IIT Bombay

Makerspace (MS101)

2023 (Autumn)

EE-Lecture-11

EE- Electro-Mechanical Components

Relays, Solenoids, DC Motors, DC Servo motors

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Electromechanical Relays: Types and Functions

Different Functions of Electromechanical Relays

a. Switching (contact operation)

b. Magnitude Measurement c. Comparison d. Ratio Measurement

Most Common Electromechanical Relay

Attracted Armature Type Relay

This type of relay involves

(a) A moving part (armature) capable of making electrical contact with two points

(b) An electromagnet and

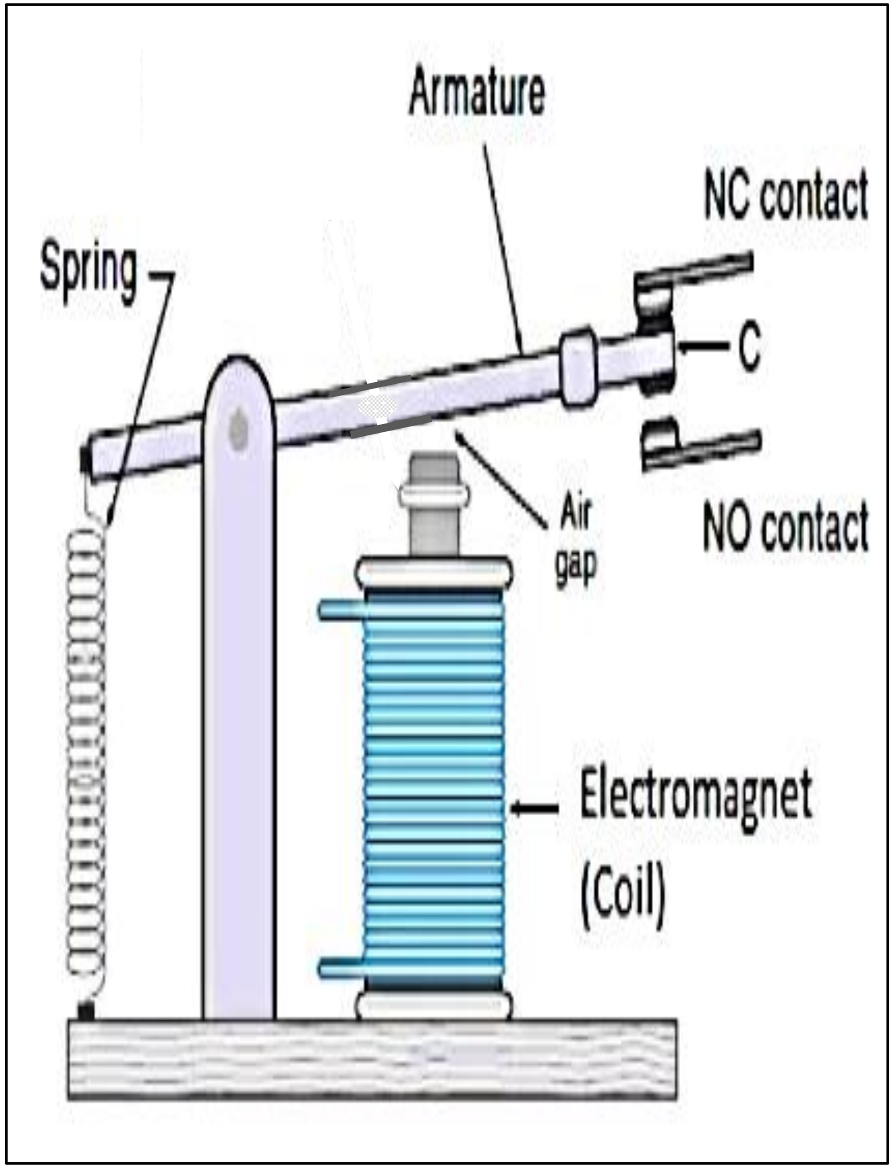
(c) A restoring spring to positions the armature to make contact to one of the points.

The force on the armature is given by → **Force** $\boldsymbol{(F) = KI_{rms}^2 + C}$

Where, I – current through the coil, K - Proportionality Constant,

C - Constant correspond to the force offered by the restoring spring

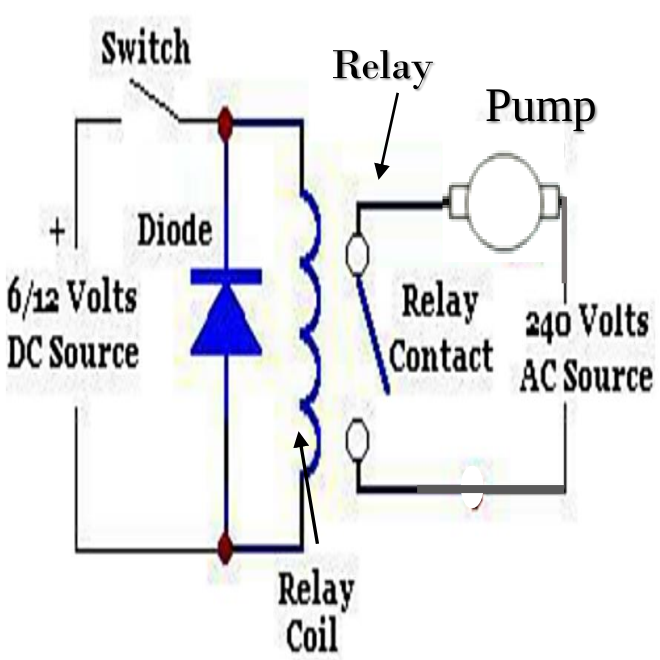
Attracted Armature Type Relay Operation



Armature: Moving part of the magnetic circuit

NC contact: **N**ormally **C**losed in unexcited mode

NO Contact: **N**ormally **O**pen in unexcited mode



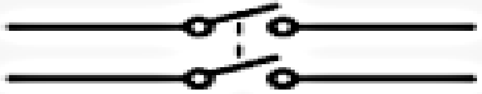
Operation of an Electromechanical Relay (EMR)

- A coil is wound over a ferromagnetic material (core) forming an electromagnet.
- The armature is positioned by a restoring spring to make contact with one of the two (NC) contacts
- On passing the current through coil, electromagnetic action prompts mechanical movement of the armature resulting in establishing contact with the other (NO) contact.
- This relay makes/ breaks the circuit by moving between two contacts.

