# Robot Drives

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## Robot Drive

- The links of the robots move about the prescribed axis by receiving power through the drive system also known as actuator.
- Actuator are the muscles of the robots which move or rotate the links to change the configuration of the robots.
- Actuators are the devices which provide actual motive force for the robot joints.
- Source of power for the actuators can be through:
  i. Electricity
  ii. Pressurized fluid
  iii. Compressed air

  based on which they are classified.



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# Robot Drive

- Actuators chosen (would depends upon) should be
  i. Light
  ii. Economical
  iii. Accurate
  iv. Responsive
  v. Reliable
  vi. Easy to maintain



# Robot Drive

❑ **Classification of Actuators:**

➢ **Electric Motors:**

Electric Motors Produce rotational movement.
Translatory movement are produced by transmission devices.

a) Servomotor
   i. AC
   ii. DC
b) Stepper motor
c) Direct drive motor

# Robot Drive

❑ **Classification of Actuators: contd…**

- **Hydraulic Actuators:**

  Hydraulic actuators use pressurised fluid.

  a) Linear actuators

  Hydraulic cylinder produce translatory motion in joints.

  i. Single acting

  ii. Double acting

  b) Rotary actuators

  Hydraulic motors produce rotation motion joints.

  i. Gear

  ii. Vane

  iii. Piston

  iv. Rack and pinion



# Robot Drive

❑ **Classification of Actuators: contd…**

- **Pneumatic Actuators:**

  Pneumatic actuators use compressed air.

  a) Air cylinders

  Air cylinders produce translatory motion in joints.

  i. Single acting

  ii. Double acting

  b) Air motors

  Air motors produce rotation motion joints.

  i. Vane

  ii. Piston

- **Shape Memory Metal Actuators**
- **Magneto Restrictive Actuators**

## Robot Drive

There are many types of electric motors that are used in robotics. They include the following:

1. DC motors
2. Reversible AC motors
3. Brushless DC motors

i. Except for stepper motors, all other types of motors can be used as a servo- motor, which will be discussed later.

ii. In each case, the torque or power output of the motor is a function of the strength of the magnetic fields and the current in the windings. Some motors have permanent magnets (PMs).

iii. These motors generate less heat, since the field is always present and no current is needed to build them.

iv. Others have a soft iron core and windings, where an electric current creates the magnetic field.





## Robot Drive

v. In this case, more heat is generated, but when needed, the magnetic field can be varied by changing the current, whereas in permanent magnet motors, the field is constant.

vi. Additionally, under certain conditions, it is possible that the permanent magnet may get damaged and loses its field strength, in which case the motor becomes useless.

vii. For example, you should never take a motor apart, as the permanent magnet will become significantly weaker.

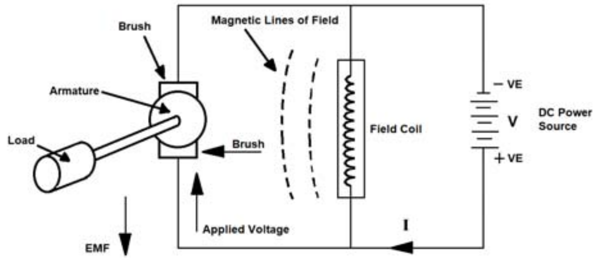
viii. This is because the iron mass around the magnet holds the field intact until they are separated.

ix. To increase the strength of the permanent magnets in motors, most manufacturers magnetize the magnets after assembling the motor. Motors without permanent magnets do not have this problem.

# Robot Drive

**DC Motors:**

i. The principle of operation of a DC machine is based on the rotation of **an armature winding within a magnetic field**.



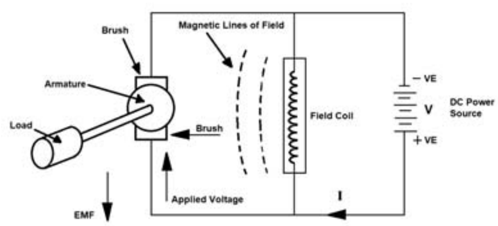

ii. The armature is the rotating member or **Rotor**.

iii. The field winding / Permanent Magnet is stationary member or **Stator**.



# Robot Drive

**DC Motors:**




iv. The armature winding is connected to commutator which is a cylinder of insulated copper segments mounted on a rotor shaft.

**v.** **Stationary** carbon brushes are connected machine terminals are held against the commutator surface enable transfer of **direct current** to rotating winding.

## Robot Drive

**DC Motors:**

v) Field winding is connected permanently to a **constant** DC source

OR

**Permanent Magnet** which replaces the field winding is used.

a. Iron Core Permanent Magnets (Made of ALNICO/ FERRITE/ CERAMIC/ RARE EARTH METALS)
b. Surface Wound Permanent Magnets
c. Printed Armature or Moving Coil Permanent Magnets

vi) When direct current is applied to field coil, a magnetic field is created and the armature coil brings to turn in magnetic field and voltage is generated.



