  - Rotary Actuators (Motors).

# *Pneumatic* and *Hydraulic* Actuators

***linear Actuators***



# *Pneumatic* and *Hydraulic* Actuators

***linear Actuators***

- The simplest power device could be used to actuate a linear joint by means of a moving piston.
- There are two relationships of particular interest when discussing actuators:
  1. The velocity of the actuator with respect to input power and
  2. Force of the actuator with respect to the input power.

# *Pneumatic* and *Hydraulic* Actuators

***linear Actuators***

$$V(t) = \frac{f(t)}{A} \qquad (1)$$

$$F(t) = P(t).A \qquad (2)$$

Where $V(t)$ is the velocity of the piston

$f(t)$ is the fluid flow rate

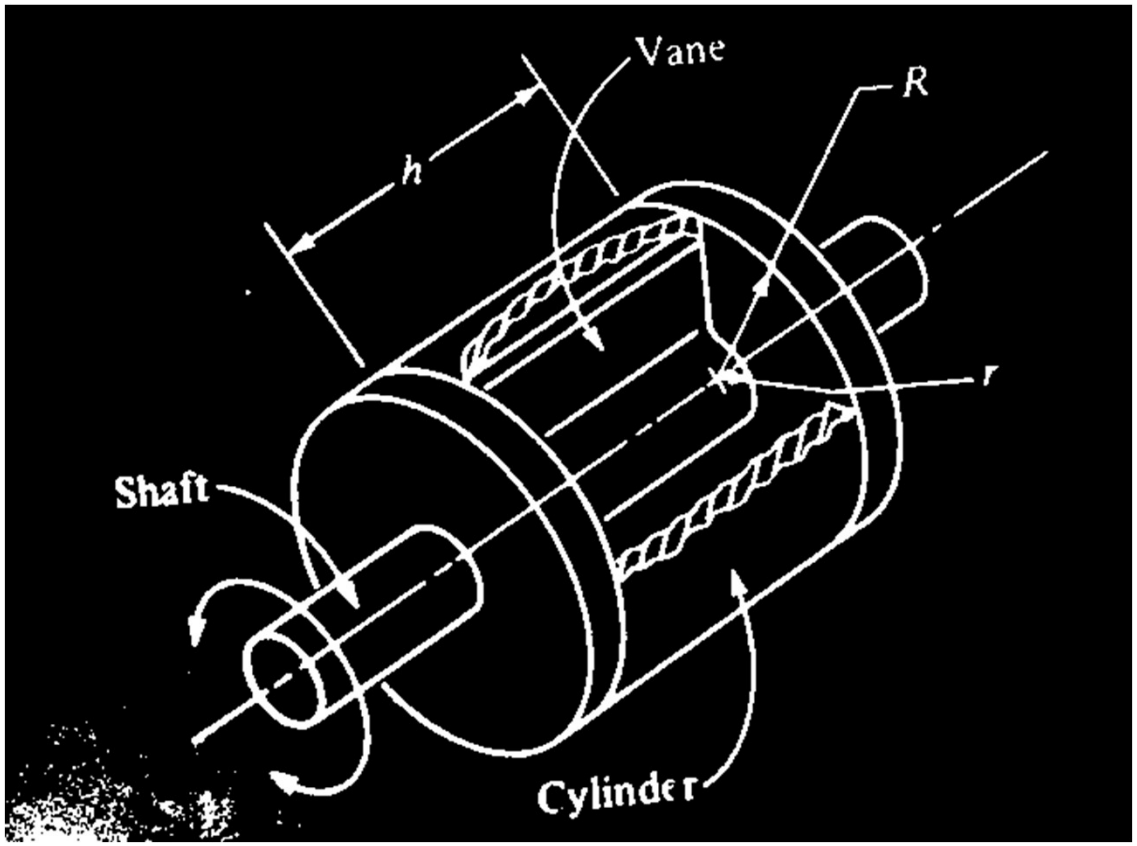
$F(t)$ is the force

$P(t)$ is the pressure of the fluid and

$A$ is the area of the piston

# *Pneumatic* and *Hydraulic* Actuators

***Rotary Actuators***



# *Pneumatic* and *Hydraulic* Actuators

***Rotary Actuators***

- There is a relationship of particular interest when discussing Rotary actuator:
- The angular velocity, ω, and Torque, T.

