Electric Motors

Some Machine Terminology

Electric machines can be classified in terms of their energy conversion characteristics.

- **Generators convert mechanical energy from a prime mover** (e.g., an internal combustion engine) **to electrical form**.

Examples of generators are those used in power-generating plants, or automotive alternator.

- **Motors convert electrical energy to mechanical form**.

Electric motors provide forces and torques to generate motion in countless industrial applications.
For Example Machine tools, robots, punches, presses, mills, and propulsion systems for electric vehicles are but a few examples of the application of electric machines in engineering.

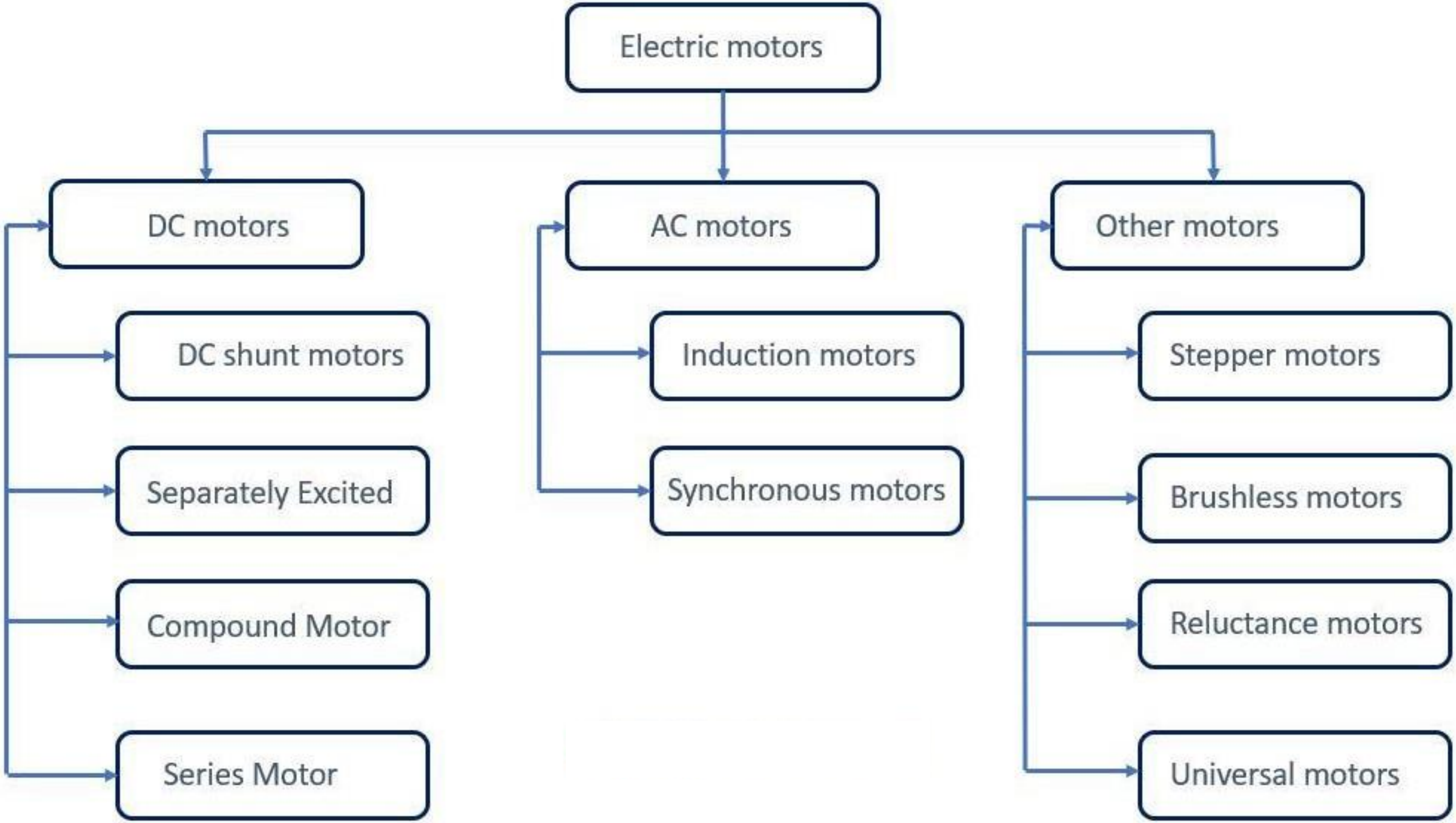
Some Windings Terminology

Distinction can be made between different types of windings characterized by the nature of the current they carry.

- If the current serves the purpose of providing a magnetic field and is independent of the load, (*it is called a magnetizing, or excitation, current)* ***the winding is termed a field winding.***
  (nearly always DC and are of relatively low power, since their only purpose is to magnetize the core).

- However, if the winding carries only the load current, it **is called an armature.**

In DC and AC synchronous machines, separate windings exist to carry field and armature currents.


Electric motors
DC motors
AC motors
Other motors
DC shunt motors
Separately Excited
Compound Motor
Series Motor
Induction motors
Synchronous motors
Stepper motors
Brushless motors
Reluctance motors
Universal motors

DC Motor

A DC motor is an electrical machine that converts electrical energy into mechanical energy. In a DC motor, the input electrical energy is the direct current which is transformed into the mechanical rotation.

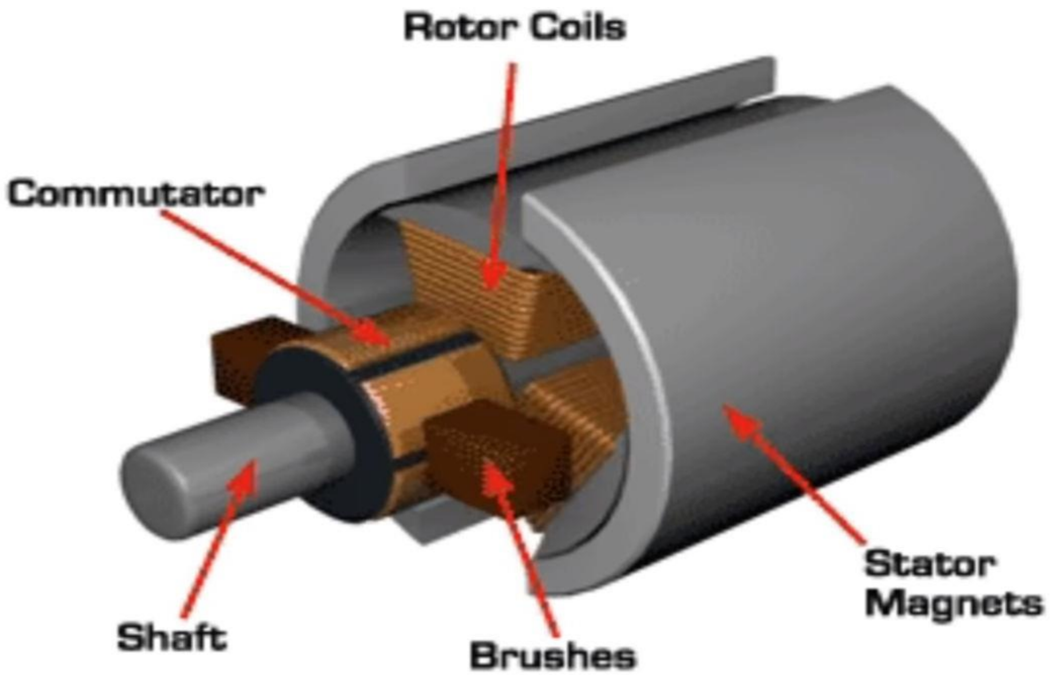


Fig. Configuration of DC Motor

Types

Based on Armature construction-

- Brushed DC Motor
- Brushless DC Motor

Based on Winding Connection-

- Shunt DC Motor
- Series DC Motor
- Compound DC Motor
- Separately excited DC Motor

DC Motor

Construction

A Motor has two major parts

- Stator : This is the stationary part, which can be a permanent magnet or an electromagnet.
- Rotor: This is the rotating part.

The rotor and stator each consist of

- Magnetic core
- Electrical insulation
- Windings necessary to establish a magnetic flux (unless this is created by a permanent magnet).

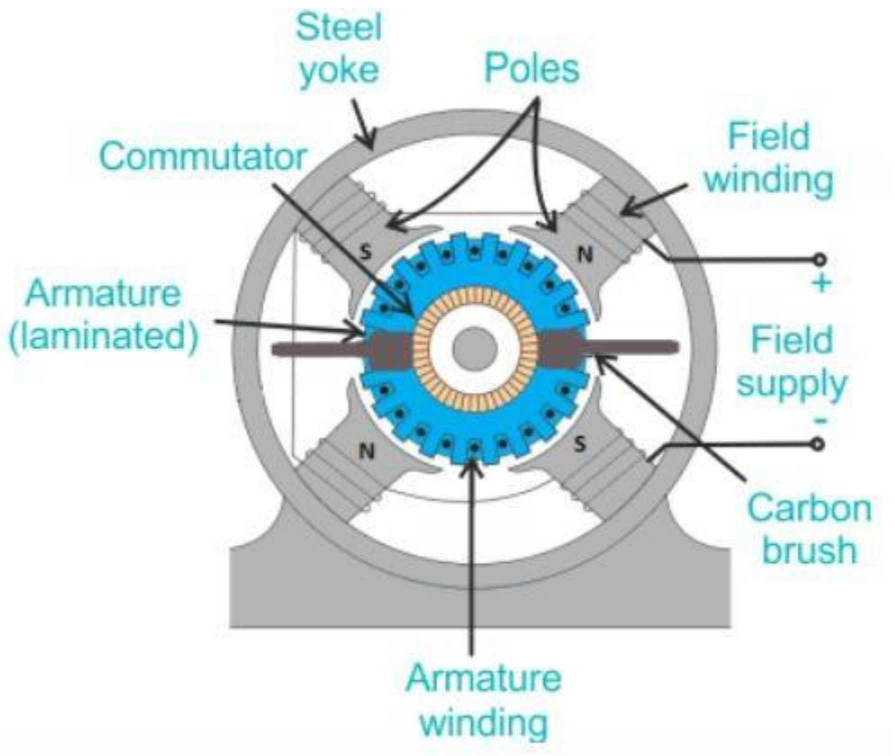
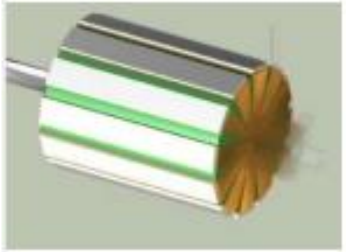


Fig. CONSTRUCTION OF DC MOTOR
{*Source: Testbook.com*}

PARTIALLY WOUNDED MOTORS CONSTRUCTION



Rotor:
Armature conductor are connected to the Commutator

+

Commutator
Mechanical rectifier converts ac to dc

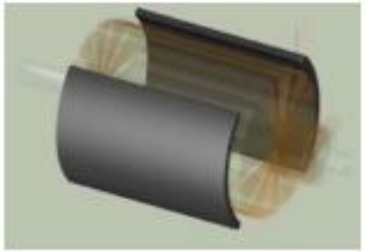
Made of copper segment insulated by mica

+

Brushes
Electrical connector between armature and power

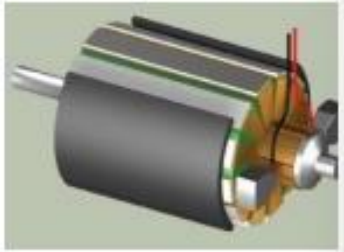
Pressure is adjusted using the spring

+

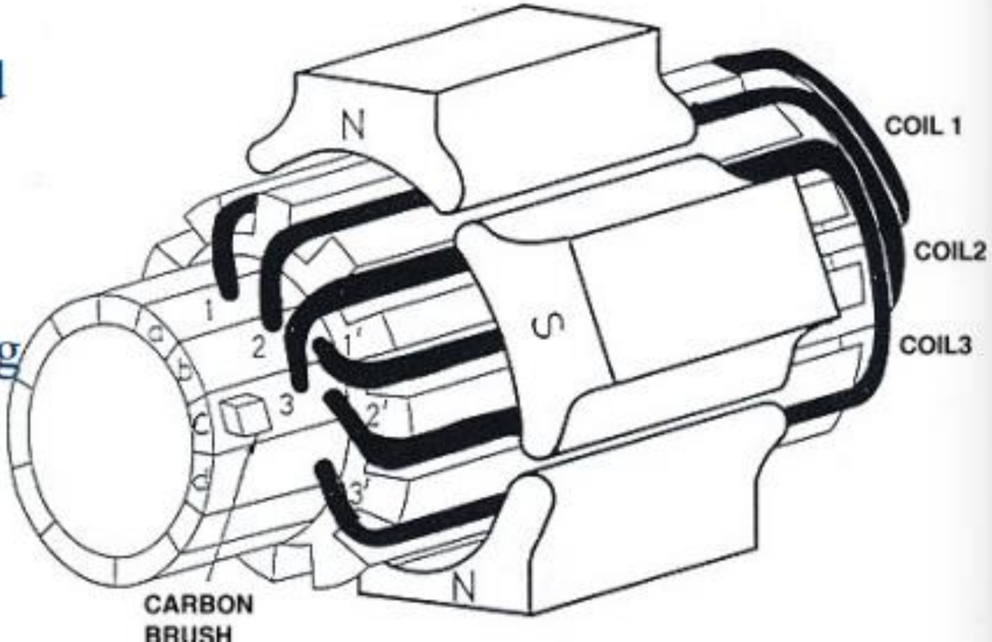


Stator
Produces an external flux

=



DC Machine



The rotor is mounted on a bearing-supported shaft, which can be connected to mechanical loads by means of different mechanical couplings.

Field Windings

The Winding used for magnetization only and attached to stator is called Field Winding.

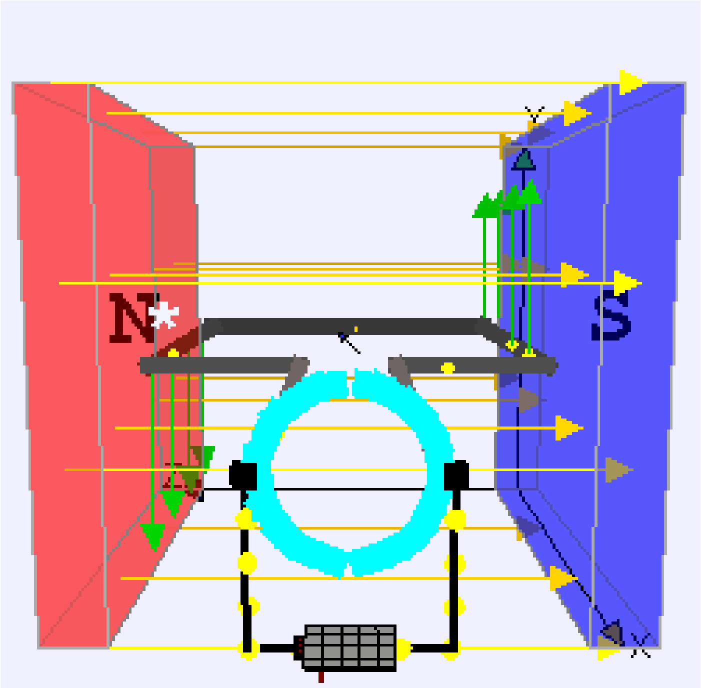
Armature Windings

Winding carrying load current and attached to rotor is called Armature Winding.

Commutator

A commutator is a device in DC motors that change the direction of current in the armature windings to maintain consistent rotational torque.

Principle Of Operation



Source: https://commons.wikimedia.org/wiki/File:Ejs_Open_Source_Direct_Current_Electrical_Motor_Model_Java_Applet_%28_DC_Motor_%29_80_degree_split_ring.gif

- When a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

- Magnitude is
  F=B.I.L Where,
  I=Current, L=Conductor Length, B=Magnetic Flux Intensity

- Direction is given by Fleming's left hand rule.

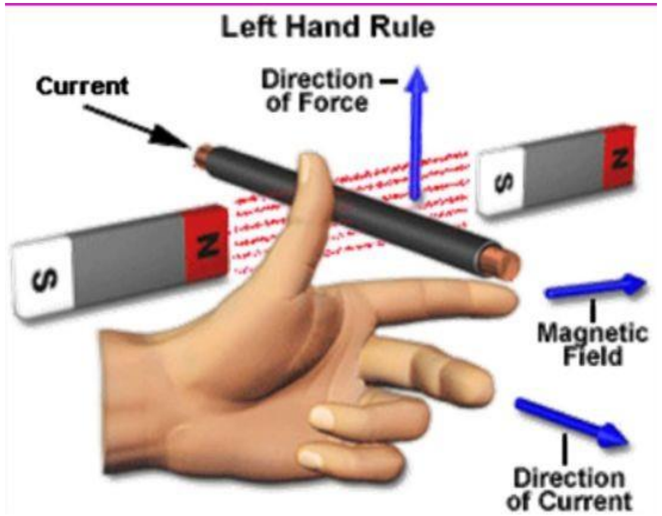


Fig. Flemings left hand rule
{*Source: Wikipedia*}

- Number of poles affects the induced emf
- Machines have several pairs of poles.
- For a machine with ***p*** pole pairs, the average emf in each conductor is given by:
- $$\left.\begin{array}{l}\text{average emf induced}\\ \text{in a conductor}\end{array}\right\} = \frac{\text{total flux per pole}}{\text{total time conductor is under a pole}} = \frac{\varphi}{\left(\frac{1}{p}\times\frac{1}{2n}\right)} = 2pn\varphi \text{ Volts}$$

$$\left.\begin{array}{l}\text{Total emf induced}\\ \text{in armature winding}\end{array}\right\} = \begin{array}{c}\text{average emf induced}\\ \text{in one conductor}\end{array} \times \begin{array}{c}\text{number of armatur}\\ \text{conductors in series}\end{array}$$

$$\mathbf{E} = \mathbf{2pn\phi\times} \quad \mathbf{A_s}$$

The number of poles ($2p$) and the number of armature conductors in series (A_s) are constant for a particular machine. Therefore $k = 2p\,A_s$

$$E = k\phi n \text{ Volts}$$

Since the angular velocity, $\omega = 2\pi n$ ➡ $$E = \frac{k}{2\pi}\varphi\omega \text{ Volts}$$

Torque

Electrical power delivered to the armature = Armature emf × Armature current

$$P_a = E \times I_a$$

This power creates the torque to make the armature rotate.