Relay Nomenclature

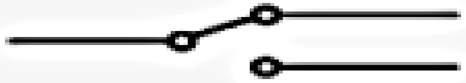
SPST

(Single Pole Single Throw)



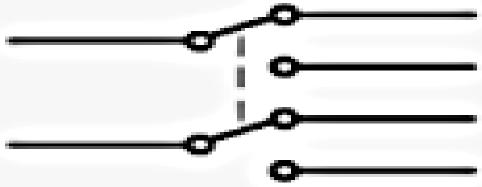
DPST

(Double Pole Single Throw)



SPDT

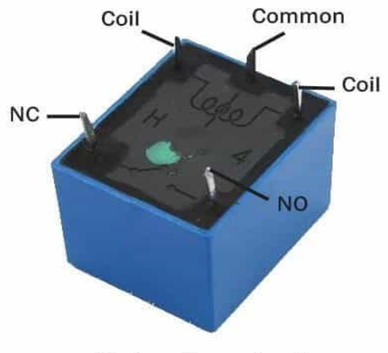
(Single Pole Double Throw)



DPDT

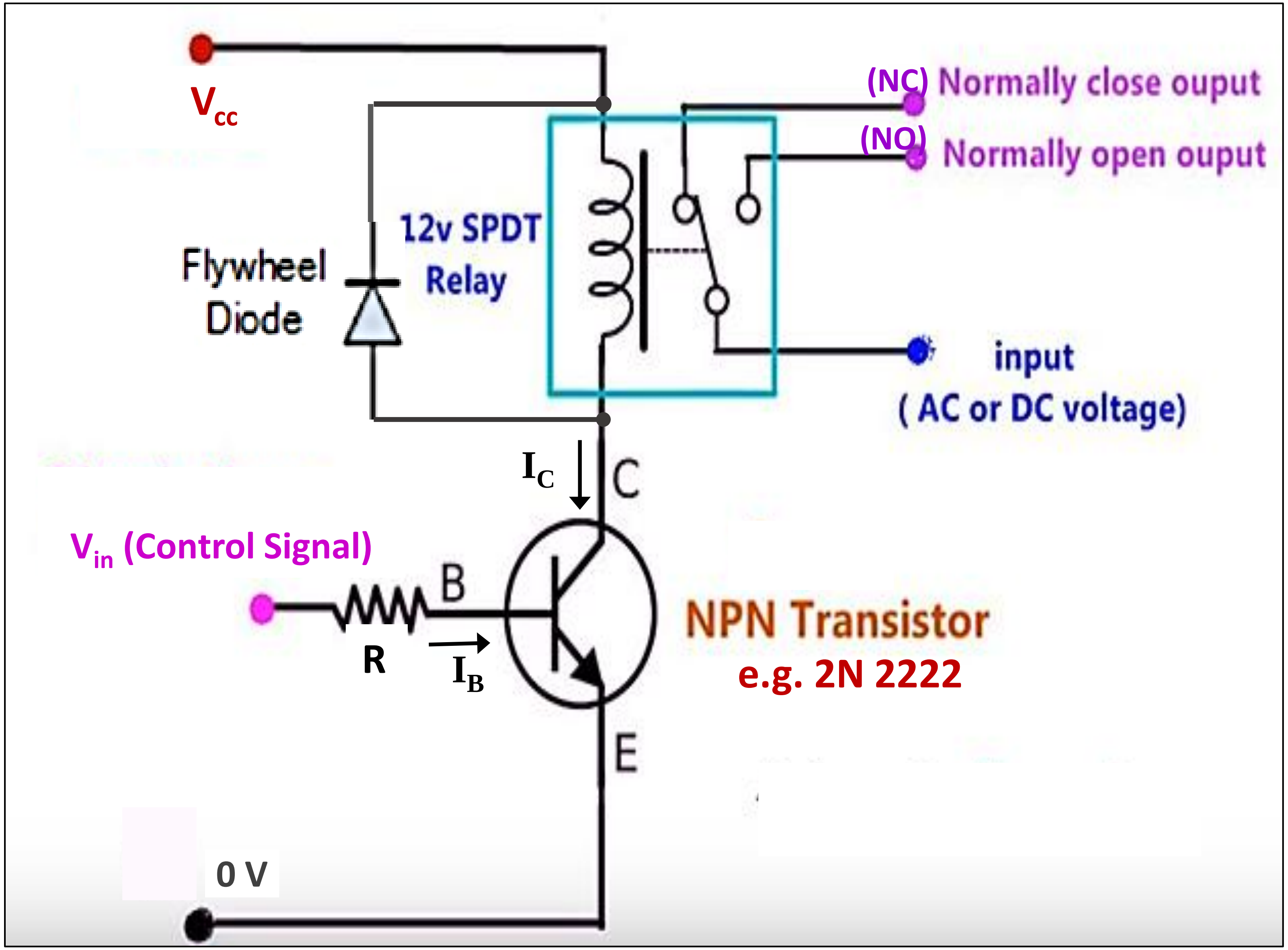
(Double Pole Double Throw)

Images of a few commercially available relay models



Relay Terminals

Drive for Relay Connected to Supply Using NPN Transistor



Coil Resistance (R_{coil}, Say) of the relay is specified by the manufacturer.

