ROBOT DRIVE SYSTEMS AND END EFFECTORS

Introduction Robot Drive Systems

- The actions of the individual joints must be controlled in order for the manipulator to perform a desired motion. The robot's capacity to move its body, arm, and wrist is provided by the drive system used to power the robot
- The joints are moved by actuators powered by a particular form of drive system
- Common drive systems used in robotics are electric drive, hydraulic drive, and pneumatic drive

Introduction Robot Drive Systems Cont.,

Types of Actuators

- Electric Motors - Servomotors, Stepper motors or Direct-drive electric motors
- Hydraulic actuators
- Pneumatic actuators

Mechanical Drive Systems

- The drive system determines the speed of the arm movement, the strength of the robot, dynamic performance, up to some extent, the kinds of application.

- The most importantly used two types of drive systems are electric and hydraulic

Electric Drive System

- The electric drive systems are capable of moving robots with *high power* or speed
- The actuation of this type of robot can be done by either DC servo motors or DC stepping motors
- It can be well – suited for rotational joints and as well as linear joints
- The electric drive system will be perfect for *small robots* and precise applications

Electric Drive System

- It has got greater accuracy and repeatability
- The one disadvantage of this system is that it is slightly costlier
- An example for this type of drive system is *Maker 110 robot*

Hydraulic Drive System

- The hydraulic drive systems are completely meant for the *large – sized robots*
- It can deliver high power or speed than the electric drive systems
- This drive system can be used for both linear and rotational joints

Hydraulic Drive System Cont.,

- The rotary motions are provided by the rotary vane actuators , while the linear motions are produced by hydraulic pistons.

- The *leakage* of hydraulic oils is considered as the major disadvantage of this drive

- An example for the hydraulic drive system is *Unimate 2000 series robot*.

Pneumatic Drive System

- The pneumatic drive systems are especially used for the *small type robots* have less than five degrees of freedom
- It has the ability to offer fine accuracy and speed
- This drive system can produce rotary movements by actuating the rotary actuators
- The translational movements of sliding joints can also be provided by operating the piston

Pneumatic Drive System Cont.,

- The price of this system is *less* when compared to the hydraulic drive

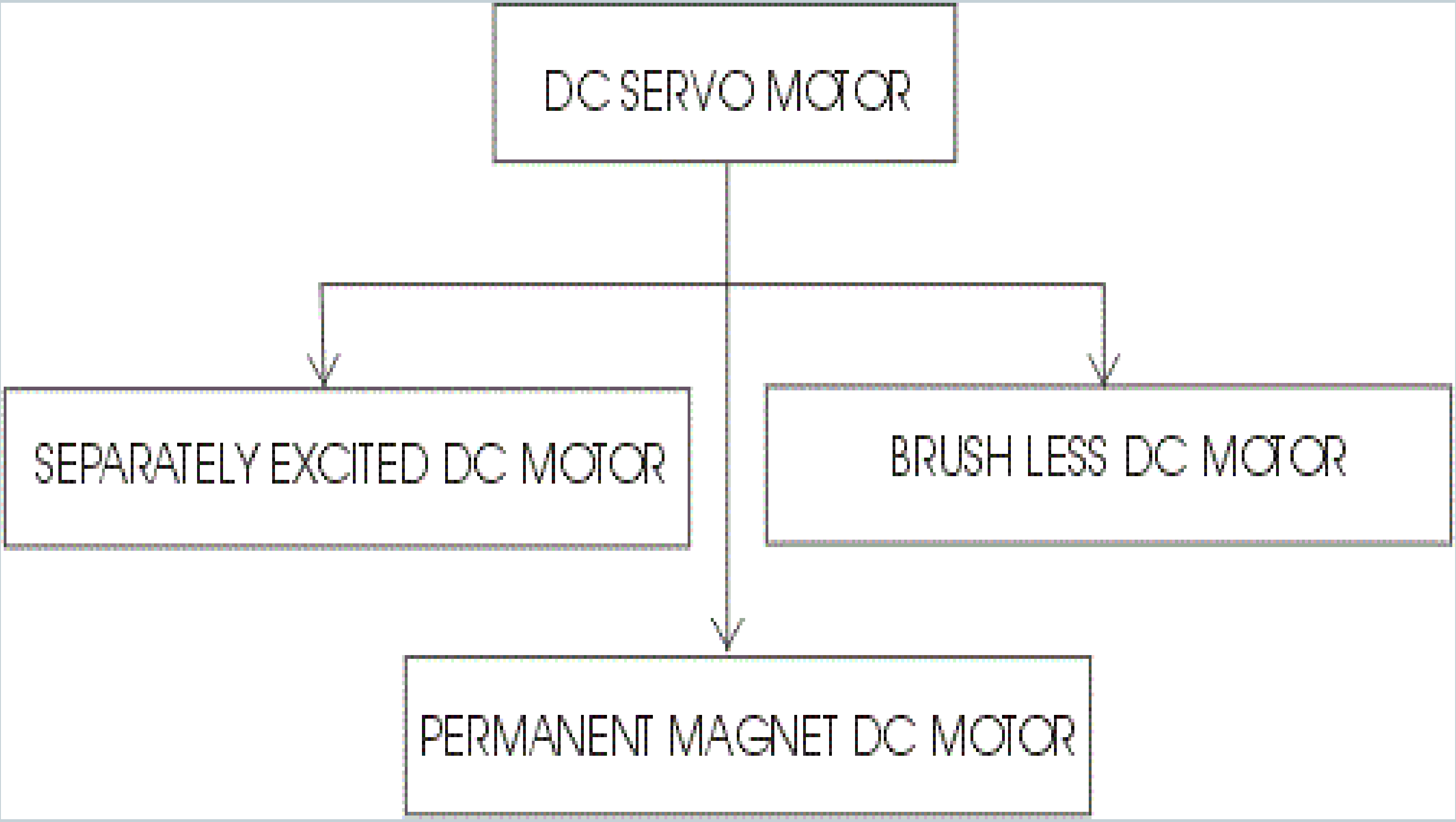
- The drawback of this system is that it will not be a perfect selection for the *faster operations*.

DC Servo Motors & Stepper Motor

- As we know that any electrical motor can be utilized as servo motor if it is controlled by servomechanism

- if we control a DC motor by means of servomechanism, it would be referred as DC servo motor
- There are different types of DC motor, such shunt wound DC motor, series DC motor, Separately excited DC motor, permanent magnet DC motor, Brushless DC motor etc