Electrical torque developed in the armature = $\dfrac{\text{Electrical power delivered to the armature}}{\text{Angular velocity}}$

Remember: Power is the rate at which work is done; Work done in 1 s = force × distance

Power = work done / time taken

$$\mathbf{T_e = \frac{P_a}{\omega} = \left(\frac{k}{2\pi}\varphi\,\omega \cdot I_a\right)\frac{1}{\omega} = \frac{k}{2\pi}\varphi\, I_a \quad \text{Newton meters}}$$

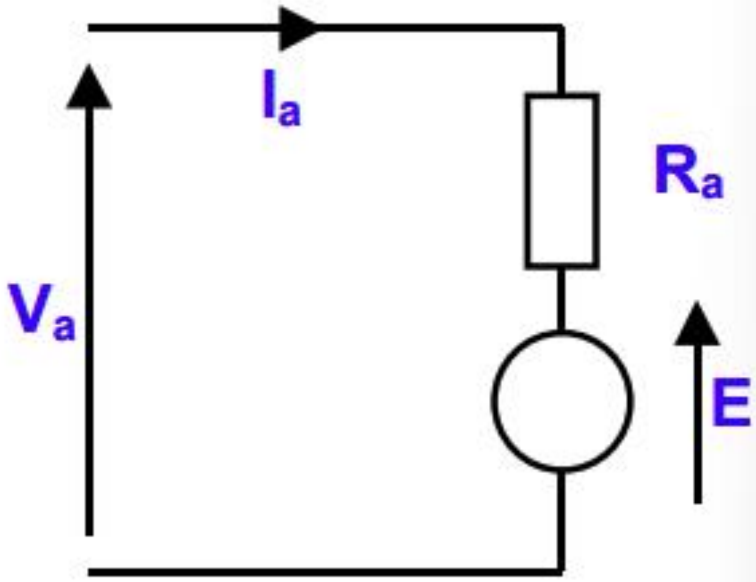
Mechanical torque$|_{\text{at the shaft}}$ = Electrical torque - "Lost" torque$|_{\text{due to frictional and other losses}}$

The "lost" torque is small and will be ignored

ARMATURE TERMINAL VOLTAGE

- The figure represents an equivalent circuit of an armature
- **E** is the **induced emf**
- R_a is the **armature resistance**
- The armature terminal voltage is given by:

$$V_a = E + I_a R_a$$



Commutation

The maximum torque occurs when δ = 90º (sin **δ** = 1)

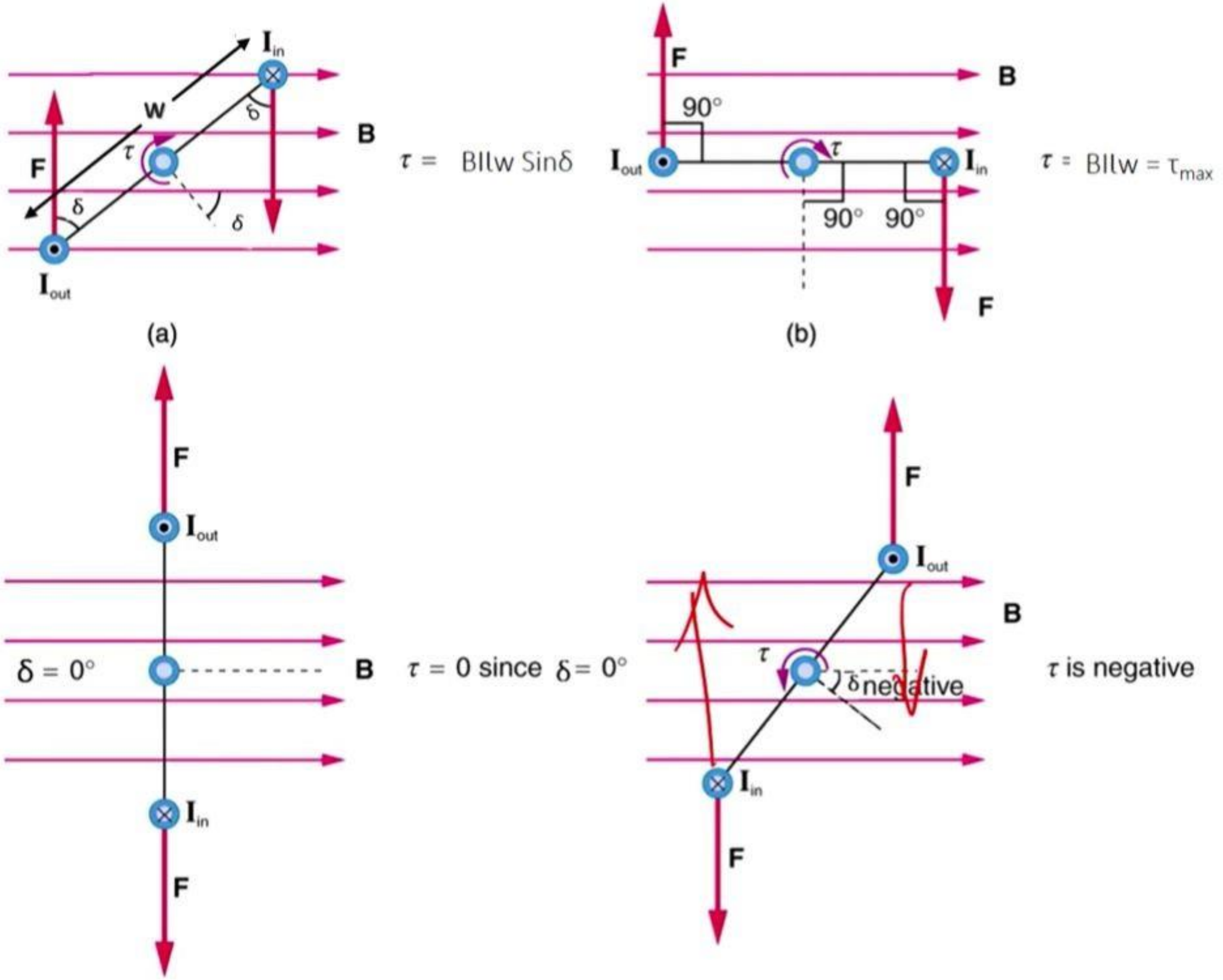
The minimum torque occurs when **δ** = 0 (sin **δ** = 0)

A negative torque is produced when **δ** < 0

Negative torque can be avoided by reversing the direction of current when **δ** = 0 . This is called **commutation.**

In a PMDC motor, this is achieved via split rings and sliding carbon brushes.

This also ensures the wires coming out don't twist around each other and snap



Credit: Lumen Physics

Methods of Winding Connection

The field and armature windings may be connected to:

- Independent supplies - Separately Excited

- Common supply - Self Excited

  Shunt wound: The field and armature windings are connected in parallel.
  Series wound: The field and armature windings are in series.
  Compound wound: Has two field windings;
  o One connected in parallel with the armature winding and
  o Other in series with the armature winding.

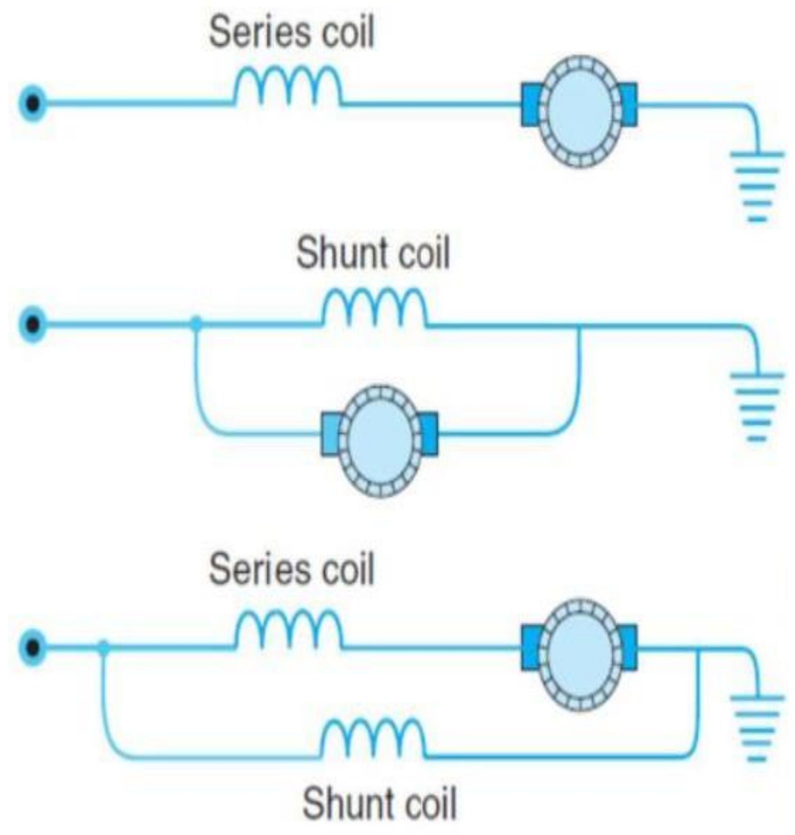
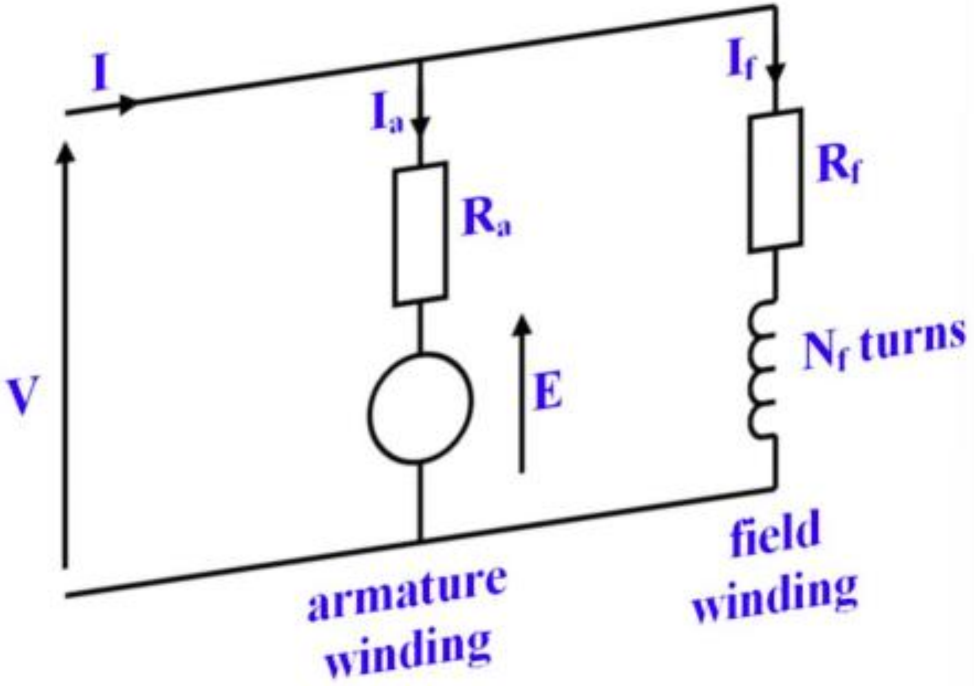


Fig. Winding Connection Methods {*Source: Testbook.com*}

Shunt Wound DC Motors



Field Winding:

$$\varphi = \frac{iN}{S} = \frac{I_f N_f}{S}$$

Where, S is the reluctance,
N is the number of turns in the coil and
i is the coil current.

Armature Winding:

Armature terminal voltage, $V = E + I_a R_a$

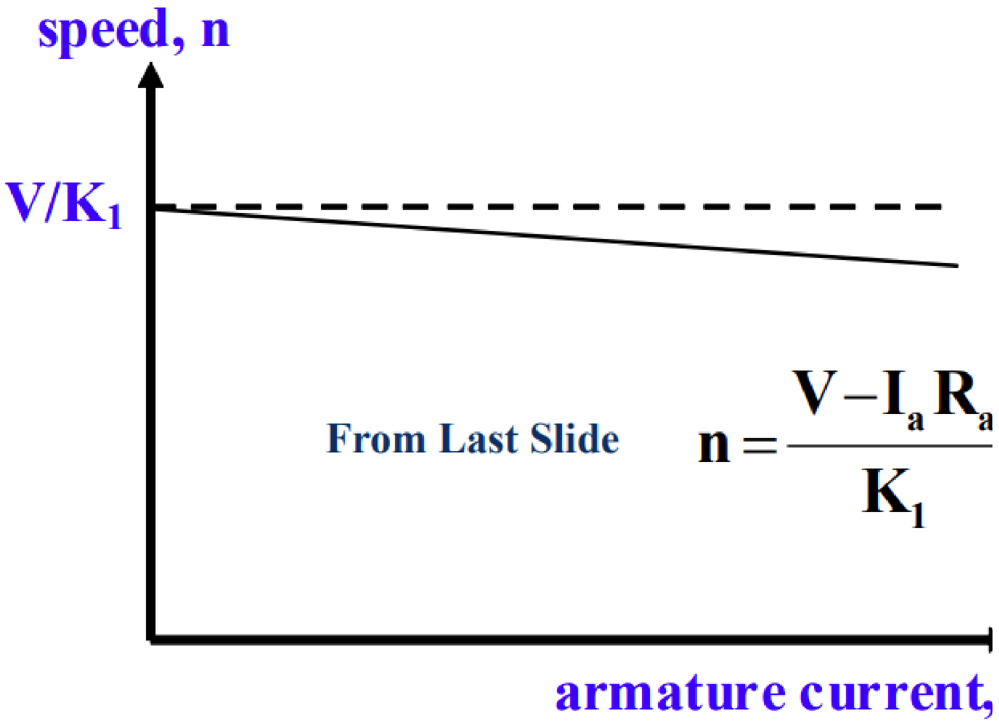
$$V = k\phi n + I_a R_a$$

with ϕ constant, let $K_1 = k\phi$ $\quad V = K_1 n + I_a R_a$

V: External supply voltage
R_f: field winding resistance
} are normally constant hence keeping I_f and hence ϕ constant.

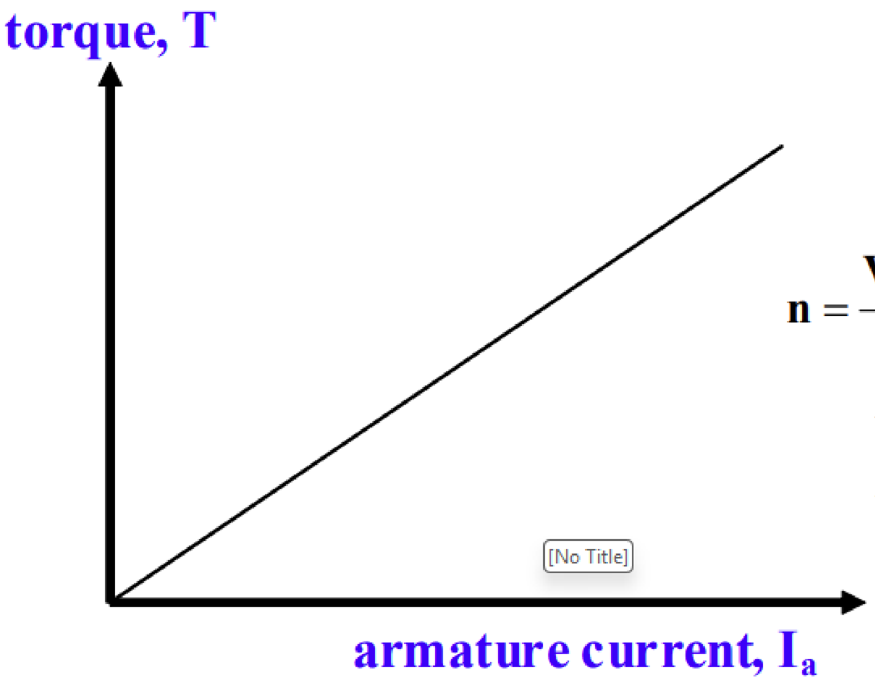
$$\therefore \text{ The steady state speed } = n = \frac{V - I_a R_a}{K_1}$$

Speed Current Characteristics



From Last Slide $$n = \frac{V - I_a R_a}{K_1}$$

Torque Current Characteristics



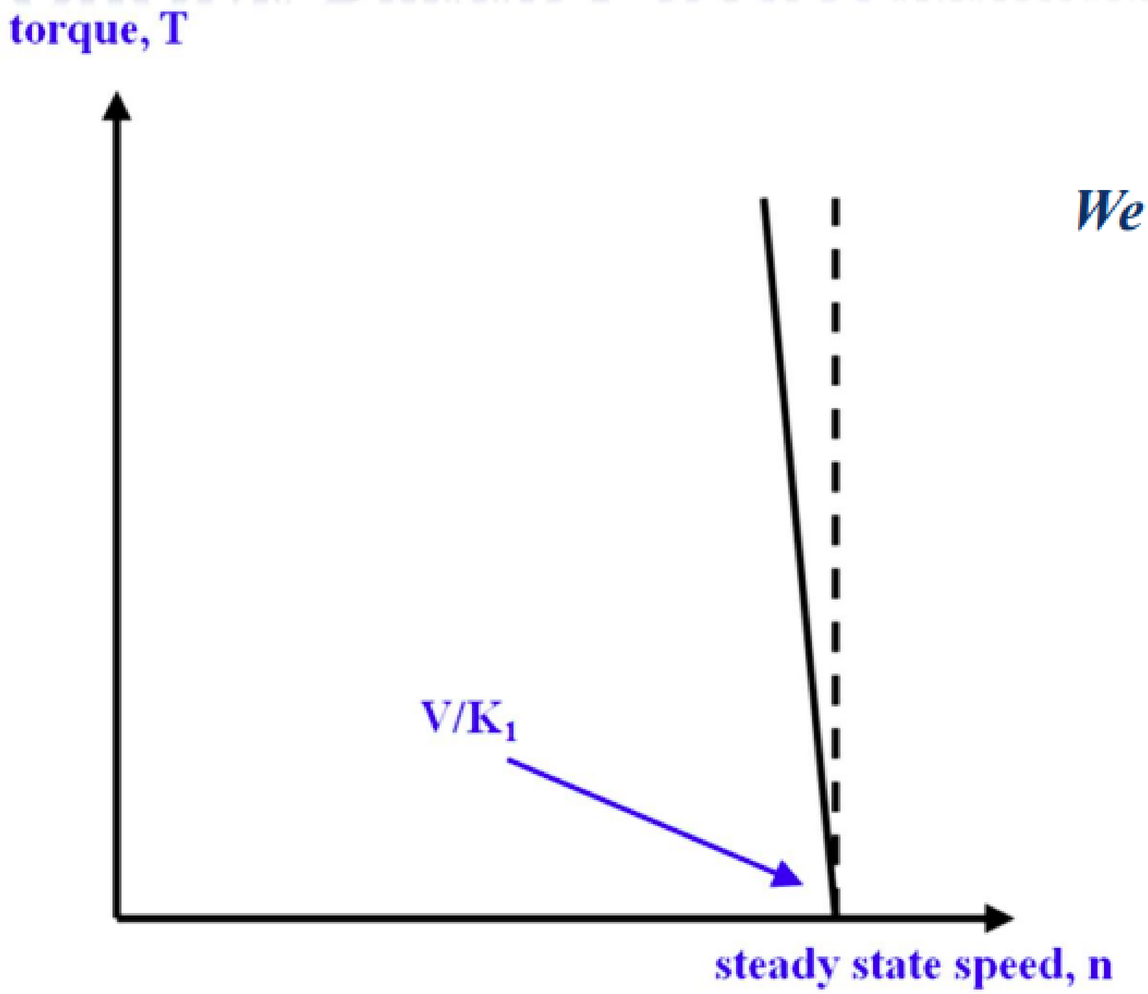
$$n = \frac{V - I_a R_a}{K_1} \quad \text{(from last slide)}$$

Using $T_e = \frac{k}{2\pi}\varphi\, I_a$

With φ constant, $K_2 = \frac{k\varphi}{2\pi}$

$$\therefore \; T = K_2 \cdot I_a \qquad \text{or} \qquad T = \frac{k}{2\pi}\varphi \cdot I_a$$

Torque Speed Characteristics



We had: $$n = \frac{V - I_a R_a}{K_1}$$

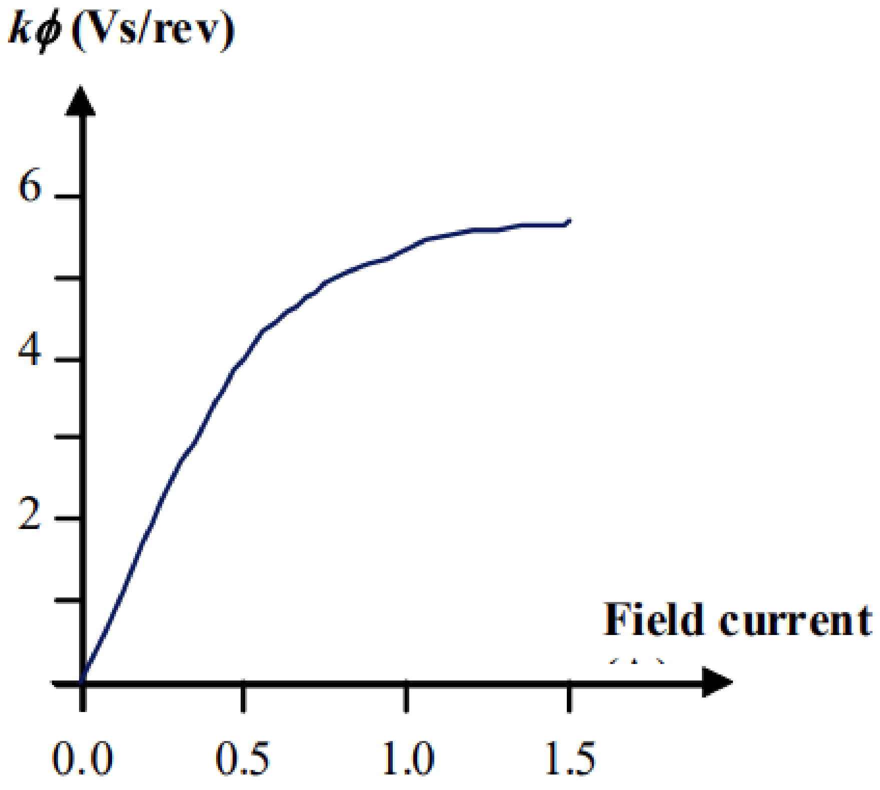
$$I_a = \frac{V - K_1 n}{R_a}$$

$$T = \frac{K_2}{R_a}[V - K_1 n]$$

The torque-speed curve shows that shunt motors can be used to drive fairly constant speed from no load to full torque

Therefore, ideal for use with machine tools, pumps, compressors etc.

EXERCISE



- A 220V dc shunt motor has an armature resistance of 0.8Ω and field winding resistance of 220Ω. The motor field characteristic [$k\phi$ *versus* field current] is shown in Figure
  a) Calculate the field current

If the motor drives a constant load torque of 17.5Nm, calculate

b) armature current

c) speed

SOLUTION

Field Circuit:

$$I_f = \frac{V}{R_f} = \frac{220V}{220\Omega} = 1\text{ A}$$

from graph $k\phi = 5.5$ Vs[rev]$^{-1}$

Torque equation: $T = \frac{k\phi}{2\pi} I_a$

$$17.5 = \frac{5.5}{2\pi} I_a$$

Armature current, $I_a = 20\text{A}$

Armature Circuit:

$$V = E + I_a R_a = k\phi n + I_a R_a$$

$$220 = 5.5n + 20 \times 0.8$$

$$\therefore \mathbf{n} = \frac{220 - 16}{5.5}$$

Speed = 37.1 rev sec^{-1}
= 2225 rev min^{-1}.