Voltages at BJT-NPN terminals when ON, are V_{BESat} ($\approx$ 0.8 V) and V_{CESat} ($\approx$ 0.2V)

The collector current for the NPN transistor can be calculated by

$$I_C = (V_{cc} - V_{CESat}) / R_{coil}$$

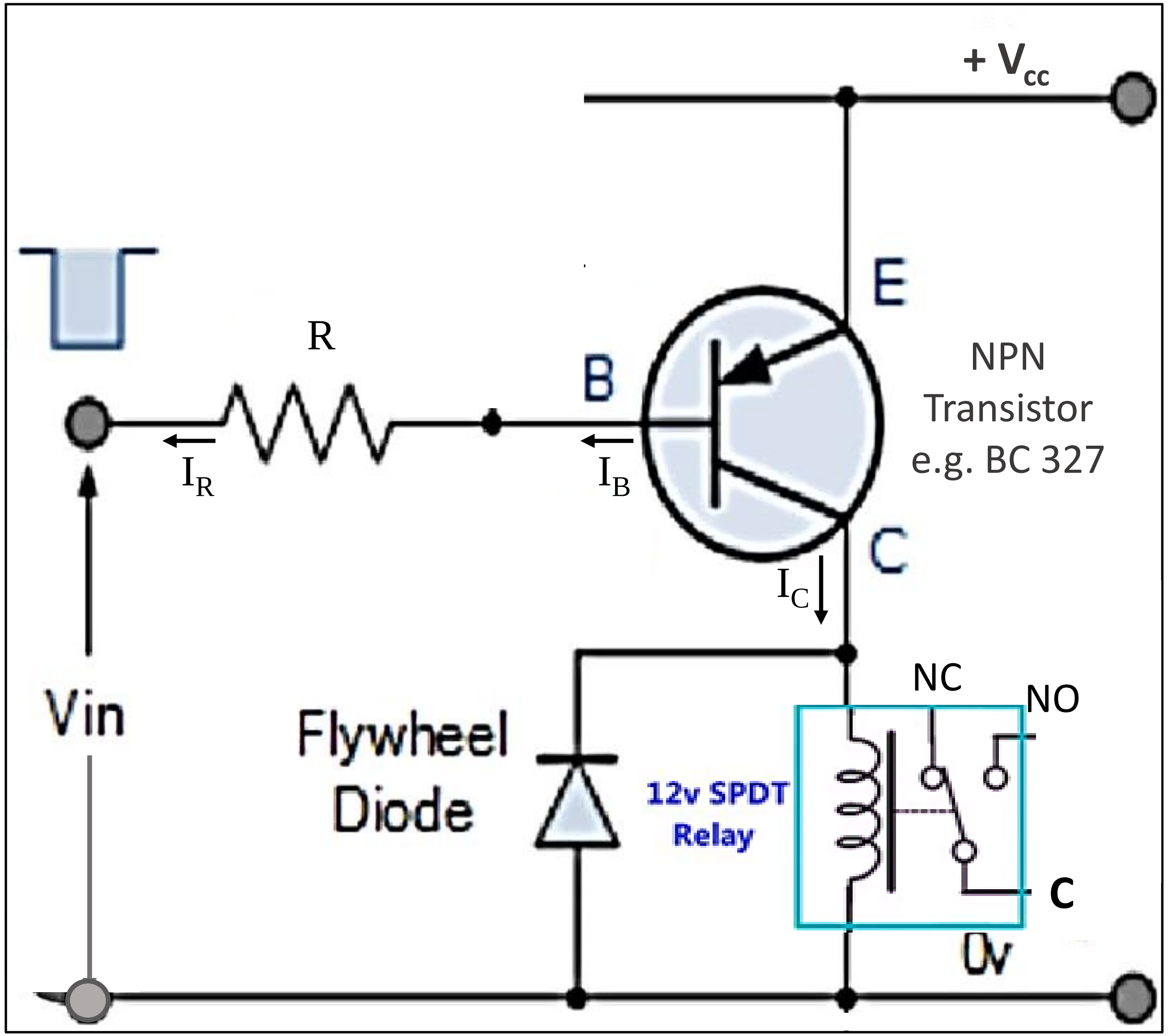
Let the current gain ($\beta = I_C / I_B$) in ON state (saturation mode), corresponding to V_{BESat} be β_{min}

$$\rightarrow \; I_B = I_c / \beta_{min}$$

The value of R_1 is

$$R = (V_{in} - V_{BESat}) / I_B$$

Drive for Relay Connected to Ground Using PNP Transistor



The relay could be operated using a PNP transistor

- Coil Resistance of the relay is specified by the manufacturer (R_{coil}, Say)
- Voltage at PNP-BJT terminals when ON are

  V_{BESat} (≈ – 0.8 V) and V_{CESat} (≈ – 0.2V)
- For V_{cc}= 12 V, The collector current for the NPN transistor can be calculated by

  $I_C = (12 + V_{CESat}) / R_{coil} = (12 - 0.2) / R_{coil}$
- The value of I_B at V_{BESat} is → $I_B = I_c / \beta_{min}$
- Lower value of V_{in} be V_{inLo} and Higher be V_{inHi}
- At V_{inLo}= 0 V, the BJT is ON.