DC Servo Motors & Stepper Motor Cont.,



DC Servo Motor

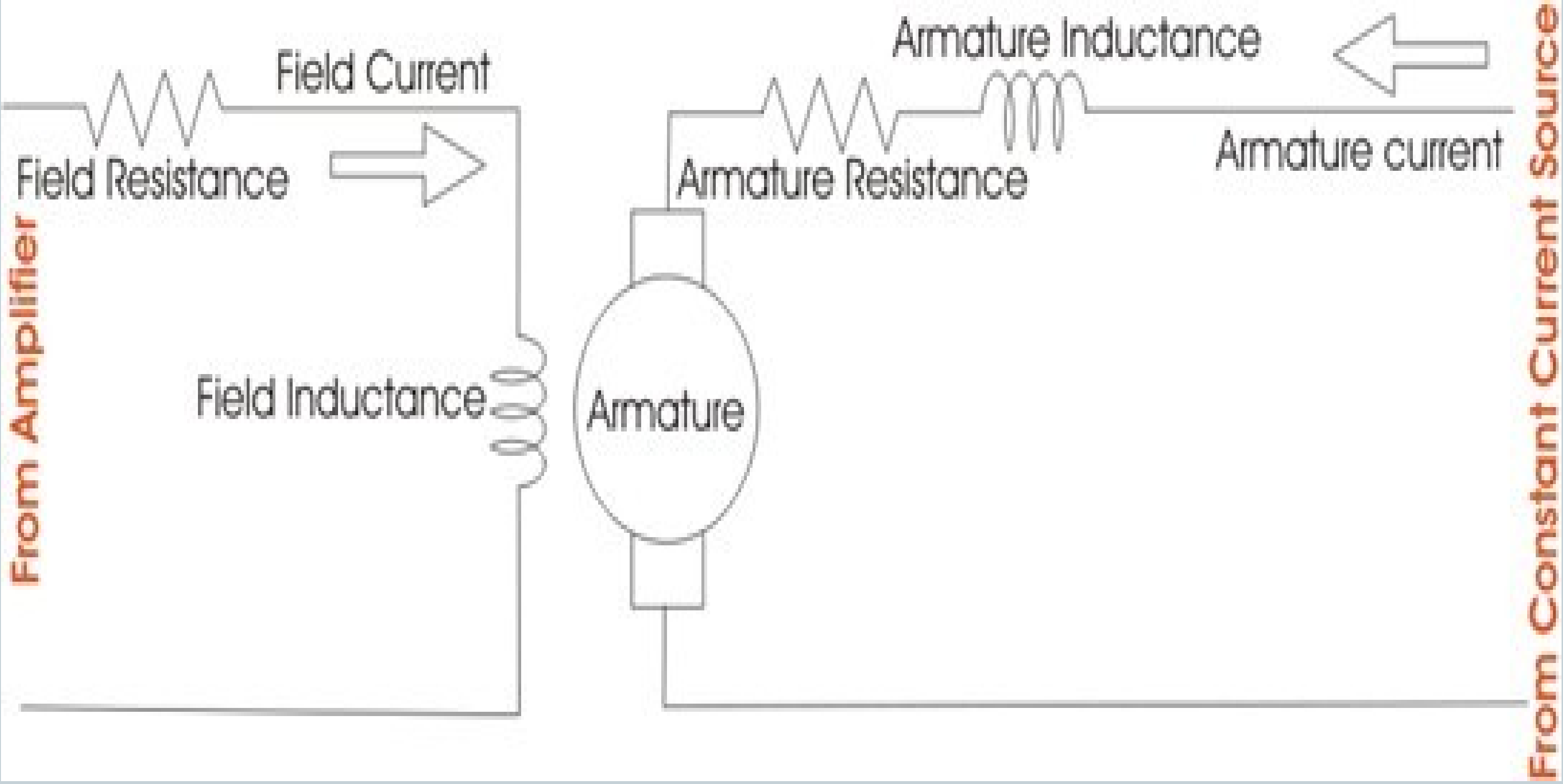
- The motors which are utilized as **DC servo motors**, generally have separate DC source for field winding and armature winding
- The control can be archived either by controlling the field current or armature current
- Field control has some specific advantages over armature control and on the other hand armature control has also some specific advantages over field control

DC Servo Motor Cont.,

- Which type of control should be applied to the **DC servo motor**, is being decided depending upon its specific applications
- Lets See the **DC servo motor working principle** for field control and armature control

DC Servo Motor Working

- **Field Controlled DC Servo Motor**



DC Servo Motor Working Cont.,

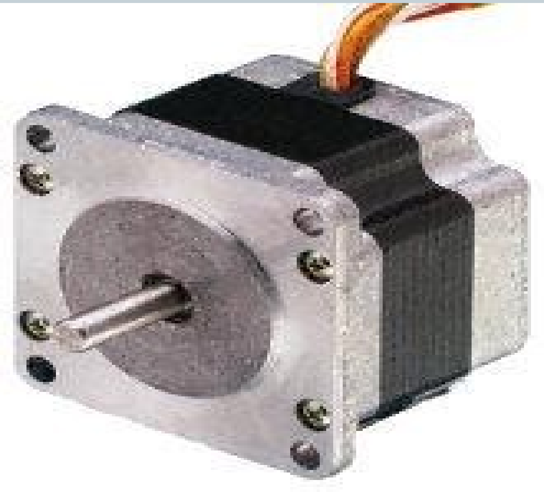
- The figure below illustrates the schematic diagram for a field controlled DC servo motor. In this arrangement the field of DC motor is excited be the amplified error signal and armature winding is energized by a constant current source
- The field is controlled below the knee point of magnetizing saturation curve. At that portion of the curve the mmf linearly varies with excitation current

DC Servo Motor Working Cont.,

- That means torque developed in the DC motor is directly proportional to the field current below the knee point of magnetizing saturation curve From general torque equation of DC motor it is found that, torque $T \propto \varphi I_a$
- Where, φ is field flux and I_a is armature current. But in field controlled DC servo motor, the armature is excited by constant current source , hence I_a is constant.

DC Stepper Motor

- Stepper Motors are also electromechanical actuators that convert a pulsed digital input signal into a discrete (incremental) mechanical movement are used widely in industrial control applications



DC Stepper Motor cont.,

- Stepper Motors are also electromechanical actuators that convert a pulsed digital input signal into a discrete (incremental) mechanical movement are used widely in industrial control applications
- As it name implies, the stepper motor does not rotate in a continuous fashion like a conventional DC motor but moves in discrete “Steps” or “Increments”, with the angle of each rotational movement or step dependent upon the number of stator poles and rotor teeth the stepper motor has

DC Stepper Motor cont.,

- Because of their discrete step operation, stepper motors can easily be rotated a finite fraction of a rotation at a time, such as 1.8, 3.6, 7.5 degrees etc
- So for example, lets assume that a stepper motor completes one full revolution (360^o in exactly 100 steps
- Then the step angle for the motor is given as 360 degrees/100 steps = 3.6 degrees per step. This value is commonly known as the stepper motors Step Angle

DC Stepper Motor cont.,

- There are three basic types of stepper motor
  - Variable Reluctance
  - Permanent Magnet
  - Hybrid
- A Stepper Motor is particularly well suited to applications that require accurate positioning and repeatability with a fast response to starting, stopping, reversing and speed control
- Its ability to hold the load steady once the require position is achieved

