IIT Bombay

Makerspace (MS101)

2022-2023-II (Spring)

EE-Lecture-5

EE- Electro-Mechanical Components

Relays, Solenoids, DC Motors, DC Servo Motors

Kushal R Tuckley, Joseph John, Prem C Pandey, Dinesh K Sharma

Topics Covered in Earlier Lecture

- Introduction to Transistors: BJT and its application as a switch

Topics to be Covered in This Lecture

Electromechanical Components: Relays, Solenoids, DC Motors and DC Servo Motors

These components execute controlled mechanical movements and switching

Electromechanical Relays: Types and Functions

Etymology: to 'pass along'- In the context of electrical engineering, Implement action prompted by a signal

Based on Principle of Operation, there are 4 Types of relays

(1) Electromechanical, (2) Solid State, (3) Reed. (4) Electrothermal

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

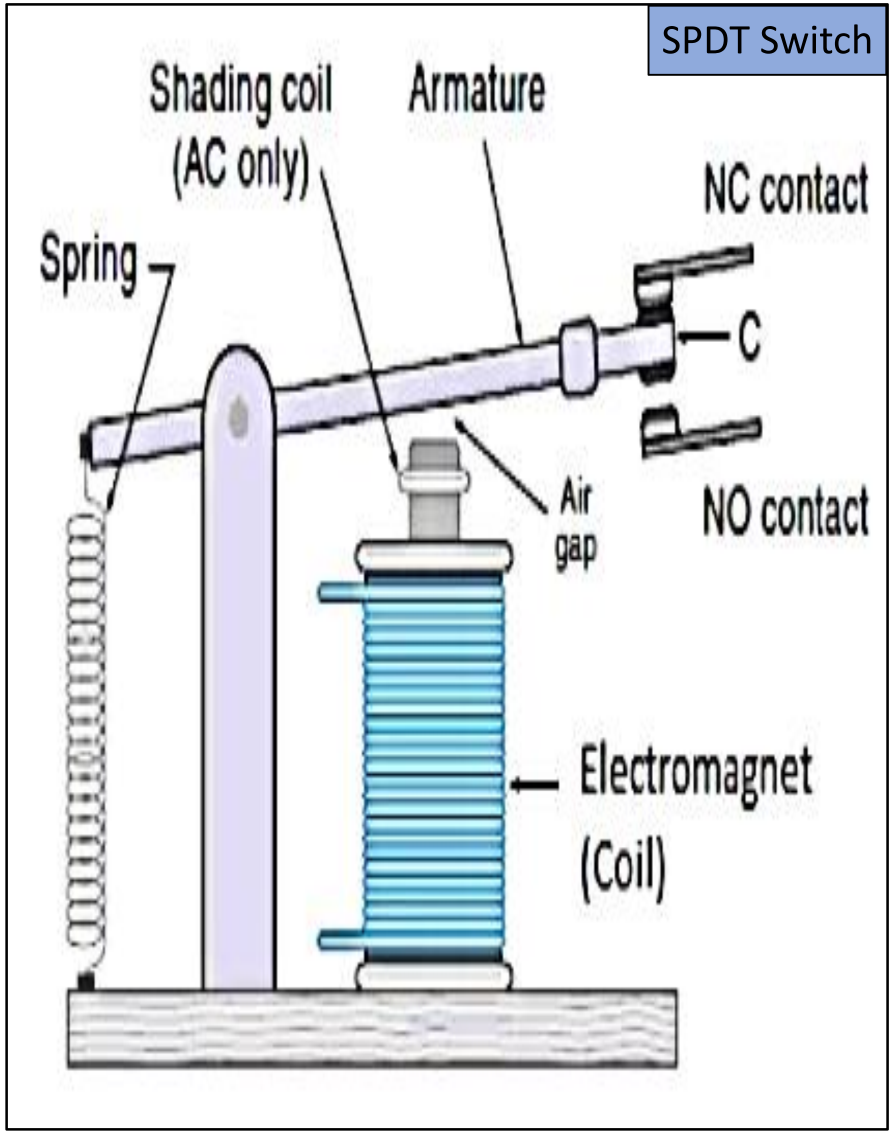
Linear movement using with

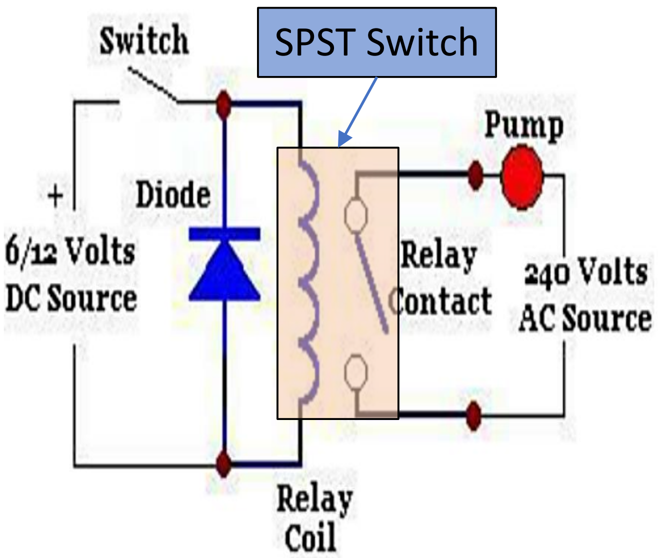
$$\textbf{Force}\ (\boldsymbol{F}) = \boldsymbol{K I^2_{rms}} + \boldsymbol{C}$$

(I–current, K- Proportionality Const. C- Initiation Const)

Attracted Armature Type Relay Operation

Attracted armature type relays are the simplest and most widely used components





Armature: Moving part of the magnetic circuit

Yoke: Magnetic circuit not covered by the coil (s)