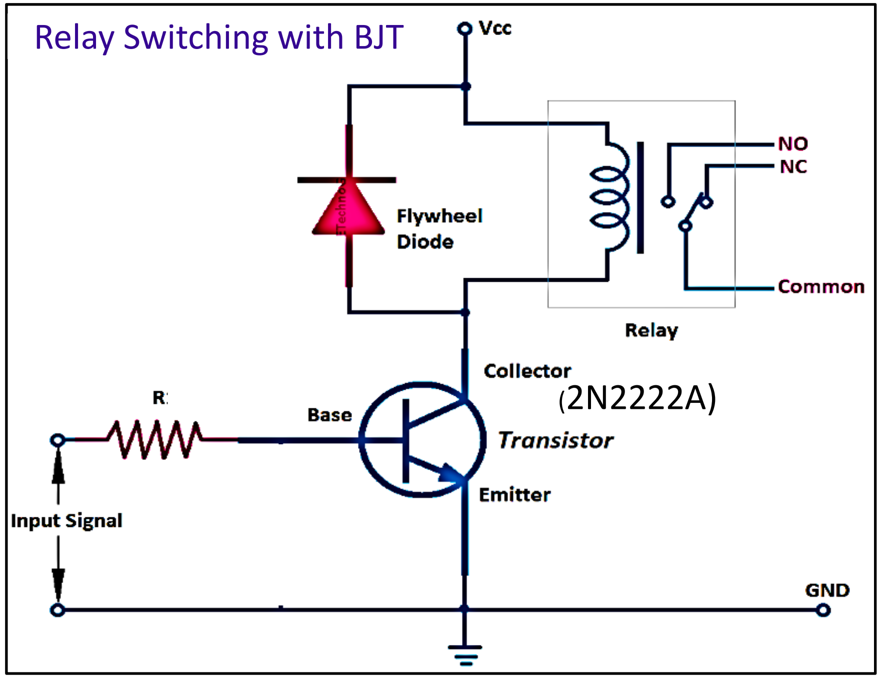
  Since, the current through R, $I_R = I_B$

  $R = ((12 + V_{BESat}) - V_{inLo}) / I_B = ((12 - 0.8) - V_{inLo}) / I_B$
- Condition→ $V_{inHi} > (V_{cc}+V_{BESat}) = (12 - 0.8) = 11.2$ V

  If $V_{inHi} = V_{cc}$ Junction BE is reverse biased, BJT is OFF.

Current Computations for Relay Switching

- The voltage developed across an inductor is → $V = L\, di/dt$
- When the Relay is put OFF, Sudden reduction in current gives rise to large voltage at the collector point (see figure)
- In order to avoid possible damage to the transistor, a 'Flywheel/ Freewheeling' diode is used



Data (Product Sheets)

R_{coil} = 71.9 Ω

V_{CEsat} = 0.2 V

V_{BEsat} = 0.8 V

β_{min} = 35

Computation of $I_c = (V_{cc} - V_{CEsat})/R_{coil}$ → (5.2-0.2) / 71.9 = 69.54 mA

$I_B = I_c/\beta_{min}$ → 69.54/ 35= 1.986 mA

Let V_{in} be the input voltage that switches the BJT ON. And the base resistor be R. The current through R is I_B. The value of the resistor is

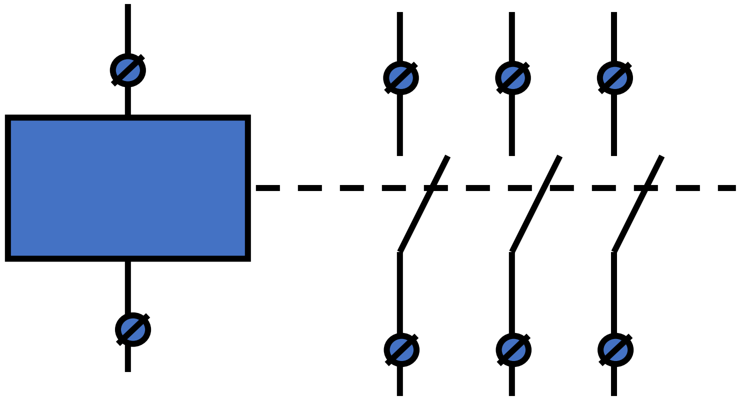
$R = (V_{in} - V_{BEsat})/\, i_B$. If V_{in} = 5 V, R = 2.1148 kΩ.

Contactors and Circuit Breakers

Contactors make and break the contact between two points on a principle similar to that for the relays

The main differentiating factor are

(a) They are **SPST** (b) Operate with **Normally Open (NO)** contact (c) **No common circuit** between the contacts