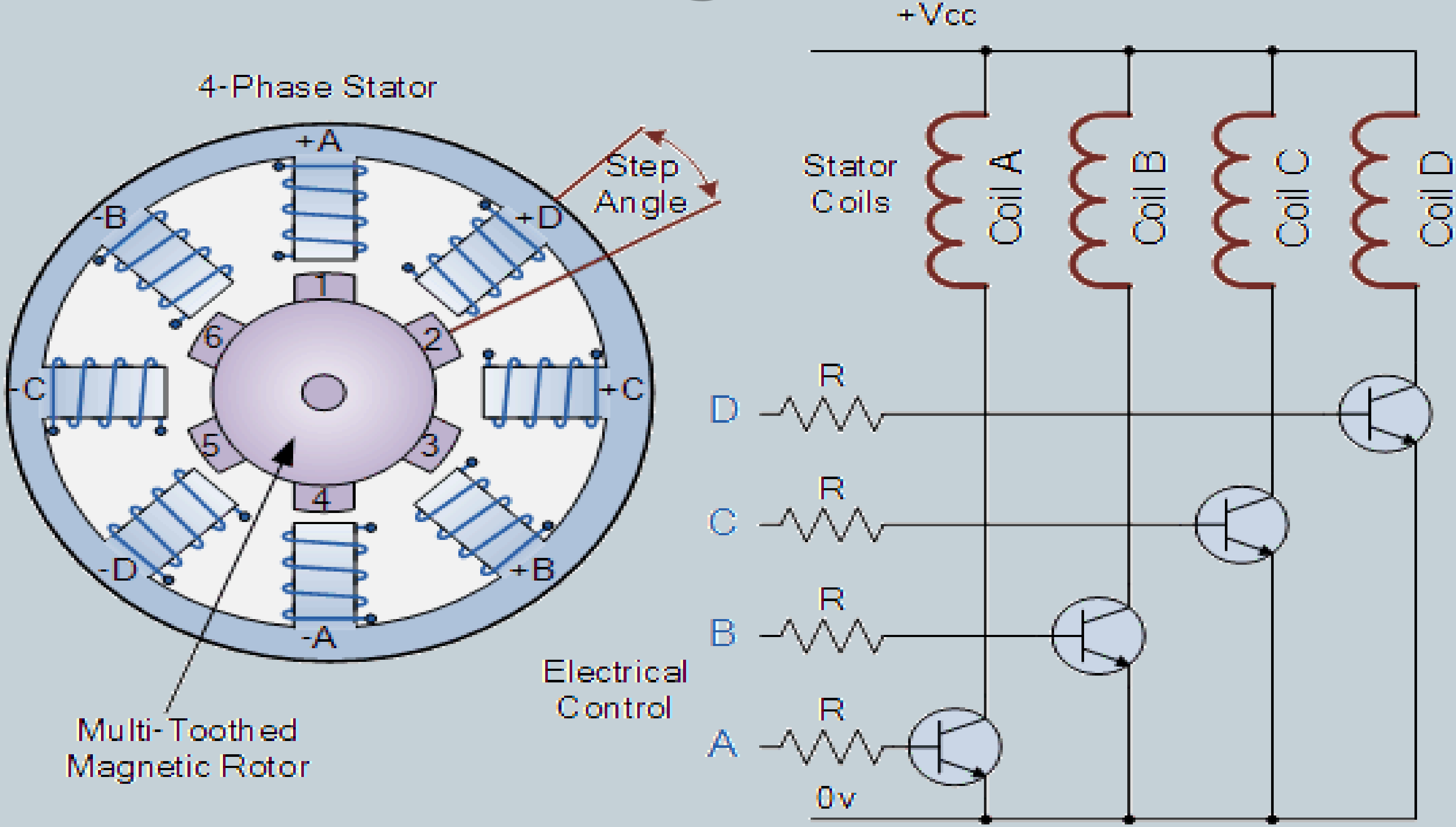
DC Stepper Motor cont.,

- Generally, stepper motors have an internal rotor with a large number of permanent magnet “teeth” with a number of electromagnet “teeth” mounted on to the stator. The stators electromagnets are polarized and depolarized sequentially, causing the rotor to rotate one “step” at a time.

DC Stepper Motor cont.,

- Modern multi-pole, multi-teeth stepper motors are capable of accuracies of less than 0.9 degs per step (400 Pulses per Revolution) and are mainly used for highly accurate positioning systems like those used for magnetic-heads in floppy/hard disc drives, printers/plotters or robotic applications.
- The most commonly used stepper motor being the 200 step per revolution stepper motor. It has a 50 teeth rotor, 4-phase stator and a step angle of 1.8 degrees (360 degs/(50×4)).

DC Stepper Motor cont.,



- In our simple example of a variable reluctance stepper motor above, the motor consists of a central rotor surrounded by four electromagnetic field coils labeled A, B, C and D.
- All the coils with the same letter are connected together so that energizing, say coils marked A will cause the magnetic rotor to align itself with that set of coils.

- By applying power to each set of coils in turn the rotor can be made to rotate or "step" from one position to the next by an angle determined by its step angle construction, and by energizing the coils in sequence the rotor will produce a rotary motion
- The stepper motor driver controls both the step angle and speed of the motor by energizing the field coils in a set sequence for example, “ADCB, ADCB, ADCB, A…” etc, the rotor will rotate in one direction (forward) and by reversing the pulse sequence to “ABCD, ABCD, ABCD, A…” etc., the rotor will rotate in the opposite direction (reverse)

- Then there are 24 (6 teeth x 4 coils) possible positions or "steps" for the rotor to complete one full revolution. Therefore, the step angle above is given as: $360^{o}/24 = 15^{o}$
- more rotor teeth and or stator coils would result in more control and a finer step angle. Also by connecting the electrical coils of the motor in different configurations, Full, Half and micro-step angles are possible
- To achieve micro-stepping, the stepper motor must be driven by a (quasi) sinusoidal current that is expensive to implement

- It is also possible to control the speed of rotation of a stepper motor by altering the time delay between the digital pulses applied to the coils (the frequency)
- The longer the delay the slower the speed for one complete revolution. By applying a fixed number of pulses to the motor, the motor shaft will rotate through a given angle

- The advantage of using time delayed pulse is that there would be no need for any form of additional feedback because by counting the number of pulses given to the motor the final position of the rotor will be exactly known
- This response to a set number of digital input pulses allows the stepper motor to operate in an “Open Loop System” making it both easier and cheaper to control