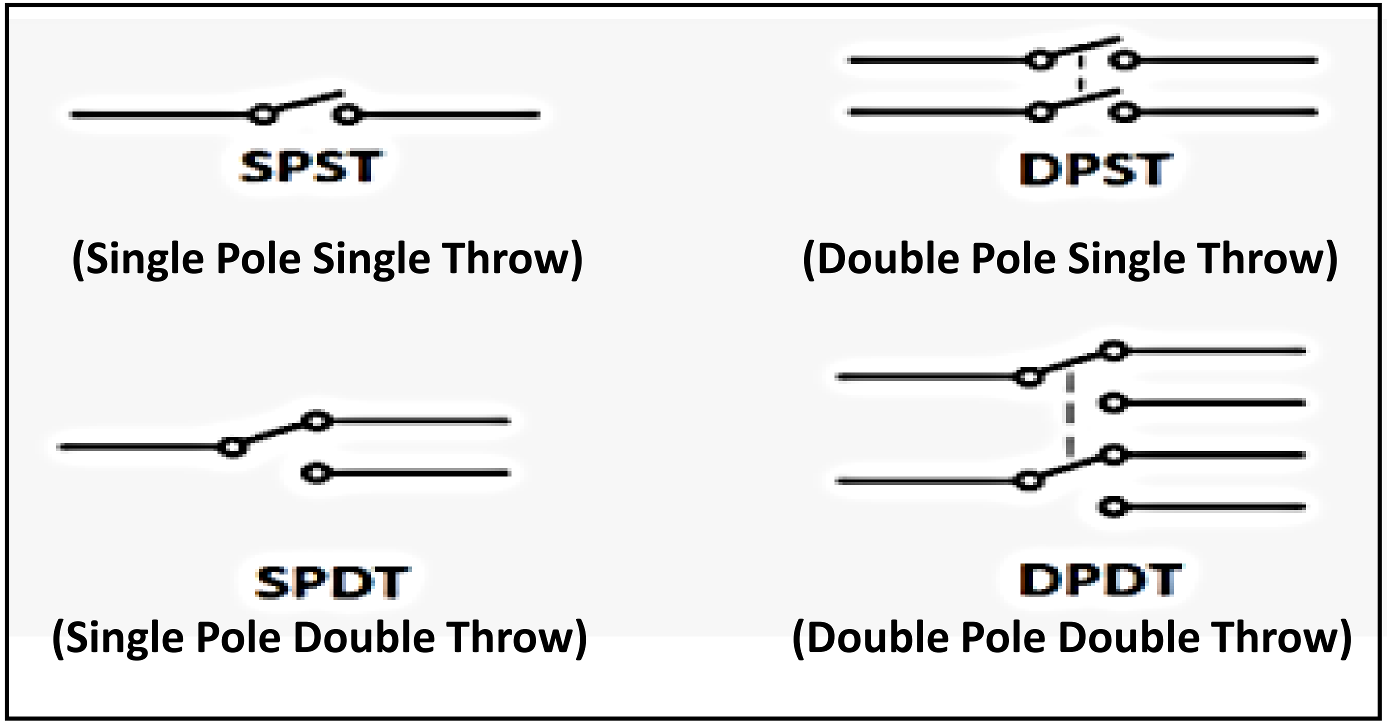
NC-contact: Connected point in un-excited state

NO-Contact: Connected when magnet is active

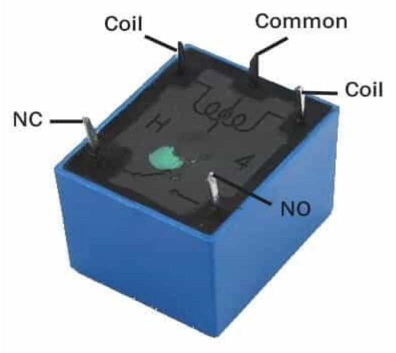
Operation of an Electromechanical Relay (EMR)

- A coil is wound over a ferromagnetic material
- On passing the current through coil, electromagnetic action results in mechanical movement.
- This movement results in Make/ break of the 'contact'