$$\omega(t) = \frac{2f(t)}{(R^2 - r^2)h}$$

$$T(t) = \tfrac{1}{2}P(t)h(R - r)(R + r)$$

- *R*, outer radius of the vane., *r*, inner radius., *h,* thickness of the vane., *ω,* angular velocity., *T,* torque.

# Advantages and limitations of Pneumatic actuators

## ADVANTAGES

- It is cheapest form of all actuators. Components are readily available and compressed air normally is an readily available facility in factories.
- Compressed air can be stored and conveyed easily over long distances.
- They have few moving parts making them inherently reliable and reducing maintenance costs.
- They have quick action and response time thus allowing for fast work cycles.
- No mechanical transmission is usually required.
- These systems are usually compact thus the control is simple e.g: mechanical stops are often used.

## LIMITATIONS

- Since air is compressible, precise control of speed and position is not easily obtainable unless much more complex electro mechanical devices are incorporated in to system.
- If mechanical stops are used resetting the system can be slow.
- If moisture penetrates the units and ferrous metals have been used then damage to individual components may happen.

# Advantages and limitations of Hydraulic actuators

## ADVANTAGES

- High efficiency and high power to size ratio.
- Complete and accurate control over speed position and direction of actuators are possible.
- No mechanical linkage is required i.e., a direct drive is obtained with mechanical simplicity.
- They generally have a greater load carrying capacity than electric and pneumatic actuators.
- Self lubricating and non corrosive.
- Hydraulic robots are more capable of with standing shock loads than electric robots.

## LIMITATIONS

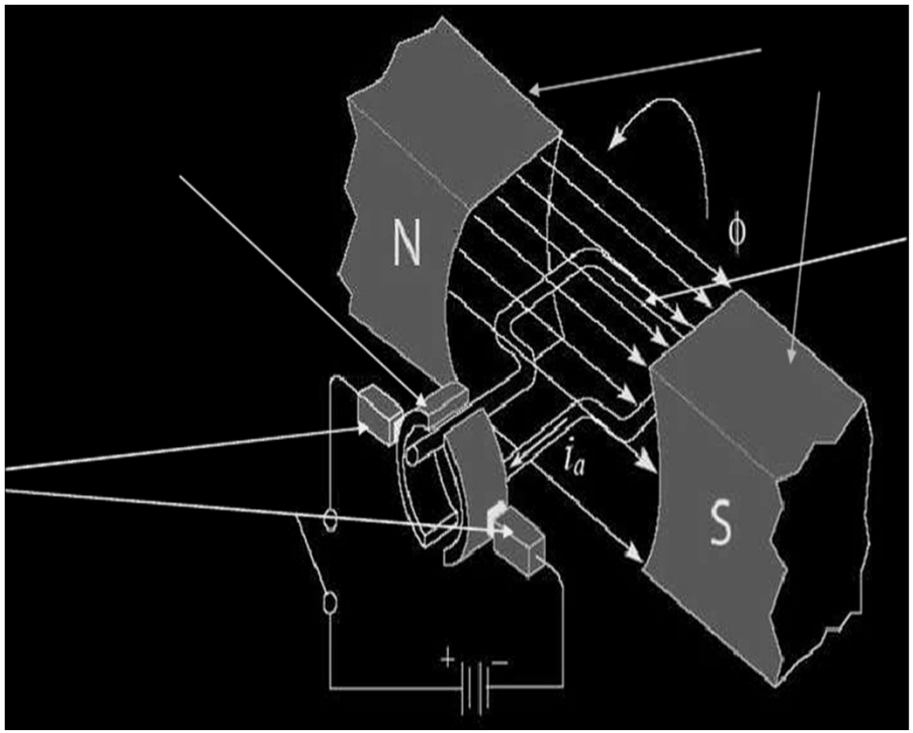
- Leakages can occur causing a loss in performance and general contamination of the work area. There is also a higher fire risk.
- The power pack can be noisy typically about 70 decibel or louder if not protected by an acoustic muffler.
- Changes in temp alter the viscosity of hydraulic fluid. Thus at low temperatures fluid viscosity will increase possibly causing sluggish movement of the robot.