## Robot Drive

**DC Motors:**

vii. When the armature is static, this voltage is applied to the armature that draws heavy current.

viii. As soon as armature rotates, the coil cuts through the magnetic line of flux and a back EMF is generated.

ix. This opposes the applied voltage.

x. The armature draws little current during its rotation when it generates counter EMF and develops a torque.

xi. Higher the armature current, higher is the torque.

# Robot Drive

**DC Motors**:

1. DC motors allows precise control of speed in manipulation of voltage applied to the motor.
2. The principle of operation of a DC motor is based on rotation of armature (rotor) winding within a magnetic field (stator).
3. The armature winding is connected to a commutator which is a cylinder of insulated copper segments mounted on a rotor shaft.
4. Stationary carbon brushes which are connected to the machine terminals are held against the commutator surface and enables the transfer of a DC current to the rotating windings.
5. Two important characteristics of a DC motor are:
   i. Motor speed varies linearly with input voltage that is induced voltage (E/emf) in the armature winding is related to the rotational speed(ω/rad/sec)

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# Robot Drive

$$E = K_f \phi \omega$$

Where, $K_f$ is the constant determined by the winding and

$\phi$ is the flux per pole in Weber (Wb).

ii. Motor torque varies linearly with input current that is, torque (T/N-m) is related to the armature current (I/Amp)

$$T = K_f \phi I$$

Where,

IR is the voltage drop across the resistance of the armature.

iii. For a motor, and input voltage V is applied is supplied to the armature and the corresponding voltage equation becomes

i.e. $$E = V - IR = \left(\frac{T}{I}\right)\omega$$

or $$VI - I^2R = \omega T = P$$

Where, $P$ is the mechanical output power

$VI$ is the electrical input power and

$I^2R$ is the electrical power loss

$$E = V - IR = (K_f \phi)\omega$$

Where, IR is the voltage drop across the resistance of the armature.

$$T = K_f \phi I$$

$$\frac{T}{I} = K_f \phi$$

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## Robot Drive

- DC motors may be classified as separately excited shunt, series and compound connected according to the method of field connection.
- Modern motors are permanent magnet field rather than separately excited field since PM saves the field voltage source and result in higher efficiency.



## Robot Drive

A DC servomotor used to drive a robot joint has a torque constant, 1.25 N-m/A and voltage constant of 12 X $10^{-3}$ V/rpm. The armature resistance of 2.5 ohms. A voltage of 25 V is applied at a point of time of robot cycle when the joint is stationary.

Determine,

(a) The torque of the motor immediately after the voltage is applied.

(b) The back e.m.f. and the respective torque corresponding to rotational speeds of 250 rpm and 500 rpm.

## Robot Drive

Sol. Data:

Torque Constant, $K_m = 1.25Nm/A$

Voltage constant, $K_b = 12 \times 10^{-3} V/rpm$

Armature resistance, $R_a = 25\ ohm$

Starting voltage applied, $V = 25\ V$

Using the equation,

$$T_m = K_m I_a$$

$$= \frac{K_m(V_{in} - e_b)x^2}{R_a} = \frac{K_m(V_{in} - K_b \cdot w)}{R_a}$$

At the start w=0

So,
$$= \frac{K_m V_{in}}{R_a} = \frac{1.25(25)}{2.5} = 12.5\ \text{N.m.}$$

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## Robot Drive

When the speed of rotation, ω= 250 rpm

$$e_b = K_b . w = 12 \times 10^{-3} \times 250 = 3V$$

$$T_m = \frac{K_m(V_{in} - e_b)}{R_a} = \frac{1.25(25-3)}{2.5} = 11\ \text{N.m.}$$

When the speed of rotation is, ω= 500 rpm

$$e_b = K_b\ .\ w = 12 \times 10^{-3} \times 500 = 6V$$

$$T_m = \frac{K_m(V_{in} - e_b)}{R_a} = \frac{1.25(25-3)}{2.5} = 9.5\ \text{N.m}$$

Ans. a) Torque at the start = **12.5 Nm**

b) Torque at 250 rpm =**11 Nm**

c) Torque at 500 rpm = **9.5 Nm**

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# Robot Drive

**Advantages of DC Motor Provide :**

i. Excellent speed regulation
ii. high torque and high efficiency

**Disadvantages of DC Motor:**

a) The operation of DC motor must take place within its thermal range.
b) Maintenance owing to carbon deposits on brushes.
c) Used in positioning systems where slower response can be tolerated in comparison to hydraulic systems.