Relay Nomenclature

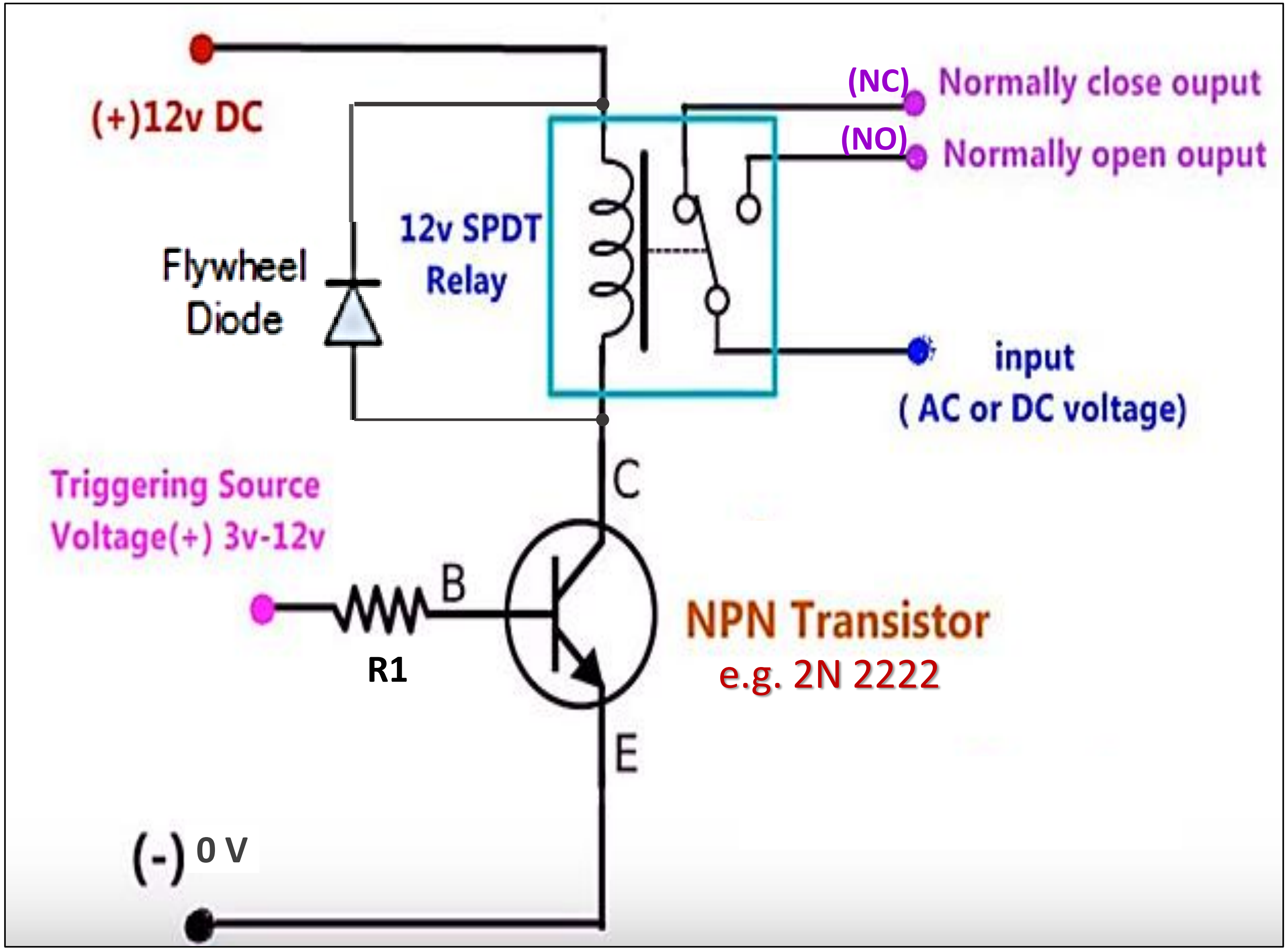


Some commercially available relays : Images



Relay Terminals

Relay Driver Using an NPN Transistor



- Coil Resistance of the relay is specified by the manufacturer (R_{coil}, Say)
- The collector current for the NPN transistor can be calculated by

$$I_C = (12 - V_{CESat}) / R_{coil}$$

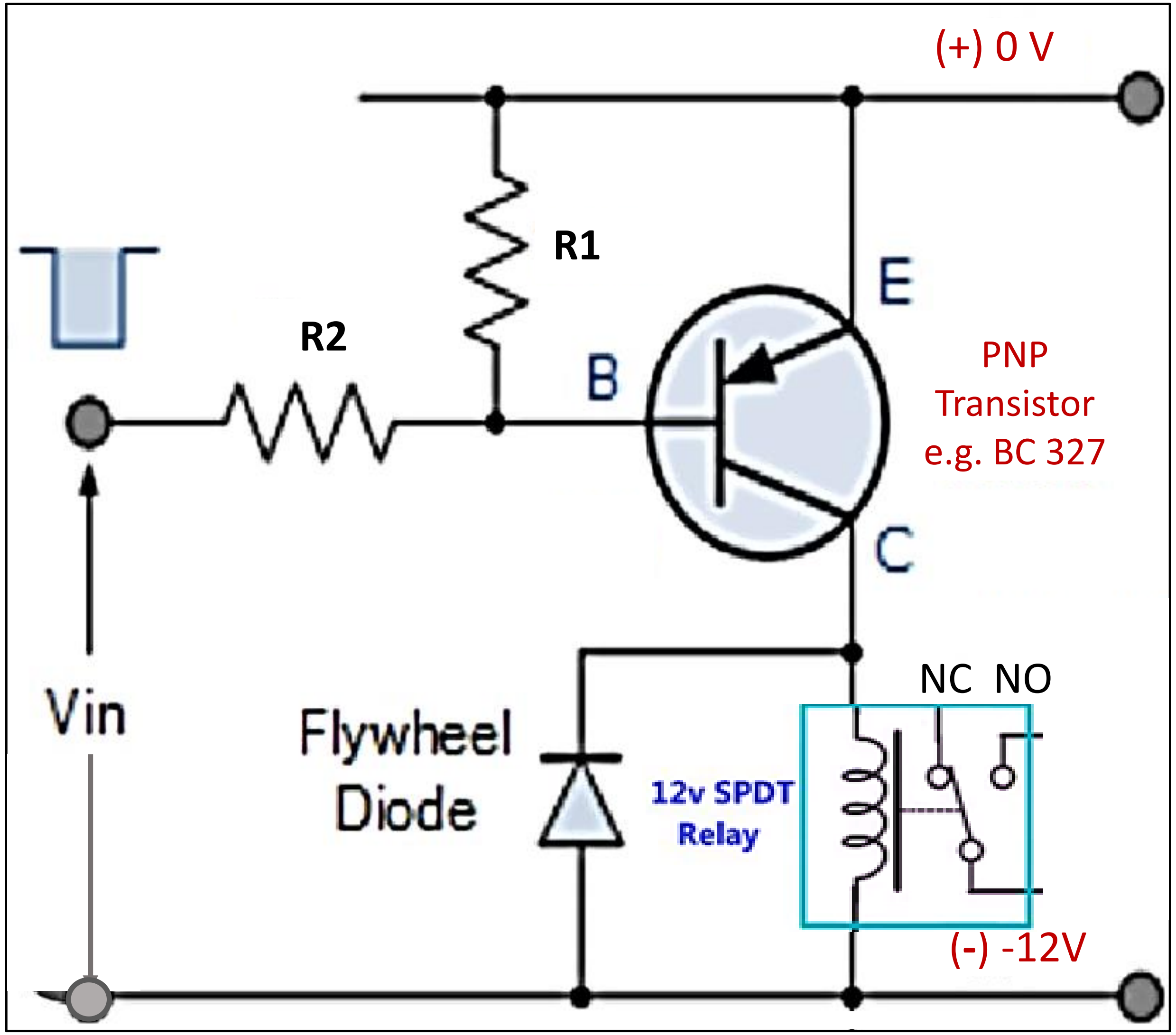
- Let the current gain in saturation mode/ corresponding to V_{BESat} be β_{min}