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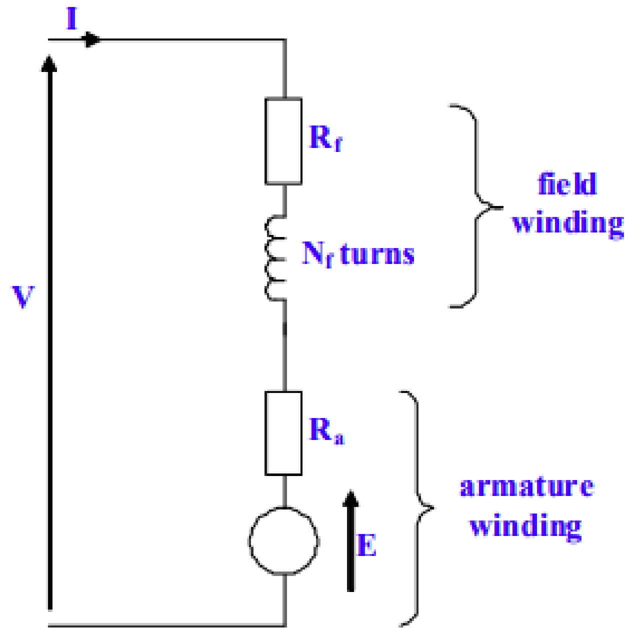
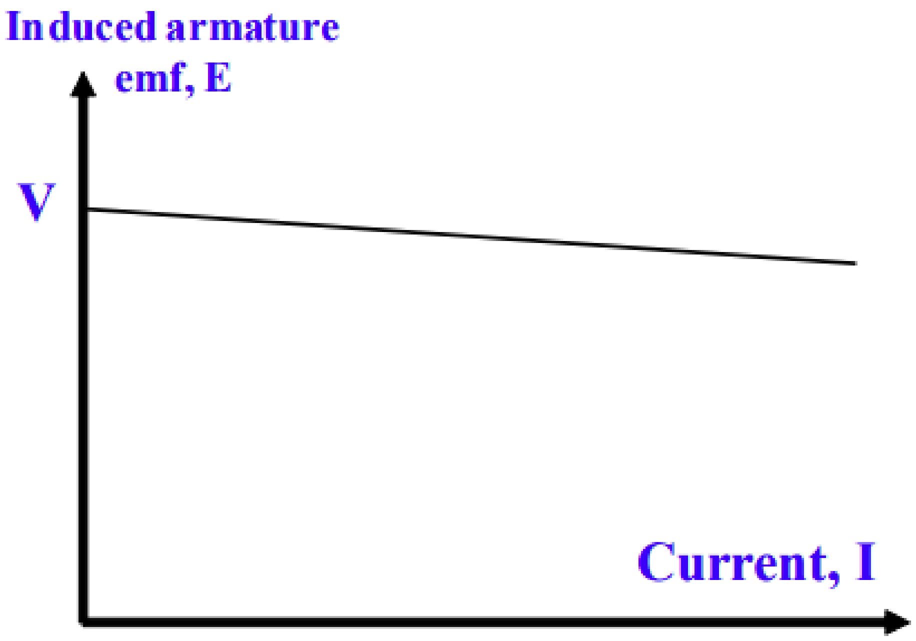
Series Wound DC Motors





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In the series motor current, ***I*** flows through both field and armature windings so:

$$V = E + I(R_a + R_f)$$

let $R = R_a + R_f$ ⇨ $V = E + IR$

⇨ $E = V - IR$

Speed Current Characteristics

All dc motors, flux, $\phi \propto$ field winding current

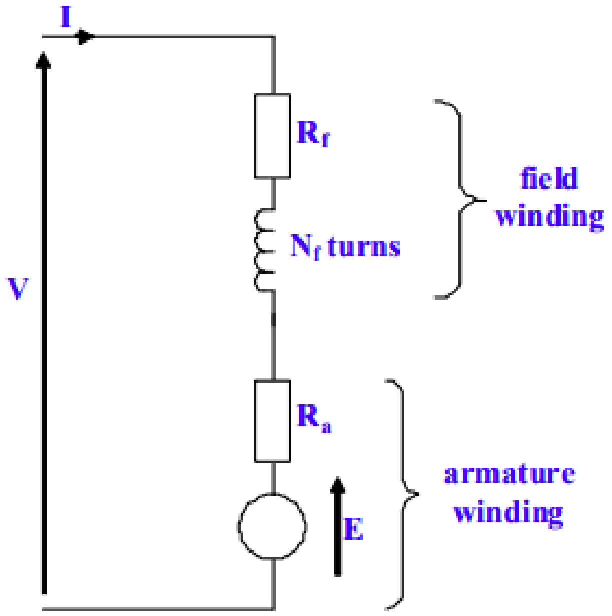
For Series wound motor $\quad \phi \propto I;\ \phi = K_3 I$

N.B. this assumption only applies for low currents.

$$E = k\phi n$$
$$E = kK_3 In$$
$$\mathrm{E} = K_4 In \qquad \text{where } K_4 = kK_3$$

$$\therefore \qquad \mathbf{V = K_4.I.n + I.R}$$

$$\therefore \ \mathbf{n} = \frac{1}{\mathbf{K}_4}\left[\frac{\mathbf{V}}{\mathbf{I}} - \mathbf{R}\right]$$



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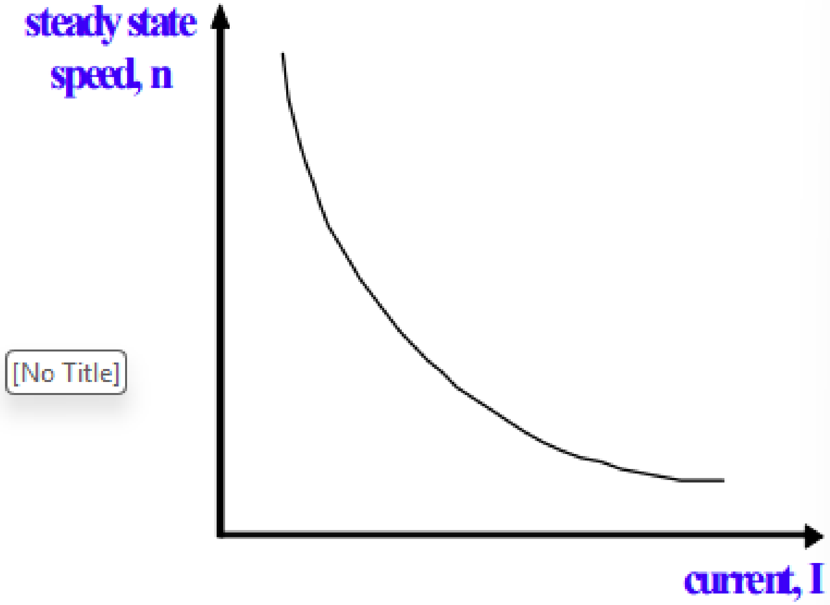
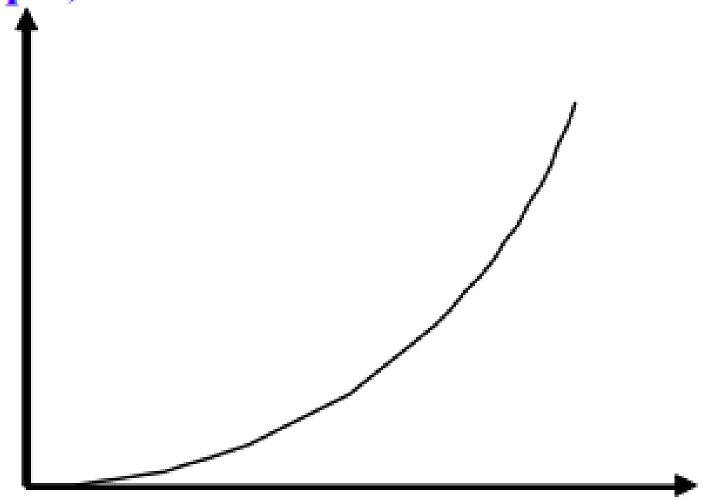
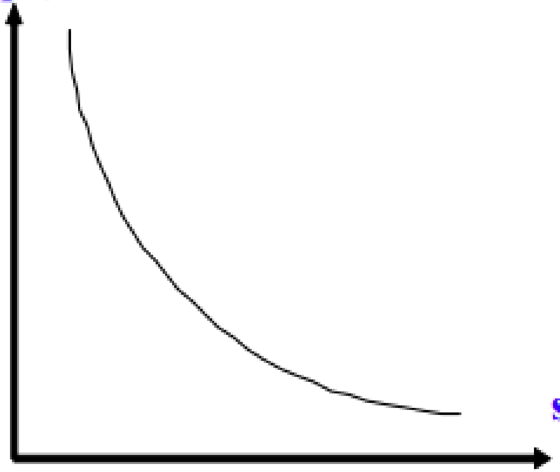


Torque Current and Torque Speed Characteristics





$$\mathbf{n} = \frac{1}{K_4}\left[\frac{V}{I} - R\right]$$

$$T = \frac{k\phi I_a}{2\pi} = \frac{kK_3}{2\pi} I.I$$

$$\therefore\ T = K_5 I^2 \qquad \text{where } K_5 = \frac{kK_3}{2\pi}$$

$$I = \frac{V}{K_4 n + R}$$

$$T = K_5\left[\frac{V}{K_4 n + R}\right]^2$$

- The series motor is a variable speed machine ideally suited to drive permanently coupled loads.
- They are often used for electric traction and lifts. They must never be used on “no load” as the speed will become dangerously high.

Exercise

A 220V dc series motor has armature and field resistances of 0.2Ω and 0.5Ω respectively. When running at 1000 rev min^{-1} the motor draws 10A from the supply. Calculate the torque delivered.

Solution

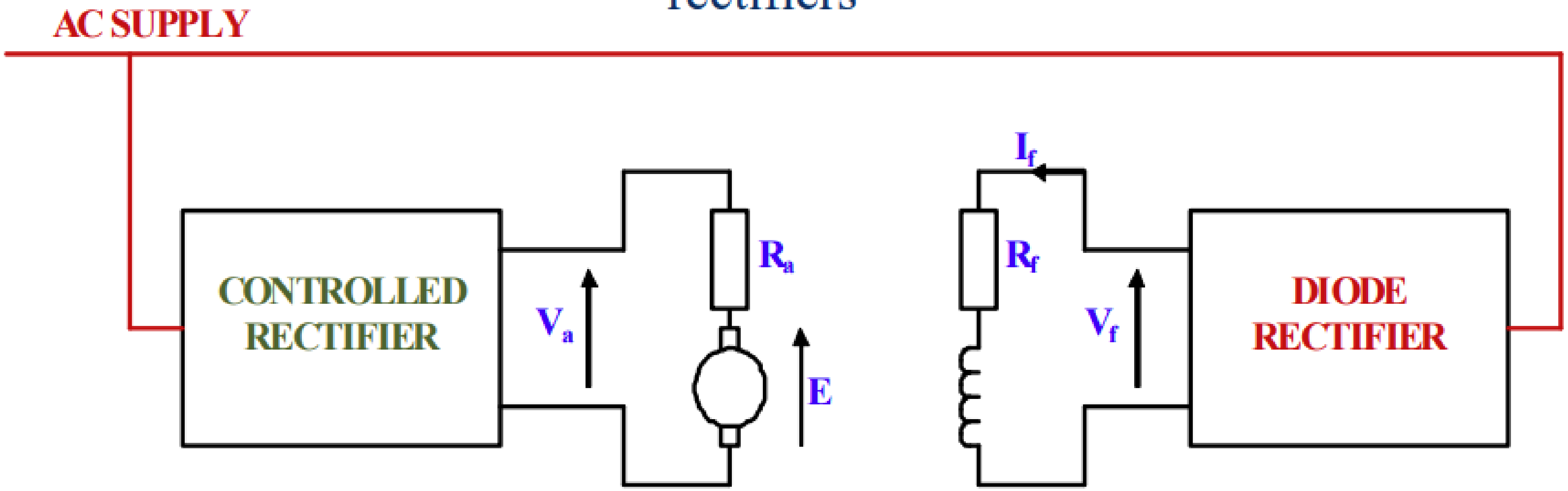
$$V = E + I_a (R_a + R_f)$$
$$220 = E + 10\,(0.2 + 0.5)$$
$$220 = E + 7$$
$$E = 213 \text{ volts}$$

$$T\omega = T(2\pi n) = EI_a$$
$$T = \frac{213 \times 10}{2\pi \times (1000/60)}$$

$$T = 20.34 \text{ Nm}$$

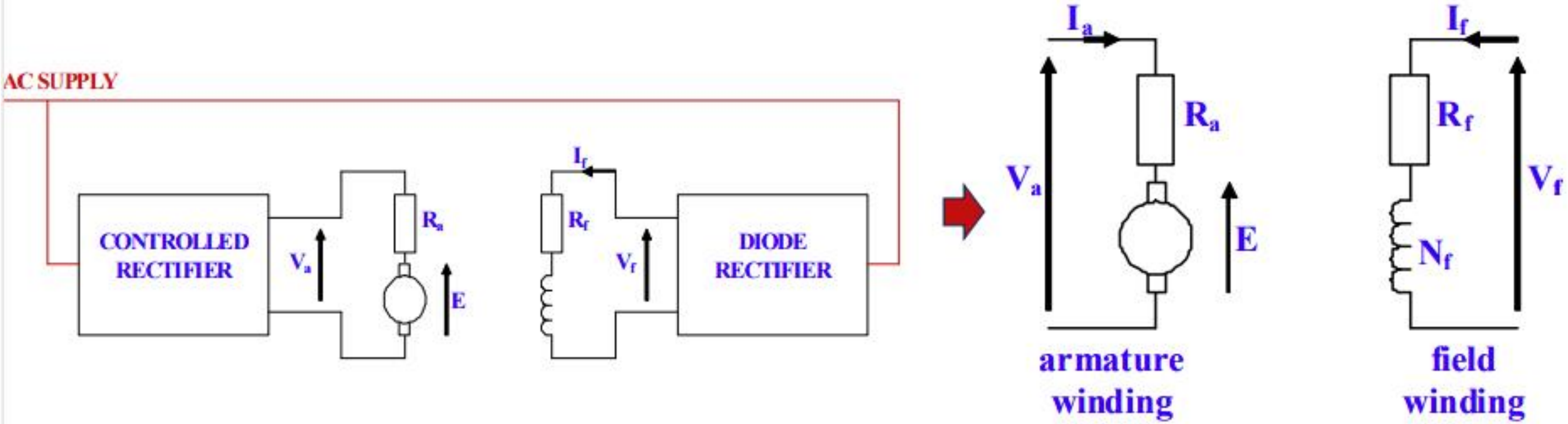
Separately Excited dc Motors

For accurate speed control it is advisable to use **a separately excited motor**
i.e. Armature and Field Windings supplied through independent dc rectifiers



- The diode rectifier supplies constant field current maintaining a fixed value of flux, ϕ.
- The controlled rectifier (supplying the armature winding) provides a fully variable armature terminal voltage, V_a.

SEPARATELY EXCITED DC MOTORS, EQUIVALENT CIRCUIT



$$\mathbf{V_a = E + I_aR_a} \qquad \text{But, } E = k.\phi.n \qquad \therefore \mathbf{V_a = k\phi n + I_aR_a} \qquad \therefore \mathbf{n = \frac{V_a - I_aR_a}{k\varphi}}$$

- R_a is usually small so $V_a > I_aRa$. Thus with ϕ constant the speed n, is almost directly proportional to V_a.
- Used for accurate speed control.

PROBLEMS

Q1 A 240V dc shunt motor has armature and field resistances 0.2 Ω and 320 Ω respectively. The motor drives a load at a speed of 950 rev min^{-1} and the armature current is 50A. Assuming that the flux is directly proportional to the field current, calculate the additional resistance necessary in the field circuit to increase the speed to 1100 rev min^{-1} while maintaining the armature current constant.

Calculate the speed of the machine with the original field current and an armature current of 90A.

50.5 Ω, 917 rev min^{-1}

Q2 *A 230V dc shunt motor has armature and field resistances of 0.3 Ω and 140 Ω respectively. Calculate the induced emf and the torque developed by the motor when it runs at a speed of 800 rev min^{-1} and the armature current is 2A.*

To drive a larger load at 1000 rev min^{-1} an additional resistance, R is connected in series with the field winding. In this situation the armature current is 30A. Calculate the new induced emf and torque and the value of R. Assume that the flux is directly proportional to the field current.

229.4V, 5.48Nm; 221V, 63.3Nm, 41.7 Ω

Q3 *A 240V dc series motor has armature and field resistances of 0.5 Ω and 1 Ω respectively. When running at 1200 rev min^{-1} the motor draws 15A from the supply. Calculate the torque delivered.*

A 2 Ω resistor is connected in series with the motor. The torque is adjusted so that the armature current remains unchanged. Calculate the new speed and torque. *26Nm; 1034 rev min^{-1}; 26Nm*

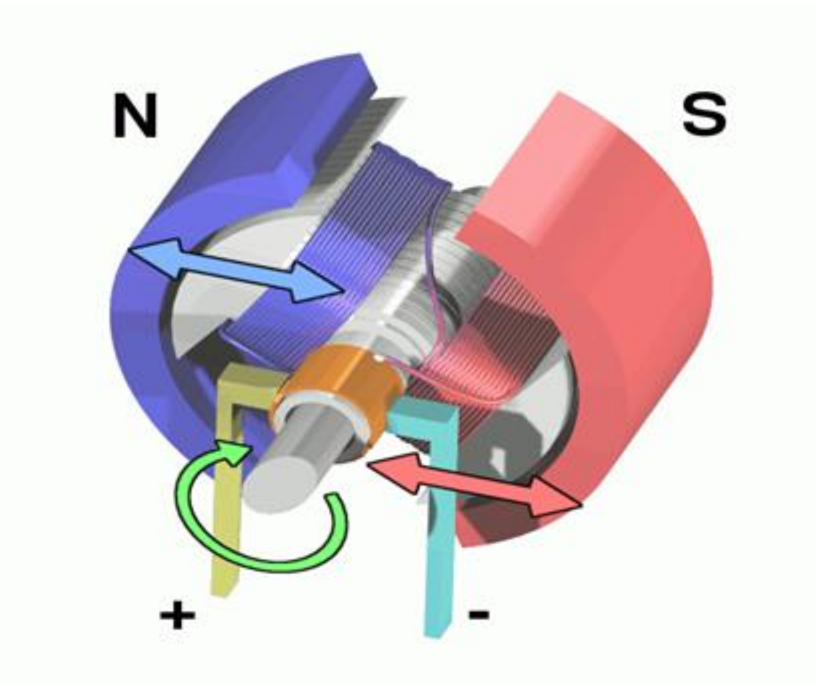
Q4 *A 550V dc series motor with an armature resistance of 0.35 Ω and and field resistance of 0.15 Ω drives a load at a speed of 750 rev min^{-1}. The supply current is 74A. Calculate the load torque.*

The load torque is doubled and the supply current rises to 110A. Calculate the new speed and power output. *483.3Nm; 537.8 rev min^{-1}; 54.45 kW*

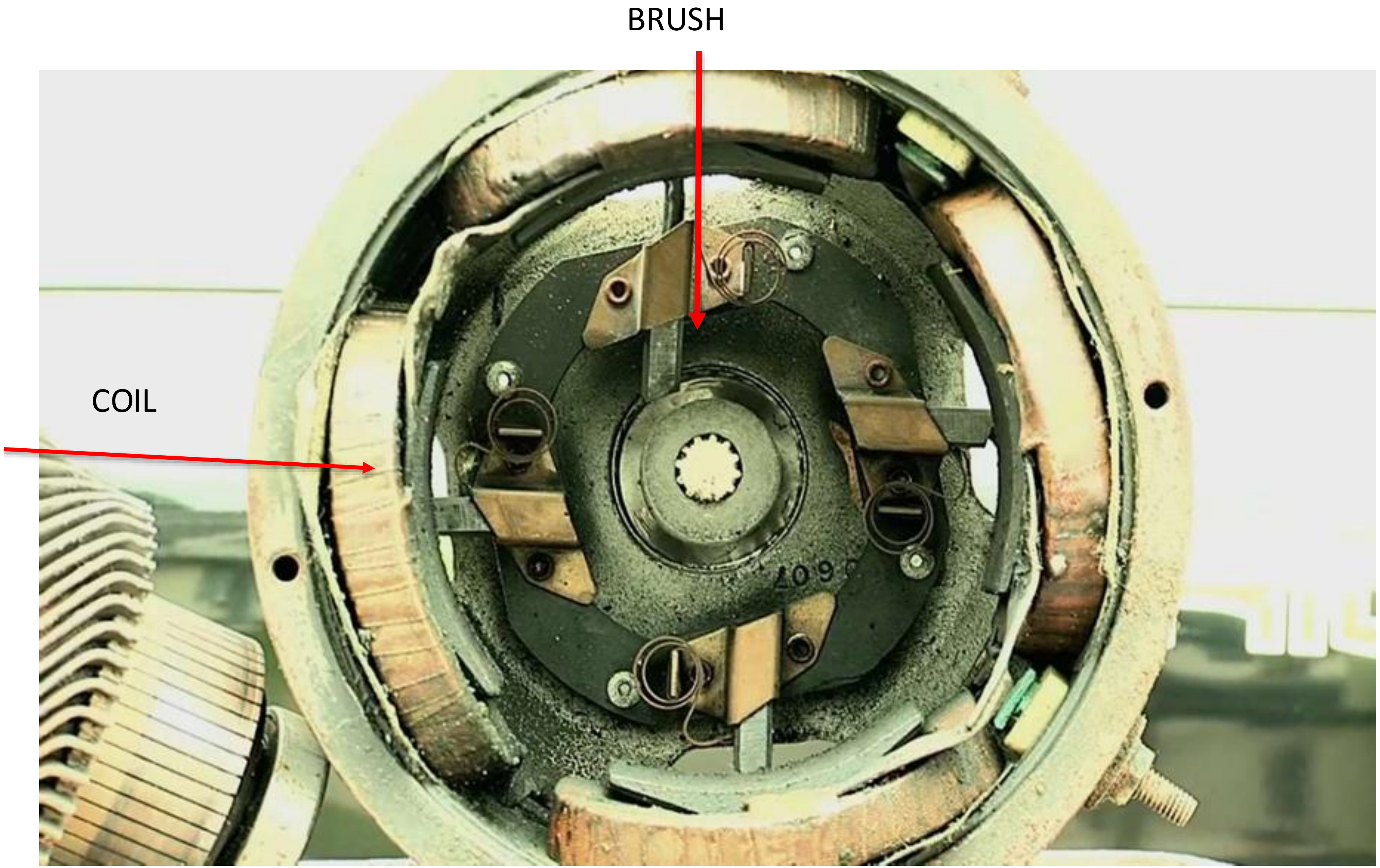
BLDC Motors

DC Motor

- Converts electrical energy to mechanical energy
- Principle- When a current carrying conductor placed in a magnetic field experiences a force
- Stator is made up of permanent magnet and rotor is of silicon steel stampings with copper wire wound on it.

