# Actuators



33

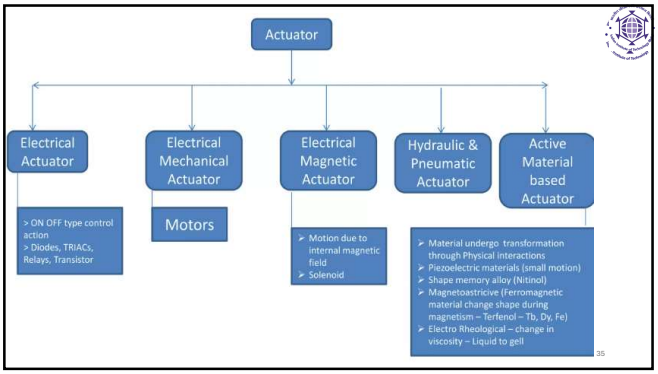
## Actuators


Actuators are the devices that lead to the physical motion of the actuators itself, along with any attached components

- Car actuators differ from bullet train actuators.
- Robot wheelchair actuators differ from lens camera actuators.
- 3D printer actuators differ from Stewart platform actuators.



34






35

## Actuators

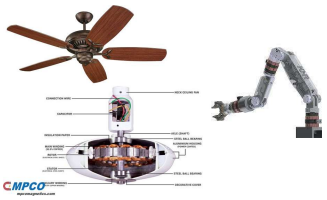
- The actuators used for mechatronics systems classified into two categories

Linear actuators

Linear actuators are the actuators that move in linear fashion.

Example: Roof opener, actuators of crane.

Rotary actuators




Rotary actuators are used to turn things in a circular fashion.
Example: Ceiling fan, actuators of robot arm joints.



36

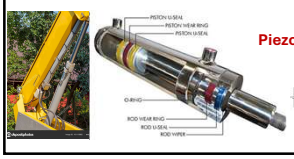
## Actuator types

- Actuator needs to move objects.

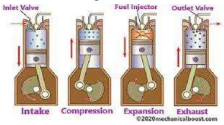
**Electric actuator:** Works based on electro magnetic induction.

Servos, Stepper, Direct drive

**Hydraulic:** Pressurized fluid is used to actuate things.

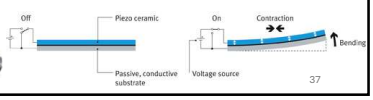


**Internal Combustion:** Burning of fuel is used to move the objects.




**Pneumatic:** Pressurized air to actuate

**Piezoelectric:** Piezoelectric effect is used to actuate.






37

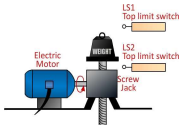
## Actuator Key Characteristics

- Maximum **extension** or linear/rotary **displacement**
- Maximum output **force** or **torque**
- Maximum **actuation speed** and/or **bandwidth**
- Actuator **size/volume**
- Actuator **efficiency**



38

## Electrical Actuator




With an electrical system we have three basic choices;

- Solenoid,
- DC motor or
- AC induction motor.

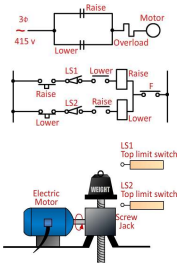
Of these, the **Solenoid** produces a linear stroke directly but its stroke is normally limited to a maximum distance of around **100** mm.

Both **DC and AC motors** are rotary devices and their outputs need to be converted to linear motion by mechanical devices such as worms screws or rack and pinions.

39

39

## Electrical Actuator




- System shown in Figure comprising a **Mechanical Jack** driven by an AC motor controlled by a reversing starter.
- Neither type of motor can be allowed to **Stall** against an end of travel stop, so end of travel limits are needed to stop the drive.
- Auxiliary equipment comprises two **limit switches**, and a **motor overload** protection device.

40

40

## Electric Actuators

- Many smaller mechatronic devices use **electric motors** for actuation
- Advantages of electric actuators
  - Clean (do not require fluids, oil, etc.)
  - Require no extra equipment (no pressure tanks, etc.)
  - Can operate indoors (no emissions)
  - Can be made small economically
- Disadvantages of electric actuators
  - Low power-to-size ratio

41

41

## Fluid Power

**Technology that deals with**

- Generation
- Control
- Transmission

} of **Power** using Pressurised fluids

**Muscle that moves industry**

**Used to Push, Pull, Regulate, or Drive all machines of modern industry**

**Fluid**

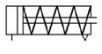
- **Liquid** (Hydraulics)
- **Gas** (Pneumatics)

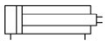
42

42

## Fluid Power Actuators

**Linear Actuators**

Single acting 

Double acting 

Hydraulic / Pneumatic Cylinders

**Rotary Actuators**

Hydraulic / Pneumatic Motors

43

43

## Electromagnetic Principles

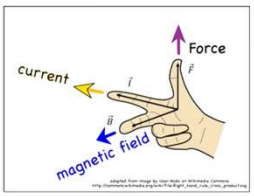
- When a current carrying conductor is moved in a magnetic field, a force is produced in a direction $\perp^r$ to the current and magnetic field direction.
- Lorentz's law in vector form is:

$$\vec{F} = \vec{I} \times \vec{B}$$

Where: $\vec{F}$ = Force vector (per unit length of conductor).