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

- For a triggering voltage V_{Trig} (3V to 12 V)

$$R1 = (V_{Trig} - V_{BESat}) / I_B$$

Relay Driver Using a PNP Transistor



With –ve DC supply, the relay could be operated using a PNP transistor

- Coil Resistance of the relay is specified by the manufacturer (R_{coil}, Say)
- The collector current for the NPN transistor can be calculated by

$$I_C = (12 - |V_{CESat}|)/R_{coil}$$

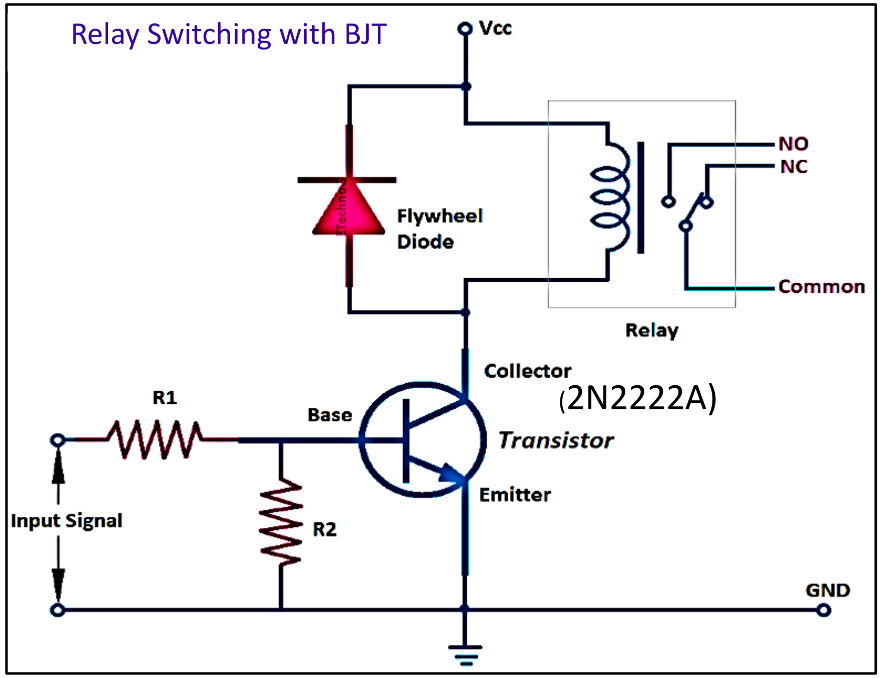
- Let the current gain in saturation mode/ corresponding to V_{BESat} be β_{min}

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

- The branch R1-R2, must ensure driving transistor to saturation.
- Let the current through R1 be 5 x I_B (arbitrary).
- $R1 = |V_{BESat}| / (5xI_B)$
- For V_{Trig} (-3V to -12 V), $R2 = (V_{Trig} - |V_{BESat}|)/(6 \times I_B)$

Current Calculation 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, a 'Flywheel/ Freewheeling' diode is used



Data (Product Sheets)

R_{coil}= 71.9Ω

V_{CEsat}= 0.2V

V_{BEsat}=0.8V

β_{min}=35

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

$i_b = i_c/\beta_{min}$ → 69.54/35= 1.986mA

Assume R_2=10kΩ (arbitrary); Current through R_2(i_{R2})=0.8/10000=80μA

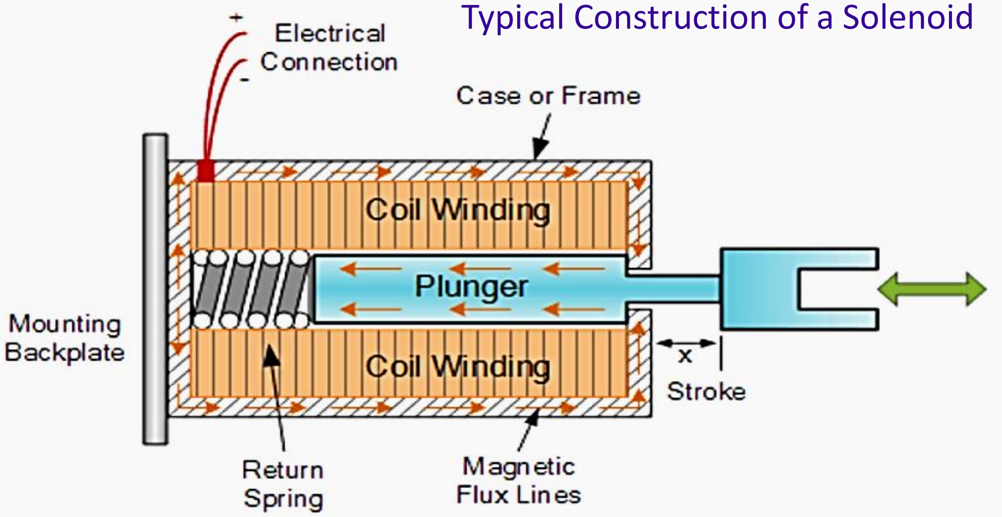
Current through R_1 → $i_{R1}=i_b+i_{R2}$ = 2.066mA → $R_1=(V_s-V_{BEsat})/i_{R1}$= 2.14kΩ

Solenoids

Solenoids are electromechanical devices that use **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) =$\frac{(NI)^2 \mu_0 A}{2g^2}$