# Robot Drive

**AC Motor:**

a) Unlike DC motors, AC motors operate without brushes this eliminating one of the main maintenance problems associated with the DC motors.
b) The velocity of the AC motor is regulated by voltage frequency rather than voltage magnitude as in the case of DC motors.
c) The frequency manipulation requires use of an electrical inverter (The inverter contains a DC power supply and a circuit that invert the resultant DC voltage into AC voltage with a continuously controllable frequency.)
d) The use of AC motors was limited earlier because intervals were expensive huge in size compared to DC power amplifiers which are required to control the voltage magnitude applied to the DC motor drives.
e) Nowadays cost-effective, small size inverters are used, thus enabling prominence of AC motors in CNC machines.

# Robot Drive

**AC And DC:**

i. One important issue in the design and operation of all motors is the dissipation of heat.
ii. The heat is generated primarily from the resistance of the wiring to electric current (load related), but includes heat due to iron losses, including eddy current losses and hysteresis losses, friction losses, brush losses, and short-out circuit losses (speed related) as well.
iii. The higher the current, the more heat is generated, as $W = RI^2$.
iv. Thicker wires generate less heat, but are more expensive, are heavier (more inertia), and require more space.
v. However, what is important is the path that the heat must take to leave the motor since if the heat is dissipated faster, more generated heat can be dissipated before damage occurs.

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# Robot Drive

vi. Figure shows the heat leakage path to the environment for an AC-type motor and a DC-type motor.
vii. In DC-type motors, the rotor contains the winding and carries the current, and thus, heat is generated in the rotor.
viii. This heat must go from the rotor, through the air gap, through the permanent magnets, through the motor's body, and be dissipated into the environment (It may also go through the shaft to the bearings and out.)
ix. As air is a very good isolator.
x. Thus, the total heat transfer coefficient for the DC motor is relatively low.

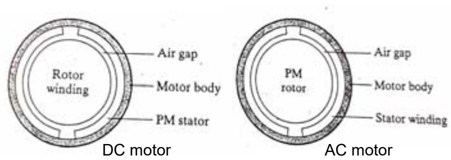

Fig. Heat dissipation path of motors.

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# Robot Drive

xi. On the other hand, in an AC type motor, the rotor is a permanent magnet, and the winding is in the stator.

xii. The generated heat in the stator is dissipated to the air by conduction through the motor's body.

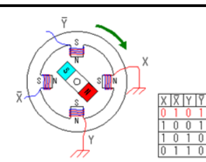
xiii. As a result, the total heat transfer coefficient is relatively because no air gap exists.

xiv. As a result, AC-type motors can be exposed to relatively higher currents without damage, and thus they are generally more powerful for the same size.

xv. Stepper motors, although not AC motors, have a similar construction.



# Robot Drive



**Stepper motors**:

1. a) In most applications stepper motors are used without feedback.
   b) This is because a unless a step is missed stepper motors steps a known angle each time it is moved.
   c) Thus its angular position is always known and no feedback is necessary.
2. a) Unlike AC or DC motors, stepper motor will not rotate when connected to power.
   b) Stepper motors rotate only when magnetic field is rotated through the different windings.
   c) Even when not powered, stepper motors have a residual torque called defend torque.
   d) It requires an external torque to turn a stepper motor.

# Robot Drive

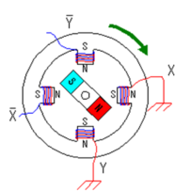
e) As a result stepper motors need a microprocessor or a driver or controller (indexer) circuit for rotation.

3. a) For industrial robotic application, stepper motors are hardly used except in small tabletop robots.

   b) However stepper motors are extensively used in non industrial robots as well as robotic devices (used in conjunction with robots) from tooling machines to peripheral devices and from automatic manufacturing to control devices.



# Robot Drive




| X | $\bar{X}$ | Y | $\bar{Y}$ |
|---|---|---|---|
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 |