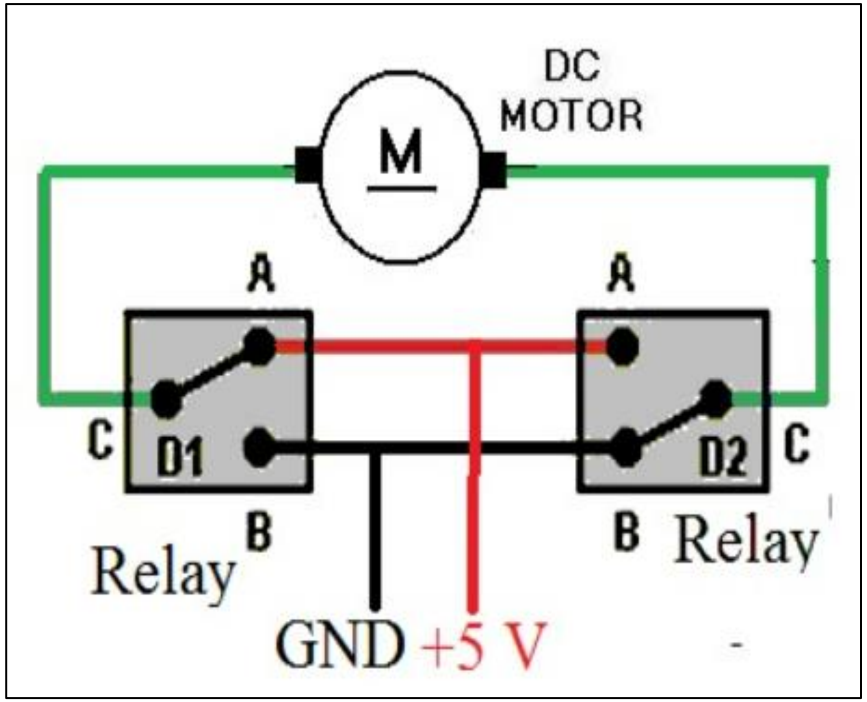


Often user in High Power circuits for safety operations

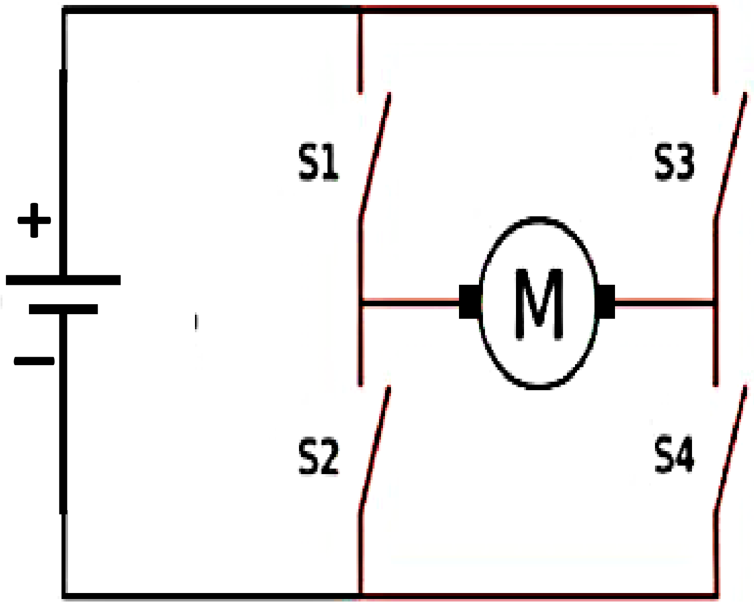
Power distribution relays are packaged as 3 X SPST configuration

Reversing Direction of Rotation by Current Reversal in DC motor

Direction Reversal Using
2 SPDT Switches



Direction Reversal H- Bridge

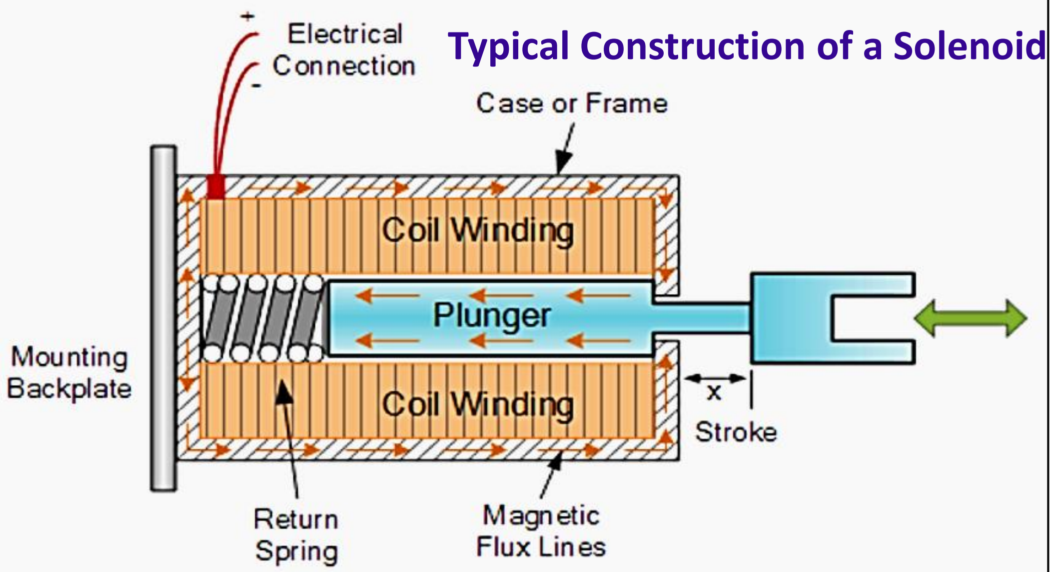


S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor coasts
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes
1	1	0	0	Short circuit
0	0	1	1	Short circuit
1	1	1	1	Short circuit

Solenoids

Solenoids are electromechanical devices that uses **electrical energy** to cause **mechanical movement**
Depending on the application, mechanical movement could be organized to
(a) **Push** or **Pull** the plunger (b) Realize **clapper** or **rotatory** motion (c) **Open** or **close** valve

Typical Construction of a Solenoid



Electrical current creates Magnetic field → $(B_{ext}) = \mu_0 \mu_r \frac{NI}{L}$