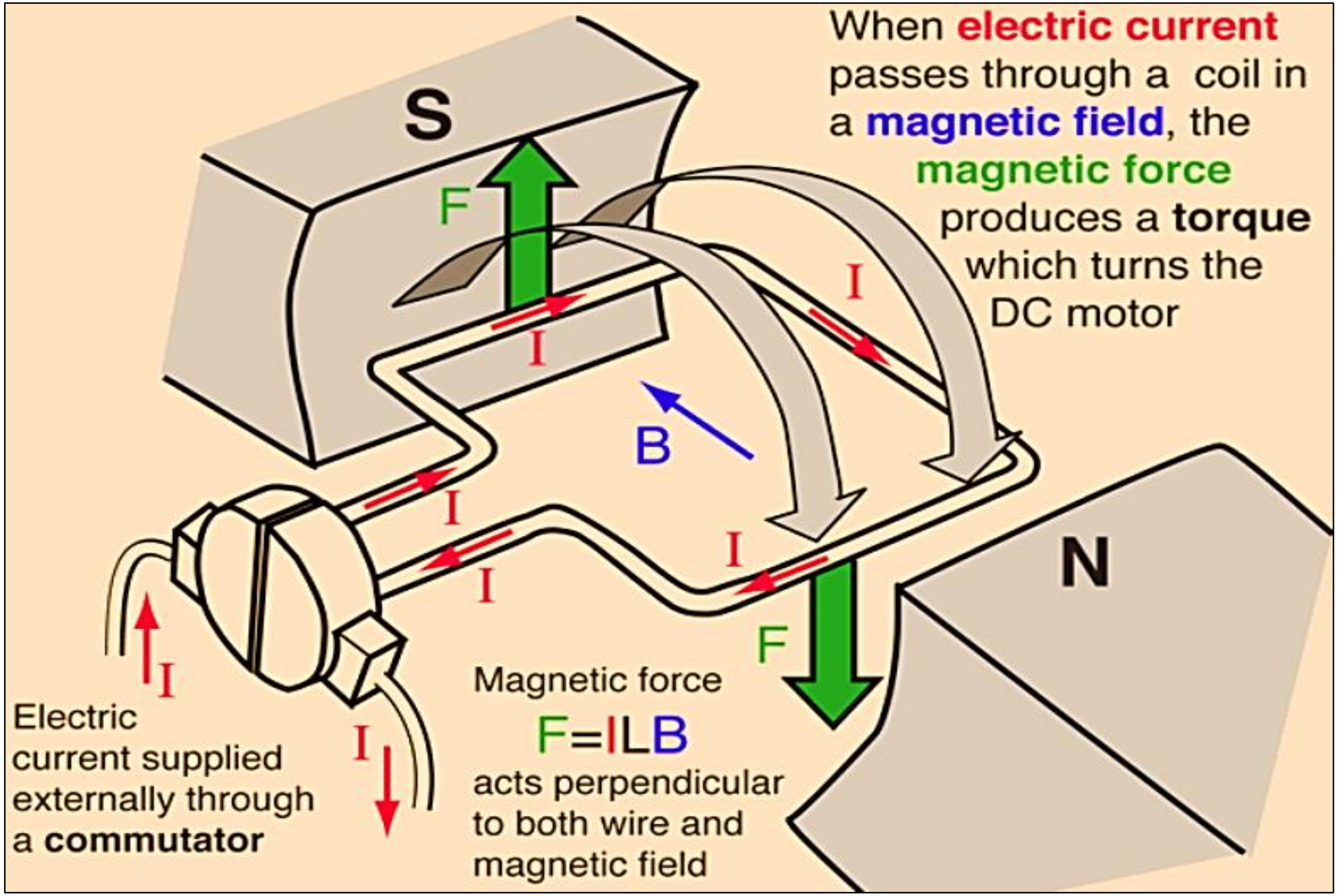
Where, N– No of turns I –current, L –coil length, A-*Area*, g=*gap length*

$\mu_0 \mu_r$ are permeability of vacuum and 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

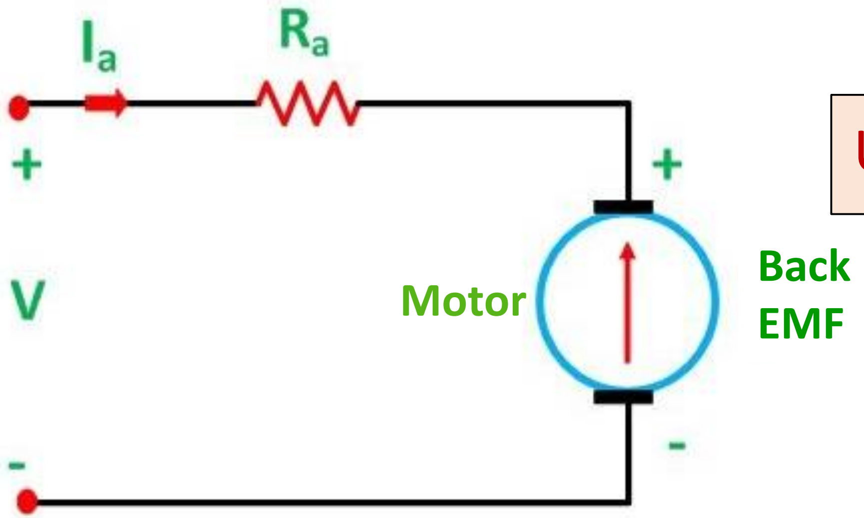
In DC Motors, **Multiple current carrying conductors** pass through the **magnetic field** lines Therefore, EMF generated across the armature coil (or the commutator terminals). This EMF is referred as 'Back EMF'

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

Where, ***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) $= V - I_a R_a \rightarrow$ N(rpm) $= \dfrac{V - I_a R_a}{k\varphi}$