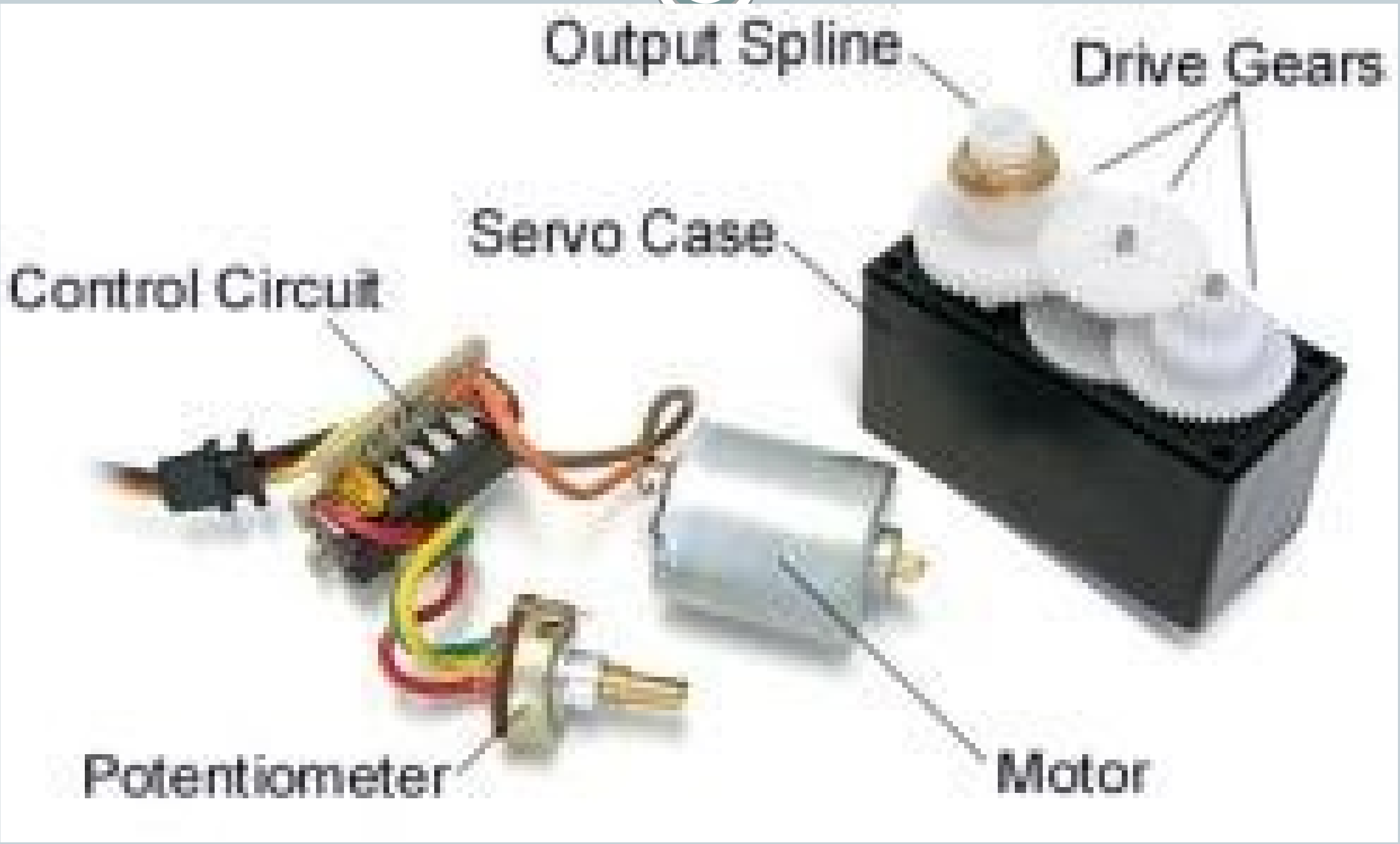
AC Servo Motor

- Servos are controlled by sending an electrical pulse of variable width, or pulse width modulation (PWM), through the control wire
- There is a minimum pulse, a maximum pulse and a repetition rate. A servo motor can usually only turn 90° in either direction for a total of 180° movement
- The motor's neutral position is defined as the position where the servo has the same amount of potential rotation in the both the clockwise or counter-clockwise direction

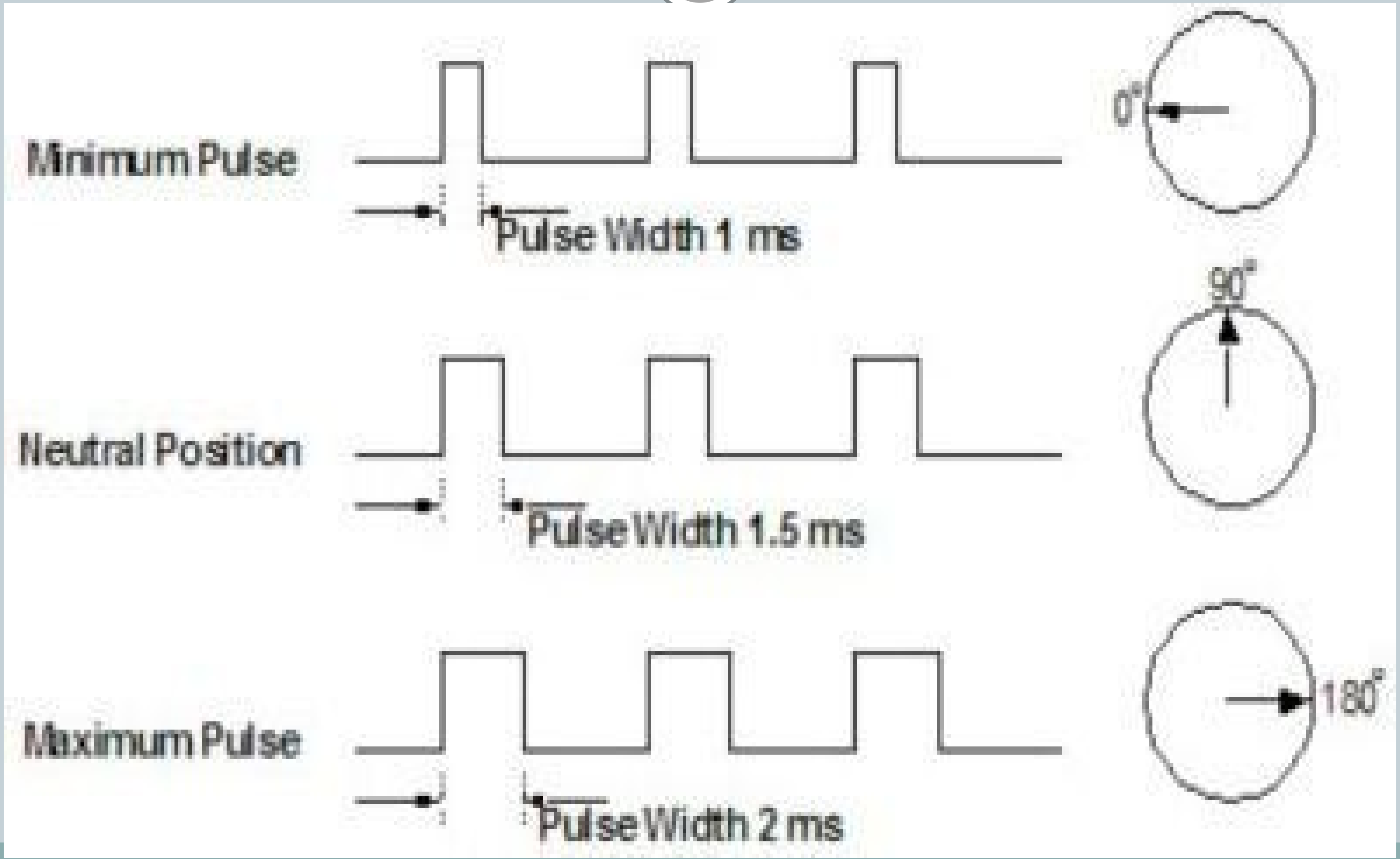
AC Servo Motor

- The PWM sent to the motor determines position of the shaft, and based on the duration of the pulse sent via the control wire the rotor will turn to the desired position
- The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns
- For example, a 1.5ms pulse will make the motor turn to the 90° position. Shorter than 1.5ms moves it to 0° and any longer than 1.5ms will turn the servo to 180°

AC Servo Motor



AC Servo Motor



AC Servo Motor

- When these servos are commanded to move, they will move to the position and hold that position
- If an external force pushes against the servo while the servo is holding a position, the servo will resist from moving out of that position
- The maximum amount of force the servo can exert is called the torque rating of the servo.
- Servos will not hold their position forever though; the position pulse must be repeated to instruct the servo to stay in position

Grippers

- In robotics, an end effector is the device at the end of a robotic arm, designed to interact with the environment
- The exact nature of this device depends on the application of the robot. In the strict definition, which originates from serial robotic manipulators, the end effector means the last link (or end) of the robot
- At this endpoint the tools are attached. In a wider sense, an end effector can be seen as the part of a robot that interacts with the work environment