**Stepper motors:**

**Principle of operation:**

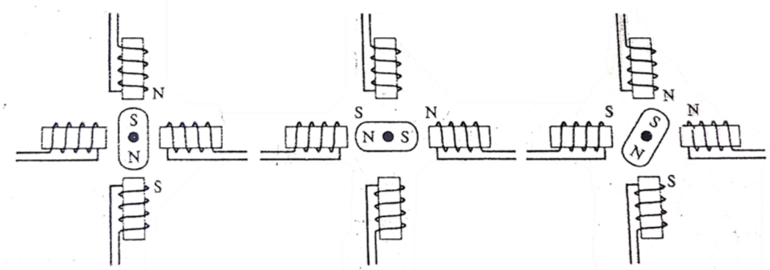
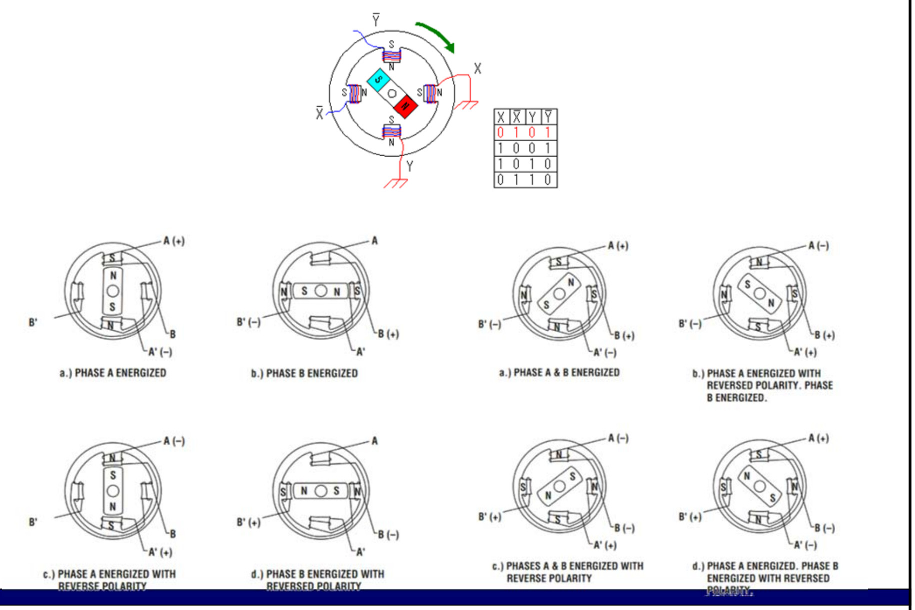



Figure: Basic principle of operation of a stepper motor as the coils in the stator are turned on and off the rotor will rotate to align itself with the magnetic field






# Robot Drive

1. Stepper motors with two coils in its STATOR and a permanent magnet as its ROTOR is shown.
2. When each of the coils of the status is energized, the permanently magnetized rotor will rotate to align itself with the stator magnetic field.
3. The rotor will stay at this position unless the field rotates.
4. As the power to present coil is disrupted and is directed to the next coil the rotor will rotate again to align itself with the field in position.
5. Each rotation is equal to the step angle, which may vary from 180 to as little as a fraction of a degree in this example $90^0$ .
6. Next, the first coil will once again be turned on, but in opposite polarity while second is turned off. This will cause the rotor to rotate another step in the same direction.

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# Robot Drive

7. The process continues as one coil is turn off another is turned on.
8. A sequence of four steps will bring the rotor back to back exactly the same state it was at the beginning of the sequence.
9. If both coils are turned on, the rotor would rotate to align itself to the path of least reluctance.
10. Later, if the first coil is turned off while the second remains on, the router with rotate another $45^0$.
11. This is called half step operation and includes a sequence of eight movements.
12. With opposite on-off sequence rotor will rotate in opposite direction.
13. steppers run between to $1.8^0$ to $7.5^0$ at full step .



# Robot Drive

- To reduce size of steps, number of poles need to be increased. However there is a physical limit to how many poles may be used.
- To further increase the number of steps for revolution different number of teeth can be built into the stator and rotor.
- For instance, 50 teeth on the rotor $\left(\frac{360}{50} = 7.2^\circ\right)$,and 40 teeth on the stator $\left(\frac{360}{40} = 9^\circ\right)$ will result in ($9^0 - 7.5^0$) $1.8^0$ step angle with 200 steps per evolution.

# Robot Drive

Example:

- A stepper motor actuates a arm of a pick and place robot. The step angle of the motor is 10 degree. For each pulse received from the pulse train source, the motor rotates through a distance of one step angle.



Sol. Data:

The step angle, $A_s = 10^\circ$

a) Resolution of the stepper motor

$$R_s = \frac{A_s}{360^\circ} = \frac{10^\circ}{360^\circ} = 0.027$$

b) Control resolution, $R_s = 0.027$

$$\text{Accuracy} \geq \frac{0.027}{2} = 0.0135^\circ$$

c) Pulse count $n = \frac{(N_R)360^\circ}{N_R} = \frac{N_R}{R_S}$

Where $N_R$ = number of revolutions = 4

$$n = \frac{4}{(1/36)} = 144\,pulses$$

d) Pulse rate, $n_r = \frac{N_m}{A_s R_s}$

Where $N_m$ number of revolution per minute =20 rpm

So, $$n_r = \frac{120}{(1/36)} = 720\ pulses/min$$

Ans.

a) Resolution of stepper motor $\frac{1}{36} = 0.027°$

b) Control resolution = $0.027^0$, Accuracy = $0.0135^0$

c) Number of pulses for 4 rotation = 144 impulses.

d) Pulse rate for 20 rpm $= 720 \frac{pulses}{min}$



# Robot Drive

**Concepts of Servo System**

i. The word **servo** is derived from the Latin word which means **slave**.

ii. That is, **a servo mechanism** unables to control **large powers** at will by the movement of for example control levers at **low power levels.**

iii. Its operation depends upon the difference between the actual position and the desired position.

iv. A control mechanism which is automatic and actuated by an error signal in the form of a closed loop cycle and possessing power amplification is said to be a servo mechanism.