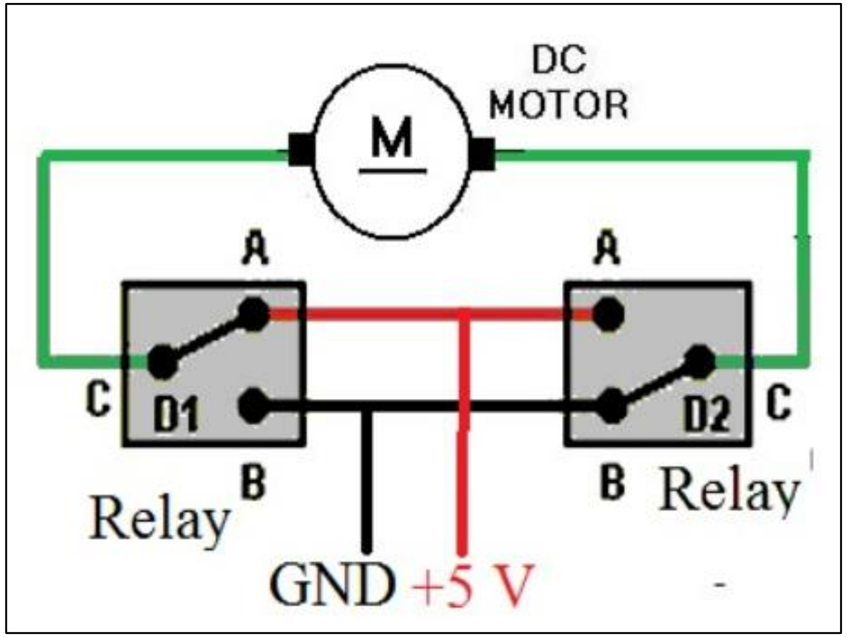
Where, Ia and Ra are the armature currents and resistance

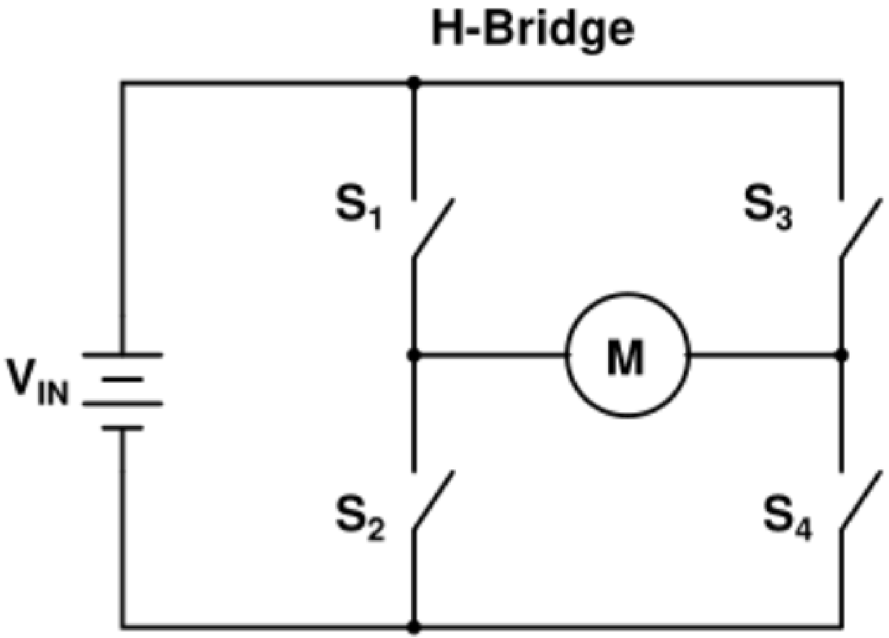
Power to the DC motor (P) $= VI_a = E_b I_a + I_a^2 R_a$

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

Switch Configurations: Reversal and Bridges





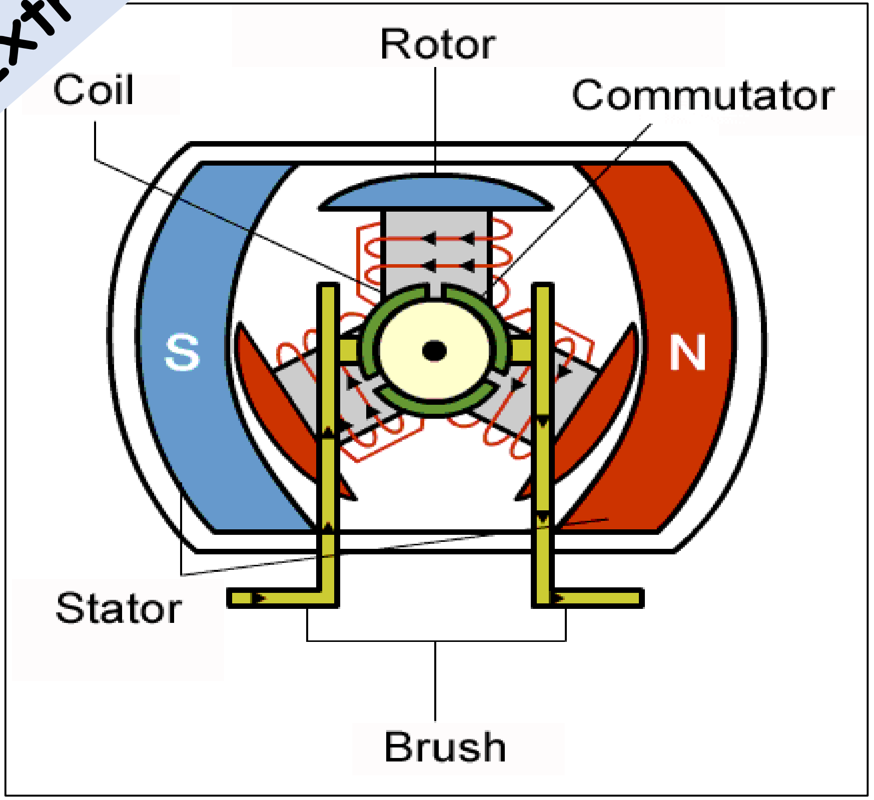
S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor coasts
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes
1	1	0	0	Short circuit
0	0	1	1	Short circuit
1	1	1	1	Short circuit