Grippers

- This does not refer to the wheels of a mobile robot or the feet of a humanoid robot which are also not end effectors—they are part of the robot's mobility

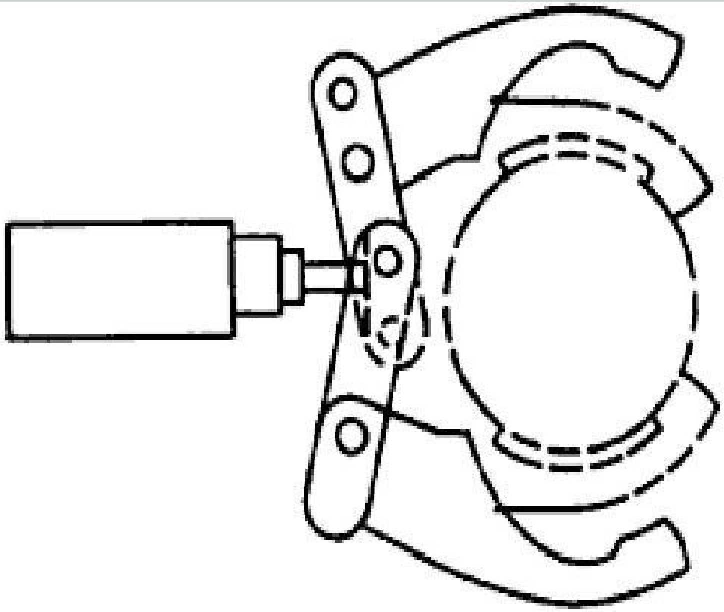


Figure 1 External gripper.

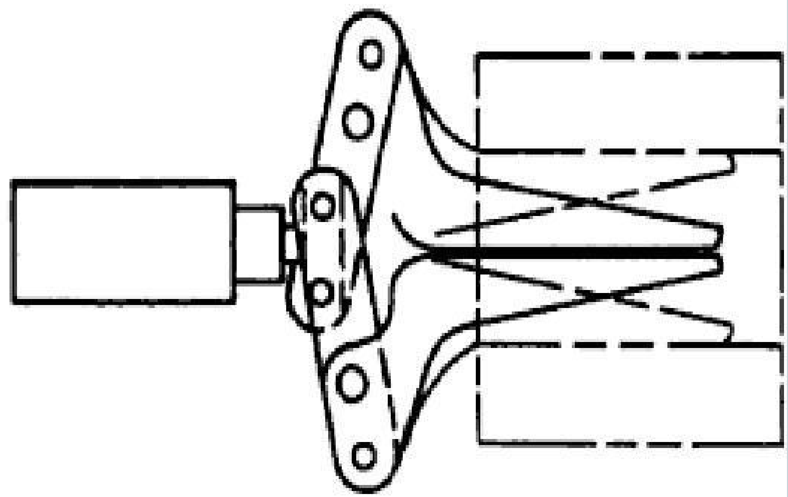


Figure 2 Internal gripper.

Grippers

- End effectors may consist of a gripper or a tool
- Four general categories of robot grippers
  - Impactive – jaws or claws which physically grasp by direct impact upon the object
  - Ingressive – pins, needles or hackles which physically penetrate the surface of the object (used in textile, carbon and glass fiber handling).
  - Astrictive – suction forces applied to the objects surface (whether by vacuum, magneto- or electro adhesion).
  - Contigutive – requiring direct contact for adhesion to take place (such as glue, surface tension or freezing)

Grippers

- They are based on different physical effects used to guarantee a stable grasping between a gripper and the object to be grasped
- Industrial grippers can be mechanical, the most diffused in industry, but also based on suction or on the magnetic force
- Vacuum cups and electromagnets dominate the automotive field and in particular metal sheet handling

Grippers

- A gripper is a motion device that mimics the movements of people, in the case of the gripper, it is the fingers. A gripper is a device that holds an object so it can be manipulated. It has the ability to hold and release an object while some action is being performed. The fingers are not part of the gripper, they are specialized custom tooling used to grip the object and are referred to as "jaws." Two main types of action are performed by grippers:

Grippers

- **External:** This is the most popular method of holding objects, it is the most simplistic and it requires the shortest stroke length. When the gripper jaws close, the closing force of the gripper holds that object
- **Internal:** In some applications, the object geometry or the need to access the exterior of the object will require that the object is held from the center. In this case the opening force of the gripper will be holding the object

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.

- Types of magnetic grippers
  - Electromagnets
  - Permanent magnets

Magnetic Grippers

- **Electromagnets**
- Electromagnetic grippers include 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.