$\vec{I}$ = Current vector.

$\vec{B}$ = Magnetic field vector.




Relationship is given by right hand analogy

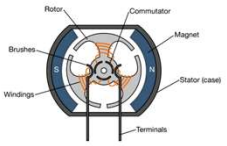
44

44

## Brushed DC Motors Operation

- Brushed DC motors are very common actuator used in mechatronic devices
- Rely on **electromagnetics** to convert current flow to physical motion

- Brushed motors composed of two main components
  - **Stator**: Remains stationary
  - **Rotor**: Turns, coupled to shaft



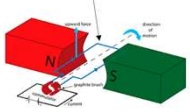

45

45

## Brushed DC Motor Operation

- Wire coil runs along back end of armature to generate B field
- **Commutator** used to change direction of current flow as armature rotates

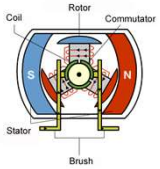
One wire coil



**Lorentz's Law:**

$$\vec{F} = \vec{I} \times \vec{B}$$

- Commutator must be composed of at least two segments
- Motors below have 3-piece commutator (left) and 2-piece commutator (right)



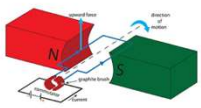

46

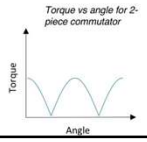
46

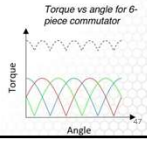
## Brushed DC Motor Operation

- As motor turns, angle of energized coil with respect to magnet changes

$$\vec{F} = \vec{I} \times \vec{B}$$ → Torque is function of sine of angle between B field and armature angle → Torque is not smooth using 2-piece commutator





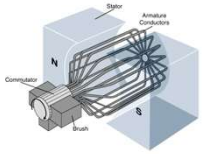




47

47

## Brushed DC Motor Operation

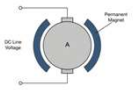
- Good drawing of a motor with multiple-piece commutator and coils




## Permanent Magnet DC Motors

- Various different types of brushed DC motors exist - differing in how magnetic field is generated
- **Permanent magnet** (PM) DC motors use a permanent magnet to generate magnetic field
  - Other types: Series wound, shunt wound, compound wound
  - These types use inductive coils to generate magnetic field

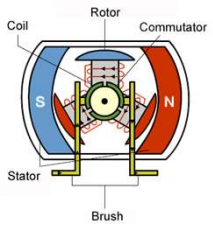
*PM DC Motor Symbol*



48

48

Brushed DC moter




49

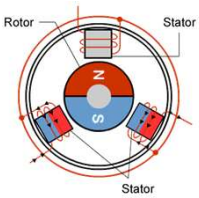
49

## Brushless DC Motors

- In brushed DC motors, brushes create mechanical point of contact between stator and rotor
  - Necessary in order to power wire coils on rotor
  - Generate heat and acoustic noise, must be replaced periodically
- Brushless DC motors do not use brushes
  - Only points of contact between rotor and stator are bearings
  - No direct wiring to rotor

*Brushed DC Motor*

*Brushless DC Motor*

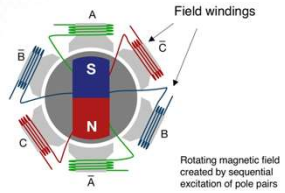



50

50

## Brushless DC Motor Operation

- In brushless DC motor, **rotor is made of permanent magnet** and **stator is made of coils**
- This is opposite of brushed motors




Concept of operation:

- Hall effect sensor used to detect position of magnet
- Coil pairs (**poles**) are activated sequentially so that magnetic field is always perpendicular (as much as possible) to rotor magnet
- Causes rotor to spin
- Thus commutation is done electrically and not mechanically

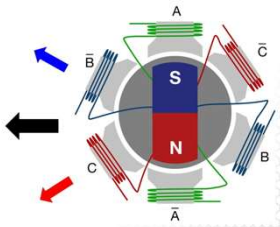
51

51

## Brushless DC Motor Operation

### 3-Pole Brushless DC Motor

- A sensor is attached to each pair of coils which detects position of PM (rotor)
- Coils are activated so that resulting magnetic field across permanent magnet is as close to perpendicular to poles as possible
- In current configuration, coils B and C would be activated (A is off)