Direction Reversal Switch

H-Bridge for Direction Reversal

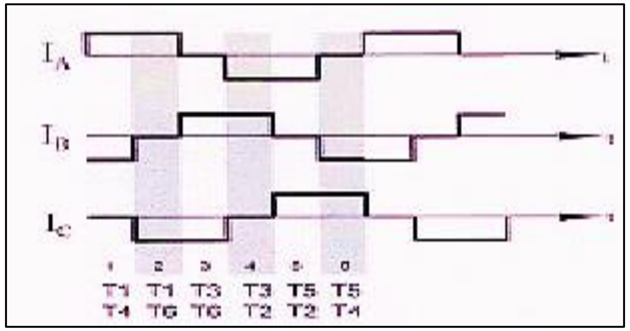
Extra Thinking

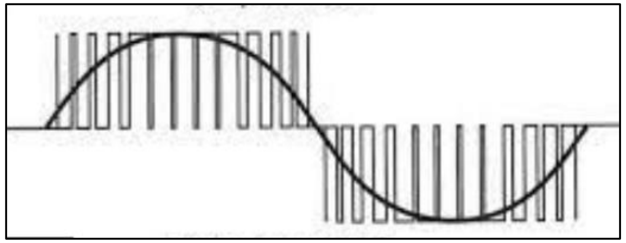
Permanent Magnet Direct Current (PMDC) motors and Brushless Direct Current (BLDC) Motors

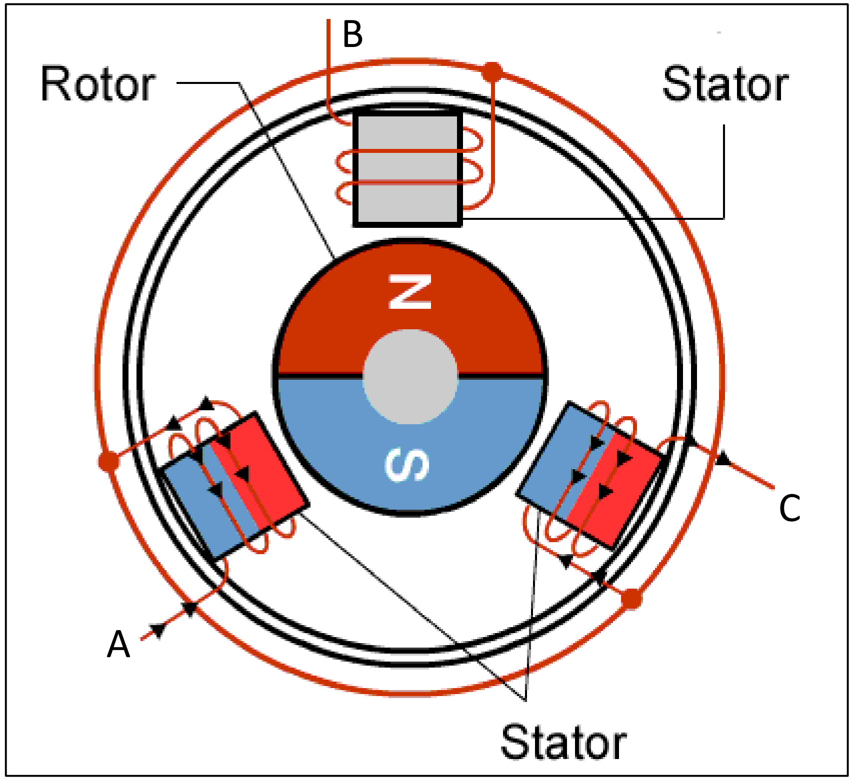


In PMDC Motors,
Permanent magnets on stator create the Field. Commutation is done using Brush contacts

Torque= $= K\,\varphi I_a = K_1 I_a$
(where, $K_1 = K\,\varphi$)
Hence the torque is dependent on armature supply.
Average Ia is varied either by changing voltage OR by pulse width modulated (PWM) control