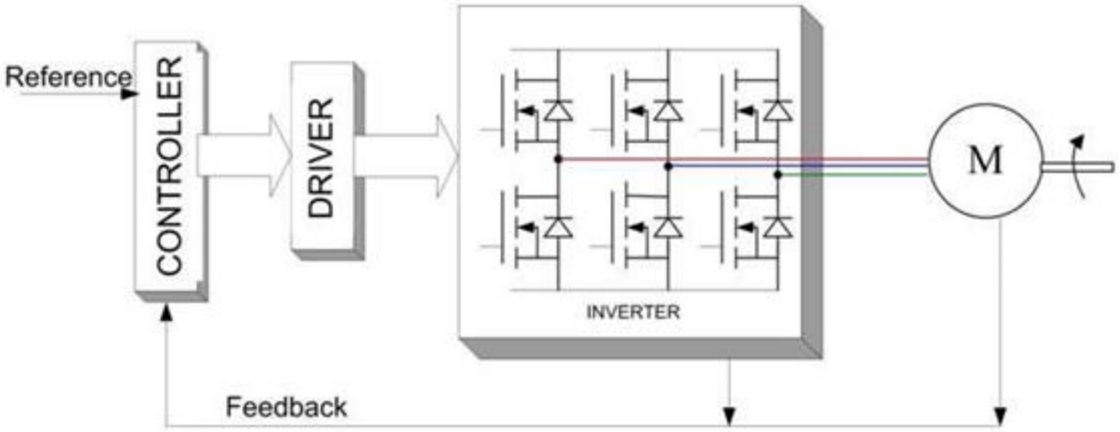


https://upload.wikimedia.org/wikipedia/commons/8/89/Electric_motor.gif

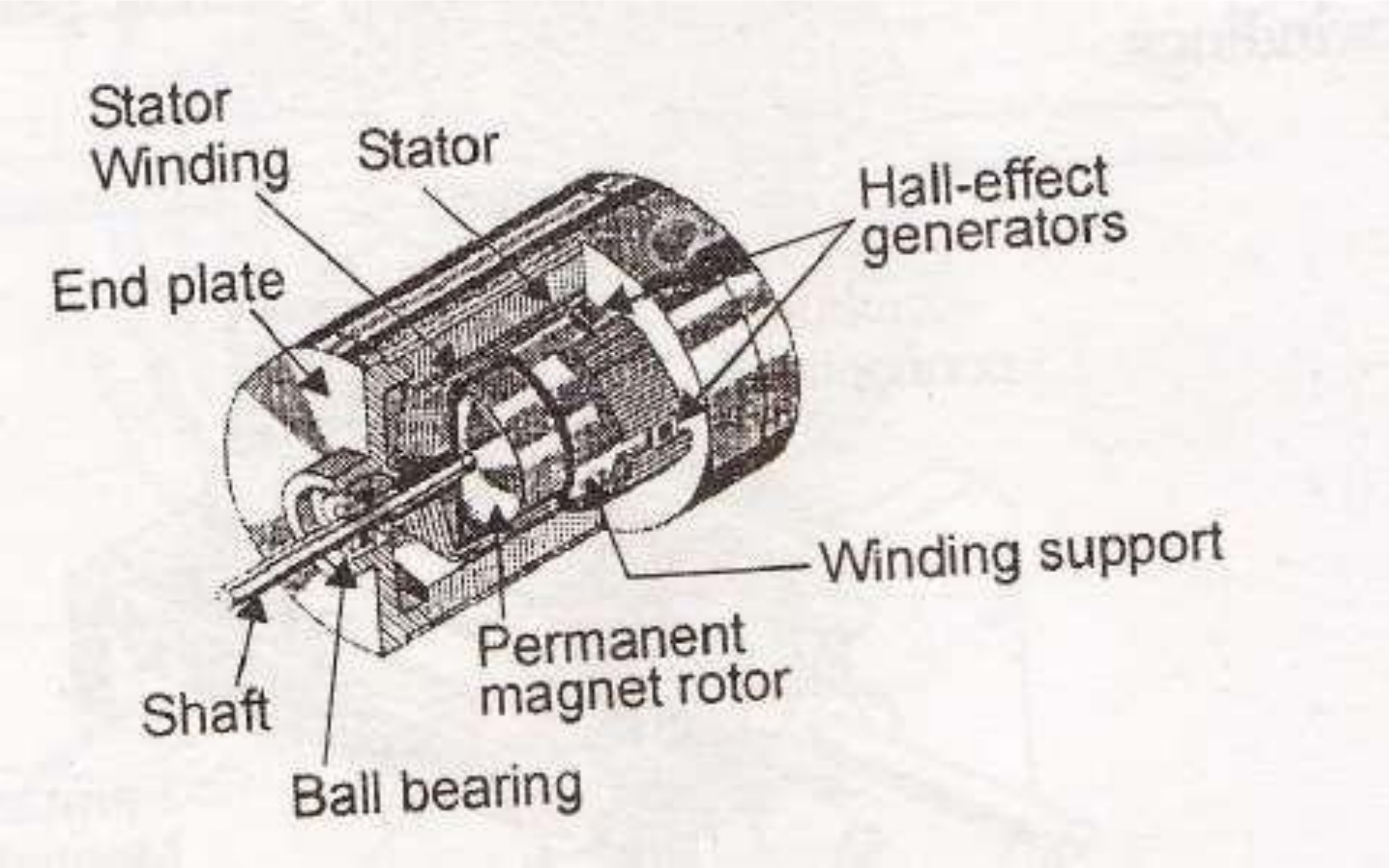

BRUSH
COIL

Brushless Permanent Magnet DC Motor

- **Brushless DC electric motor** also known as **electronically commutated motors** (ECMs, EC motors) are synchronous motors that are powered by a DC electric source via an integrated inverter/switching power supply, which produces an AC electric signal to drive the motor .
  - magnetic fields generated by the stator and rotor rotate at the same frequency
  - no slip
- The stator consists of several coils which current is led through Creating a magnetic field that makes the rotor turns .



PMBLDC Motor



Construction of BLDC

- It consist of two parts mainly **stator** & **rotor** **Stator**

➤ Stator is made up of silicon steel stampings with slots.

➤ The slots are accomodated armature windings.

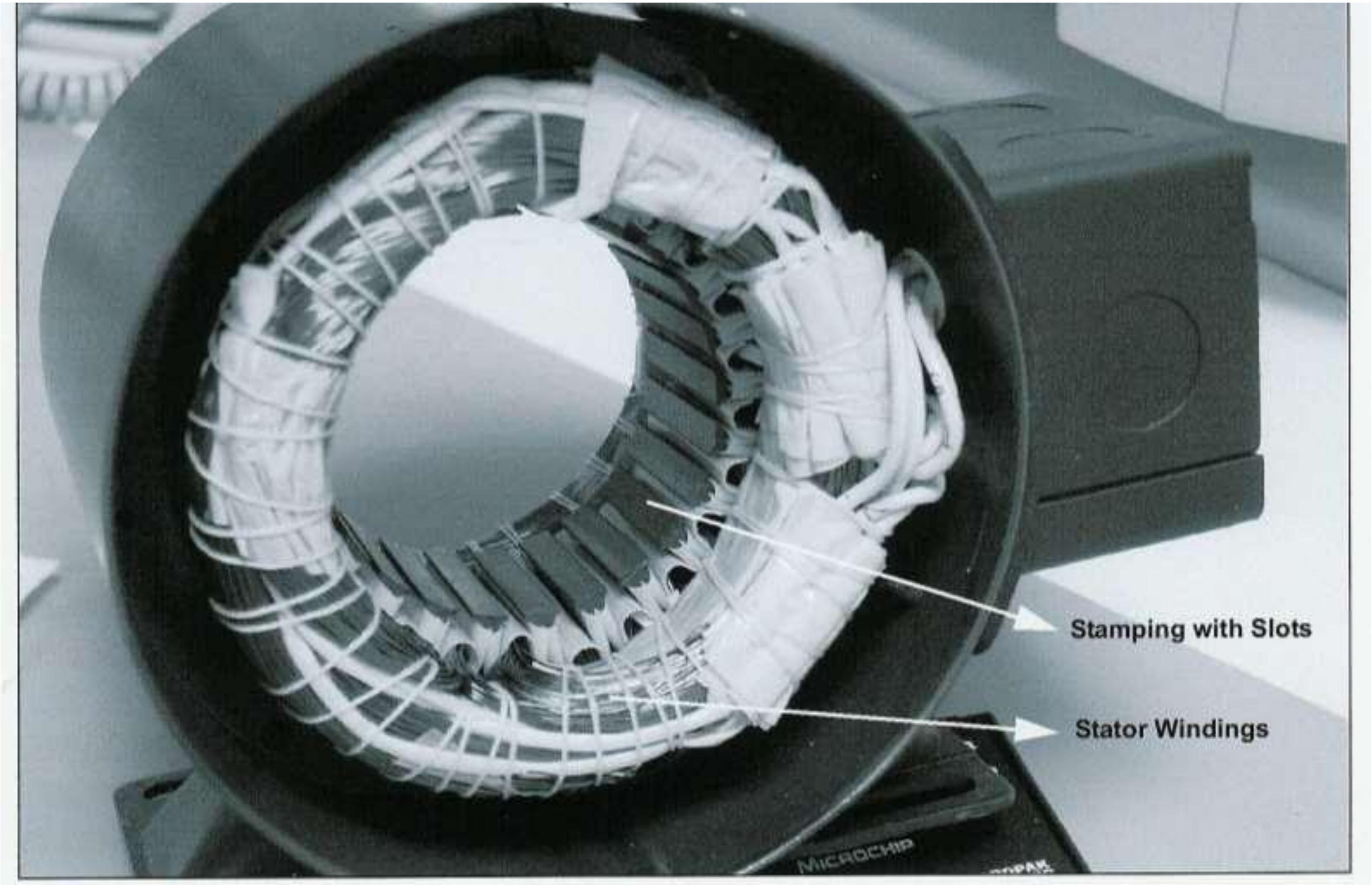
➤ This winding is wound with specified no.of poles(even number).

➤ This winding connected a dc supply through a power electronic switching circuits (inverter circuits) .

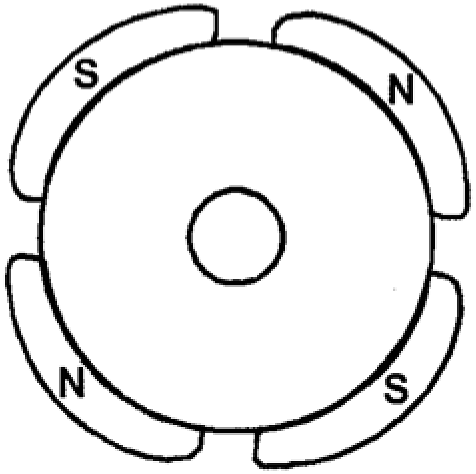
Rotor

- Rotor is of permanent magnet
- no of poles on rotor is same as that of stator
- Rotor shaft carries a RPS (Rotor position sensor) and it provides information about the position of shaft at any instant to the controller which sends signal to the electronic commutator .
- The electronic commutator function is same as that of mechanical commutator in DC motor

BLDC Motor Stator

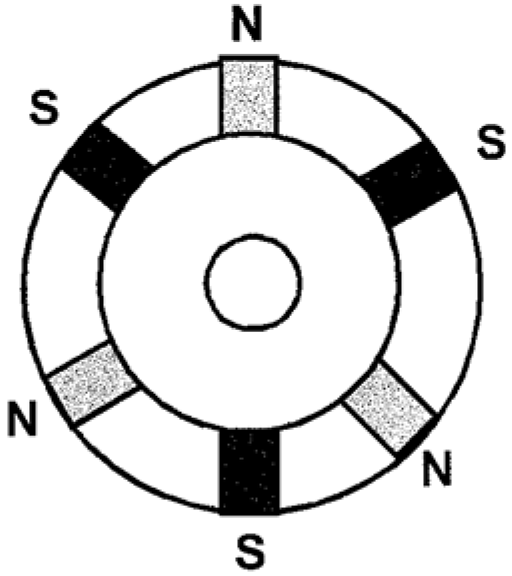


BLDC Motor Rotors



Circular core with magnets
on the periphery

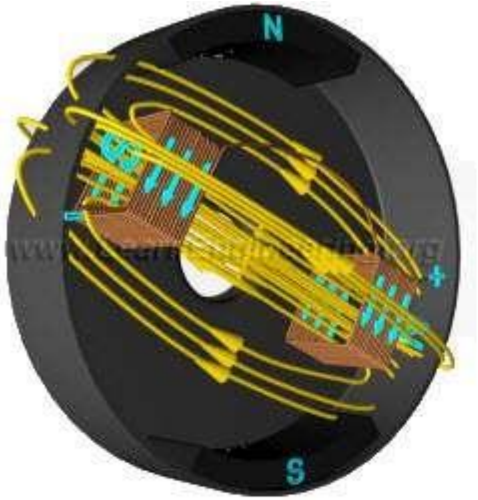
Circular core with rectangular
magnets embedded in the rotor



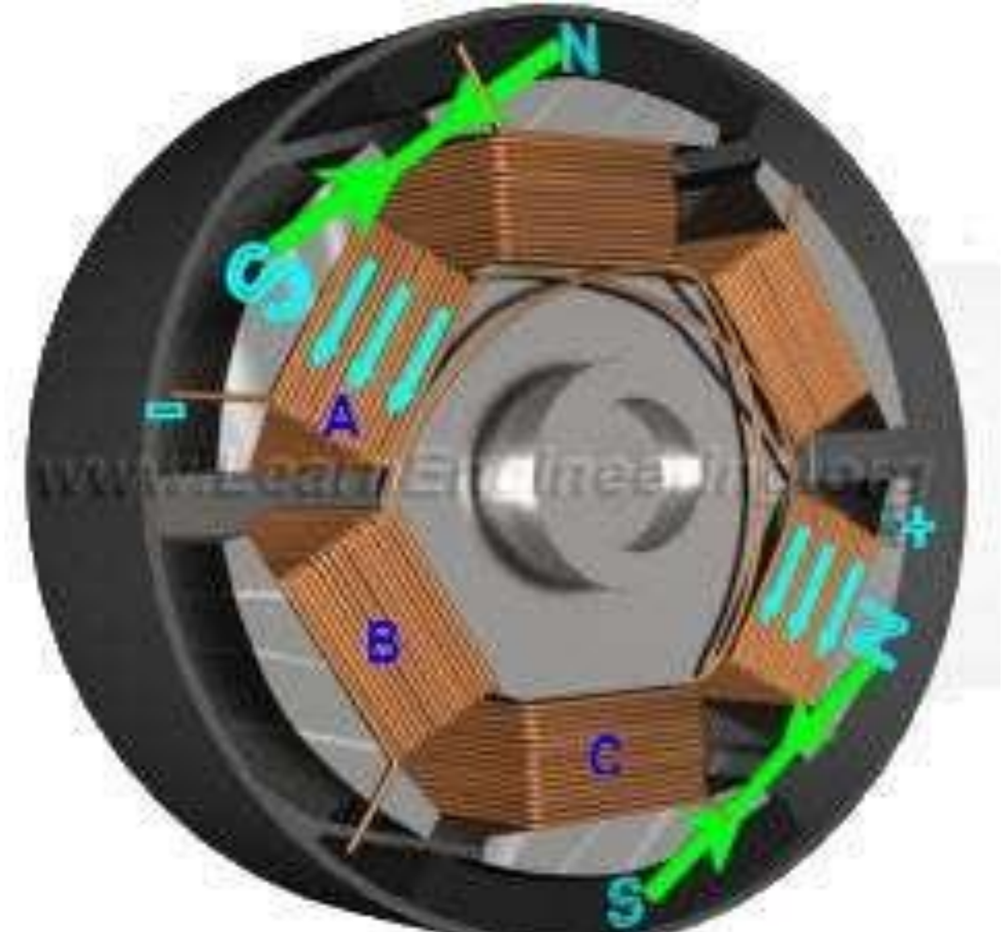
Circular core with rectangular magnets
inserted into the rotor core

The stator has a coil arrangement, as illustrated; The internal winding of the rotor is illustrated in the Fig(core of the rotor is hidden here). The rotor has 3 coils,named A, B and C.

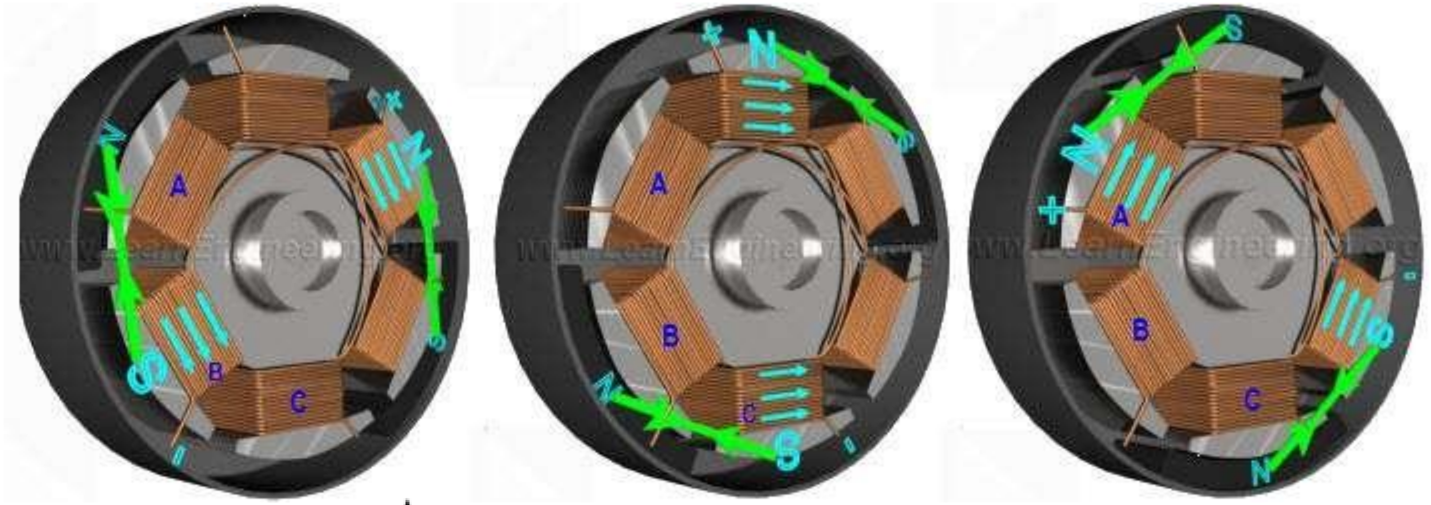
Out of these 3 coils, only one coil is illustrated in the Fig for simplicity. By Applying DC power to the coil, the coil will energise and become an electromagnet.