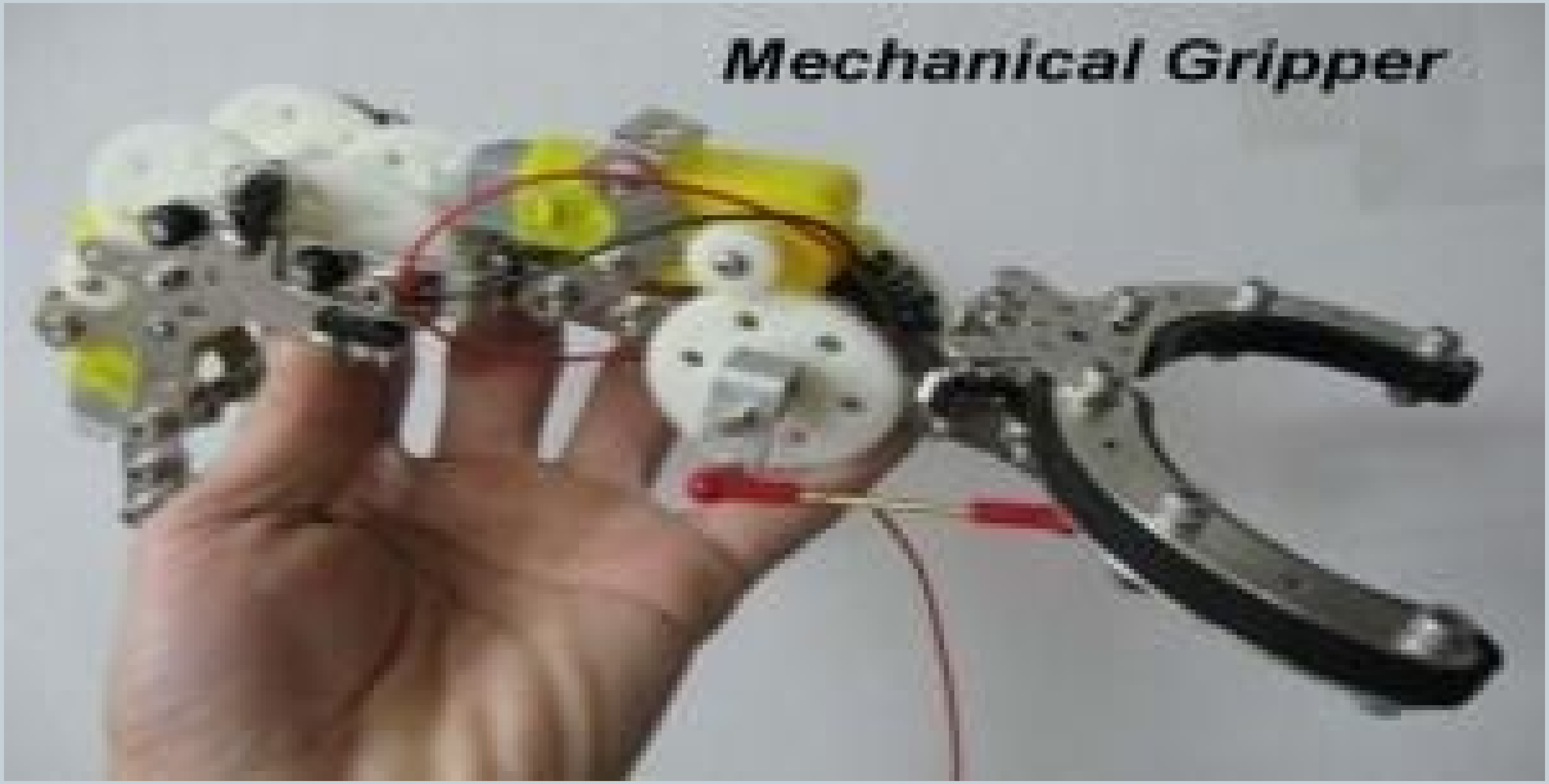
Magnetic Grippers

- **Permanent magnets:**
- The permanent magnets do 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

- **Benefits:**
  - This gripper only requires *one surface* to grasp the materials.
  - The grasping of materials is done *very quickly*.
  - It does not require *separate designs* for handling different size of the material
  - It is capable of grasping materials with *holes*, which is unfeasible in the vacuum grippers
- **Drawbacks:**
  - The gripped work part has the chance of *slipping out* when it is moving quickly.
  - Sometimes *oil* in the surface can reduce the strength of the gripper.
  - The *machining chips* may stick to the gripper during unloading

Mechanical Gripper



Mechanical Gripper

- A mechanical gripper is used as an *end effector* in a robot for grasping the objects with its *mechanically* operated fingers.
- In industries, two fingers are enough for holding purposes. More than three fingers can also be used based on the application. As most of the fingers are of *replace able* type, it can be easily removed and replaced

Mechanical Gripper

- A robot requires either hydraulic, electric, or pneumatic drive system to create the input power. The power produced is sent to the gripper for making the fingers react. It also allows the fingers to perform open and close actions. Most importantly, a *sufficient force* must be given to hold the object.

Mechanical Gripper

- In a mechanical gripper, the holding of an object can be done by *two different methods* such as:
  - Using the finger pads as like the shape of the work part.
  - Using soft material finger pads.

- In the first method, the contact surfaces of the fingers are designed according to the work part for achieving the *estimated shape*. It will help the fingers to hold the work part for some extent

Mechanical Gripper

- In the second method, the fingers must be capable of supplying sufficient force to hold the work part. To avoid scratches on the work part, *soft type pads* are fabricated on the fingers. As a result, the contact surface of the finger and co – efficient of friction are improved
- This method is very simple and as well as *less expensive*.
- It may cause slippage if the force applied against the work part is in the parallel direction. The slippage can be avoided by designing the gripper based on the force exerted

Mechanical Gripper

$$Equation\ I = \mu\, n_f F_g = w \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

- μ => co – efficient of friction between the work part and fingers
- n_f => no. of fingers contacting
- F_g => Force of the gripper
- w => weight of the grasped object

Mechanical Gripper

$$\text{Equation 2} \qquad \mu\, n_f F_g = w\, g \quad \ldots\ldots\ldots \; 2$$

- g => g factor

Mechanical Gripper

- The *values of g factor* for several operations are given below:
  - g = 1 – acceleration supplied in the opposite direction.
  - g = 2 – acceleration supplied in the horizontal direction.
  - g = 3 – acceleration and gravity supplied in the same direction

- A pneumatic gripper is a specific type of pneumatic actuator that typically involves either parallel or angular motion of surfaces, A.K.A. “tooling jaws or fingers” that will grip an object.
- When combined with other pneumatic, electric, or hydraulic components, the gripper can be used as part of a "pick and place" system that will allow a component to be picked up and placed somewhere else as part of a manufacturing system.

Mechanical Gripper

- Some grippers act directly on the object they are gripping based on the force of the air pressure supplied to the gripper, while others will use a mechanism such as a gear or toggle to leverage the amount of force applied to the object being gripped. Grippers can also vary in terms of the opening size, the amount of force that can be applied, and the shape of the gripping surfaces— frequently called "tooling jaws or fingers"

Mechanical Gripper

- Common industrial pneumatic components include:
    - pneumatic direct operated solenoid valve
    - pneumatic pilot operated solenoid valve
    - pneumatic external piloted solenoid valve
    - pneumatic manual valve
    - pneumatic valve with air pilot actuator
    - pneumatic filter
    - pneumatic pressure regulator
    - pneumatic lubricator

Hydraulic Grippers

- Grippers are devices used with pick-and-place robotic systems to pick up or place an object on an assembly line, conveyor system, or other automated system. Fingered tooling—or jaws—is attached to the grippers to grip or hold the object

Hydraulic Grippers

- They come in a variety of styles and powered designs. Three common types are parallel, three-finger, and angled designs.
- The most common are parallel designs, with two fingers that close on a work piece to grip it or open it out by creating pressure on the inside.
- Three-finger designs hold the work piece in the center, and have three fingers offset by 120°. Finally, angled designs feature jaws that work at a variety of different angle openings (for example, 30°, 40°, etc.)

Hydraulic Grippers

- Most hydraulic grippers are designed for a hydraulic system where the cylinder diameter is made with less surface area, meaning that a hydraulic gripper would have the same force at 60 bar as a pneumatic gripper of the same size at 6 bar

Hydraulic Grippers

- In general, hydraulic and pneumatic grippers have the same basic actuation principle. They include direct acting piston designs as well as piston wedge designs

Hydraulic Grippers

- The direct acting piston design is used when a hydraulic force acts directly on a piston that is directly connected to the jaw or finger that is touching or gripping the part.
- The piston wedge design features a hydraulic force acting on a piston while the piston itself is acting on a wedge
- The wedge translates this force to the jaws or fingers, providing the grip force to grip the part.

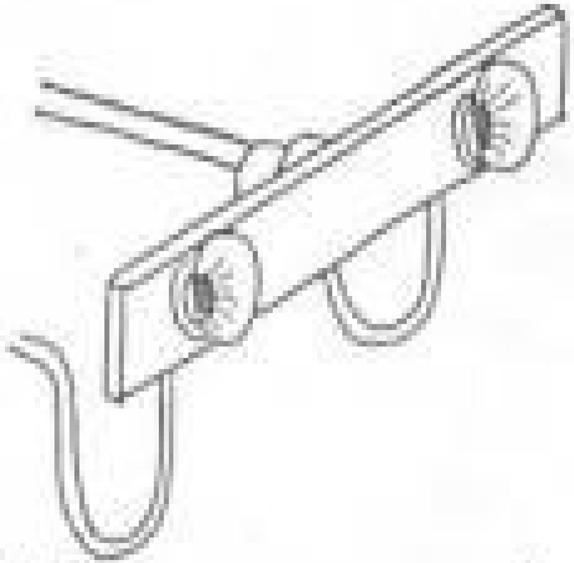
Hydraulic Grippers

- The wedge can give a mechanical advantage as it can increase grip force while keeping the piston diameter and pressure to the piston the same. This allows more grip force in a smaller package compared to the directing piston
- Unlike electromechanical grippers, which have motors on each actuator, one single motor powers the hydraulic fluid that supplies energy to multiple devices throughout a plant.

