UNIT – II

COMPONENTS OF THE INDUSTRIAL ROBOTICS

2.1 BASIC COMPONENTS OF A ROBOT SYSTEM

The four basic components of a robot system are:

1. Manipulator
2. Sensory Devices
3. Controller
4. Power Conversion Unit

Manipulator: The manipulator consists of a series of rigid members called links connected by joints. Motion of a particular joint cause subsequent links attached to it to move. The motion of the joint is accomplished by actuator mechanism.

The manipulator itself may be thought of as being composed of three dimensions.

- The major linkages
- The minor linkages (Wrist components)
- The end effector (gripper or tool)

The major linkages are the set of joint-link pairs that grossly position the manipulator in space. Usually they consist of three sets (counting from the base of the robot).

The minor linkages are those joints and links associated with the fine positioning of the end effector.

The end effector may be a tool that does a function such as welding, drilling or it may be some type of gripper to hold the objects.

Sensory Devices: For proper control of the manipulator we must know the state of each joint, i.e., its position, velocity and acceleration. To achieve this, a sensory element must be incorporated into the joint-link pair.

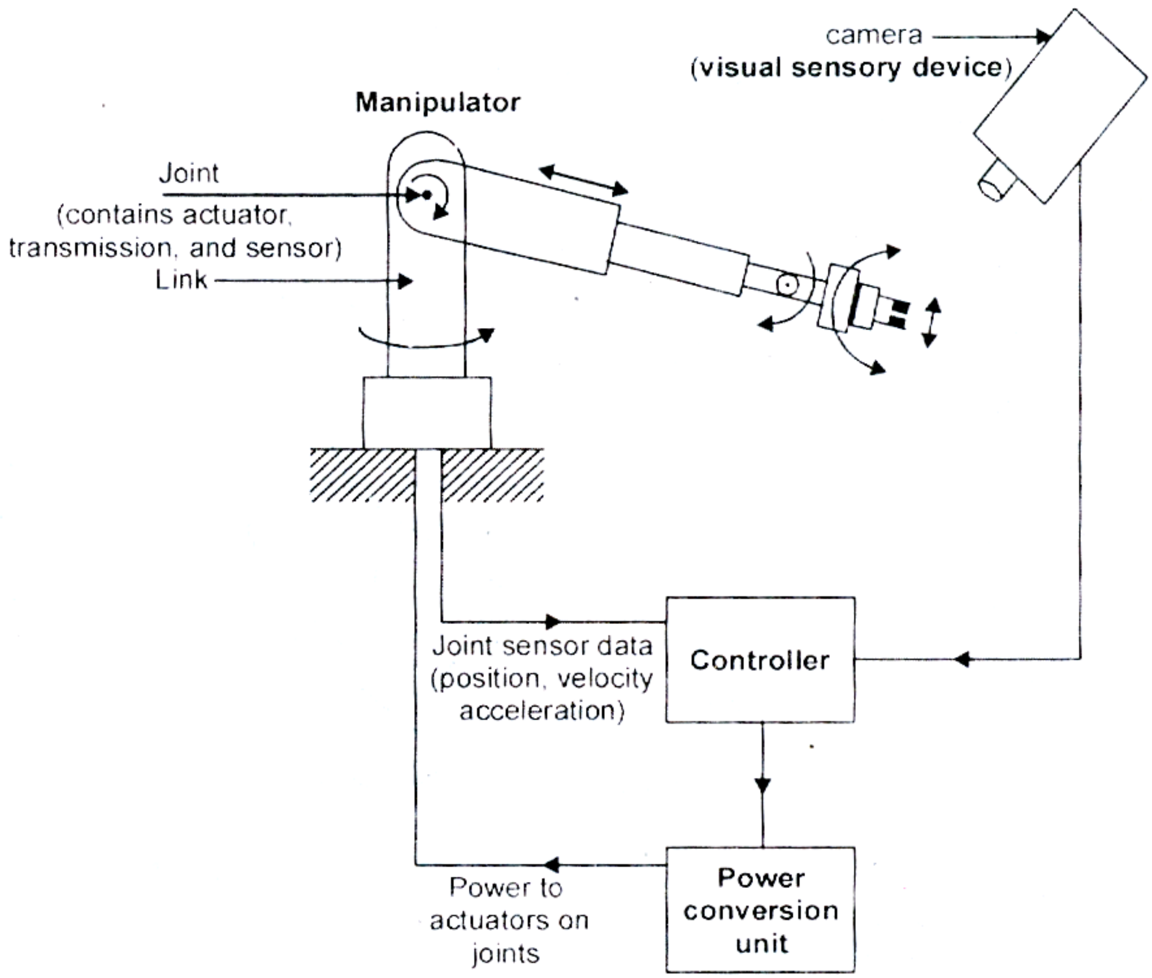


Figure: Components of a robot system

Other types of sensors may also be included in a robot system. Figure shows a camera which is part of a vision system. This sensor along with its associated electronics and control is used to locate a particular object in its field of view. Once found, it relays the coordinate of the object to the robots controller so that the robot can position its gripper over the object in order to pick it up.

Controller: The controller provides the intelligence to cause the manipulator to perform a specified task. Essentially, the controller consists of:

- A memory to store data defining the positions of where the arm is to move and other information related to the proper sequencing of system (i.e., a program)
- A sequencer that interprets the data stored in memory and then utilizes the data to interface with other components of the controller.
- A computational unit that provides the necessary computations to aid the sequencer.
- An interface to obtain the sensory data such as the position of each joint or information from vision system into the sequencer.
- An interface to transfer sequencer information to the power conversion unit so that actuations can eventually cause the joints to move in the desired manner.
- Some sort of control unit for the operator to use in order to demonstrate positions and control the robot (teach pendant)

Power Conversion Unit: The power conversion unit contains the components necessary to take a signal from the sequencer (either digital or analog) and convert into a meaningful power level so that the actuators can move.

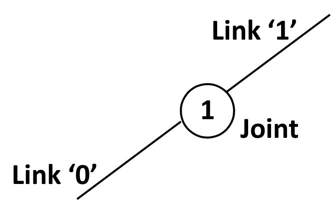
2.2 ROBOT ANATOMY

A robot is constructed with a series of joints and links. Robot anatomy is concerned with the types and sizes of these joints and links.

Joints and Links

A joint is that, which provides the relative motion between the two parts of a body. Each joint in a robot is provided with one degree of freedom (motion along one direction).

A link is a rigid element. Every joint is connected by two links. One link is called the input link and the other is called output link. The purpose of joint is to provide a controlled relative movement between the input and output links.

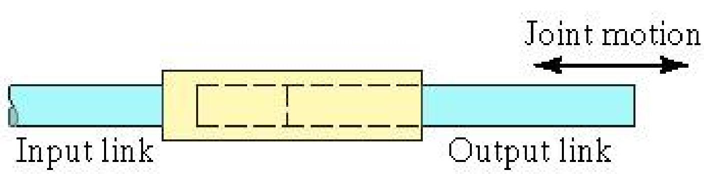


Types of joints

Joints used in the robots are classified into the following five types.

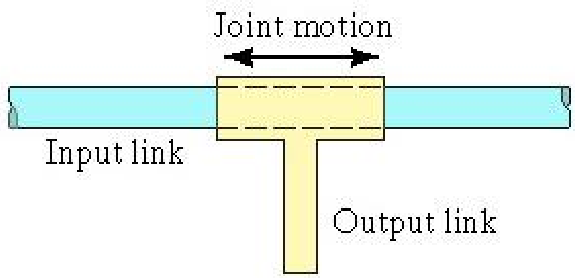
1. Linear Joint (L – type joint):

The relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links being parallel.