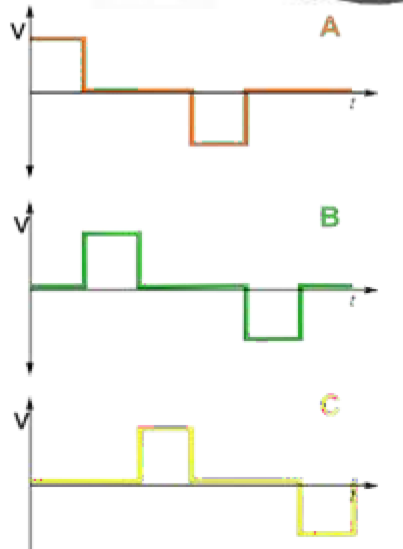


The operation of a BLDC motor is based on the simple force interaction between the permanent magnet and the electromagnet. In this condition, when coil A is energised, the opposite poles of the rotor and stator are attracted to each other (The attractive force is shown in the green arrow). As a result, the rotor poles move near the energised stator.



As the rotor nears coil A, coil B is energized. As the rotor nears coil B, coil C is energized. After that, coil A is energized with the opposite polarity . This process is repeated, and the rotor continues to rotate. The DC current required in the each coil is shown in the following graph.





Improving The BLDC Performance

Unlike a brushed DC motor, the commutation of BLDC motor is controlled electronically.

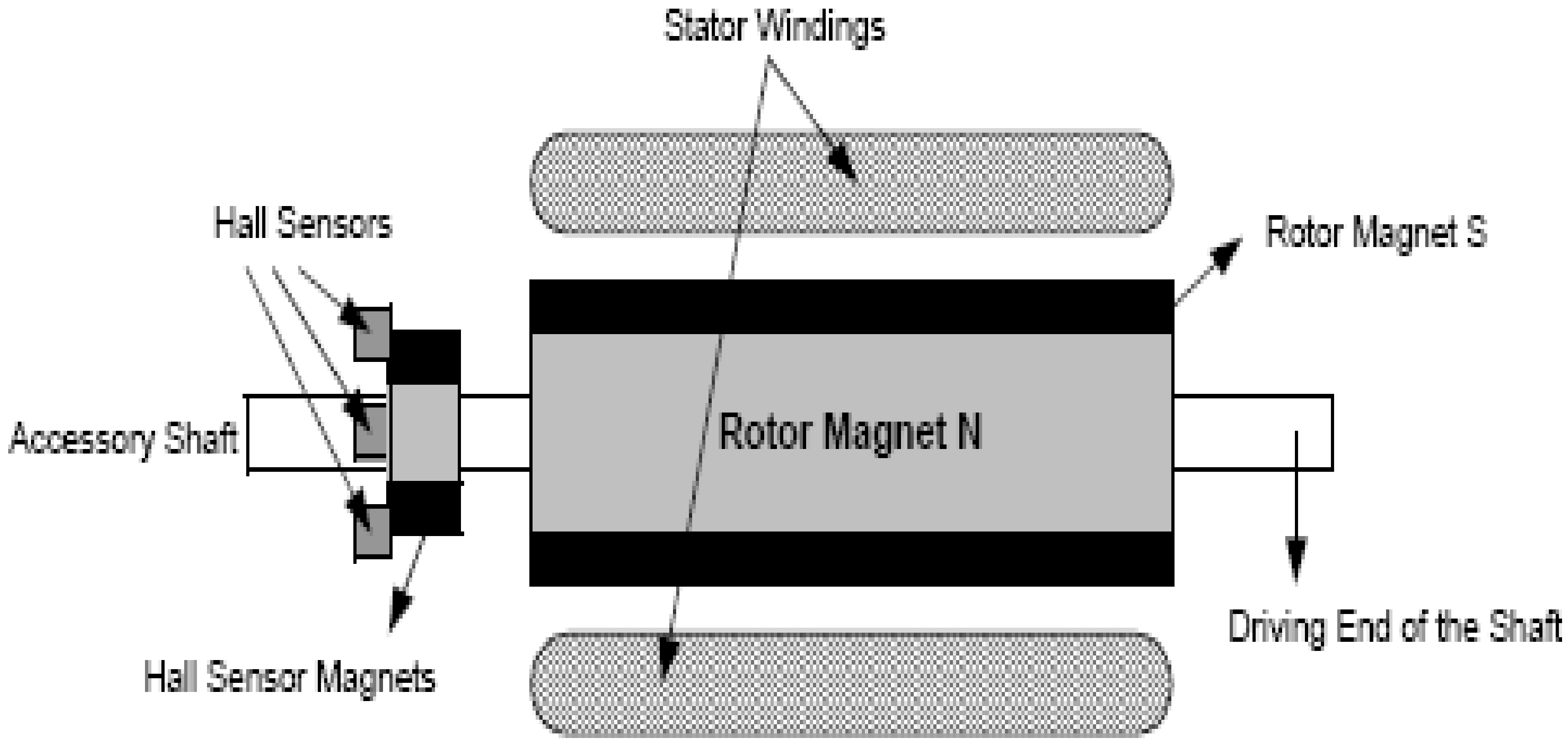
It is important to know the rotor position to understand which winding will be energized following the energizing sequence.

Rotor position is sensed by different ways some of them are

1) Hall sensors 2) Optical encoders

Hall Sensors

When a magnetic field is applied to a system with electric current a hall voltage perpendicular to the field is generated. This was discovered by Edwin Hall in 1879.



COMPARISON BETWEEN BDC AND BLDC

Feature	BLDC Motor	Brushed DC Motor
Commutation	Electronic commutation based on Hall position sensors.	Brushed commutation.
Maintenance	Less required due to absence of brushes.	Periodic maintenance is required.
Life	Longer.	Shorter.
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load.	Moderately flat – At higher speeds, brush friction increases, thus reducing useful torque.
Efficiency	High – No voltage drop across brushes.	Moderate.
Output Power/ Frame Size	High – Reduced size due to superior thermal characteristics. Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better.	Moderate/Low – The heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size.
Rotor Inertia	Low, because it has permanent magnets on the rotor. This improves the dynamic response.	Higher rotor inertia which limits the dynamic characteristics.
Speed Range	Higher – No mechanical limitation imposed by brushes/commutator.	Lower – Mechanical limitations by the brushes.
Electric Noise Generation	Low.	Arcs in the brushes will generate noise causing EMI in the equipment nearby.
Cost of Building	Higher – Since it has permanent magnets, building costs are higher.	Low.
Control	Complex and expensive.	Simple and inexpensive.
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control.	No controller is required for fixed speed; a controller is required only if variable speed is desired.

Advantages

- Increased Reliability & Efficiency
- Longer Life
- Elimination of Sparks from Commutator
- Reduced Friction
- Faster Rate of Voltage & Current

Disadvantages

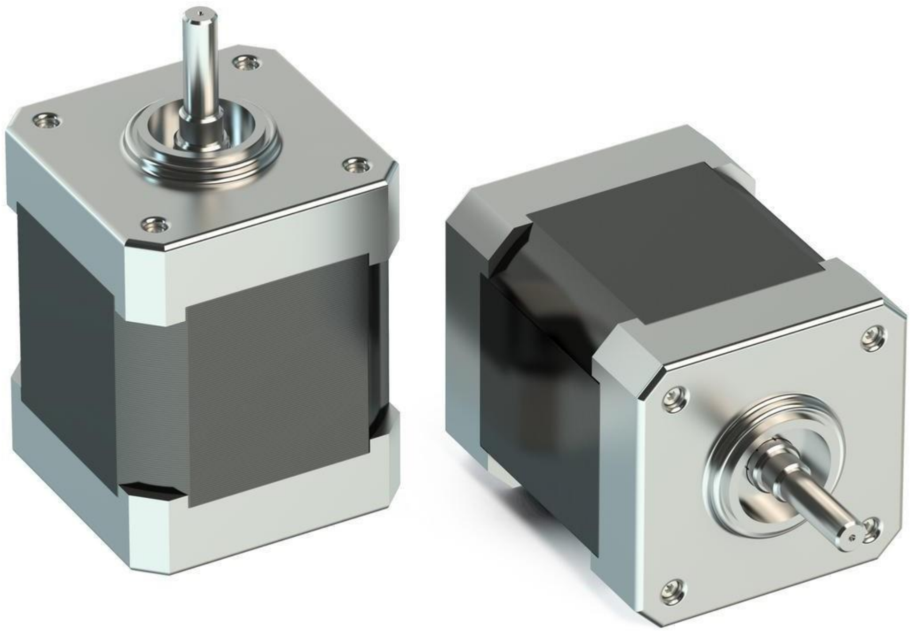
- Requires Complex Drive Circuitry
- Requires additional Sensors
- Higher Cost
- Some designs require manual labor (Hand wound Stator Coils)

Applications

- Consumer: Hard Drives, CD/DVD Drives, PC Cooling Fans, toys, RC airplanes, air conditioners
- Medical: Artificial heart, Microscopes, centrifuges, Arthroscopic surgical tools, Dental surgical tools and Organ transport pump system.
- Vehicles: electronic power steering ,personal electric vehicles
- Airplanes: an electric self launching sailplane, flies with a 42kW DC/DC brushless motor and Li-Ion batteries and can climb up to 3000m with fully charged cells

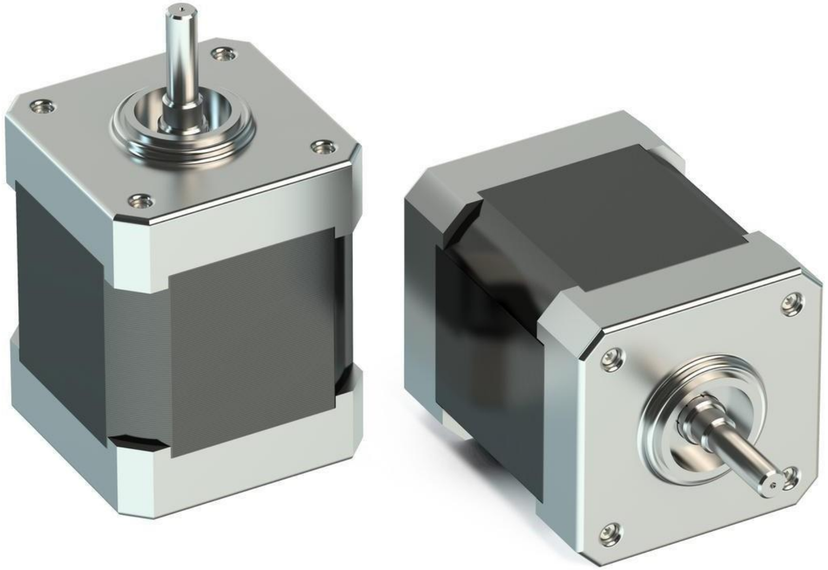

D1
R8
D4

STEPPER MOTOR



Introduction

- Stepper motor is an **electromechanical device** which converts **electrical power** into **mechanical power.**
- Stepper motor does not rotate continuously, istead it **rotates in** the form of pulses or in **discrete steps**.
- It performs **stepwise operation** either in clockwise or anticlockwise direction



Types of Stepper Motor

Permanent Magnet Stepper Motor

High toíque, pooí angulaí íesolution

Variable Reluctance Stepper Motor

Excellent angulaí íesolution, low toíque

Hybrid Stepper Motor

Combines stíuctuíe of PM and VR steppeís, píovides good toíque and angulaí íesolution

Permanent Magnet Stepper Motor

- **Rotor – Permanent Magnet**
- **Stator – Electromagnet**
- **Phase** - two-phase motors
- High torque, poor angular resolution

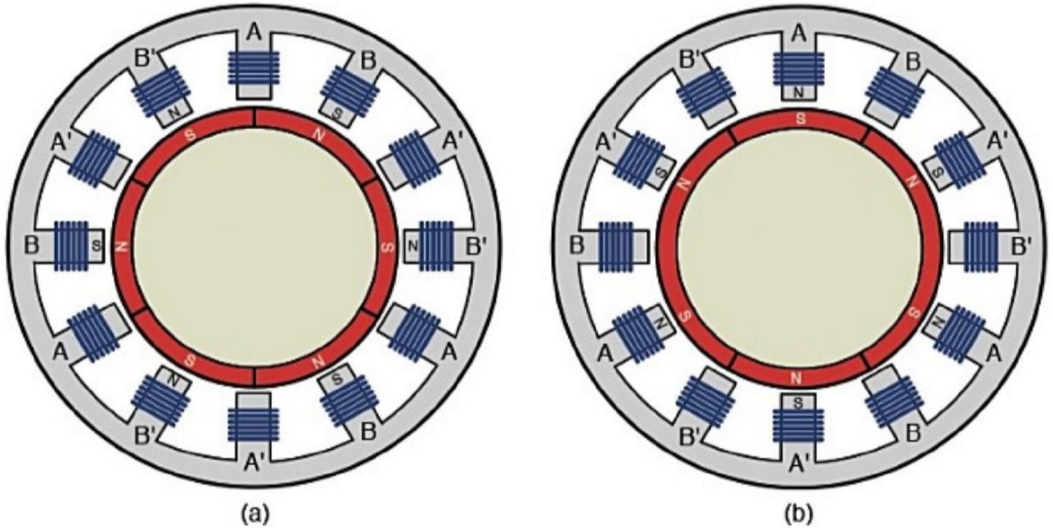


Fig - 30° rotation of a PM stepper motor [2]

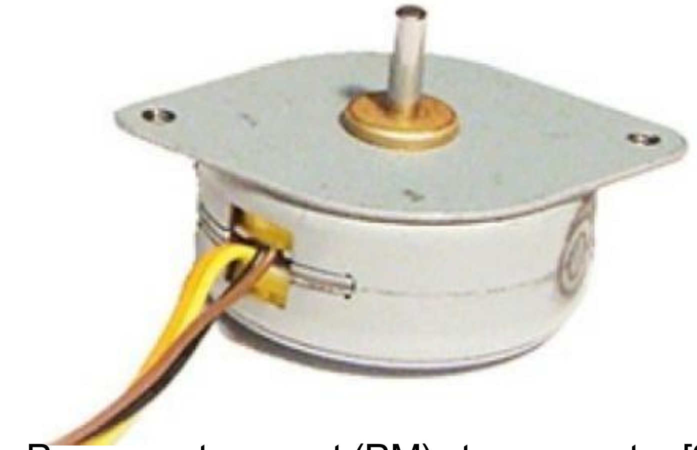


Fig - Permanent magnet (PM) stepper motor [2]

Variable Reluctant Stepper Motor

- **Rotor – iron disk** with small protrusions called *teeth*

  Stator – Electromagnet
- **Phases -** N windings, it receives N/2 signals from the controller.
  - Because the teeth aren't magnetized, it doesn't matter whether a winding behaves as a north pole or as a south pole

$$Step\ angle = 360° \times \frac{N_w - N_t}{N_w N_t}$$

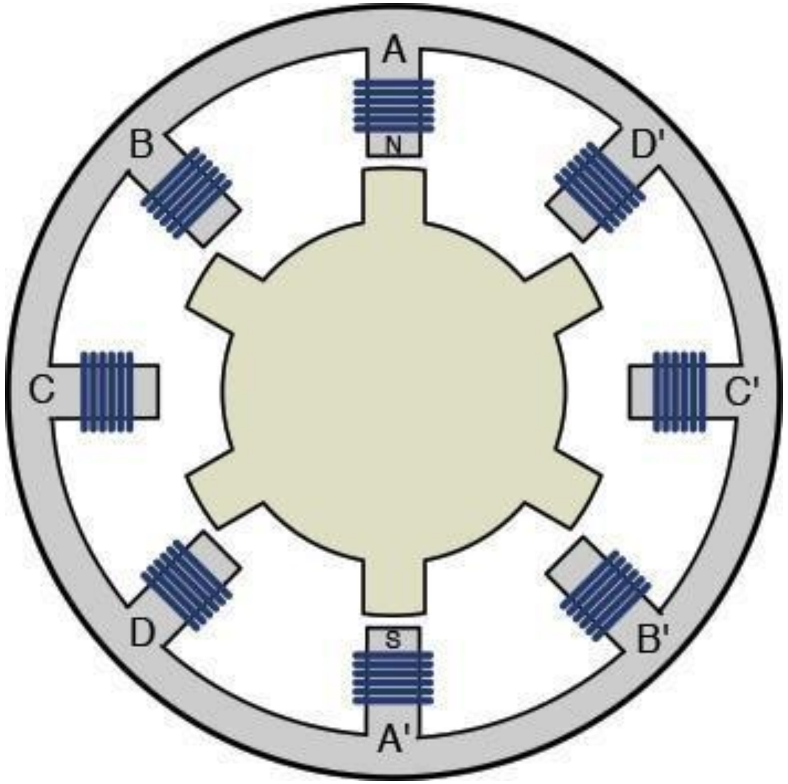


Fig - Structure of a variable reluctance (VR) stepper [2]

Hybrid Stepper Motor

- It is a combination of PM and VR stepper motor
- **Rotor – Permanent Magnet** toothed with two sections of opposite polarity and offset teeth
- **Stator – Electromagnet**
- **Phases -** two-phase motors

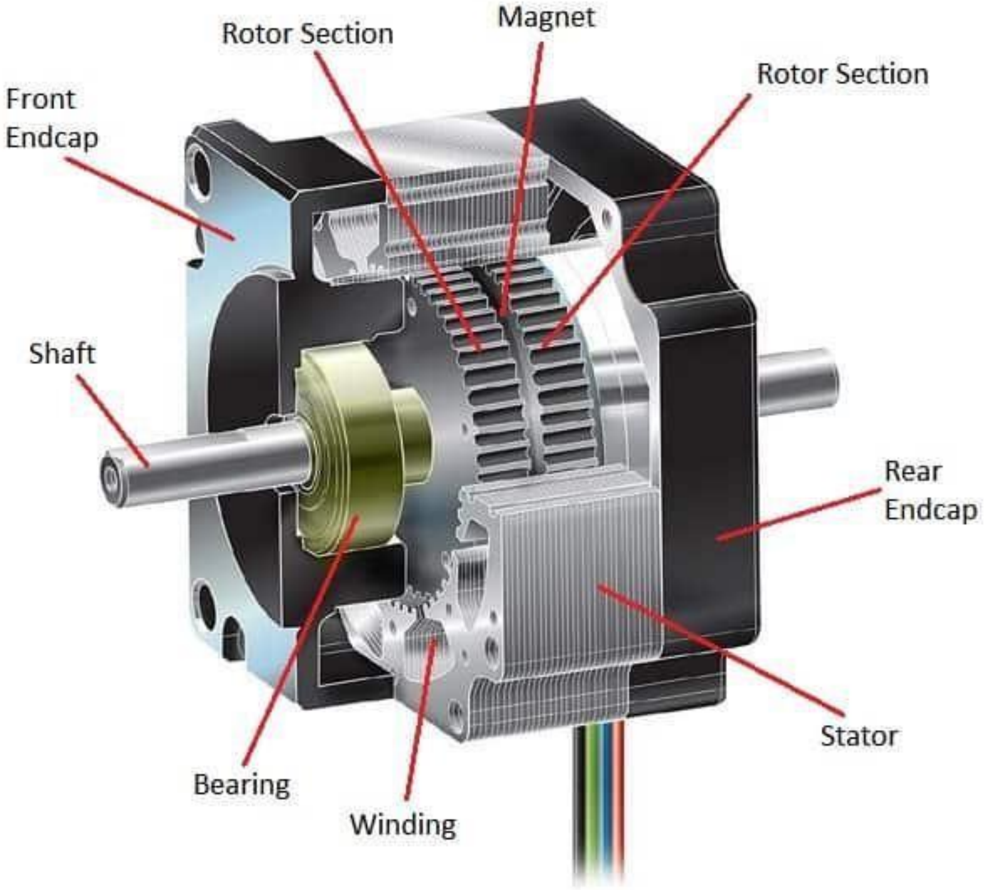


Fig - Internal Structure of Hybrid Stepper Motor [1]

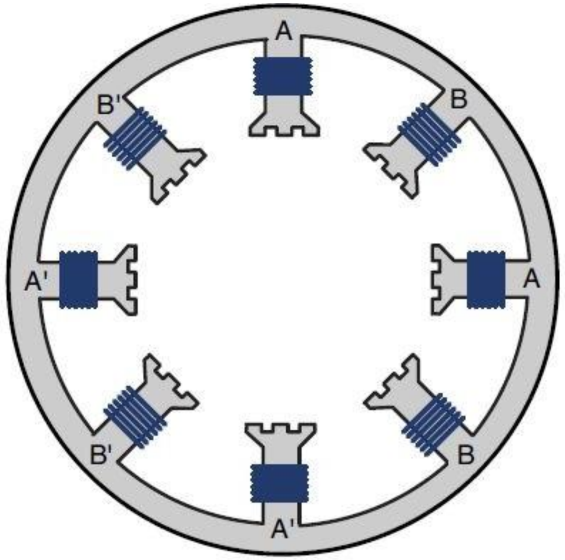


Fig - Stator [2]