# *Electric* and *Stepper* Motors

- There are a variety of types of motors used in robots. The most common types are Servomotors and Stepper motors.
- Electric actuators are simply electro-mechanical devices which allow movement through the use of an electrically controlled systems of gear.
- Electric motors usually have a small rating, ranging up to a few horsepower.
- They are used in small appliances, battery operated vehicles, for medical purposes and in other medical equipment like x-ray machines.
- Electric motors are also used in toys, and in automobiles as auxiliary motors for the purposes of seat adjustment, power windows, sunroof, mirror adjustment, blower motors, engine cooling fans.

STATOR

ROTATING
(COMMUTATOR)




ARMATURE

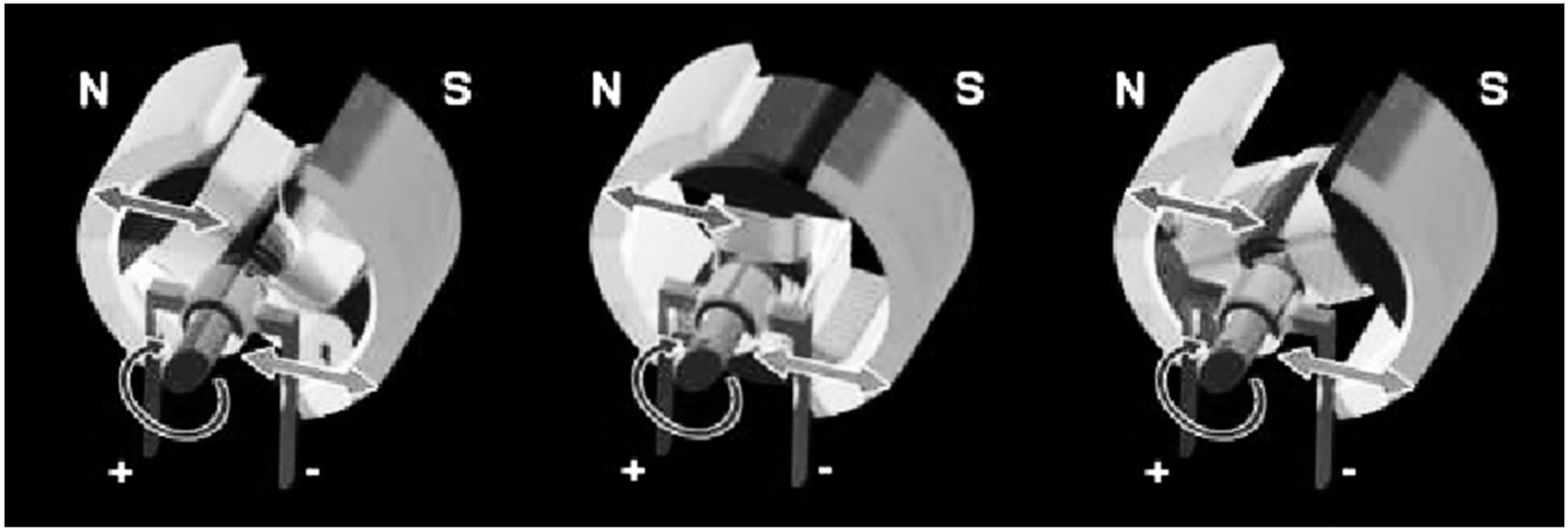
Brushes

# COMPONENTS OF DC ELECTRIC MOTOR

- The principle components of an electric motor are: North and south **magnetic poles** to provide a strong magnetic field. Being made of bulky ferrous material they traditionally form the outer casing of the motor and collectively form the stator.
- An ***armature,*** which is a cylindrical ferrous core rotating within the stator and carries a large number of windings made from one or more conductors.
- A ***commutator***, which rotates with the armature and consists of copper contacts attached to the end of the windings.
- ***Brushes*** in fixed positions and in contact with the rotating commutator contacts. They carry direct current to the coils, resulting in the required motion.
- ***DC motors :***In DC motors, the stator is a set of fixed permanent magnets, creating a fixed magnetic field, while the rotor carries a current. Through brushes and commutators, the direction of current is changed continuously, causing the rotor to rotate continuously.
- ***AC motors :*** These are similar to DC motors except that the rotor is permanent magnet, the stator houses the windings, and all commutators and brushes are eliminated.
- ***A Servomotor*** is a DC,AC, brushless, or even stepper motor with feedback that can be controlled to move at a desired speed (and consequently, torque), for a desired angle of rotation. To do this, a feedback device sends signals to the controller circuit of the servomotor reporting its angular position and velocity.

# COMPONENTS OF DC ELECTRIC MOTOR

- A simple DC electric motor: when the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation.
- The armature continues to rotate, When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats.



Since the field strength of the rotor is a function of the current through it, it can be shown that, for a DC servo motor,