## Robot Drive

v. The idea of measuring the error and then using this error to indicate the action necessary to eliminate error is the fundamental principle of servo mechanism.

vi. A servo mechanism is thus an Electromechanical (group of mechanical and electrical or hydraulic or pneumatic components) closed-loop system in which the output response is the position/Velocity/Acceleration or other position-time characteristics of a mechanical drive.



## Robot Drive

**Servo mechanism components:**

1. Error Detector:
   i. The purpose of error detector is to measure the difference between the command and the controlled variable and to convert this difference to a usable form (generally electrical voltage signal).
   ii. Linear wire-wound potentiometers are often used as error detectors.
   **iii. If they are excited by Direct Voltage**, then the actuating signal is a direct voltage of varying magnitudes.
   **iv. If they are excited by Alternating Voltage**, then the magnitude of actuating signal is the envelope of the difference voltage.

# Robot Drive

2. Means to Control Source of Power (Power Amplifiers):
   i. The servo amplifier amplifies the error signal so that the gain is made sufficiently high, such that even small errors will initiate a corrective action on the output shaft.
   ii. Servo amplifiers are often transistor, magnetic or vacuum-tube type.

3. The Prime Mover (Servomotor):
   - The source of motivating power maybe AC motor / DC motor or Hydraulic or Pneumatic drive where in it responds to the amplified error signal by applying corrective torques to the output shaft usually through gearing.



# Robot Drive

**Electromechanical Actuation System:**

- Make use of combination of motors, power amplifiers and drive components to effect slide motions.

**Stepper Motor:**

i. The stepping motor is an incremental digital drive.
ii. It translates and input pulse sequence into proportional angular movement and rotates through one step for each angular pulse.
iii. The shaft position is the determined by number of pulses.
iv. Its speed is proportional to the pulse frequency.

# Robot Drive

v. The shaft speed in steps per second = input frequency in pps (pulse per second).
vi. Because it accepts digital input, the motor is suited to open loop systems.
vii. Open loop control systems can be applied in situations in which no change in output condition occurs.
viii. That is for applications in which loading does not vary and in which the frictional and wear characteristics of the servo drives are well known.



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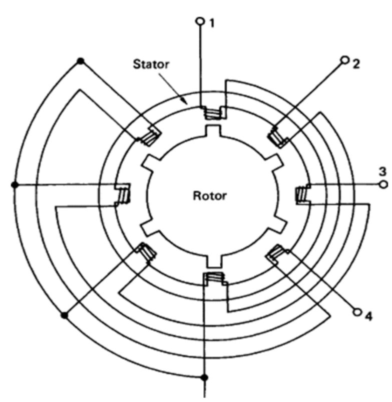
# Robot Drive

**A variable reluctance stepper motor is as shown:**

i. A ferromagnetic multi pole rotor moves inside a magnetic field generated by wound stator.
ii. When an individual stator pole is energized, the rotor moves to a stable equilibrium position corresponding to the minimum reluctance of the magnetic field, i.e. a motor poll aligns itself with the energized stator face-to-face.



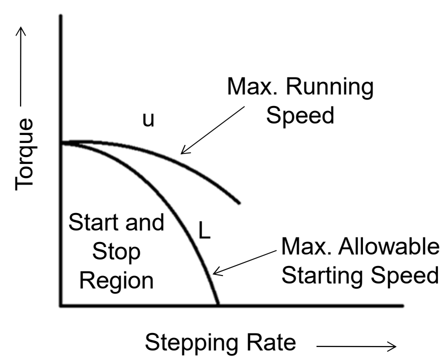
# Robot Drive

iii. As the stator poles are energized in sequence, the rotor rotates by angular steps as the equilibrium is maintained.
iv. The number of angular positions can be doubled if two stator poles are energized simultaneously.
v. In this case equilibrium falls between two stator poles.
vi. To obtain optimal stepping performance, an electronic switch is required as a part of the driver unit.
vii. The drive unit consists of steering circuit and power amplifier.
viii. The steering circuit translates incoming pulses into the correct switching sequence, which are then converted to power pulses. For reverse motion and additional input is provided.