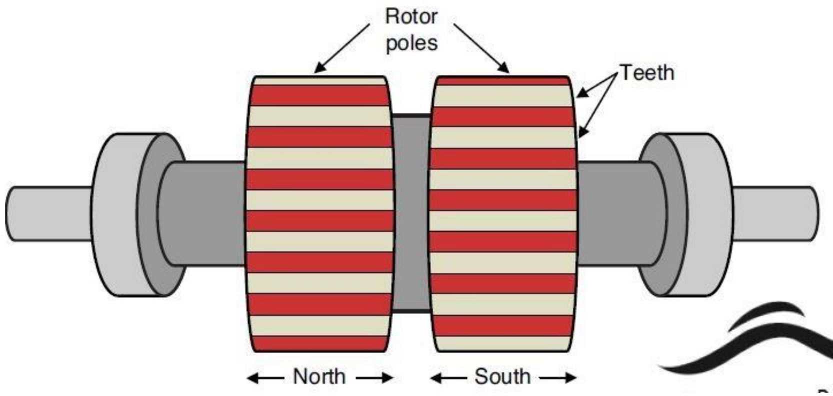
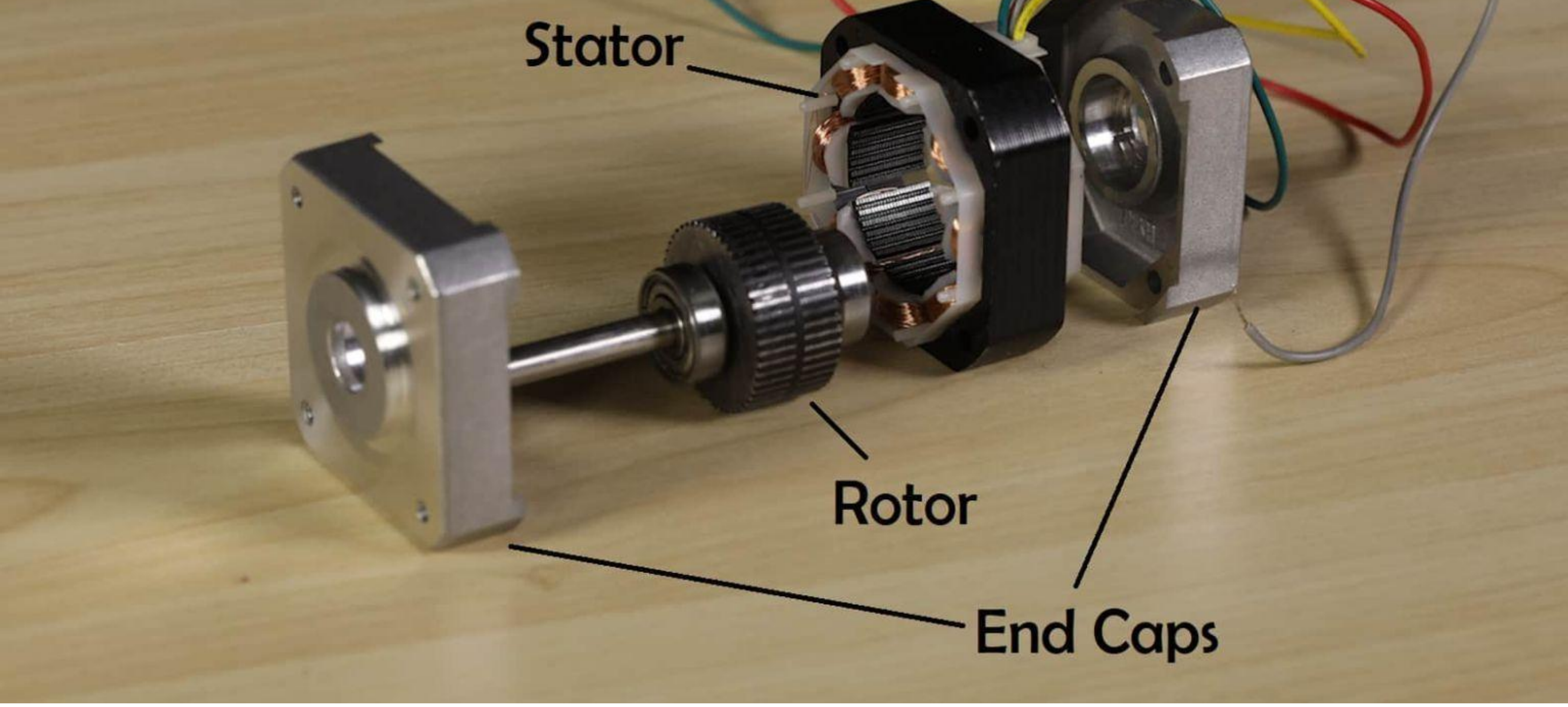
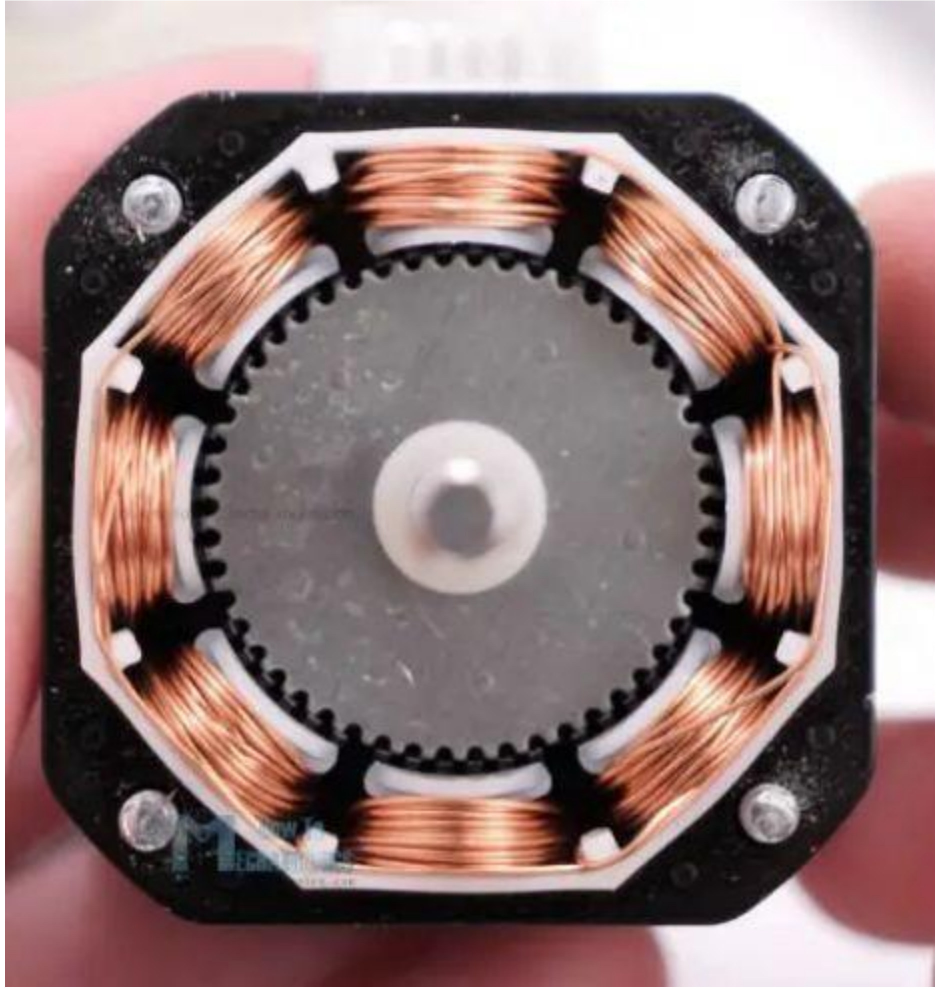
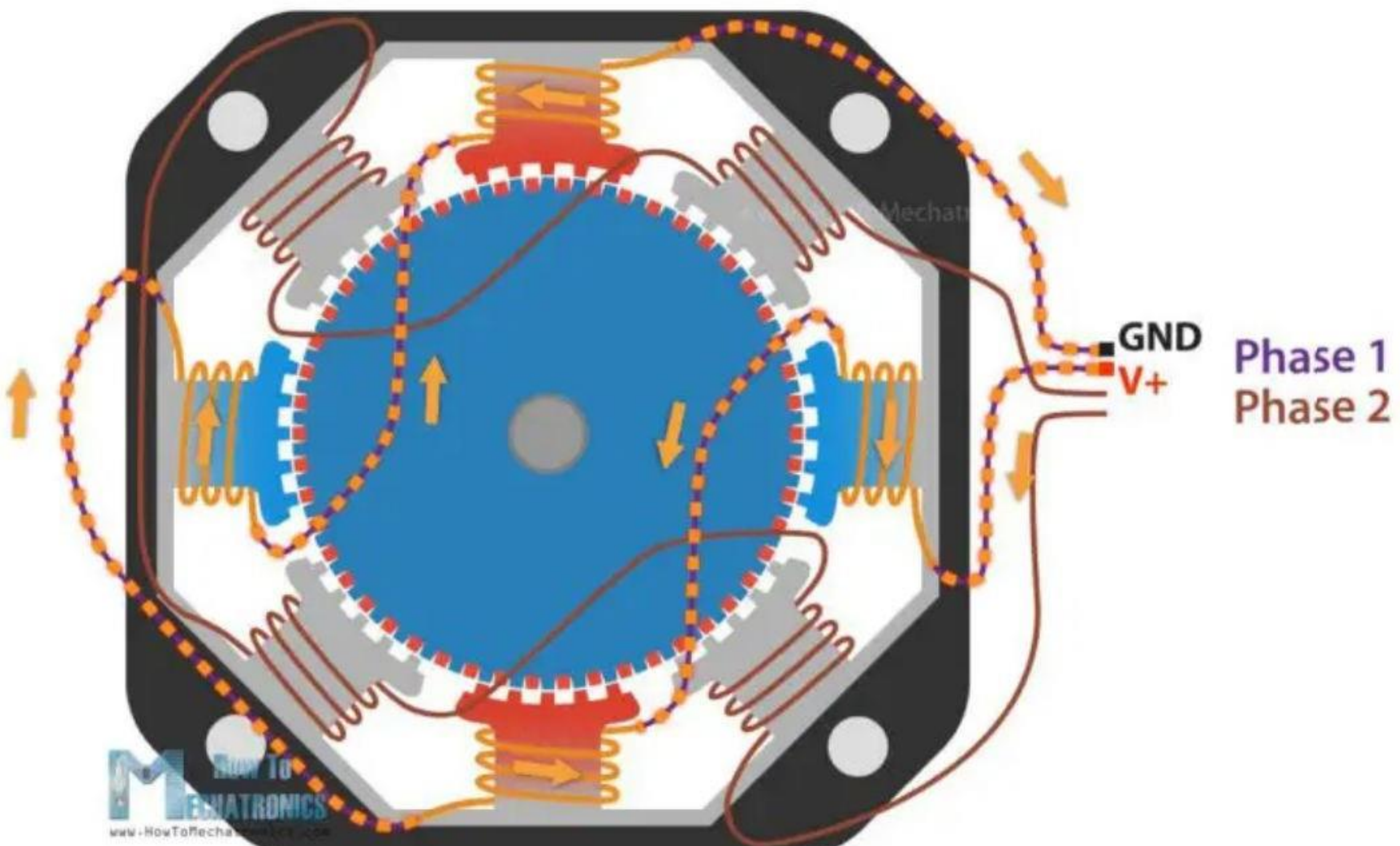


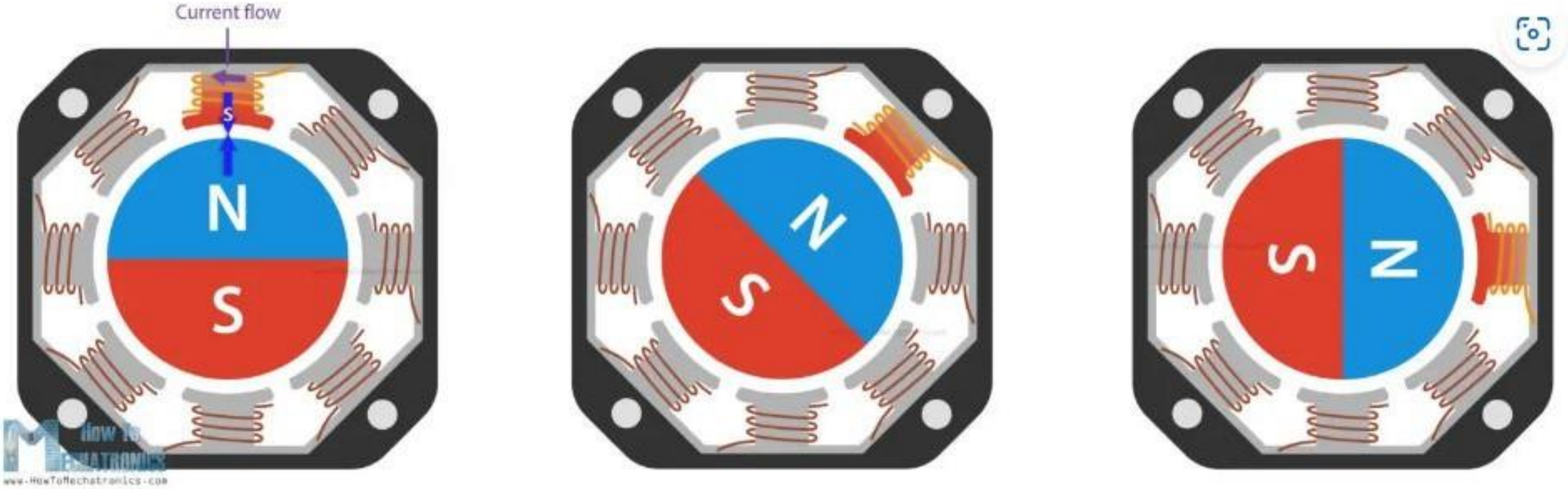
Fig - Rotor [2]

Hybrid Stepper Motor

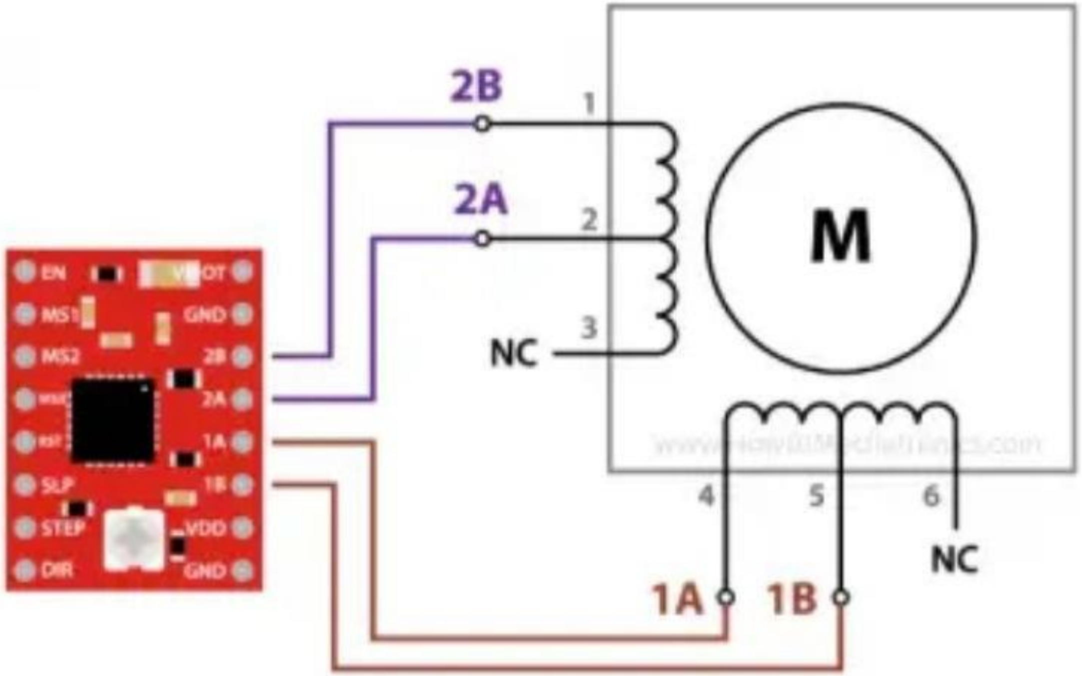




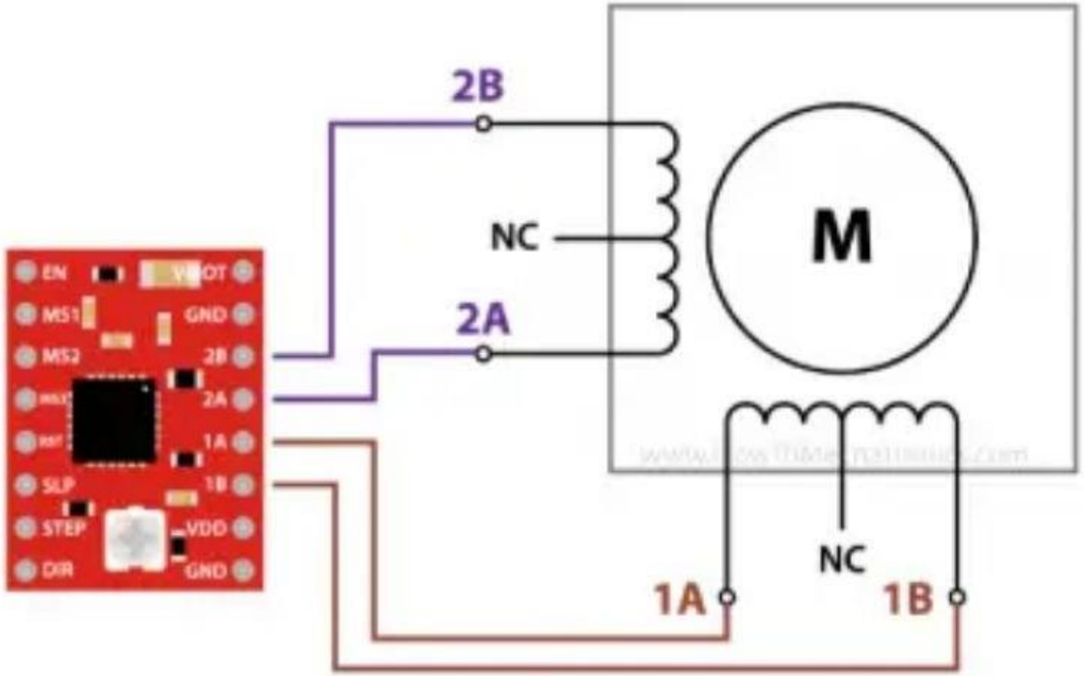

GND
V+
Phase 1
Phase 2
How To Mechatronics


Current flow
N
S
N
S
S
N

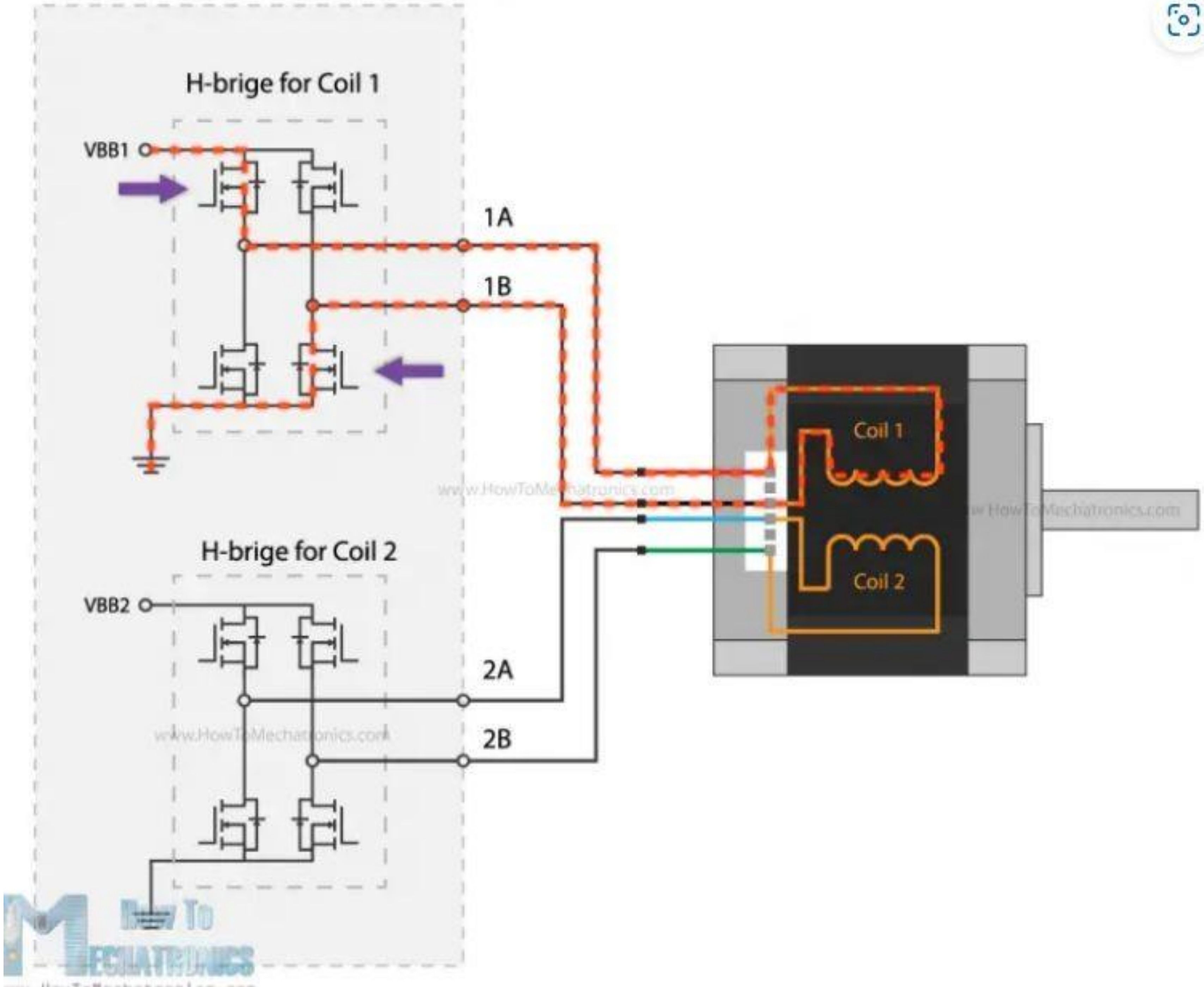
6-Wire Stepper Motor in Bi-polar Configurations