$$T_m = K_m I_a$$

Where $T_m$ is the torque of the motor

$I_a$ is the current flowing through the armature

$K_m$ is the motor torque constant

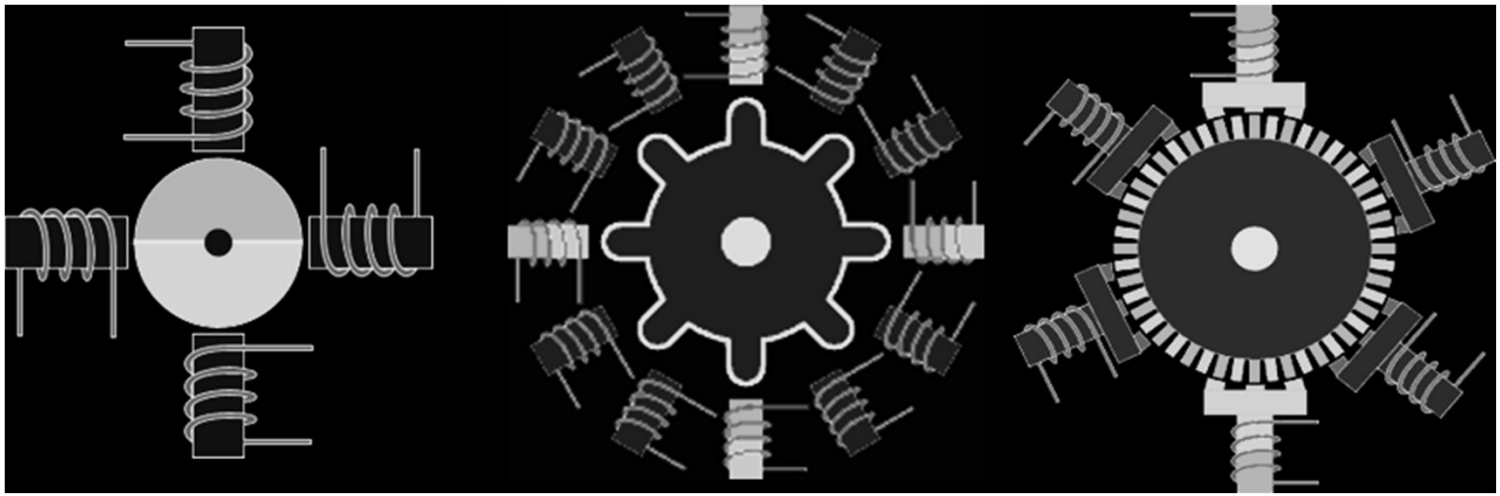
$$e_b = K_b \omega$$