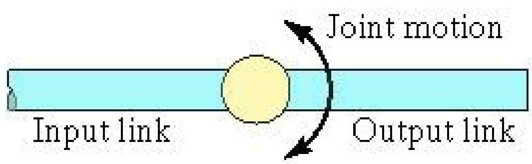
2. Orthogonal Joint (O – type joint):

This is also a translational sliding motion, but the input and output links are perpendicular to each other during the move.



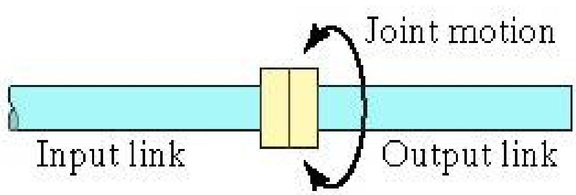
3. Rotational joint (R – type joint):

This type of joint provides rotational relative motion, with the axes of rotation perpendicular to the axes of the input and output links.



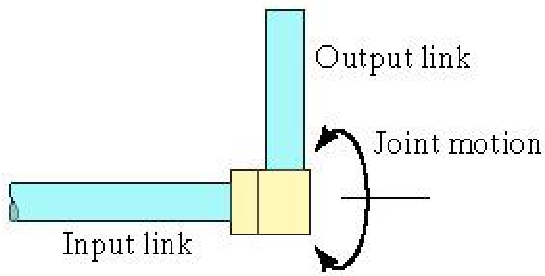
4. Twisting joint (T – joint):

This joint also involves rotary motion, but the axis of rotation is parallel to the axes of the two links.



5. Revolving joint (V- type joint):

In this joint, the axis of input link is parallel to the axis of rotation of the joint and the axis of the output link is perpendicular to the axis of rotation.



2.3 JOINT – LINK MECHANISM OF ROBOT

A robot is mounted on a stationery base on the floor. The base and its connection to the first joint i.e. joint 1 is called link „0".

Link „0" is the input to joint 1. The output of the joint 1 is link „1".

Link 1 is the input to joint 2 whose output link is link „2" and so on.

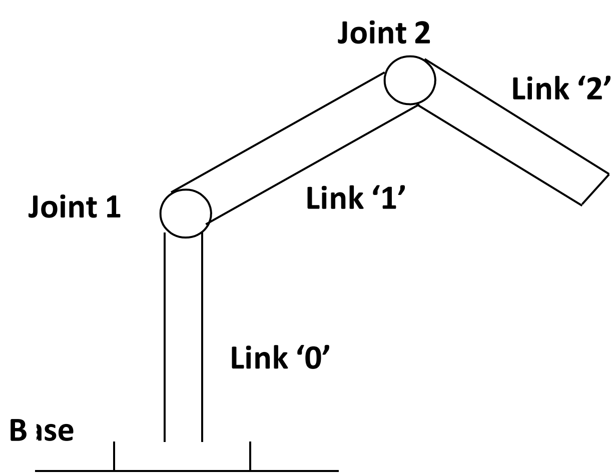


Figure: Joint-link mechanism

A robot manipulator can be divided into two sections:

(1) A body and arm assembly

(2) Wrist assembly

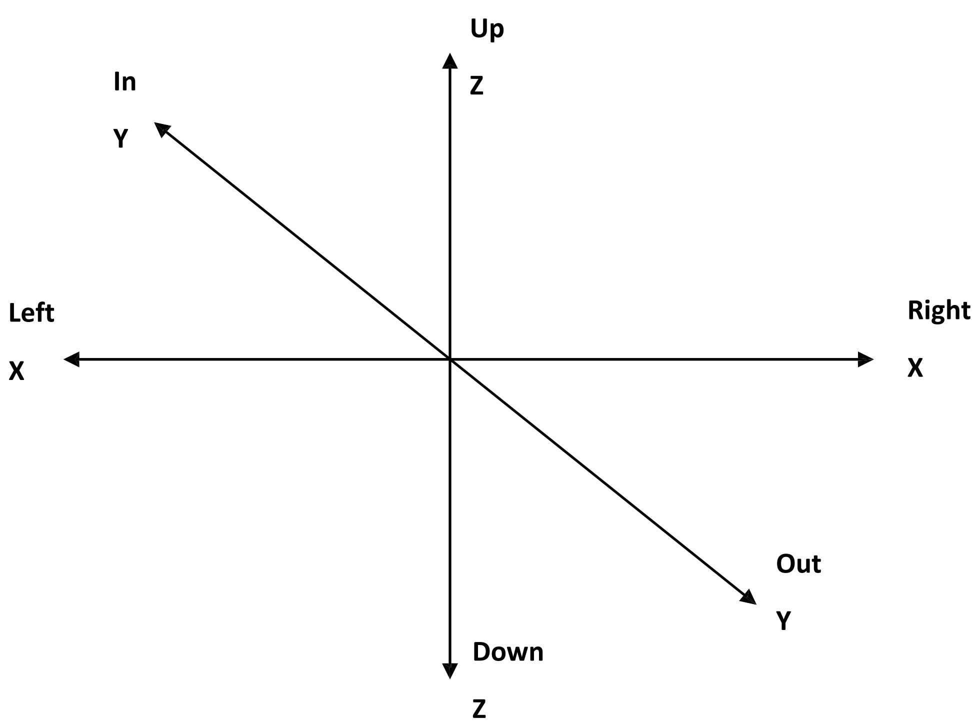
There are usually 3 dof associated with the body and arm and either 2 or 3 dof associated with the wrist. The body and arm of the robot is used to position the object and the robots wrist is used to orient the object.

To establish the positioning of the object, the body and arm assembly must be capable of moving the object in any of the following three directions.

1. Vertical motion (Z – axis motion)

2. Radial motion (in-and-out or Y – axis motion)

3. Right to left motion (X – axis motion or Swirl about vertical axis on the base)



Wrist Configuration

The robot wrist is used to establish the orientation of the end effector. Robot wrists usually consist of two or three dof. Figure below shows one possible configuration for a 3 dof wrist assembly. The three joints are defined as (1) Roll (2) Pitch and (3) Yaw

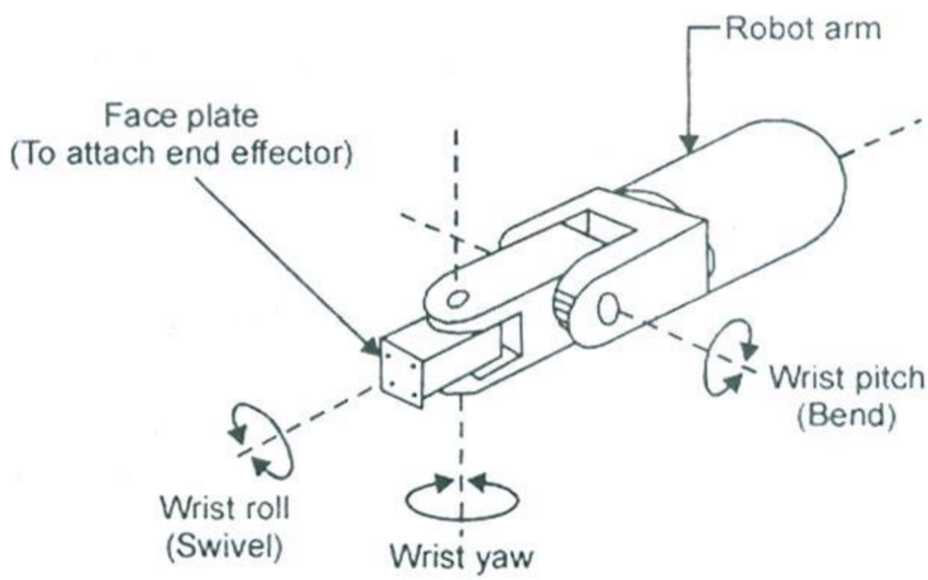


Figure: Three dof associated with the robot wrist

Roll: This dof is accomplished by a twisting joint (T – joint) to rotate the object about the arm axis.