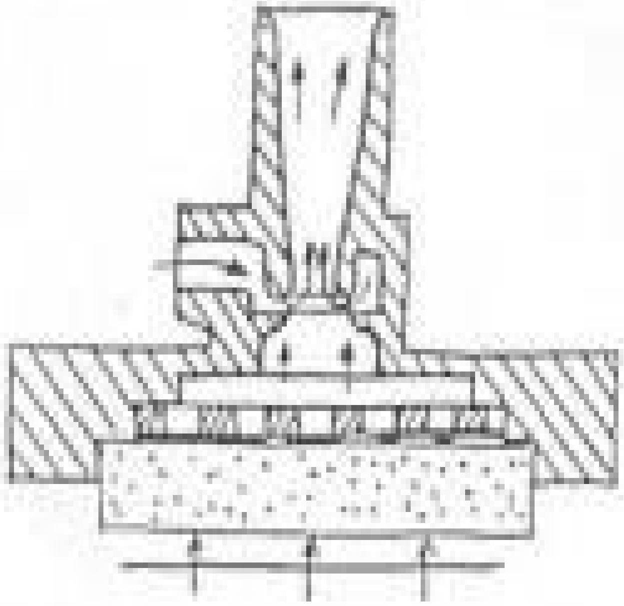
Hydraulic Grippers

- When selecting a hydraulic gripper, it is important to consider the following:
  - Part weight and size to be lifted
  - Part material
  - Clearance issues around the part that could interfere with the gripping part
  - The environment the gripper will be used in (corrosive, food or beverage, etc.)
  - The motion path of the robot or linear device that is moving the gripper
  - The power supply that will be available and the pressure ratings available

Vacuum grippers



Suction cups vacuum gripper



Venturi type vacuum gripper

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

Vacuum grippers

- Vacuum cups: Generally, the vacuum cups (suction cups) will be in the round shape. These cups will be developed by means of *rubber* or other elastic materials. Sometimes, it is also made of *soft plastics*. Moreover, the vacuum cups are prepared of hard materials for handling the soft material objects

Vacuum grippers

- Two different devices are used in the suction cups for creating the vacuum. They are:
  - Venturi
  - Vacuum pump
- Venturi device is operated with the help of *shop air pressure*, while the vacuum pump is driven either by means of *vane or piston* device.
- The vacuum pump has the ability to create the *high vacuum*. As the venturi is a simple device, it is more *reliable* and *inexpensive*. Both these devices are very well capable of providing high vacuum if there is a sufficient supply of air pressure.

Vacuum grippers

- Types of vacuum grippers
- The *ball joint* type vacuum gripper is capable of changing into various contact angles automatically. Moreover, the bending moments in the vacuum cups are also decreased. It is used for carrying irregular materials, heavy objects, etc
- A vacuum gripper with *level compensator* can be very helpful in balancing the objects with different levels. It also has the capability to absorb the shocks

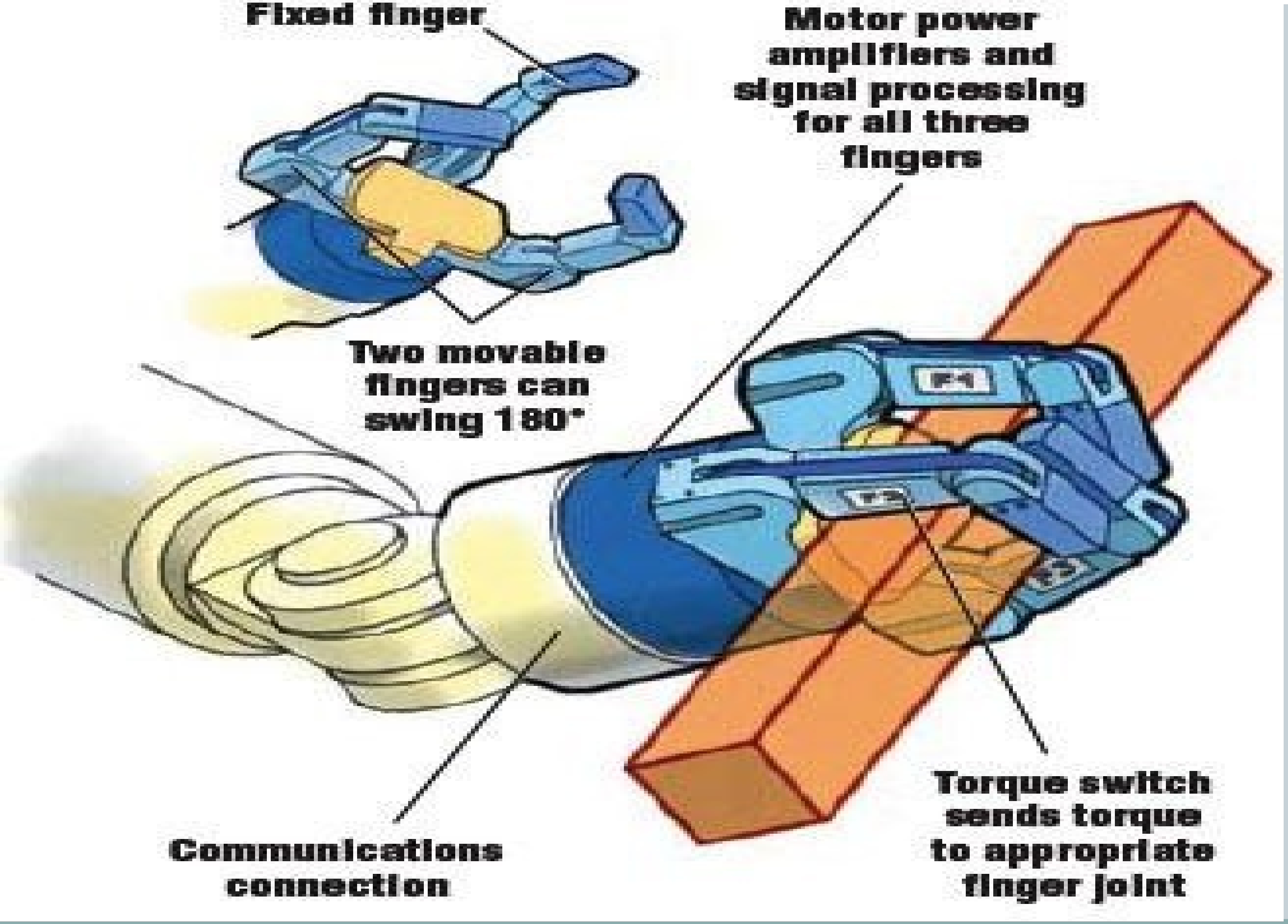
Vacuum grippers

- Applications of vacuum grippers
  - Vacuum grippers are highly useful in the heavy industries, automobiles, compact disc manufacturing, and more for *material handling* purposes.
  - It is also used in the tray & box manufacturing, labeling, sealing, bottling, and so on for *packaging* purposes.