The force is given by $(F) = \frac{(NI)^2 \mu_0 A}{2g^2}$

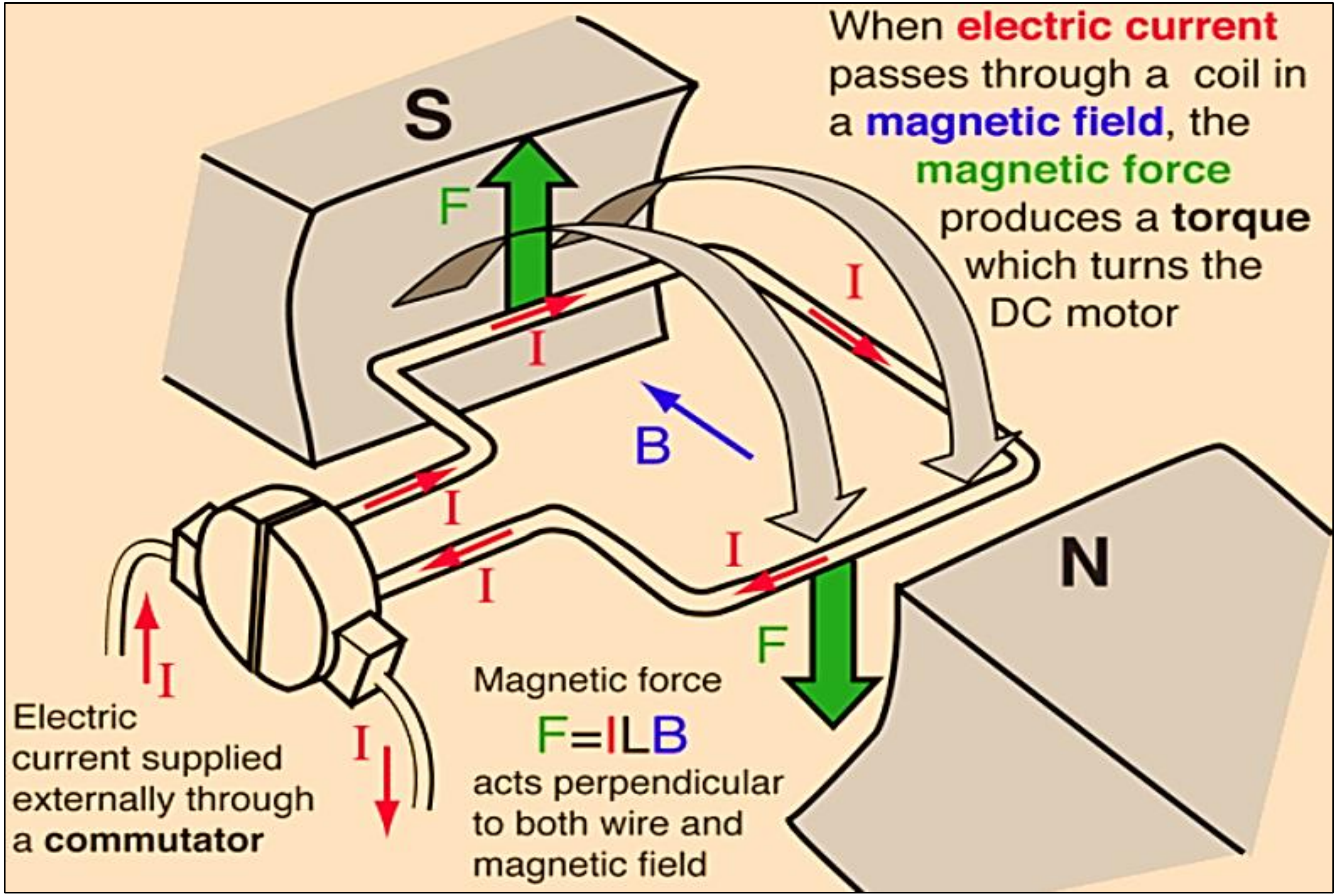
N - No of turns I - current, L - coil length, A- *Area*, g = gap length

$\mu_0 \mu_r$ are permeability of vacuum and plunger-material respectively

Solenoid	Peak (mA)	Hold(I)	Coil (Ω)	Peak (mW)	Hold (mW)
ROB11015	1100	220	4.5	5500	217.8

Why is the 'holding current' much lower than peak (pulling) current? In 'energized state' the gap (g) is much smaller compared to initial state. Hence, the required force is achieved by much smaller current

2-Pole Permanent Magnet (PM) DC Motor: Working Principle



Source: https://www.magneticinnovations.com/faq/dc-motor-how-it-works/

Electrical to Mechanical Energy Conversion

In DC Motors, the magnetic field is set in the gap between the poles. When the current is passed through the motor windings, **multiple current carrying conductors** pass through the **magnetic field** lines.

As a result, an EMF generated across the armature coil (or the commutator terminals).

This EMF is referred as 'Back EMF'

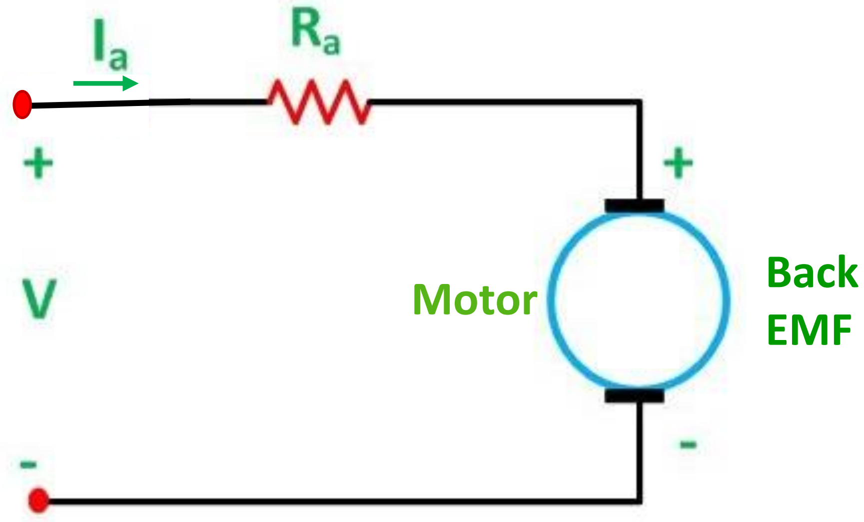
$$\text{Back EMF } (E_b) = \frac{P\varphi NZ}{60A} = k\varphi N$$