Pitch: This involves up and down rotation, typically done by means of R – type joint.

Yaw: It involves right-to-left rotation of the object, accomplished by means of an R-type joint.

A two dof wrist typically include only roll and pitch joints (T & R joints)

Joint Notation System

The letter symbols for the five joint types (L, O, R, T & V) can be used to define a joint notation system for the robot manipulator.

In this notation system, the manipulator is described by the joint types that make up the body-and-arm assembly; followed by the joint symbols that make up the wrist.

For example, the notation TLR:TR represents a five dof manipulator whose body-and-arm is made up of a twisting joint (joint 1 = T), a linear joint (joint 2 = L) and a rotational joint (joint 3 = R). The wrist consists of two joints, a twisting joint (joint 4= T) and a rotational joint (joint 5=R). A colon separates the body-and-arm notation from the wrist notation.

Common wrist joint notations are TRR and TR.

Joint notations for five common robot body-and-arm configurations are as below.

Body-and-arm	*Joint Notation*
1. Cartesian Coordinate	LOO
2. Cylindrical	TLO
3. Polar Coordinate	TRL
4. Jointed arm robot	TRR
5. SCARA	VRO

Work Volume

Work volume is the term that refers to the space within which the robot can manipulate its wrist end. The convention of using the wrist end to define the robots work volume is adopted to avoid the complication of different sizes of end effectors that might be attached to the robot‟s wrist. *The end effector is an addition to the basic robot and should not be counted as part of robot's working space.*

The work volume is determined by the following physical characteristics of the robot:

- The robot‟s physical configuration
- The sizes of the body, arm and wrist components
- The limits of the robot‟s joint movements

A Cartesian coordinate robot has a rectangular work volume, a cylindrical robot has a cylindrical work envelope, a polar coordinate robot has a work volume that is partial sphere and a jointed arm robot approximates a work volume that is spherical.

2.4 ROBOT CHARACTERISTICS

1. Payload: It is the weight a robot can carry and still remain within its other specifications. For example, a robots 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.

2. Reach: It is the maximum distance a robot can reach within its work envelope. Many points within the work envelope of the robot may be reached

with any desired orientation (called dexterous). However, for other points close to the limit of robots reach capability, orientation cannot be specified as desired (called non-dexterous points). Reach is function of the robots joint lengths and its configuration.

3. Robot Movement and Precision: Speed of response and stability are the two important characteristics of robot movement. Speed defines how quickly the robot arm moves from one point to another.

Stability refers to robot motion with the least amount of oscillations. Speed and stability are often conflicting goals.

The precision of a robot movement is defined by three basic features.

(a) Control resolution & Spatial Resolution

(b) Accuracy

(c) Repeatability

Control Resolution: It relates to the system‟s capability to divide the range of total movement into closely spaced points that can be identified. Thus it would represent the minimum noticeable movement achievable.

The controller can generate pulses of very small duration, but the positioning device should be able to respond and change its position accordingly. In such a case:

$$Control\ resolution = \frac{Range\ of\ movement}{2^n}$$

Where, n = number of bits in the control memory devoted to a joint

2^n = number of increments or addressable points

Spatial Resolution: The control resolution is concerned with only one link and one motion, whereas the spatial resolution combines the control resolution of all motions and also considers the mechanical errors in the points and associated links.

Accuracy: It can be defined as the ability of a robot to position its wrist end at a desired target point within its reach. In terms of control resolution, the accuracy can be defined as one-half of the control resolution. This definition of accuracy applies in the worst case, when the target point is between two control points. The reason is that, displacements smaller than one basic control resolution unit (BCRU) can be neither programmed nor measured and on an average they account for one-half of a BCRU.

The accuracy of a robot is affected by many factors. For example, when the arm is fully stretched out, the mechanical inaccuracies tend to be larger because the loads tend to cause larger torques at joints, resulting in greater deformations. When the arm is closer to the base, the inaccuracies tend to be minimal and better accuracy can be observed.

The inaccuracies in mechanical positioning system can be considered to have normal distribution with a constant variance over the range of movement.

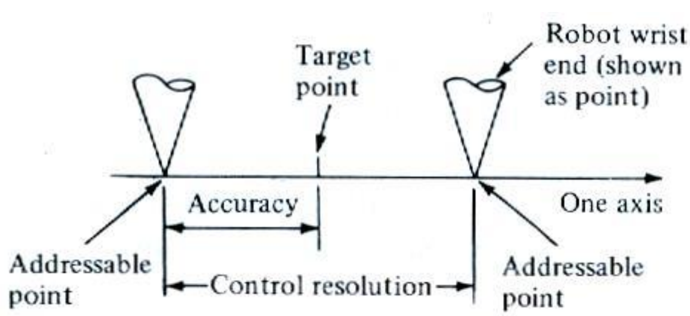


Figure: Illustration of accuracy and control resolution when mechanical inaccuracies are assumed to be zero

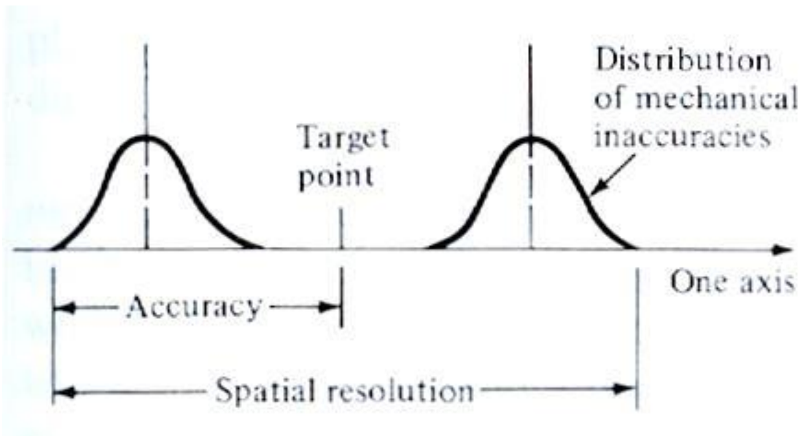


Figure: Illustration of accuracy and spatial resolution in which mechanical inaccuracies are represented by a statistical distribution

With reference to the Figure above, the following relations can be established:

$$Accuracy = \frac{Control\ Resolution}{2} + 3\sigma$$

Where, σ = standard deviation of mechanical error.