Two and Three-fingered gripper

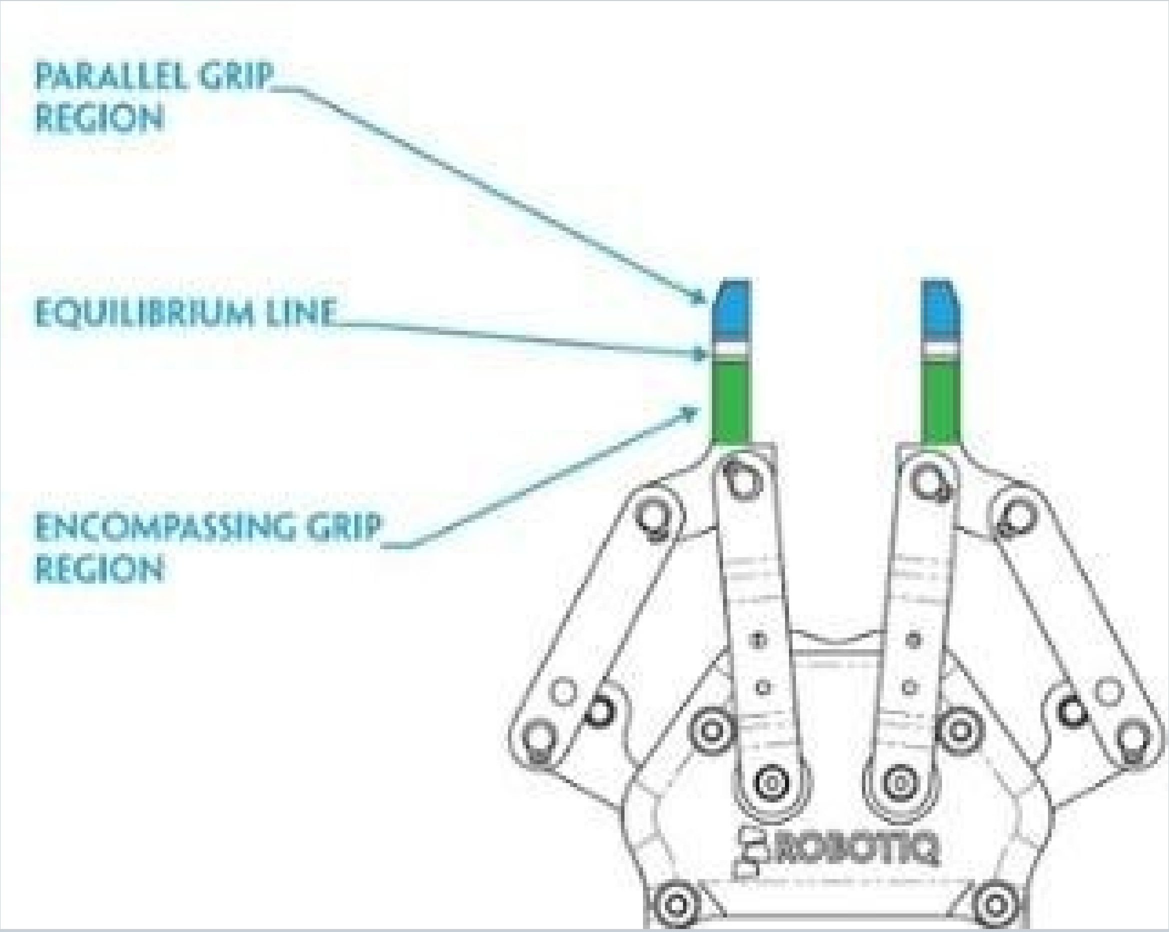
- It's also costly to order custom-made handlers for special parts. To solve these problems, engineers at Barrett Technology Inc., Cambridge, Mass. (barrett.com), developed the Barrett Hand, a three-fingered gripper that can securely hold a wide variety of shapes and parts
- The device has three articulated fingers. The center finger is fixed, and the other two rotate up to 180° around the outside of the hand's palm.

- This gives the hand a wide variety of grips and configurations. Each finger has two sections which act in concert to grab objects.
- When the first section touches an object, the second section continues retracting until it is also in contact. With all the fingers in play, and including the palm, the hand can have a seven-point grip on the object. This lets it deal with objects of unknown or inconsistent shapes. The hand can lift about 1.2 kg.


Fixed finger
Motor power amplifiers and signal processing for all three fingers
Two movable fingers can swing 180°
F1
F2
F3
Torque switch sends torque to appropriate finger joint
Communications connection

- The hand's eight joints are controlled by four brushless-dc motors, all in the wrist section. A torque switch lets four motors control eight axes of motion.
- The gripper's communications, five microprocessors, sensors, and signal processor are packed inside the palm body. A small umbilical cable connects the hand to an array of robotic arms from different manufacturers.

Two-fingered gripper



- The mechanism driving the fingers of this Gripper is optimized to obtain two distinct contact regions. The first one, called the “encompassing grip region”, is located at the base of the fingers, while the second one, called the “pinch grip region”, is located at their end/tip
- The boundary between these two adjacent regions is called the “equilibrium point”.

- When the contact of the finger with the object to be grasped occurs in the encompassing grip region, the finger automatically adapts to the shape of the object and curls around it
- On the other hand, when the contact is made in the pinch grip region, the finger maintains its parallel motion and the object is pinched.
- Since the finger keeps its parallel motion when a contact is made above the equilibrium point during a pinch grip, the same is true for a contact made below the equilibrium point during an inside grip

- **Coupling between the fingers**

In addition to the mechanism used inside each of its fingers, the Gripper also relies on a special coupling architecture between the fingers. In fact, it is mechanically designed to ensure that the two fingers move in conjunction with each other in order to center the object grasped in the middle of the Gripper. This self-centering avoids the need to use expensive sensor sand is above all safer

- In the same vein to make this Robot Gripper as reliable as possible, a self-locking feature has been incorporated into it between the actuator and the fingers. By doing so, we are sure that the Gripper will never release the object and let it fall if the power is shut down. It is also economically interesting, as the actuator doesn’t need to apply torque continually when an object is grasped, thus in addition to the power saved, the lifespan of the Gripper is thereby maximized

Selection and design considerations in robot gripper

- A robot can perform good grasping of objects only when it obtains a proper gripper selection and design
  - The gripper must have the ability to *reach* the surface of a work part.
  - The change in work part size must be *accounted* for providing accurate positioning.
  - During machining operations, there will be a change in the work part size. As a result, the gripper must be *designed* to hold a work part even when the size is *varied*.

Selection and design considerations in robot gripper

- A robot can perform good grasping of objects only when it obtains a proper gripper selection and design
  - The gripper must not create any sort of *distort* and *scratch* in the fragile work parts.
  - The gripper must hold the *larger area* of a work part if it has various dimensions, which will certainly increase *stability* and *control* in positioning.
  - The gripper can be designed with resilient pads to provide more grasping contacts in the work part. The replaceable fingers can also be employed for holding different work part sizes by its interchangeability facility

- Moreover, it is difficult to find out the *magnitude of gripping force* that a gripper must apply to pick up a work part. The *following significant factors* must be considered to determine the necessary gripping force
  - Consideration must be taken to the *weight* of a work part.
  - It must be capable of grasping the work parts constantly at its *center of mass*.
  - The *speed* of robot arm movement and the connection between the direction of movement and gripper position on the work part should be *considered*.

- Moreover, it is difficult to find out the *magnitude of gripping force* that a gripper must apply to pick up a work part. The *following significant factors* must be considered to determine the necessary gripping force
  - It must determine either *friction* or *physical constriction* helps to grip the work part.
  - It must consider the *co-efficient of friction* between the gripper and work part.