Half coil connections - Higher speeds



Full coil connections - Higher torque


H-brige for Coil 1
VBB1
1A
1B
Coil 1
Coil 2
H-brige for Coil 2
VBB2
2A
2B
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Bipolar Stepper Control

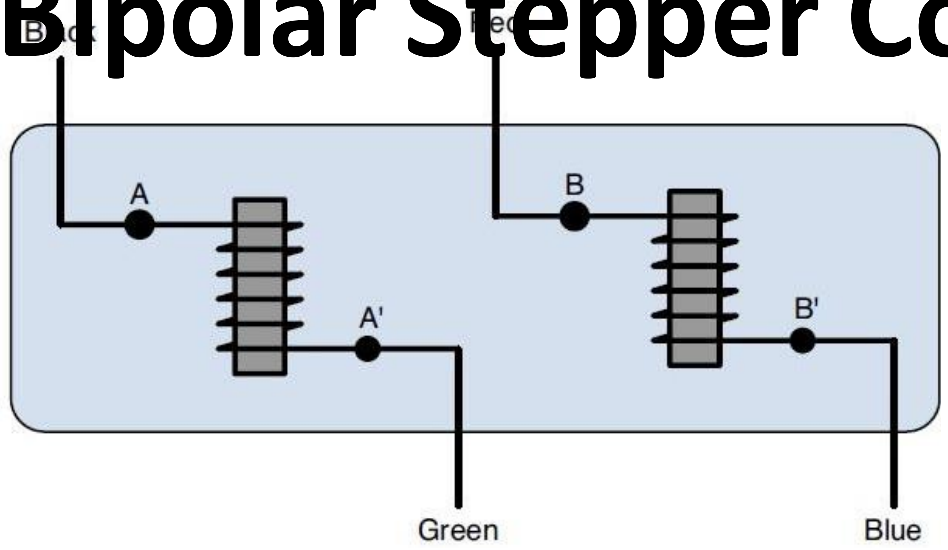


Fig - Connections of a bipolar stepper [2]

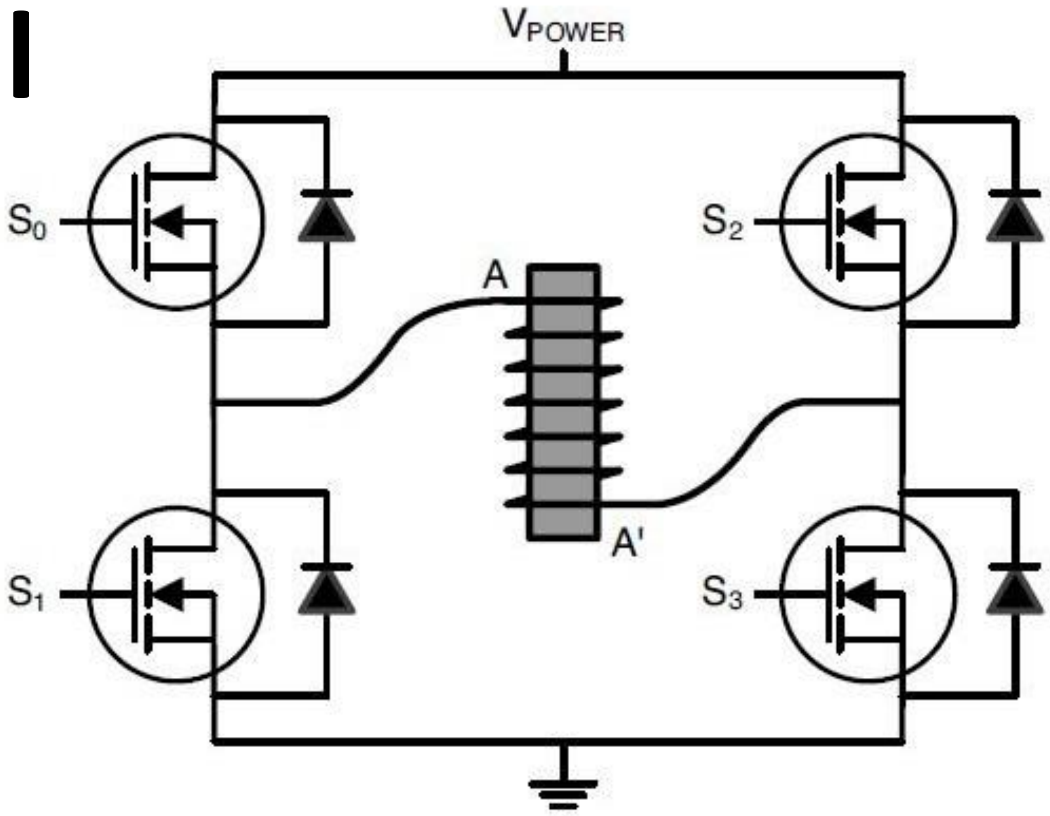


Fig - Controlling one phase of a bipolar stepper with an H bridge [2]

- Two-phase bipolar stepper has **four wires**
- Controlled by **H-bridge** which deliver current in the forward and reverse directions.
- S0, S3 – HIGH & S1, S2 - LOW then current travels from A to A’, making A – North, B- South

Unipolar Stepper Control

- Two-phase Unipolar stepper motor has **five** or **six wires**
- V_{POWER} is connected to the center of the electromagnet's winding called a **center tap**
- When the MOSFET's gate voltage exceeds its threshold, the wire is connected to ground.
- When a MOSFET switches on, the corresponding end of the winding becomes the south pole

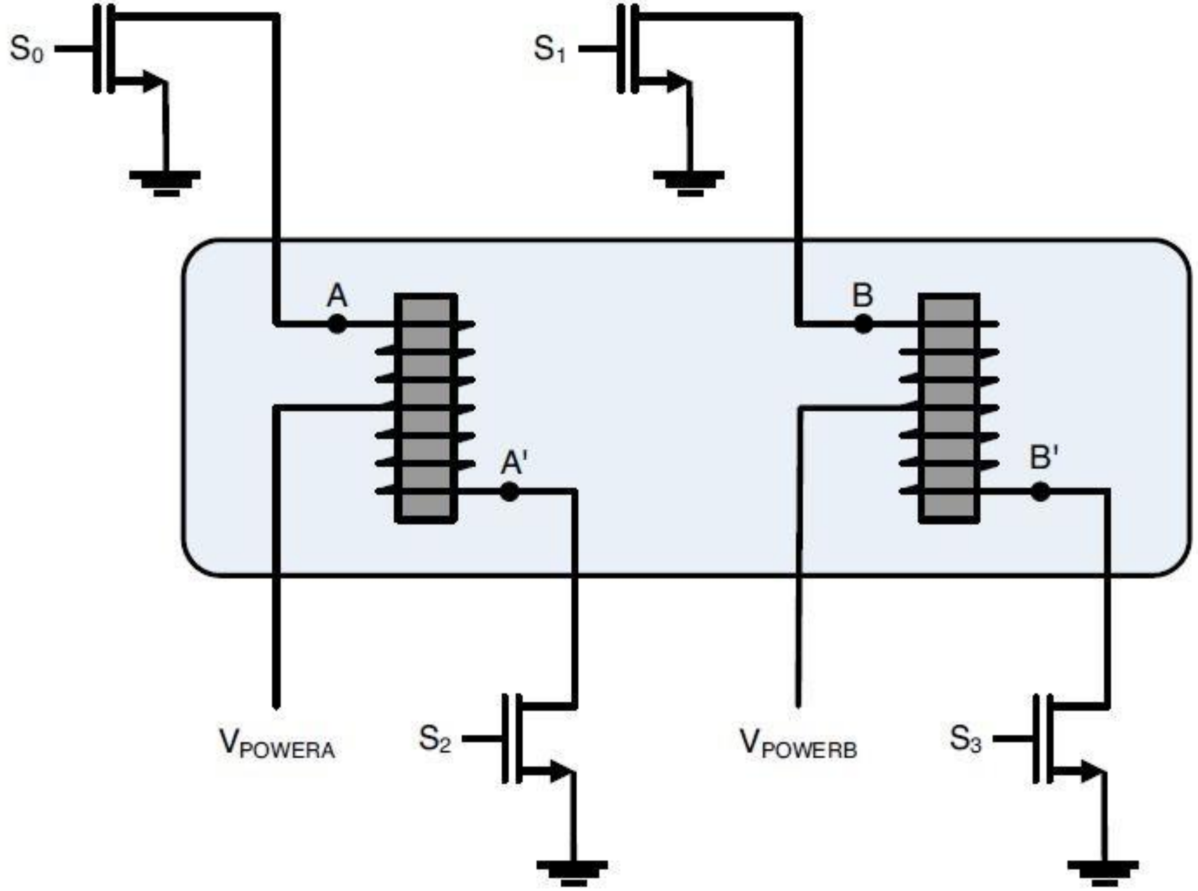


Fig - Connections of a unipolar stepper [2]

Drive Modes of Stepper Motor

Wave Drive Mode

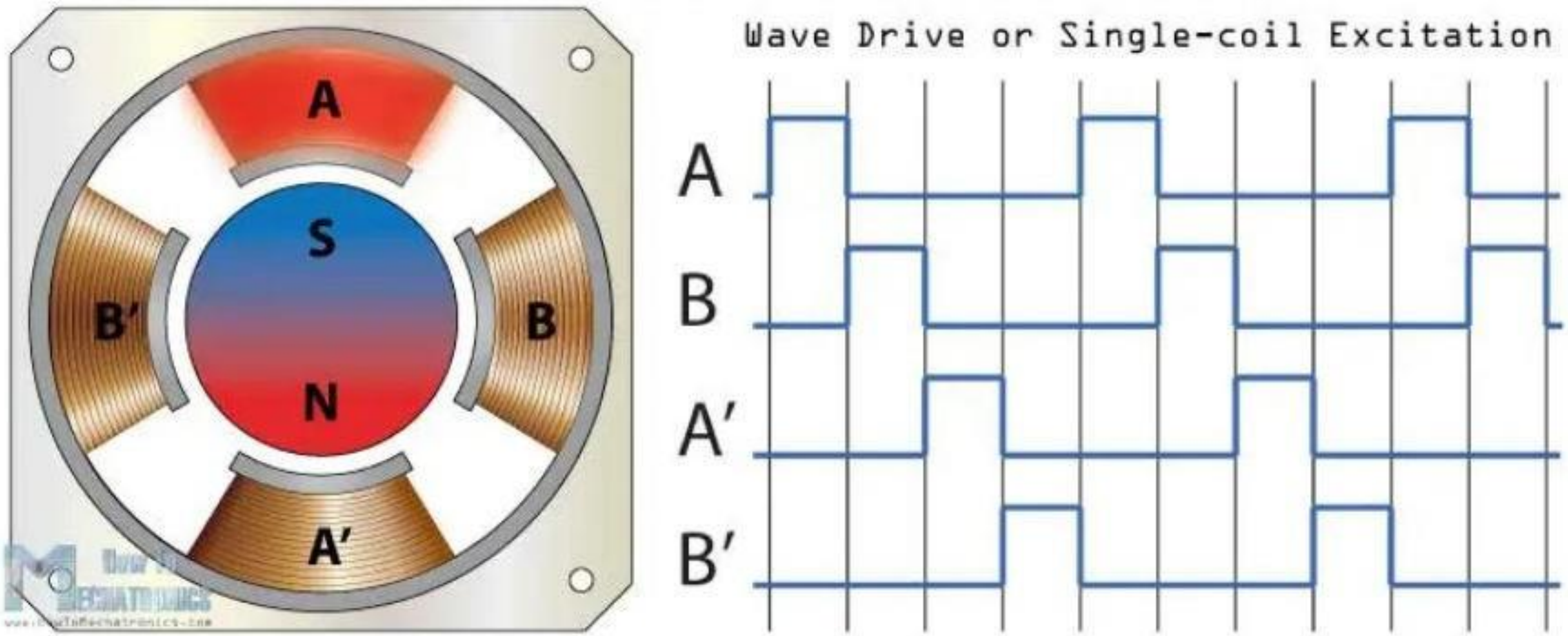


Fig - Wave Drive or Single-coil Excitation [3]

- Energize one coil at a time
- For given example of motor with 4 coils, the rotor will make full cycle in 4 steps

Full-Drive Mode

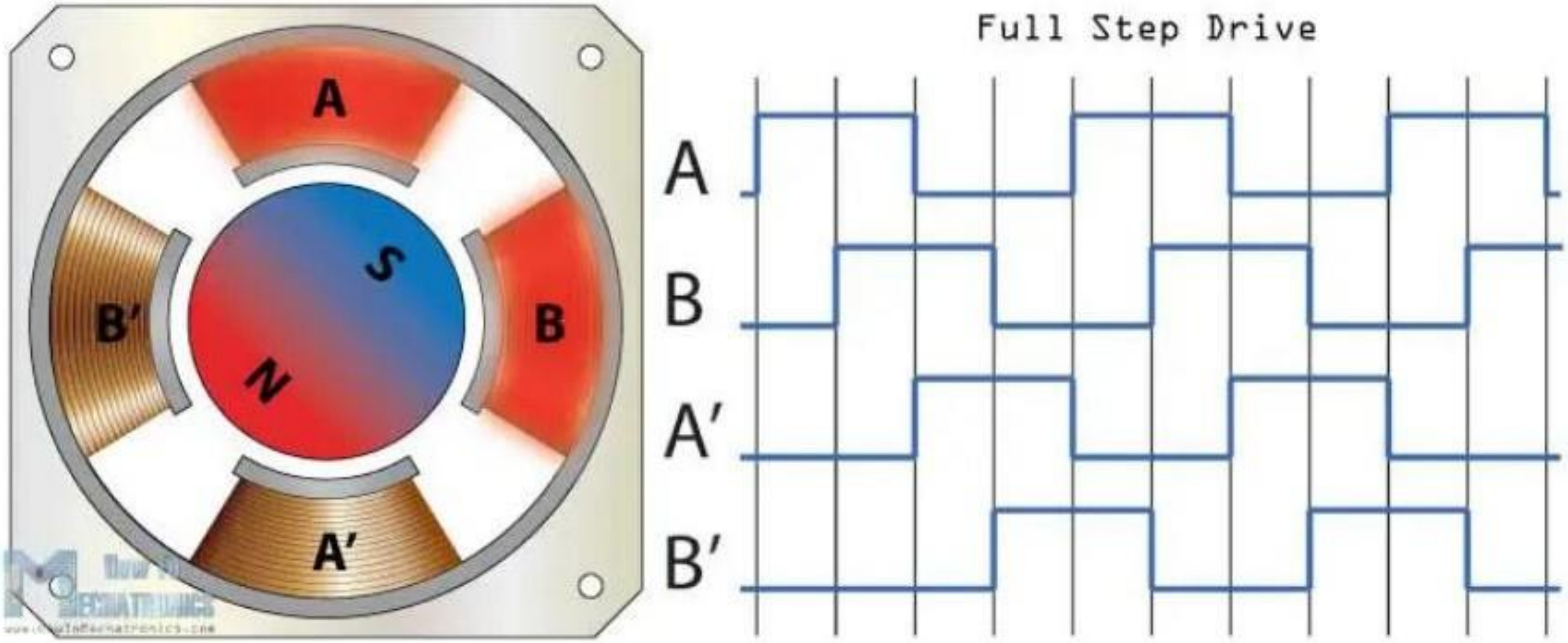


Fig - Full Drive Mode [3]

- Energize two coil at a time
- Provides much higher torque output
- For given example of motor with 4 coils, the rotor will make full cycle in 4 steps

Half Step Drive Mode

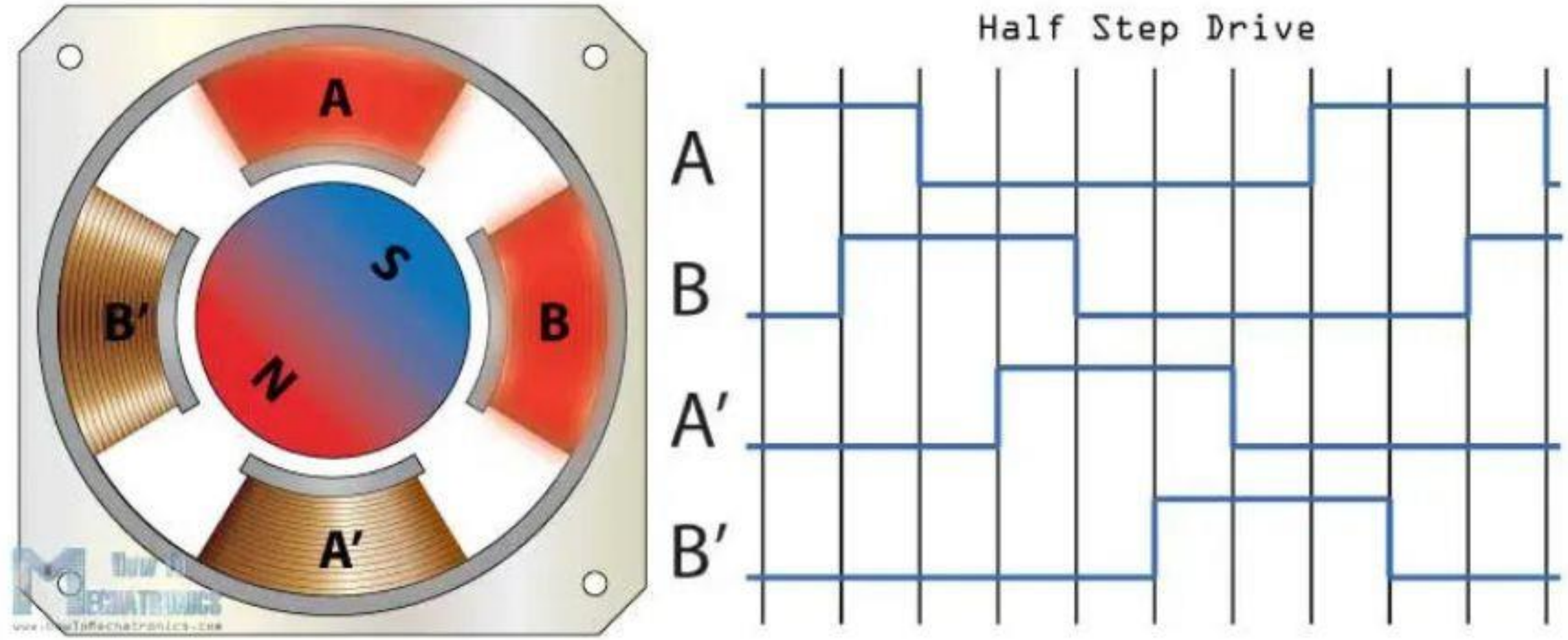


Fig - Half Step Drive Mode [3]

- Controller alternates between energizing one winding and two windings
- Increasing the resolution
- For given example of motor with 4 coils, full cycle in 8 steps.