Repeatability = $\pm 3\sigma = 6\sigma$

Spatial Resolution = Control resolution + 6σ

Accuracy in terms of spatial resolution = $\frac{Spatial\ Resolution}{2}$

For modern robots the repeatability values are of the order of $\pm 0.05\,mm$

Repeatability: It is the ability of the robot to position its end effector at a point that had previously been taught to the robot. The repeatability error differs from accuracy. Because of the limitation of the spatial resolution and therefore accuracy, the programmed point becomes point „B" instead of „A". The distance between points A & B is a result of robots limited accuracy due to spatial resolution.

When the robot is instructed to return to programmed point „B", it returns to point „C" instead. The distance between B & C is the result of limitation on the robots repeatability.

However, the robot does not always go to point „C", every time it is asked to return to the programmed point „B". Instead, it forms a cluster of points. This gives rise to a random phenomenon of repeatability errors.

2.5 END EFFECTORS

An end effector is a device that attaches to the wrist of the robot arm and enables the general purpose robot to perform a specific task. The end effectors are classified into two major categories:

1. Grippers
2. Tools

Grippers are end effectors used to grasp and hold objects. The objects are generally workparts that are to be moved by the robot.

Grippers can be classified as *single grippers* or *double grippers*. The single gripper is distinguished by the fact that only one grasping device is mounted on the robot"s wrist. A double gripper has two gripping devices attached to the wrist and is used to handle two separate objects. The two gripping devices can be actuated independently. The double gripper is especially useful in machine loading and unloading applications.

To illustrate, suppose that a particular job calls for a raw workpart to be loaded from a conveyor onto a machine and the finished part to be unloaded onto another conveyor. With a single gripper, the robot would have to unload the finished part before picking up the raw part. This would consume valuable time in the production cycle because the machine would have to remain open during these handling motions. With a double gripper, the robot can pick the part from the incoming conveyor with one of the griping devices and have it ready to exchange for the finished part. When the machine cycle is completed, the robot can reach in for the finished part with available grasping device and insert the raw part into the machine with the other grasping device. The amount of time that the machine is open is minimized.

Mechanical Grippers

A mechanical gripper is an end effector that uses mechanical fingers actuated by a mechanism to grasp an object. There are two ways of constraining the part in the gripper.

The first is by physical constriction of the part within the fingers. In this approach, the gripper fingers enclose the part to some extent, thereby constraining the motion of the part. This is usually accomplished by designing the contacting surfaces of the fingers to be in the approximate shape of the part geometry. This method of constraining the part is illustrated in the Figure below.

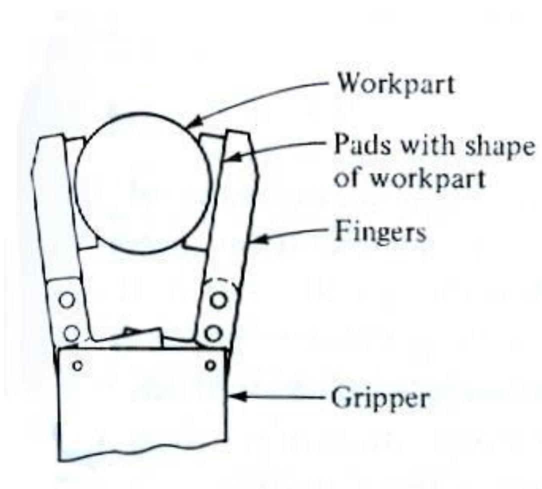


Figure: Physical constriction method of finger design

The second way of holding the part is by friction between the fingers and the workpart. With this approach, the fingers must apply a force that is sufficient for friction to retain the part against gravity, acceleration and any other force that might arise during the holding portion of the work cycle. The fingers or the pads attached to the fingers which make contact with the part are generally fabricated out of a material that is relatively soft. This tends to increase the coefficient of friction between the part and the contacting finger surface. It also serves to protect the part surface from scratching or other damage.

However, there is a problem with the friction method that is avoided with the physical constriction method. If a force of sufficient magnitude is applied, against the part in a direction parallel to the friction surfaces of the fingers as shown in the Figure, the part might slip out of the gripper. To resist this, the gripper must be designed to exert a force that depends on the weight of the part, the coefficient of friction between the part surface and the finger surface, the acceleration (or deceleration) of the part and the orientation between the direction of motion during acceleration and the direction of fingers.

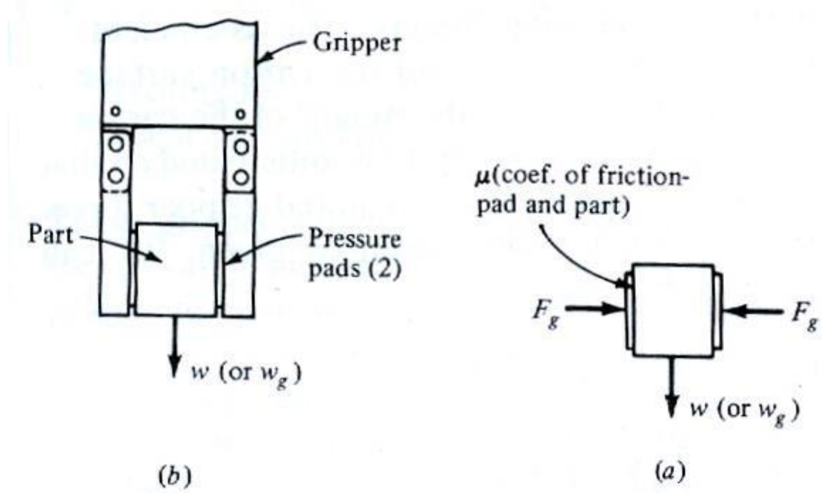


Figure: Force against part parallel to finger surfaces tending to pull part out of gripper

The following equation covers the simple case in which weight alone is the force tending to cause the part to slip out of the gripper.

$$\mu n_f F_g = w \qquad (1)$$

where μ = coefficient of friction of the finger contact surface against the part surface

n_f = number of contacting fingers

F_g = gripper force

w = weight of the part or object being gripped

This equation would apply when the force of gravity is directed parallel to the contacting surfaces. If the force tending to pull the part out of the fingers is greater than the weight of the object, then equation (1) would have to be altered. For example, the force of acceleration would be a significant factor in fast part-handling cycles. Engelberger suggests using a „g" factor in the revised equation.

$$\mu n_f F_g = wg \qquad (2)$$

The g factor is supposed take account of the combined effect of gravity and acceleration. If the acceleration force is applied in the same direction as the gravity force, then g value = 3.0. If the acceleration is applied in the opposite direction, then the g value = 1.0. If the acceleration is applied in the horizontal direction, then use g = 2.0

Types of Gripping Mechanism

Mechanical grippers can be classed according to the type of kinematic device used to actuate the finger movement. The classification includes the following:

1. Linkage actuation

2. Gear-and-Rack actuation
3. Cam actuation
4. Screw actuation
5. Rope-and-pulley actuation
6. Miscellaneous

The linkage category covers a wide range of design possibilities to actuate the opening and closing of the gripper. A few examples are illustrated in the Figure. The design of the linkage determines how the input force F_a to the gripper is converted into the gripping force F_g applied by the fingers.