# Robot Drive

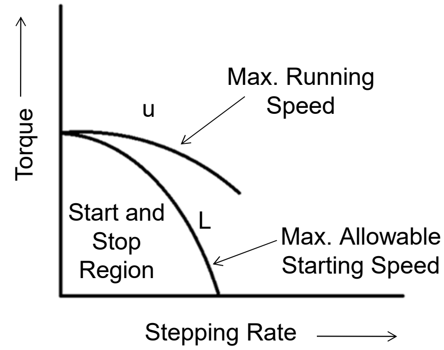
ix. A '**0**' logic level causes clockwise rotation and '**1**' logic level causes counter clockwise rotation.
x. The torque always decreases with an increase in the stepping rate.
xi. The characteristics comparison of two curves lower **L** and upper **u**.
xii. The motor can start, stop and be reversed without missing a step in the region between the axis and lower curve.



## Robot Drive

xv. Once the motor has started, the stepping rate can be gradually increased towards the upper curve.

xvi. Starting, stopping and reversing the direction of rotation are not permitted in the region between lower and upper curves. Acceleration and deceleration should be performed gradually within this region.

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## Robot Drive

xv. Stepper motors are intended for low torque outputs. However the accuracy depends upon the motor's ability to step through the exact number of pulses sent to its input.

xvi. Stepping motors are limited in power and available torque and thus suitable for small machining tools.

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# Robot Drive

**In hydraulic system:**

Hydraulic systems comprise of the following:

1. A hydraulic power supply,
2. A servo valve for each axis of motion to effect power amplification,
3. A hydraulic actuator cylinder / motor for each axis of motion,
4. A sump.

**i. Hydraulic Power Supply:**

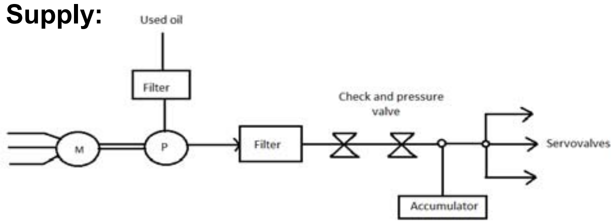



Fig. Hydraulic Power supply



# Robot Drive

i. The power source for hydraulic actuation system (cylinder/ Motor/ servo valves) wall is high pressure oil supplied by an oil pump.

ii. The main components of the hydraulic power supply are:

a. A pump(P), either gear pump vane pump for piston pump (radial or axial type) is used for supplying high-pressure oil.

b. An electric motor (M) for driving the pump usually three phase induction motor.

c. A fine filter for protecting the servo system for a dirt or chips.

d. A coarse filter for protecting the pump.

e. A check valve for eliminating a reverse flow from the accumulator to the pump.

f. A pressure regulating valve for controlling supply pressure to the servo system.

# Robot Drive

g. An accumulator for storing hydraulic energy and smoothing the pulsating flow.

Accumulators:

- Can provide large amount of energy in a short period of time and a smooth the pulsations carried by the pump.
- In hydraulic actuator systems the oil undergoes a considerable amount of temperature change (rise) therefore a necessary part of all high pressure hydraulic systems in an cooling device which would maintain a relatively stable oil temperature, so that properties of hydraulic fluid are maintained.



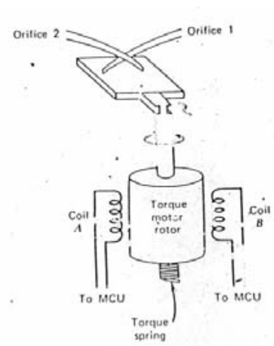
# Robot Drive

**2. Servo Valve:**

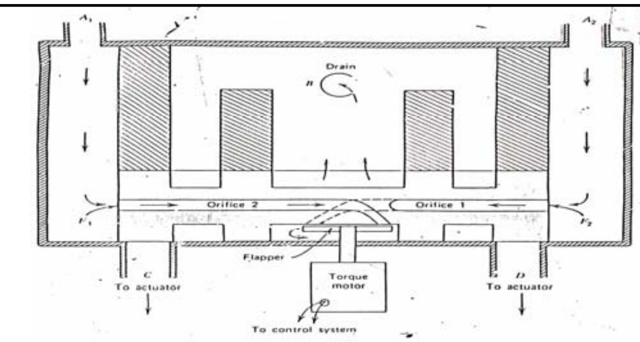
i. The electro hydraulic servo valve controls the flow of high pressure oil to the hydraulic motor.

ii. That is, power amplification in a hydraulic system requires that an electrical signal processed in MCU be converted to appropriate hydraulic pressure.

iii. In NC machines the common hydraulic power amplification device is 4-way proportional servo valve.