P - No of poles, ***φ*** - flux per pole (*Wb*), ***N*** - motor speed (*rpm*), ***Z*** - No of parallel conductors,

A - No of parallel paths (= 2 , for 2 pole motor) ***k*** - proportionality constant (= *PZ* / *60A* = Z / 60. for 2 pole motor)

Source: https://www.electricaltechnology.org/2020/10/dc-motor-emf-equation-formulas.html

Electrical Parameters of 2 pole PM-DC motor



Using KVL

Back EMF (E_b) $= V - I_a R_a = k\varphi N$

Where, Ia and Ra are the armature currents and resistance

→ $$N\ (\text{rpm}) = \frac{V - I_a R_a}{k\varphi}$$

Electrical Power to the DC motor (P)

$$= V \times I_a$$

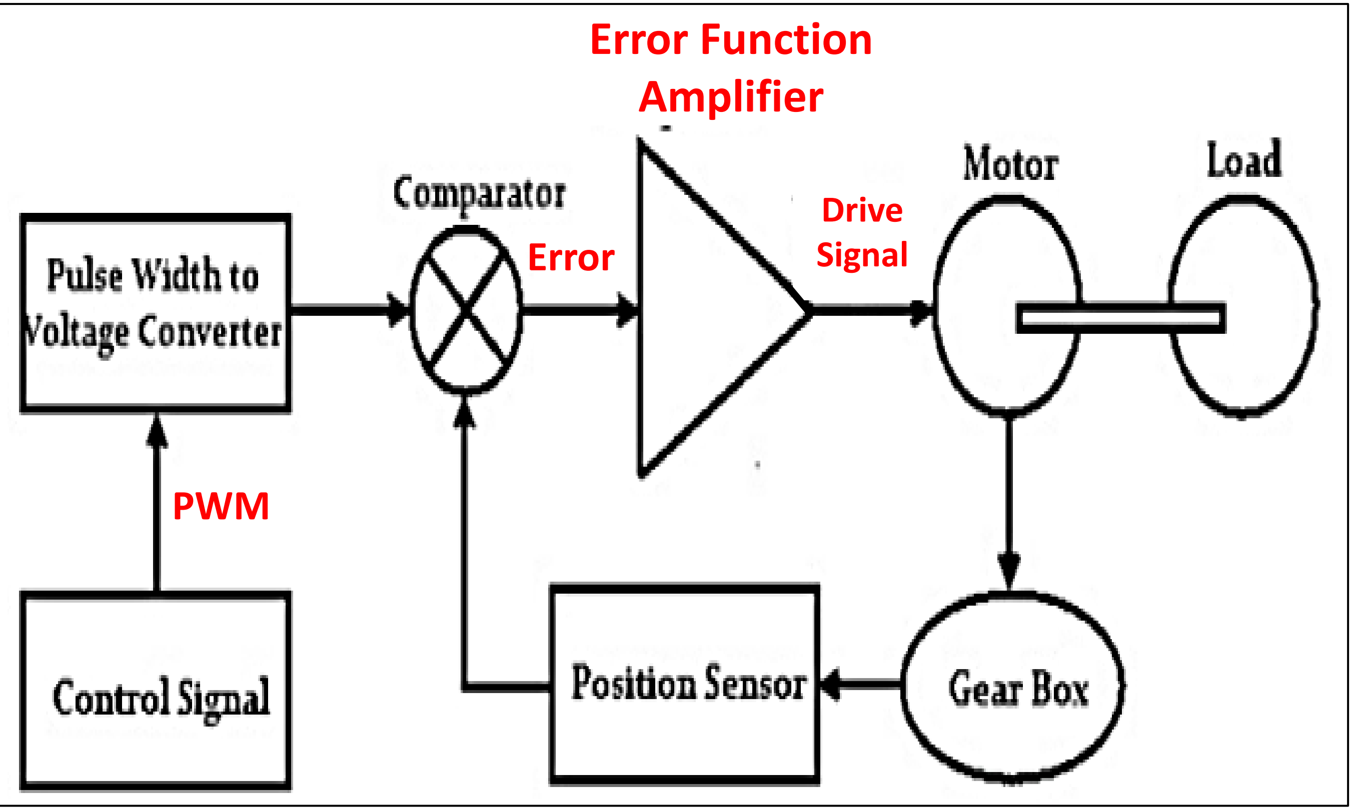
$$= E_b I_a + I_a^2 R_a$$

Where, VI_a=Input Power, $E_b I_a$= Mechanical power delivered, $I_a^2 R_a$ Resistive loss

Source: https://www.electricaltechnology.org/2020/10/dc-motor-emf-equation-formulas.html

DC Servo Motor: Working Principle

A motor that uses **DC electrical input** to produce **precise mechanical movement** as output like angular position, angular velocity is called a **DC servomotor;** sometimes referred as **rotatory actuators**



Functional Block diagram of the DC Servomotor

DC servomotor has **3-pin** Interface→

(i) Supply (ii) Ground

and **(iii) Control** (corresponding to the desired position)

These motors are used as **prime movers** where application requires precise mechanical movement

Application areas:

(a) Robotics:- **pick and place**

(b) Industrial:- **assembly machinery**,

(c) Telescope and antenna:- **steering systems**

Additional Components

1. Position sensor (encoder)
2. Gearing set/ Gear box
3. Control electronics

Source: https://www.elprocus.com/dc-servo-motor/

Operation of a Servomotor

DC Servomotor operation

- It is operated with a **close-loop feed back** with a position sensor (**encoders**)
- Error signal is generated based on difference in **'present** (motor's position at the time of measurement**)** and **desired'** (corresponding to the control input) position
- The drive signal (input current) to the motor is provided in order to '**null the error**' or make the error zero.
- Depending the dynamics of the system, for smooth transition, DC-drive function is generated using **one or more** of the following functions of the error.
- (a) **P**roportional (b) **I**ntegral components (c) **D**ifferential

e.g. If the drive depends on only proportional error→ '**P**-control'

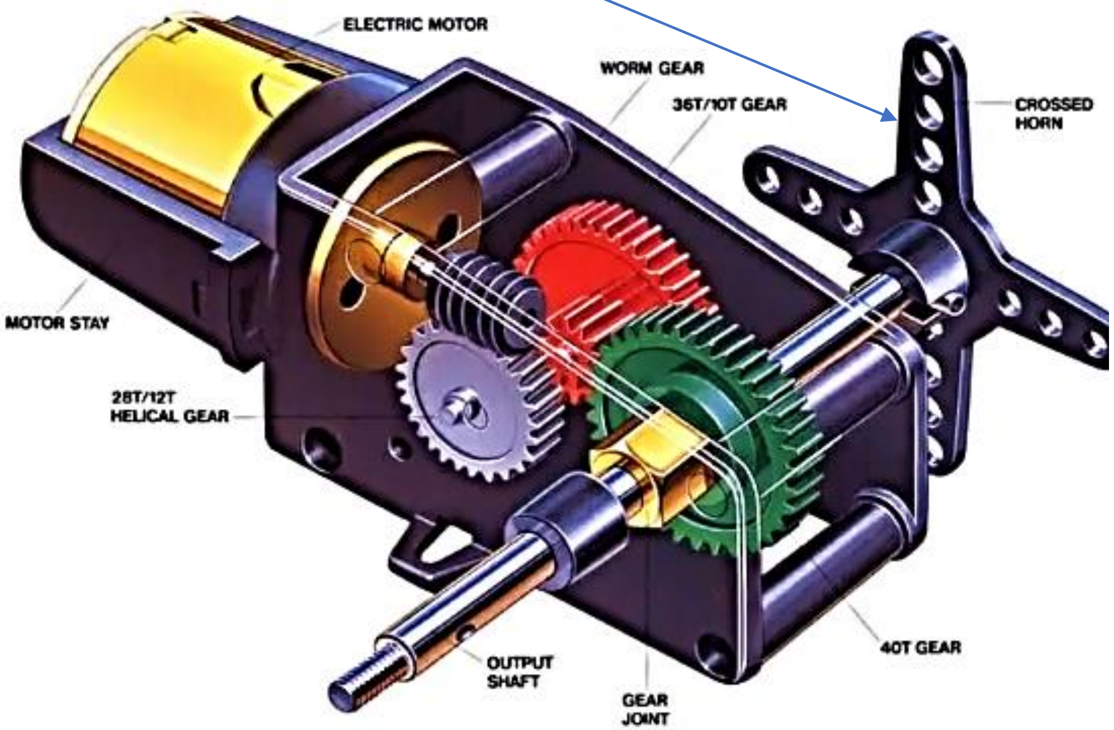
If the drive signal considers Proportional and Integral error → '**PI** - control'

If all three functions is known as **PID** control

Servomotor Images

Cross horns/arms are used to indicate angular positions. Holes on the arm are for deriving standard values of torque

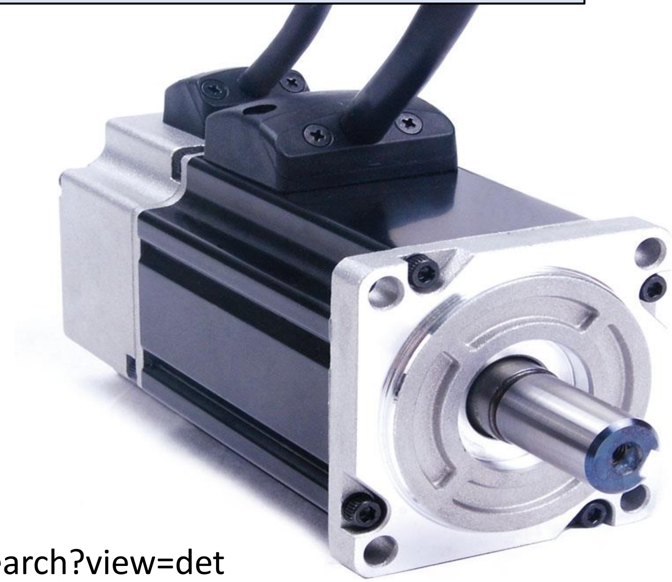
- DC servo motors are invariably used for '**position control**' applications
- On some special occasions they are used for precise angular speed control.
- In such configuration the **sensors measure angular speed** (tachometers) and the drive is provided to the motor to maintain the desired angular speed



Representative picture of gear System in a Servomotor

Source: https://www.electricaltechnology.org/2019/05/servo-motor-types-construction-working.html

Representative picture of a Servomotor



Source:
https://www.bing.com/images/search?view=detailV2&ccid=KVEdylel&id=77A4E0C94A1DEFC6E7F3B48D9242CF1191239B7A&thid

Questions and Discussions