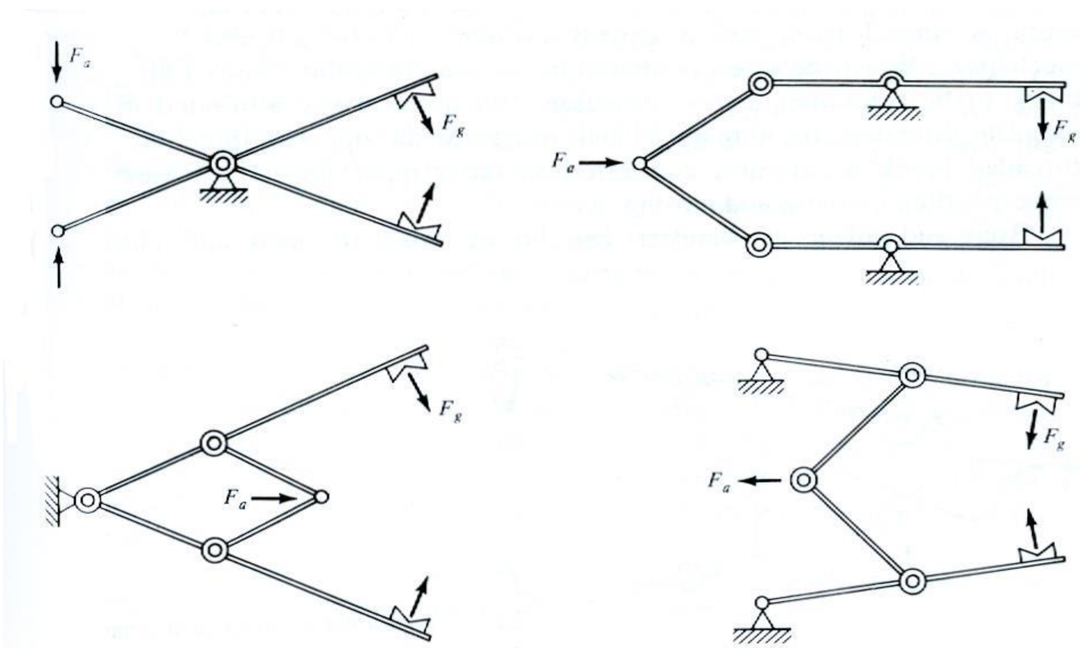


Figure: Some possible linkages for robot grippers.

Figure below illustrates one method of actuating the gripper fingers using a gear-and-rack configuration. The rack gear would be attached to a piston or some other mechanism that would provide a linear motion. Movement of the rack would drive two partial pinion gears, and these would in turn open and close the fingers.

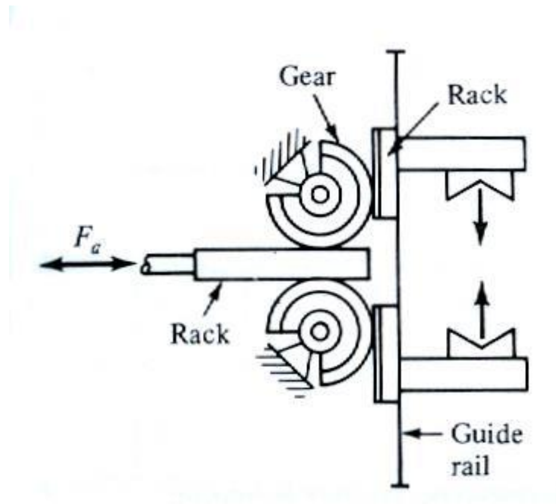


Figure: Gear-and-Rack method of actuating the gripper

The cam actuated gripper includes a variety of possible designs, one of which is shown in the Figure. A cam-and-follower arrangement, often using a spring loaded follower, can provide the opening and closing action of the gripper. For example, movement of the cam in one direction would force the gripper to open, while movement of the cam in the opposite direction would cause the spring to force the gripper to close. The advantage of this arrangement is that the spring action would accommodate different sized parts.

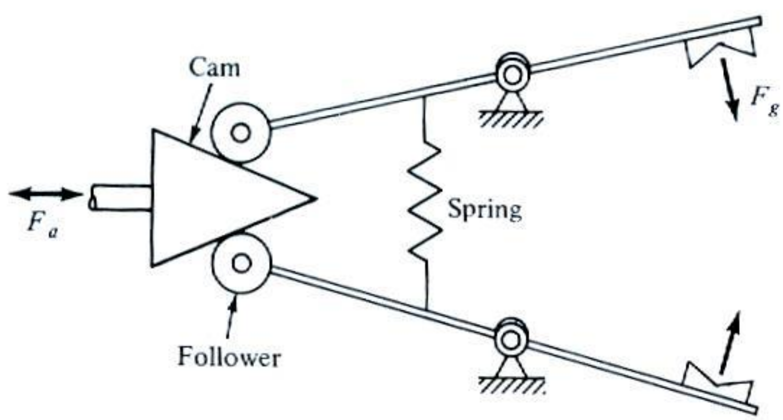


Figure: Cam actuated gripper

An example of a screw type actuation method is shown in the Figure below. The screw is turned by a motor, usually accompanied by a speed reduction mechanism. When the screw is rotated in one direction, this causes a threaded block to be translated in one direction. When the screw is rotated in the opposite direction, the threaded block moves in the opposite direction. The threaded block is, in turn, connected to the gripper fingers to cause the corresponding opening and closing action.

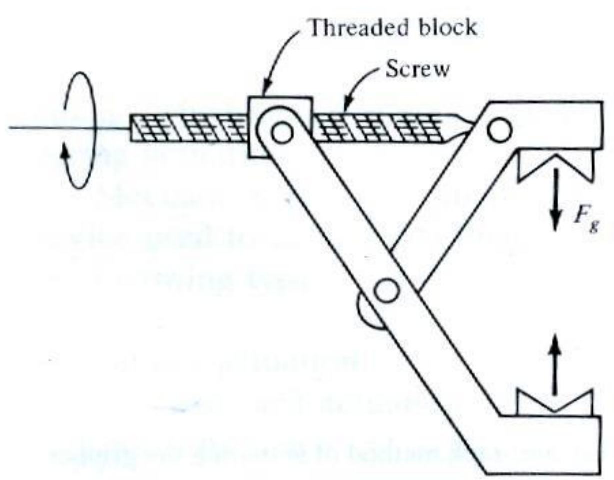


Figure: Screw-type gripper actuation

Rope and pulley mechanisms can be designed to open and close a mechanical gripper. Because of the nature of these mechanisms, some form of tension device must be used to oppose the motion of the rope in the pulley system. For example, the pulley system might operate in one direction to open the gripper, and the tension device would take up the slack in the rope and close the gripper when the pulley system operates in the opposite direction.

Other types of Grippers

In addition to mechanical grippers, there are a variety of other devices that can be designed to lift and hold objects. Some of them are discussed below.

1. Vacuum cups
2. Magnetic grippers
3. Adhesive grippers
4. Hooks, Scoops and other miscellaneous devices

Vacuum Cups

Vacuum cups, also called suction cups can be used as gripper devices for handling certain types of objects. The suction cups used in this type of robot gripper are typically made of elastic material such as rubber or soft plastic. The shape of the vacuum cup, as shown in the Figure, is usually round. Some means of removing the air between the cup and the part surface to create the vacuum is required. The vacuum cup and venturi are two common devices used for this purpose.

The vacuum pump is a piston-operated or vane-driven device powered by an electric motor. It is capable of creating a relatively high vacuum.

The venturi is a simpler device as shown in Figure and can be driven by means of "shop air pressure." Its initial cost is less than that of a vacuum pump and it is relatively reliable because if its simplicity.