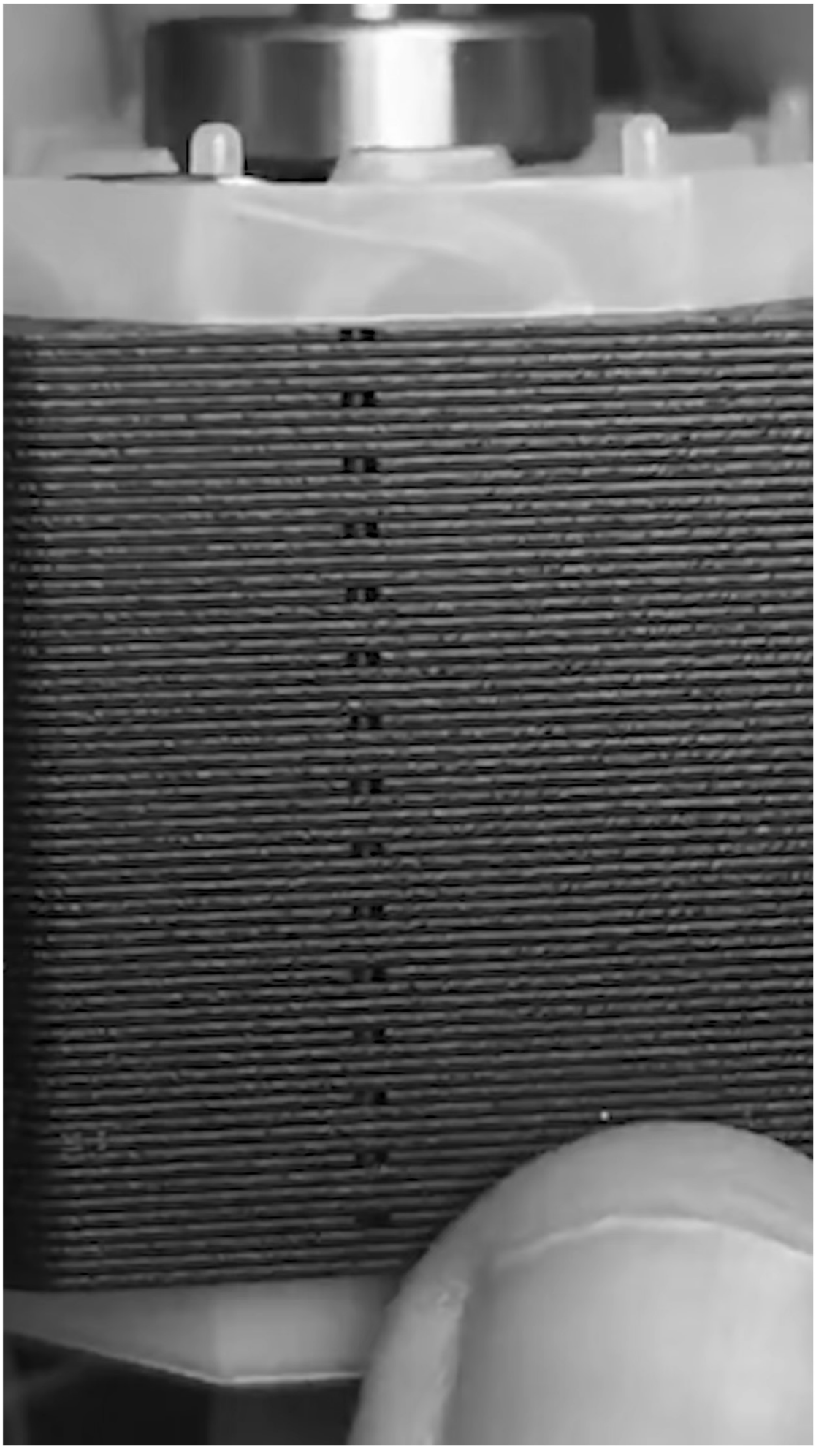
Where $e_b$ is the back emf, $K_b$ is called voltage constant of motor and $\omega$ is the angular velocity. The effect of back emf is to act as viscous damping for motor.