Four-way proportional servo valve and flapper control




a. High pressure oil enters the valve at parts A1 and A2 such that it will pass to C or D respectively provided the piston is displaced to the left or right.
b. If the piston is displaced to the right, high pressure oil flows from A1 to C and returns from the actuator (cylinder or motor) through port D, subsequently draining through port (to the sump).
c. If pressure F1< >F2, then displacement of piston occurs.



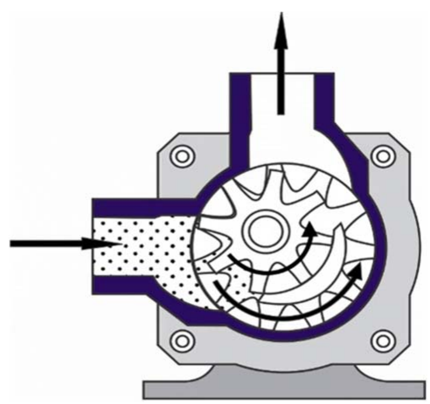
# Robot Drive

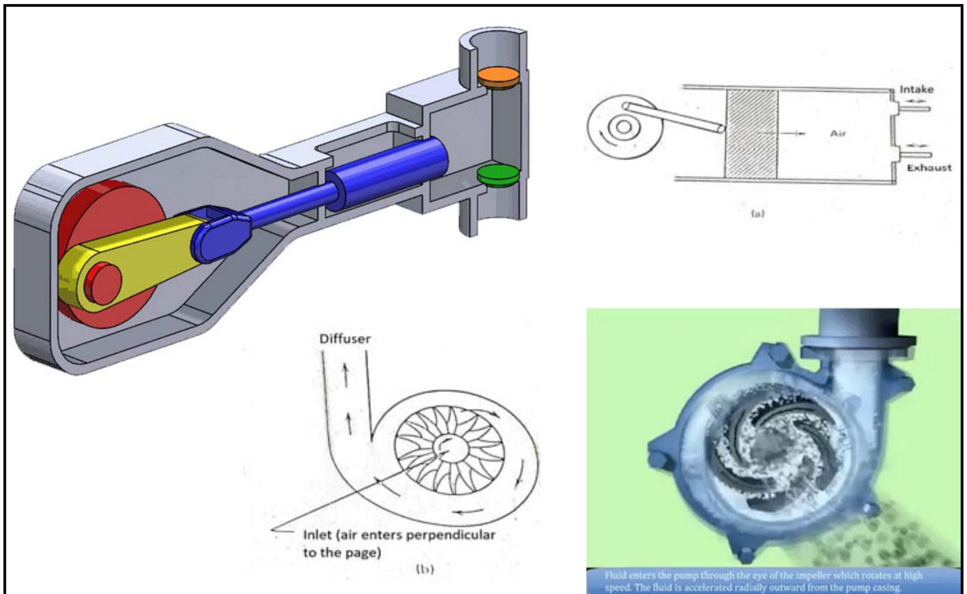
c) To obtain this pressure difference, the flapper valve (valve spool) must be displaced so that flow through one orifice is greater than the flow through the other.
d) The torque motor is so designed that the rotor turns only if current in coil A is less than or greater than current in coil B.
e) The rotor is held in central rest position by the torque spring.
f) If the imbalance in current from control system comes the valve spool to rotate to the right, the flow in orifice 2 is reduced while through orifice 1 is increased.
g) Hence pressure builds up on face F1 and piston moves to the right.
h) This process enables a low level electrical signal to transformed to high pressure input to the actuator (cylinder on motor).
i) The rate of flow of soil is proportional to the velocity of the hydraulic actuator. The time constant of a servo valve is to the order of 5 ms and is negligible compared with other time lags in the system.

# Robot Drive

3. **Hydraulic Actuator:**
   i. The hydraulic actuator is either a hydraulic cylinder for linear motion or a rotary type motor for angular motion
   ii. The hydraulic cylinder due to large quantity of high pressure oil which contains is limited for short throw applications, 0.6mm or less.
   iii. The rotary hydraulic motor is used in large power servo systems and is preferred for longer travel and heavier workloads.
4. **The Sump:**
   ➢ The used oil is returned to the sump. The oil is feedback to the hydraulic power supply and forms a source of the fluid for power supply.







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**Advantages of hydraulic systems:**

i. Deliver large power while being relatively small in size that is (i.e. they provide high torque output).
ii. They have small time constants resulting in smooth operation of machine tool slides, and also thus provide rapid system response.
iii. Are used for multi-axis countering applications for vacuum accurate positioning and rapid acceleration where rapid and smooth response is required under conditions of transient or heavy loading.
iv. Good performance in areas of shock or vibration.
v. Develop higher maximum angular accelerations than DC motors of the same power.