The lift capacity of the suction cup depends on the effective area of the cup and the negative air pressure between the cup and the object. The negative pressure is the pressure difference between the inside and the outside of the vacuum cup.

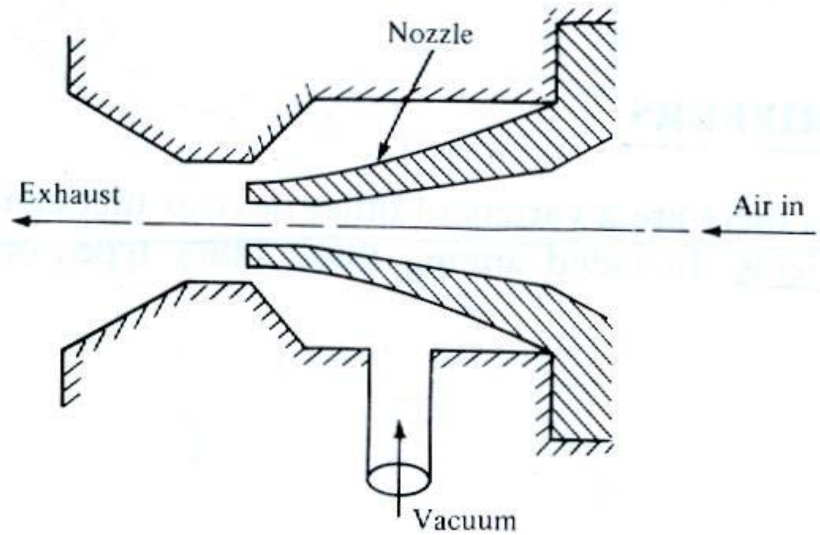


Figure: Venturi device used to operate a suction cup

The relationship can be summarized in the following equation.

$$F = PA$$

Where, F = the force or lift capacity

P = the negative pressure

A = the total effective area of the suction cup(s) used to create the vacuum

Some of the features and advantages of suction cup grippers used in robotic applications are:

- Requires only one surface of the part for grasping
- Applies a uniform pressure distribution on the surface of the part
- Relatively light weight gripper
- Applicable to a variety of different materials.

Magnetic grippers

Magnetic grippers can be a very useful means of handling ferrous materials. In general, magnetic grippers offer the following advantages in robotic handling applications.

- Pick up time is very fast
- Variations in part size can be tolerated. The gripper does not have to be designed for one particular work part.
- They have the ability to handle metal parts with holes (not possible with vacuum grippers)
- They require only one surface for gripping

The disadvantage of a magnetic gripper is the problem of picking up only one sheet from a stack. The magnetic attraction tends to penetrate beyond the top sheet in the stack, resulting in the possibility that more than a single sheet will be lifted by the magnet.

Magnetic grippers can be divided into two categories: (1) grippers using electromagnets and (2) grippers using permanent magnets.

Electromagnetic grippers are easier to control, but require a source of dc power and an appropriate controller unit. As with any other robotic gripping device, the part must be released at the end of the handling cycle. This is easier to accomplish with an electromagnet than with a permanent magnet. When the part is to be released, the controller unit reverses the polarity at a reduced power level before switching off the electromagnet.

Permanent magnets have the advantage of not requiring an external power source to operate the magnet. However, there is a loss of control that accompanies this apparent advantage. For example, when the part is to be released as the end of handling cycle, some means of separating the part from the magnet must be provided. The device which accomplishes this is called a stripper or stripping device. Its function is to mechanically detach the part from the magnet. One possible stripper design is shown in the Figure below.

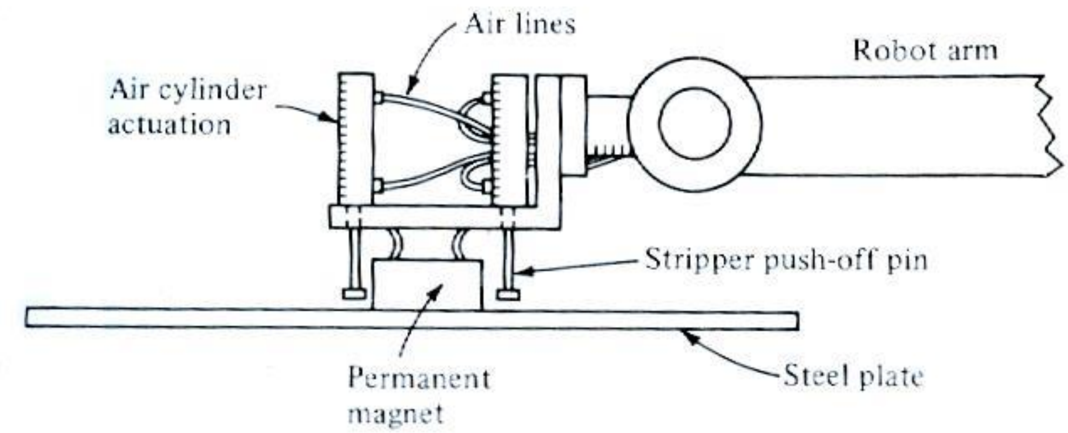


Figure: Stripper device operated by air cylinders used with a permanent magnet gripper.

Adhesive Grippers

Gripper designs in which an adhesive substance performs the grasping action can be used to handle fabrics and other lightweight materials. The requirements on the items to be handled are that they must be gripped on one side only and that other forms of grasping such as a vacuum or magnet are not appropriate. One of the potential limitations of an adhesive gripper is that the adhesive substance loses its tackiness on repeated usage. Consequently, its reliability as a gripping device is diminished with each successive operation cycle. To overcome this limitation, the adhesive material is loaded in the form of a continuous ribbon into a feeding mechanism that is attached to the robot wrist. The feeding mechanism operates in a manner similar to a typewriter ribbon mechanism.

Hooks, Scoops and Other Miscellaneous Devices

A variety of other devices can be used to grip parts or materials in robotics applications. Hooks can be used as end effectors to handle containers of parts and to load and unload parts hanging from overhead conveyers.

Scoops and ladles can be used to handle certain materials in liquid or powder form. Chemicals in liquid and powder form, food materials, granular substances and molten materials are the examples that can be handled by a robot using this method of holding.

Other types of grippers include, inflatable devices, in which an inflatable bladder or diaphragm is expanded to grasp the object. The inflatable bladder is fabricated out of rubber or other elastic material which makes it appropriate for gripping fragile objects. An example of the inflatable bladder type gripper is shown in Figure below. Figure (a) shows the bladder which is fully expanded. Figure (b) shows the bladder used to grasp the inside diameter of a bottle.