$$I_a = \frac{V_{in} - e_b}{R_a}$$

# STEPPER MOTOR

- When incremental rotary motion is required in a robot, it is possible to use **stepper motors.**
- A stepper motor possesses the ability to move a specified number of revolutions or fraction of a revolution in order to achieve a fixed and consistent angular movement.
- This is achieved by increasing the numbers of poles on both rotor and stator
- Additionally, soft magnetic material with many teeth on the rotor and stator cheaply multiplies the number of poles(reluctance motor)





# STEPPER MOTOR

The resolution (number of steps per revolution) of a stepper is determined by the number of poles in the stator and rotor. The relation between a stepper motor resolution and its step angle is given by

$$n = \frac{A}{360^{\circ}}$$

Where „n" is the resolution and „A" is the step angle.

# ADVANTAGES & LIMITATIONS OF *ELECTRIC* ACTUATORS

## ADVANTAGES

- Wide spread availability of power supply.
- The basic dive element in an electric motor is usually lighter than that for fluid power.
- High power conversion efficiency.
- No pollution of working environment
- The accuracy and repeatability of electric power driven robots are normally better than fluid power robots in relation to cost.
- Easily maintained and repaired.
- The drive system is well suited to electronic control.

## LIMITATIONS

- Electric actuators often require some sort of mechanical transmission system this increases the unwanted movement, additional power and may complicate control.
- Due to increased complexity of the transmission system additional cost is incurred for their procurement and maintenance.
- Electric motors are not intrinsically safe. They cannot therefore be used in for example explosive atmospheres.

# APPLICATIONS

- Stepper motors can be a good choice whenever controlled movement is required.
- They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism.
- These include :
  - printers
  - plotters
  - medical equipment
  - fax machines
  - automotive and scientific equipment etc.

# Comparison of actuating systems

| Hydraulic | Electric | Pneumatic |
|---|---|---|
| + Good for large robots and heavy payload | + Good for all size of Robots | + Many components are usually off-the-shelf |
| +Highest Power/Weight Ratio | +Better control, good for high precision robots | +Reliable components. |
| +Stiff system, High accuracy, better response | +Higher Compliance that Hydraulics | +No leaks or sparks |
| +No reduction gear needed | +Reduction gears used reduce inertia on the motor | +Inexpensive and simple |
| +Can work in wide range of speeds without difficulty | +does not leak, good for clean room | +Low pressure compared to hydraulics |
| +Can be left in position without any damage | +Reliable, low maintenance | + Good for on-off applications and for pick and place |

# Comparison of actuating systems

| Hydraulic | Electric | Pneumatic |
|---|---|---|
| - May leak. Not fit for clean room application | +Can be spark-free. Good for explosive environment. | +Complaint systems. |
| -Requires pump, reservoir, motor, hoses etc. | -Low stiffness | -Noisy systems. |
| -Can be expensive and noisy, requires maintenance. | -Needs reduction gears, increased backlash, cost, weight, etc. | - Require air pressure, filter, etc. |
| -Viscosity of oil changes with temperature | -Motor needs braking device when not powered. Otherwise, the arm will fail. | -Difficult to control their linear position |
| -Very susceptible to dirt and other foreign material in oil | - | -Deform under load constantly |
| -Low compliance | - | -Very low stiffness. Inaccurate response. |
| -High torque, High pressure, large inertia on the actuator. | - | -Lowest power to weight ratio |