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vi. Complete and accurate control over speed position and direction of actuators.
vii. Accuracy maintained under extreme load conditions since hydraulic oil is virtually incompressible (0.5% it at 7000).
viii. Minimises of leakages liquid required.
ix. Self lubricating and non control

**Disadvantages of hydraulic systems:**

i. Electromechanical actuation systems draw power only when the machine member is in motion. However hydraulic and pneumatic systems must have a high pressure power supply available at all times, hence, pumps run continuously.



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ii. Maintenance and leakage of oil from transmission lines and system components.
iii. Dynamic legs caused by transmission lines being clogged with dirt and viscosity variations with oil temperature.
iv. Hydraulic systems require a closed circuit, and exhaust fluid must be directed back to the pump for circulation

**Pneumatic actuation systems:**

- They operate on the same principle as hydraulic systems except that pneumatic devices used compressed air as the power transmission medium
- Pneumatic systems are generally comprised of the following components:

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1. A pneumatic power supply (air compressor)
2. A servo valve for each axis of motion
3. A pneumatic actuator (Pneumatic Cylinder / Pneumatic Motor) for each axis of motion.

**1. Pneumatic power supply:**

a) The air compressor is the power source for pneumatic actuation systems.

b) They may be either positive displacement: piston compressor or non positive displacement (dynamic) type: centrifugal compressor

i. In positive displacement compressor, air is confined in a progressively diminishing space, thereby reducing the volume of air and increasing its pressure.



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ii. The centrifugal compressor uses a an impeller to impart considerable kinetic energy to the air as it is turned from an axial to a radial direction that is, at as it draws in air compresses it by mass acceleration, there by converting in kinetic energy to pressure energy as the air moves through the diffuser.

- For extremely high pressure multistage compressor are used to boost pressure in stages.
- Before air is admitted to the circuit it is ONCONDITION

I. Filters are used to protect the server systems from dirt and foreign particles this increases system reliability by,:

a) lessening wear and damage,
b) tendency to jam or block up delicate control devices,
c) Miss operation of circuit components.

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II. Since air absorbs moisture which can condense out within the circuit components it must be dried which is achieved through dehydrator.
III. Air is enriched with fine oil mist to provide lubrication for various system components.

**2. Servo Valve:**

i. With modifications, the four way proportional valve is used in pneumatic actuation systems.
ii. In this case the flapper control has been replaced by a controller that moves the piston directly.



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**3. Pneumatic actuators:**

i. Compressed air can be applied to both linear and rotary actuators.
ii. Linear actuators in the form of double acting pneumatic cylinder are similar in construction and principle of operation, to their hydraulic components except that the cylinder piston arrangement makes possible only a limited traverse motion.
iii. Rotary actuators in the form of pneumatic motors, consists of a rotary vane driver by applied air pressure and unlike its hydraulic counterpart the torque developed by the pneumatic motors is proportional to the supply pressure and independent of motor speed.

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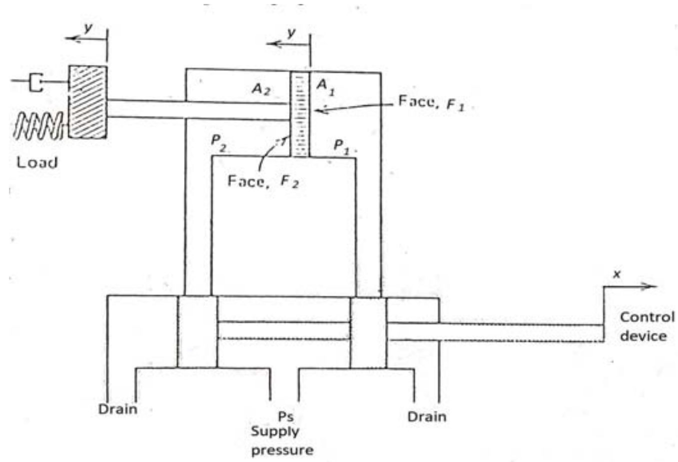
**Advantages of pneumatic drives:**

i. Air is plentiful.
ii. Compressed air can be stored and conveyed easily over long distances.
iii. Compressed air need be returned to sump tank, it can be vented to atmosphere after it has perform its useful work.
iv. Compressed air is clean, explosion proof and insensible to temperature fluctuations.
v. Operation can be fast and speed and forces can be infinitely adjusted between their operational limits.
vi. Digital and logic switching can be performed by pneumatic fluid logic elements.





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vii. Pneumatic cylinders, comprising proximity sensor to sense the position of the piston allow easily integration of pneumatic systems with computer sensing and control.

viii. Pneumatic elements are simple, reliable in operation and relativity cheap.

**Disadvantages of Pneumatic Drives:**

i. Since there is compressible, precise control of speed and position is difficult to achieve and power amplification is less than that achievable by hydraulic systems.

ii. System response is slower as compared to hydraulic drives since air will compress significantly before activation begins.