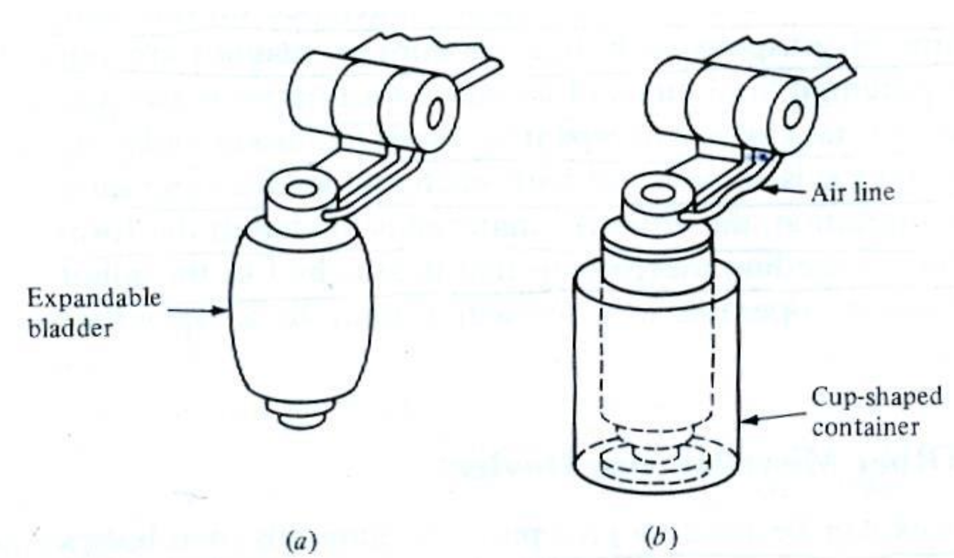


Figure: Expansion bladder used to grasp inside of a cup-shaped container

2.6 THE ROBOT/END EFFECTOR INTERFACE

Physical Support of the End effector: It is achieved by the mechanical connection between the end effector and the robot wrist. This mechanical connection often consists of a faceplate at the end of the wrist to which the end effector is bolted. Ideally there should be three characteristics to be considered in the design of mechanical connection: strength, compliance and overload protection.

The strength of the mechanical connection refers to its ability to withstand the forces associated with the operation of the end effector. These force include the weight of the end effector, the weight of the object being held by the end effector if it is a gripper, acceleration and deceleration forces, and any applied forces during the work cycle (e.g., thrust forces during a drilling operation). The wrist socket must provide sufficient strength and rigidity to support the end effector against these various forces.

The second consideration in the design of mechanical connection is compliance. Compliance refers to the wrist socket"s ability to yield elastically when subjected to a force. In effect it is opposite of rigidity. Certain assembly operations require the insertion of an object into a hole where there is a very little clearance between the hole and the object to be inserted. If an attempt is made to insert the object off center, it is likely that the object will bind against the sides of the hole. To overcome this limitation, remote center compliance (RCC) devices have been designed to provide the high lateral compliance for centering the object.

The third factor which must be considered relative to the mechanical interface between the robot wrist and the end effector is overload protection. An overload results when some unexpected event happens to the end effector such as part becoming stuck in the die, or tool getting caught in a moving conveyor.

Whatever the cause, the consequences involve possible damage to the end effector or maybe even the robot itself. Overload protection is intended to eliminate or reduce this potential damage. The protection can be provided either by means of a breakaway feature in the wrist socket or by using sensors to indicate that an unusual event has occurred so as to somehow take preventive action to reduce further overloading of the end effector. A shear pin is an example of a device that is designed to fail if subjected to a shear force above certain value. It is relatively inexpensive and its purpose as a component in the mechanical interface is to be sacrificed in order to save the end effector and the robot.

Power and Signal Transmission: End effectors require power to operate. They also require control signals to regulate their operation. The principal methods of transmitting power and control signals to the end effector are:

Pneumatic

Electric

Hydraulic

Mechanical

Pneumatic power using shop air pressure is one of the most common methods of operating mechanical grippers. Actuation of the gripper is controlled by regulating the incoming air pressure. A piston device is typically used to actuate the gripper. Two air lines feed into opposite ends of the piston, one to open the gripper and the other to close it. A schematic diagram of the piston is illustrated in the Figure below. When the air pressure enters the left portion of the piston chamber, the piston is extended and when the air is forced into the opposite end of the chamber, the piston is retracted. The force supplied by the piston in the extension stroke is equal to the air pressure multiplied by the area of the piston diameter. Because of the diameter of the piston ram, the force supplied by the piston on the retraction stroke is less than on the extension stroke.

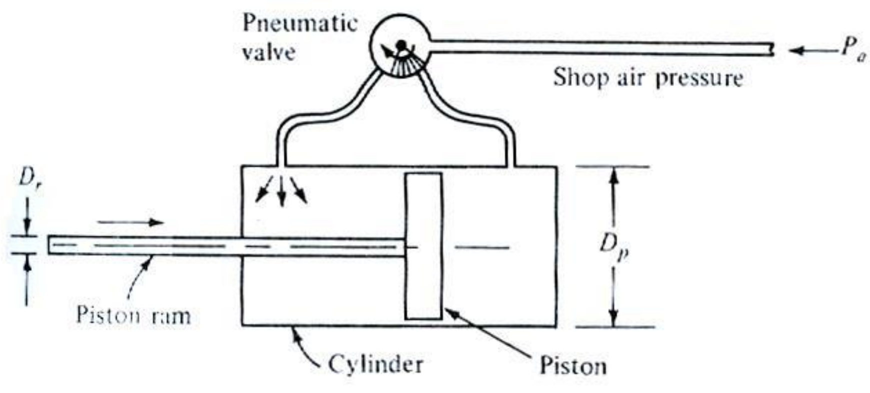


Figure: Schematic diagram of a piston

These piston forces can be calculated as follows

$$F_{exten} = P_a \times \frac{\Pi}{4} D_p^2$$

$$F_{retract} = P_a \times \frac{\Pi}{4} \left(D_p^2 - D_r^2\right)$$

Where, F_{exten} = the piston force on the extension stroke.

$F_{retract}$ = the piston force on the retraction stroke

D_p = the piston diameter

D_r = the piston rod diameter

P_a = Air pressure

A second method of power transmission to the end effector is electrical. Pneumatic actuation of the gripper is generally limited to two positions, open and closed. The use of an electric motor can allow the designer to exercise a greater degree of control over the actuation of the gripper and of the holding force applied. Instead of merely two positions, the gripper can be controlled any number of partially closed positions. This feature allows the gripper to handle variety of objects of different sizes.

Hydraulic and mechanical power transmissions are less common means of actuating the end effector in current practice. Hydraulic actuation of the gripper has the potential to provide very high holding forces, but its disadvantage is the risk of oil leaks.

2.7 LOCOMOTION DEVICES (OR) ACTUATORS

Actuators are the devices which provide the actual motive force for the robot joints. They commonly get their power from one of the three sources: Compressed air, Pressurized fluid or Electricity. They are called respectively pneumatic, hydraulic or electric actuators.

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. The operation of these actuators is generally similar except in their ability to contain the pressure of the fluid. Pneumatic systems typically operate at about 100 lb/in^2 and hydraulic systems at 1000 to 3000 lb/in^2.

The simplest power device is the cylinder as illustrated in Figure, which could be used to actuate a linear joint by means of a moving piston.

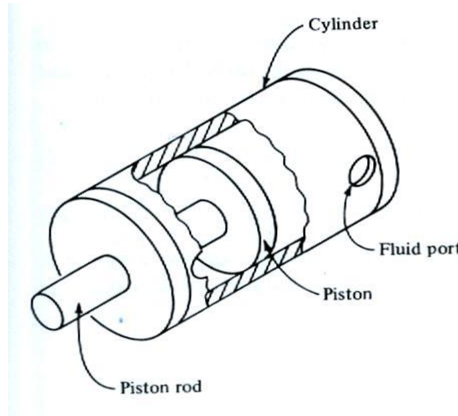


Figure: Cylinder and piston arrangement

The following two relationships are important with respect to actuators.