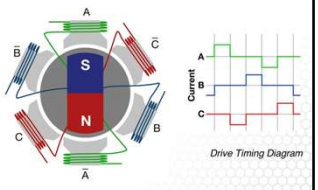

52

52

## Brushless DC Motor Operation

### 3-Pole Brushless DC Motor

- As rotor spins, current in coils must be switched on and off rapidly
- This is commutation
- Commutation is performed by a high-speed integrated circuit using feedback from Hall effect sensors



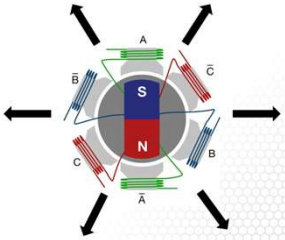

53

53

## Brushless DC Motor Operation

### 3-Pole Brushless DC Motor

- For a 3-pole BLDC in this configuration, there are 6 possible magnetic field vectors that can be produced by the coils
- How often does the commutator sequence through them (in terms of deg rotation of rotor)?




54

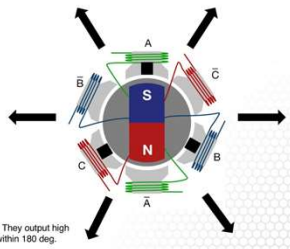
54

## Brushless DC Motor Operation

### 3-Pole Brushless DC Motor - Commutation Sequence

| Sensor Output | | | CW Rotation | | |
|---|---|---|---|---|---|
| C | B | A | A | B | C |
| 1 | 0 | 0 | NC | Hi | Low |
| 1 | 0 | 1 | Low | Hi | NC |
| 0 | 0 | 1 | Low | NC | Hi |
| 0 | 1 | 1 | NC | Low | Hi |
| 0 | 1 | 0 | Hi | Low | NC |
| 1 | 1 | 0 | Hi | NC | Low |

NC = No Current
Hi = +Voltage
Low = -Voltage



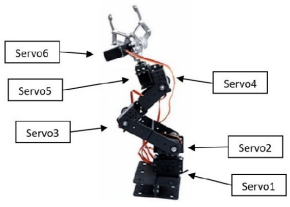

Black boxes indicate sensors. They output high (1) when N pole of magnet is within 180 deg.

55

55

## Servos

- Servos are used in many industrial and robotics applications
  - Provides **precise positioning**
  - Used often in mechatronic system requiring precise position control
  - Convenient packaging allows enables easy integration

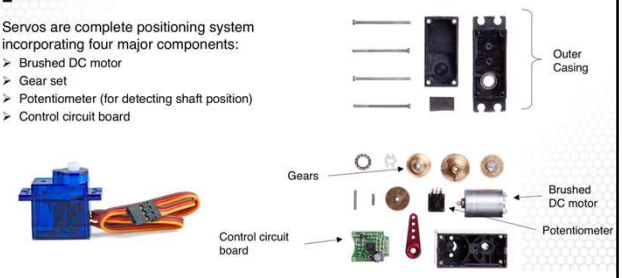



56

56

## Servo Motor Operation

- Servos are complete positioning system incorporating four major components:
  - Brushed DC motor
  - Gear set
  - Potentiometer (for detecting shaft position)
  - Control circuit board

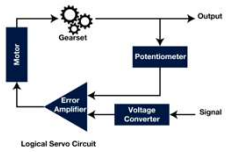



57

57

## Servo Motor Operation

- Servo operates as a **closed loop** system where a position input is provided
- Control circuitry drives motor shaft to commanded position using feedback control




## Servo Inputs

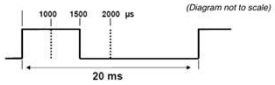
- Most hobby servos are driven from 5V power supply
- Three wires:
  - Power (red)
  - Ground (black or brown)
  - Control (white, yellow, orange, or blue) - PWM signal

58

58

## Servo Control

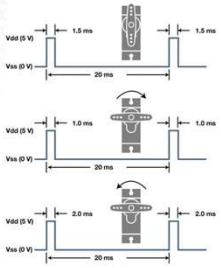
- How do you command a servo to a specific rotational position?
- PWM signal
- Servos require PWM signal of specific format
  - Signal period of **20 ms** (frequency of **50 Hz**)
  - Valid duty cycle is **5%** (full neg. throw) to **10%** (full pos. throw)
  - Equates to pulse width between 1000 µs and 2000 µs




59

59

## Servo Control




Pulse width of 1500 µs (1.5 ms) is neutral or centered position. This is 7.5% duty cycle.

Pulse width of 1000 µs (1.0 ms) is full clockwise position (usually 90 deg). This is 5% duty cycle.

Pulse width of 2000 µs (2.0 ms) is full counter-clockwise position (usually -90 deg). This is 10% duty cycle.

Note: You must maintain PWM signal to servo continuously during operation.

60

60