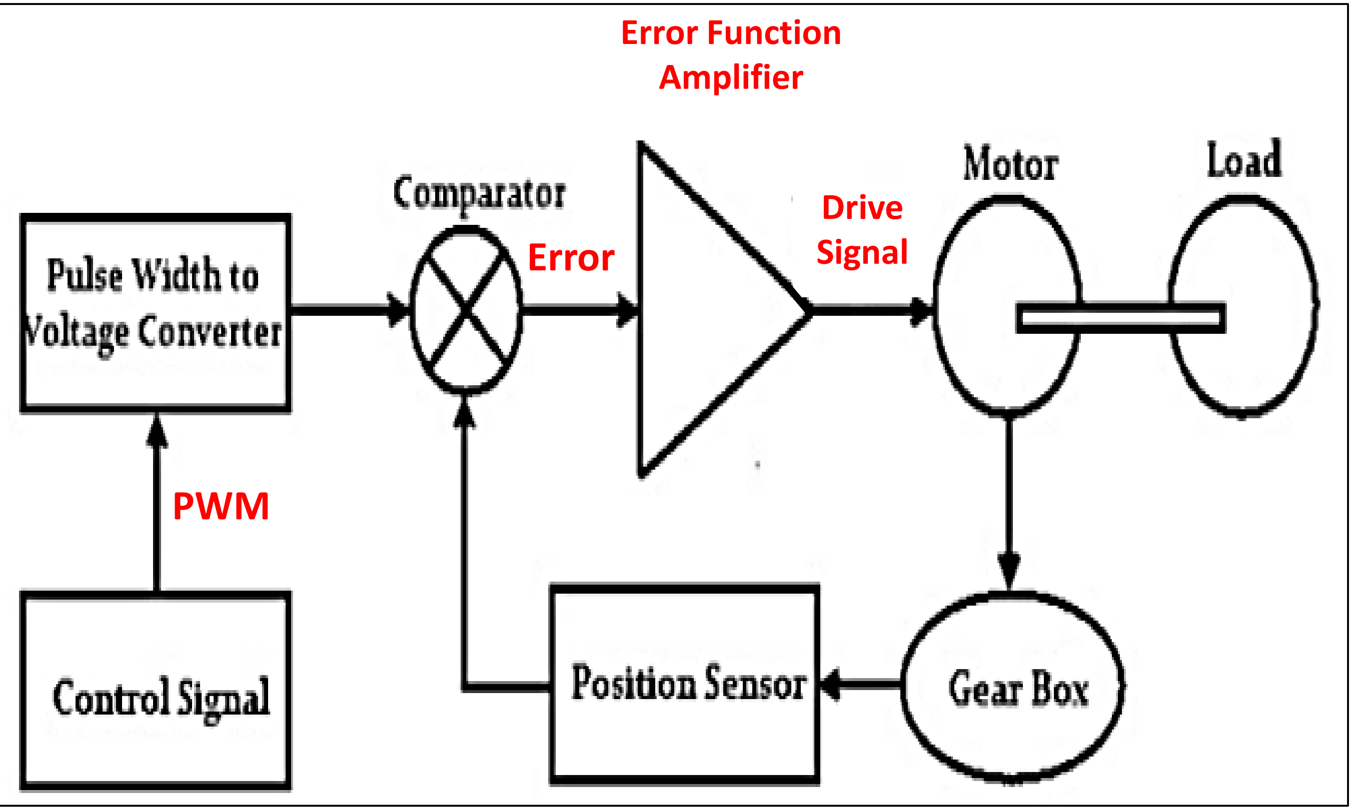


In BLDC Motors,
Permanent magnets on the rotor create the Field. Commutation is electronically done by switching the windings. This eliminates the 'brushes' and the mechanical wear and tear.

Source: https://www.renesas.com/us/en/support/engineer-school/brushless-dc-motor-01-overview

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 system** with position sensor (**encoders**)
- Error signal is generated based on **difference in current** and **desired** (corresponding to the control input) position
- The drive signal to the motor is derived from the error in order to '**null the error**'
- Depending the dynamics of the system, for smooth transition, DC-drive function is generated using **one or more** of the following parameters derived from the error value.

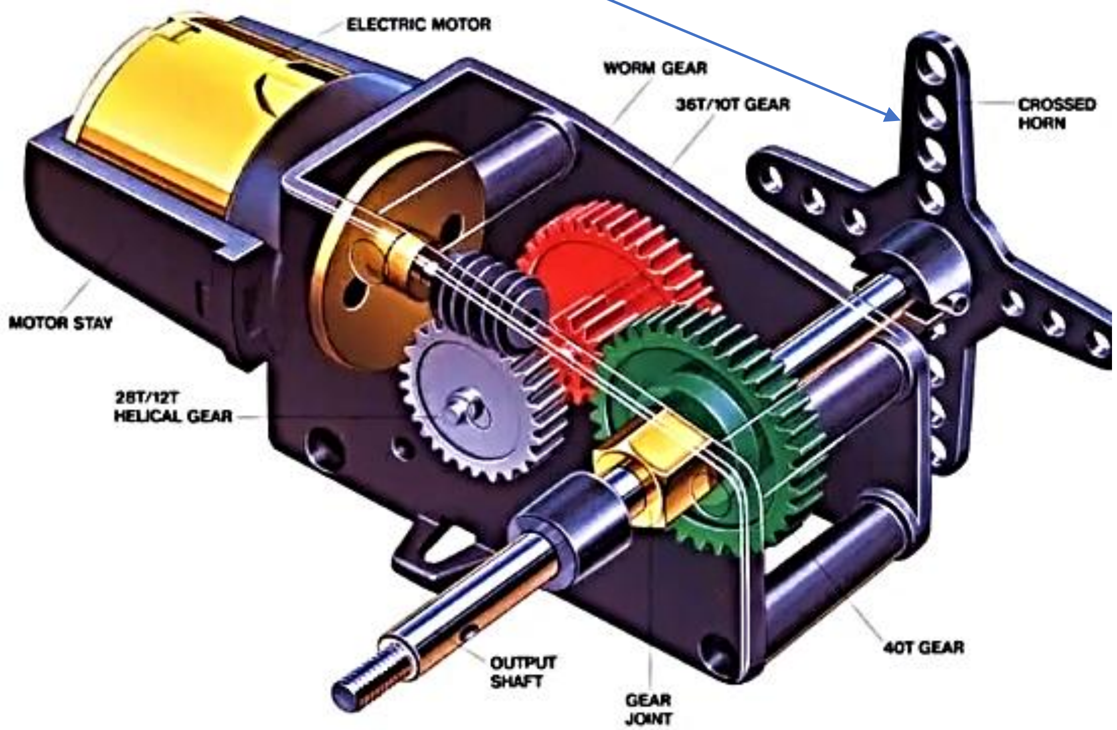
(a) **P**roportional (b) **I**ntegral components (c) **D**ifferential

Technique using 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

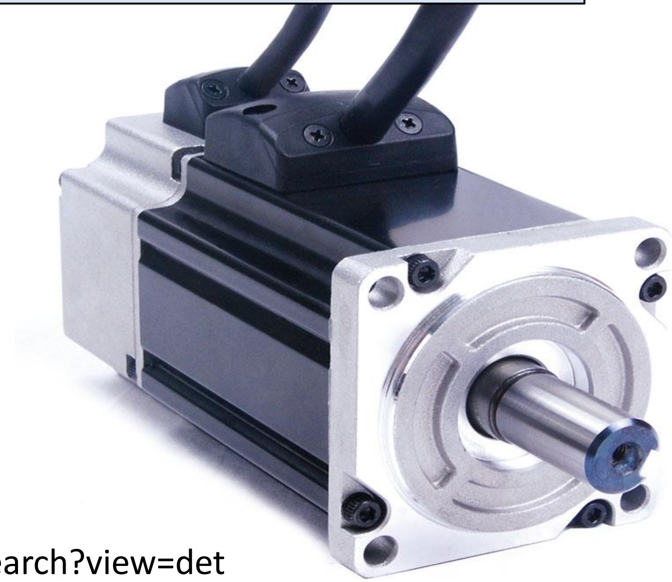
- DC servo motors are invariably used for '**position control**' applications
- On some special occasions they are used for precise angular speed control.
- In such configuration the **sensors measure angular speed** (tachometers) and the drive is provided to the motor to maintain the desired angular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