1. The velocity of the actuator with respect to input power and
2. Force of the actuator with respect to the input power.

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

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

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

Electric Motors

There are a variety of types of motors used in robots. The most common types are Servomotors and Stepper motors.

The main components of the DC servomotor are the rotor and the stator. Usually, rotor includes the armature and commutator assembly and the stator includes the permanent magnet and brush assemblies. When current flows through the windings of the armature, it setup a magnetic field opposing the field setup by the magnets. This produces a torque on the rotor.

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

Another effect associated with a DC servo motor is the back emf. Spinning the armature in the presence of a magnetic field produces a voltage across the armature terminals. The voltage is proportional to angular velocity of the rotor.

$$e_b = K_b \omega$$

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

If V_{in} is the voltage supplied across the motor terminals and R_a is the resistance of the armature then the current through the armature would be $\frac{V_{in}}{R_a}$. This current produces a torque on the rotor and causes the motor to spin. As armature spins, it generates a back emf equal to e_b or $K_b\,\omega$. This voltage must be subtracted from V_{in} in order to calculate the armature current.

The actual armature current is therefore

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

Stepper Motors

A stepper motor provides output in the form of discrete angular motion increments. It is actuated by a series of discrete electrical pulses. For every electrical impulse there is a single step rotation of the motor shaft. In robotics, stepper motors are used for relatively light duty applications.

Figure: Stepper motor

Figure provides a schematic representation of one type of stepper motor. The stator is made up of four electromagnetic poles and the rotor is a two-pole permanent magnet.

If the electromagnetic stator poles are activated in such a way that pole 3 is N (magnetic north) and pole 1 is S (magnetic south) then the rotor is aligned as illustrated. If the rotor is excited so that pole 4 is N and pole 2 is S, the rotor makes 90° turn in the clockwise direction. By rapidly switching the current to the stator electronically, it is possible to make the motion of the rotor appears continuous.

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.

Comparison of locomotion devices

Electric Drive System	Pneumatic Drive System	Hydraulic Drive System
The accuracy and repeatability of electric drive system is better	The accuracy and repeatability of pneumatic drive system is relatively less.	The accuracy and repeatability of hydraulic drive system is moderate.
This drive system requires less floor space.	This drive system requires moderately or relatively less floor space.	This drive system requires more floor space
This drive system is ideally suited for actuation of rotation.	This drive system is ideally suited for both rotation and linear motion	This drive system is ideally suited for translation or rotational motions.
This system of drive is suited for smaller robots.	This drive system suits moderately smaller robots	This drive system suits for large robots.
This drive is suitable for both continuous and pick and place robots.	This drive is suitable for pick-and-place operations	Suitable for continuous path control
Leakage is nil	Medium leakage	More leakage
Needs low maintenance	Needs less maintenance	Needs more maintenance

PROBLEMS

Problem 1: A robot with single degree of freedom has one sliding joint with a full range of 1.0 m. The robots control memory has a 12 bit storage capacity. Determine the control resolution for this axis of motion.

Solution:

Given, Range of movement = 1 m

Bit Storage capacity = 12 bit

$$Control\ \mathrm{Re}\,soltion = \frac{Range\ of\ movement}{2^n}$$

$$= \frac{1m}{2^{12}}$$

= 0.000244 m

$\therefore$ Control Resolution = 0.244 mm

Problem 2: A vacuum gripper is to be designed to handle flat plate glass in an automobile windshield plant. Each plate weighs 175 N. A single suction cup will be used, and the diameter of the suction cup is 125 mm. Determine the negative pressure required to lift each plate. Use a safety factor of 2 in your calculations (May, 2008: Set 2)

Solution: Given, weight of the plate W = 175 N

Number of suction cups n = 1

Diameter of the suction cup = D = 125 mm

Factor of safety = 2.0

Area of the suction cup = $A = \frac{\Pi}{4} \times D^2 = \frac{\Pi}{4} \times 125^2 = 12271.8\ mm^2$

The negative pressure $p = \frac{W}{A} = \frac{175}{12271.8} = 0.014 \frac{N}{mm^2}$

Applying the safety factor = 2.0, we have $p = 2.0 \times 0.014 = 0.028\ \frac{N}{mm^2}$

Problem 3: A part weighing 40 N is to be held by a gripper using friction against two opposing fingers. The coefficient of friction between the fingers and the part surface is 0.3. The g factor to be used in force calculations should be 3.0. Compute the required gripper force.

Solution:

Given, the weight of the part = 40 N

Number of fingers = n_f = 2

The Coefficient of friction = μ = 0.3

g – factor = 3.0

If F_g represents gripper force, then $\mu n_f F_g = wg$

$0.3 \times 2 \times F_g = 40 \times 3.0$

$\therefore F_g = 200\ N$

SELF ASSESSMENT QUESTIONS

Problem 1: A piston is to be designed to exert an actuation force of 750 pounds on its extension stroke. The inside diameter of the piston is 50mm, and the ram diameter is 18.75 mm. What shop air pressure will be required to provide this actuation force? Use a safety factor of 1.5.

Problem 2: A part weighing 40 N to be held by a gripper using friction against two opposing fingers. The coefficient of friction between the fingers and the part surface is estimated to be 0.3. The orientation of the gripper will be such that the weight of the part will be applied in a direction parallel to the contacting finger surfaces. A fast work cycle is anticipated so that the g factor to be used in force calculations should be 3.0. Use a safety factor of 1.5. Compute the required gripper force for the specifications given.

Problem 3: A part weighting 75 N is to be grasped by a mechanical gripper using friction between two opposing fingers. The coefficient of static friction is 0.35 and the coefficient of dynamic friction is 0.20. The direction of the acceleration force is parallel to the contacting surfaces of the gripper fingers. Which value of coefficient of friction is appropriate to use in the force calculations? Why? Compute the required gripper force by assuming a g factor of 2.0.

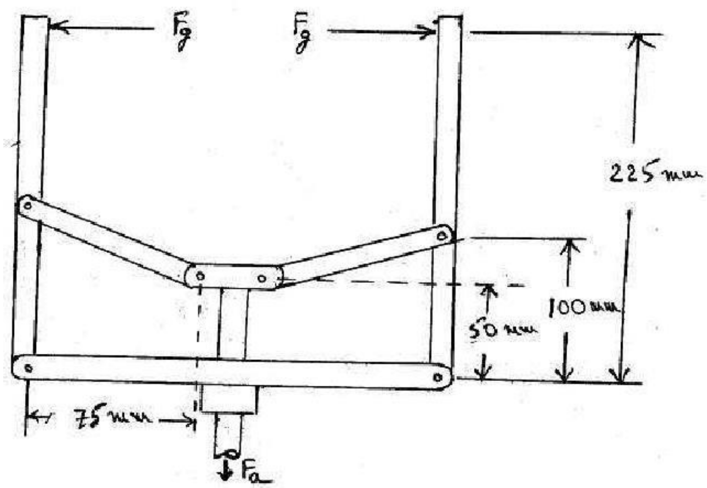
ASSIGNMENT - II

Q1. List the factors to be considered in selection and design of gripper

Q2. Describe the compliance conditions normally found in robot applications

What is an RCC device? Explain.

Q3: For the information given in the mechanical gripper design of Figure, determine the required actuating force,



Q4: For the information given in the mechanical gripper design of Figure, determine the required actuating force, if the gripper force is to be 150 N.