Microstepping Mode

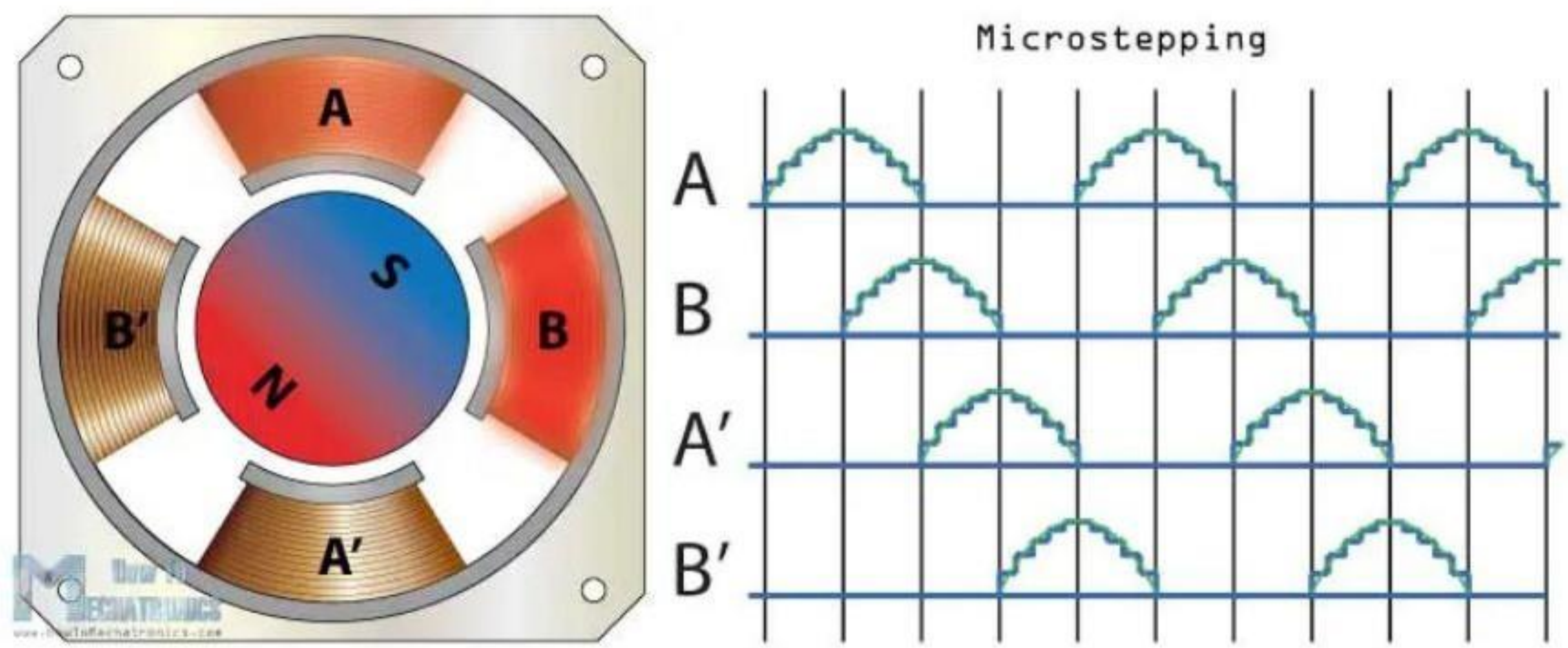


Fig - Microstepping Drive Mode [3]

- Variable controlled current to the coils in form of sin wave

Characteristic of Stepper Motor

Static Characteristics - Obtained at a stationary position.

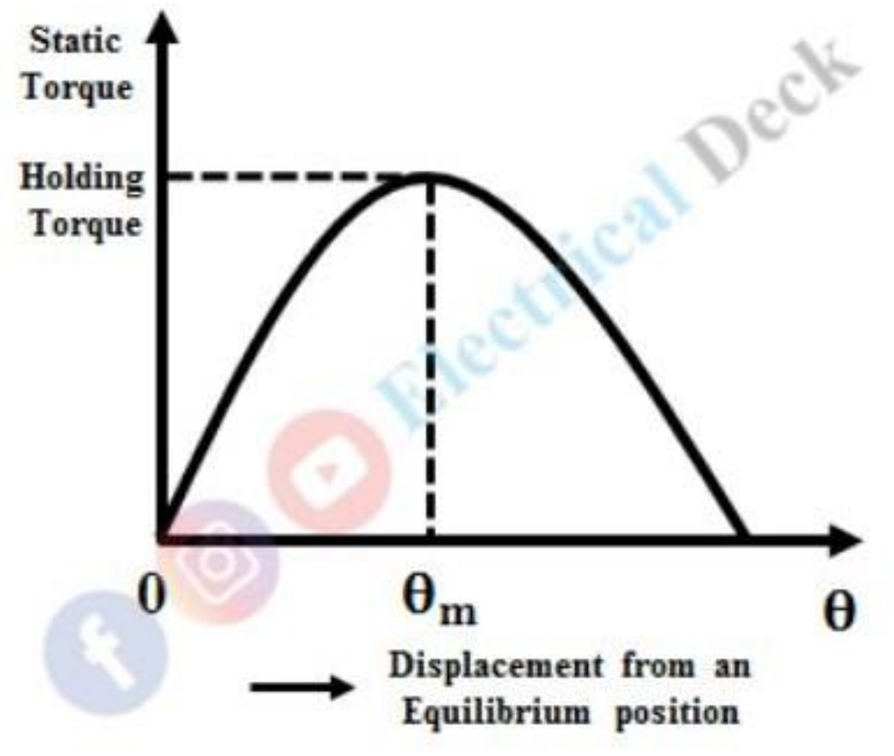


Fig - Torque-Displacement Curve [5]

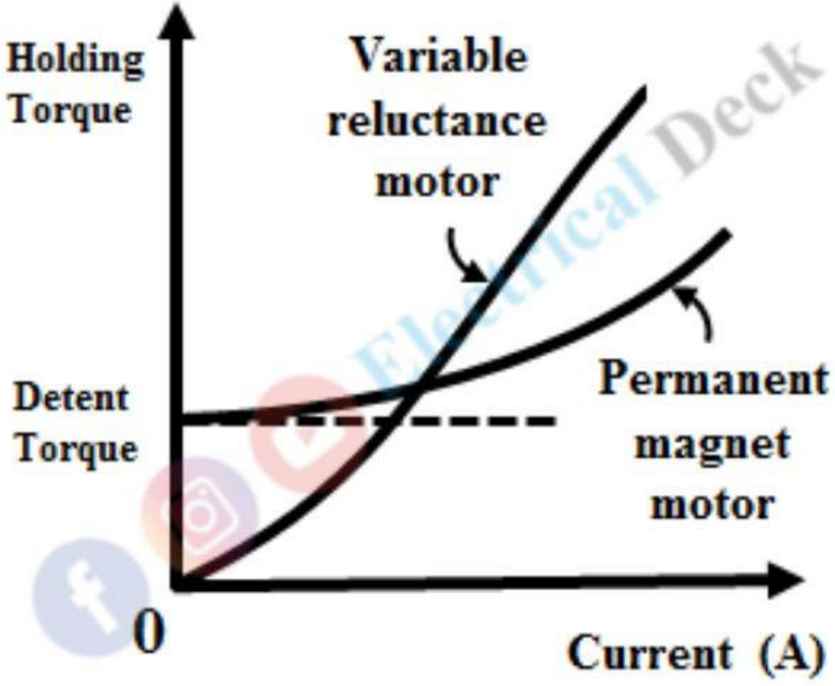


Fig - Torque-Current Curve [5]

Dynamic Characteristics - Obtained under running conditions of the motor (with respect to time)

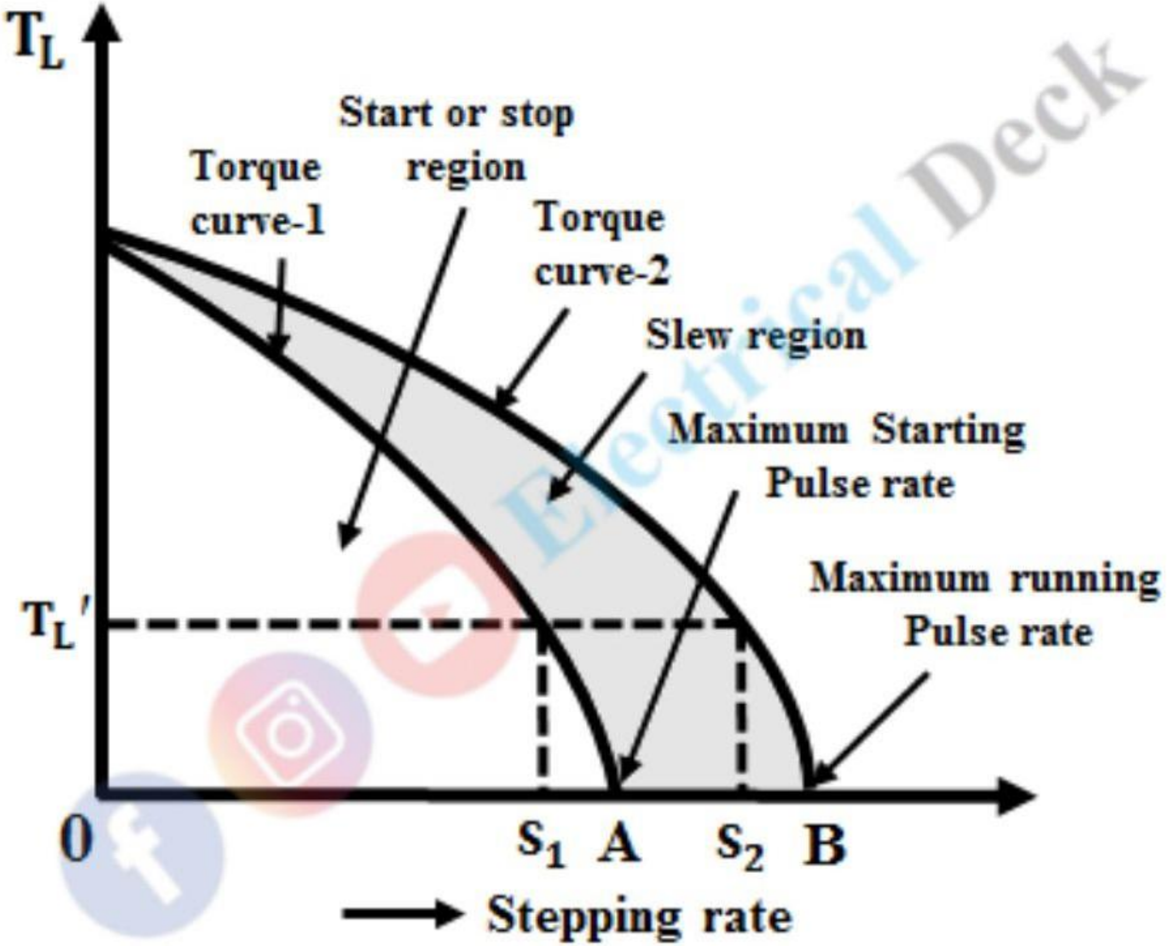


Fig - Torque- Current Characteristic of Stepper Motor [5]

Advantages of Stepper Motor

1. Low cost.
2. Small in size.
3. Available in a wide range of step angles (e.g., from 1.8° to 90°).
4. Excellent torque at low speeds.
5. Low maintenance (brushless).
6. Low starting current.
7. Excellent for precise positioning control.
8. Has low speed without reduction gears.

Disadvantages of Stepper Motor

1. Overall efficiency is low
2. Limited size availability
3. Noisy
4. Torque decreases with speed

Applications of Stepper Motor

Stepper motors are used in various applications where precise control and positioning are necessary. Some common applications include:

1. Printers (printheads, paper feed, scan bar)
2. 3D printers (XY table drive, media drive)
3. Robots (arms, end effectors)
4. DSLR cameras (aperture/focus regulation)
5. CNC machines
6. Medical equipment
7. Manufacturing and robotics
8. Machine tools and metal forming

Stepper Motor : Position Control

- Pulses Generation

$$Pulses = \frac{d \times Ms \times P}{L}$$

Pulses	-	Required pulses
d	-	Distance entered by user
Ms	-	Micro-stepping
P	-	Pulses required for one rotation when Ms = 1
L	-	Lead of lead-screw

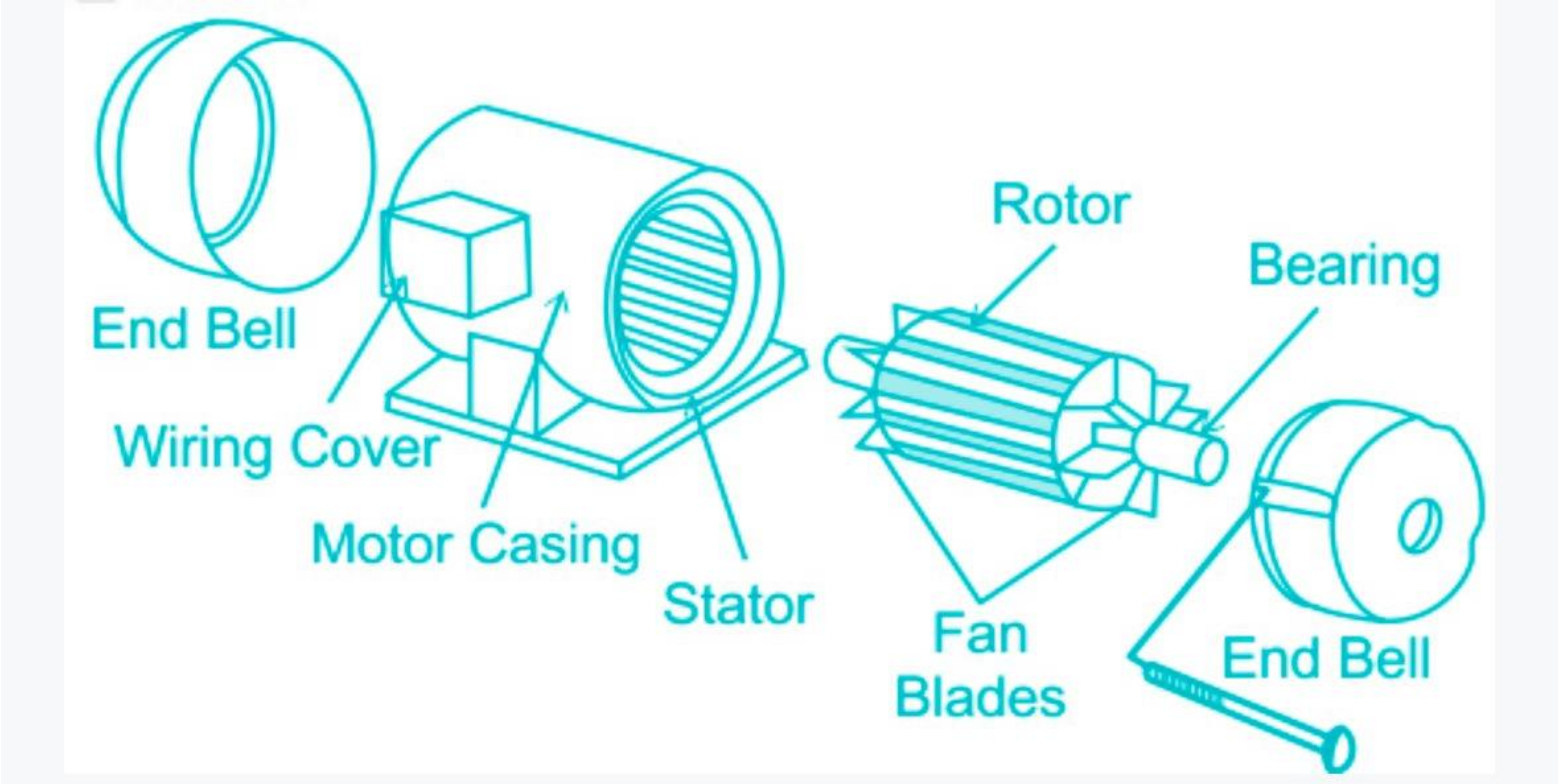
*Here speed of stepper motor is same for each micro-stepping.

Introduction to AC Motors

What is an AC Motor?

An AC motor is a motor that uses the electromagnetic induction phenomena to convert alternating current into mechanical power. An alternating current is used to power this motor. AC motors are the most common type of electric motor because they are relatively simple and inexpensive to manufacture, and they are very reliable. They work by using the principle of electromagnetic induction.

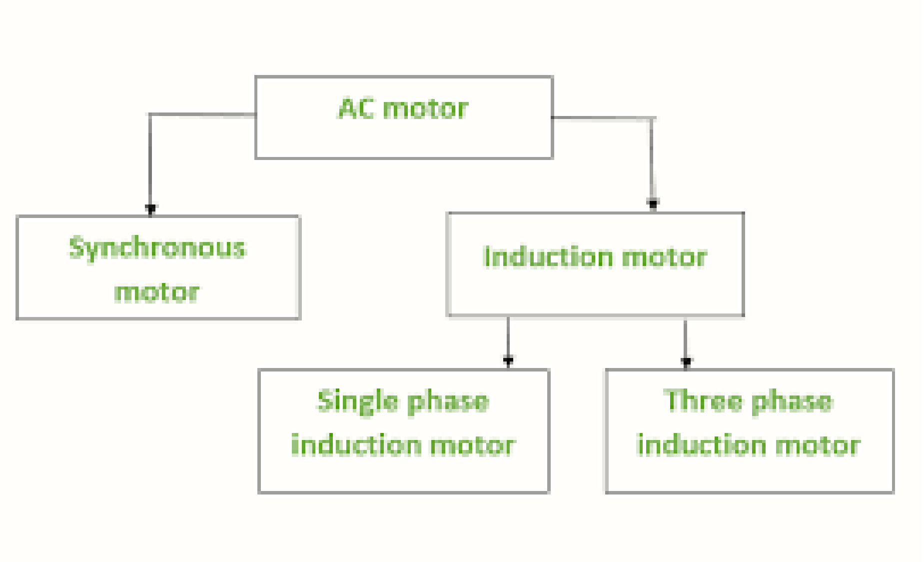
CONSTRUCTION OF AC MOTOR



WORKING PRINCIPLE OF AC MOTOR

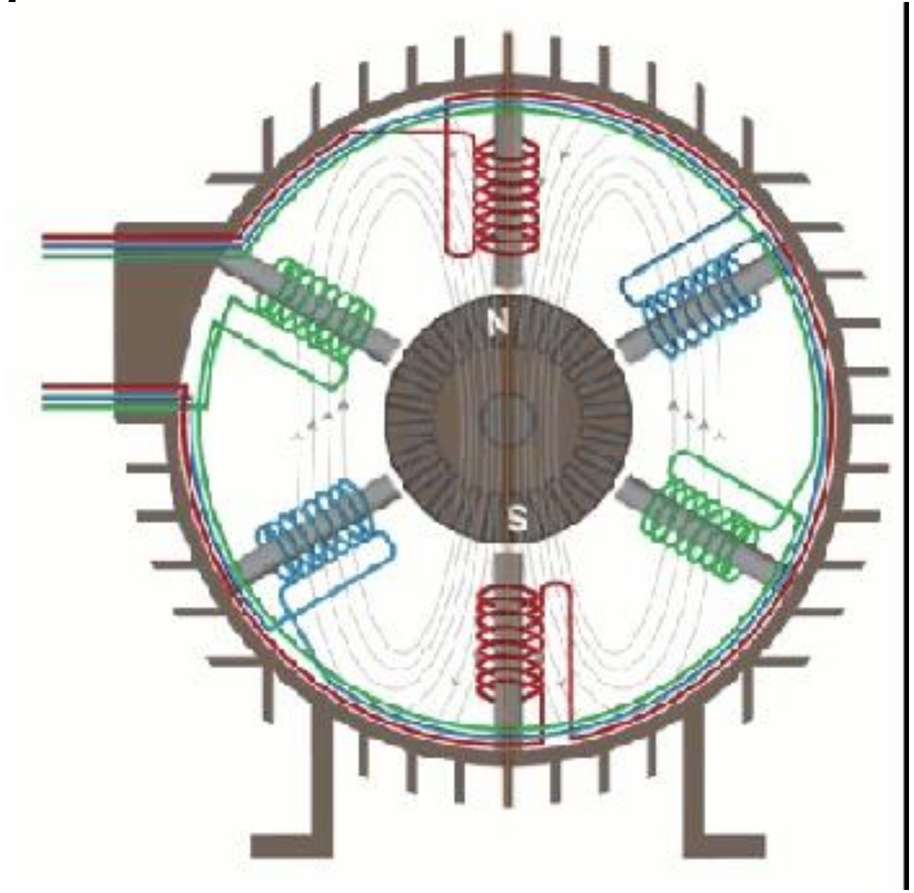
- It operates on the Lorentz force equation, which states that when a current-carrying conductor is subjected to a magnetic field, it produces magnetic lines of force.
- Due to the Lorentz force equation, when an alternating current source is delivered to the rotor's coil, it experiences some force. Torque will be created in a clockwise direction as a result of this force, allowing the rotor to rotate.

TYPES OF AC MOTOR



- ❑ **Synchronous AC Motors:**
  - **Operation:** In these motors, the rotor speed is synchronized with the AC frequency.
- ❑ **Asynchronous (Induction) AC Motors:**
  - **Operation:** The rotor speed lags behind the AC frequency slightly because of the slip, allowing for variable speed control.
  - The difference between the rotor's theoretical position and actual position is called slip.

Synchronous AC motor

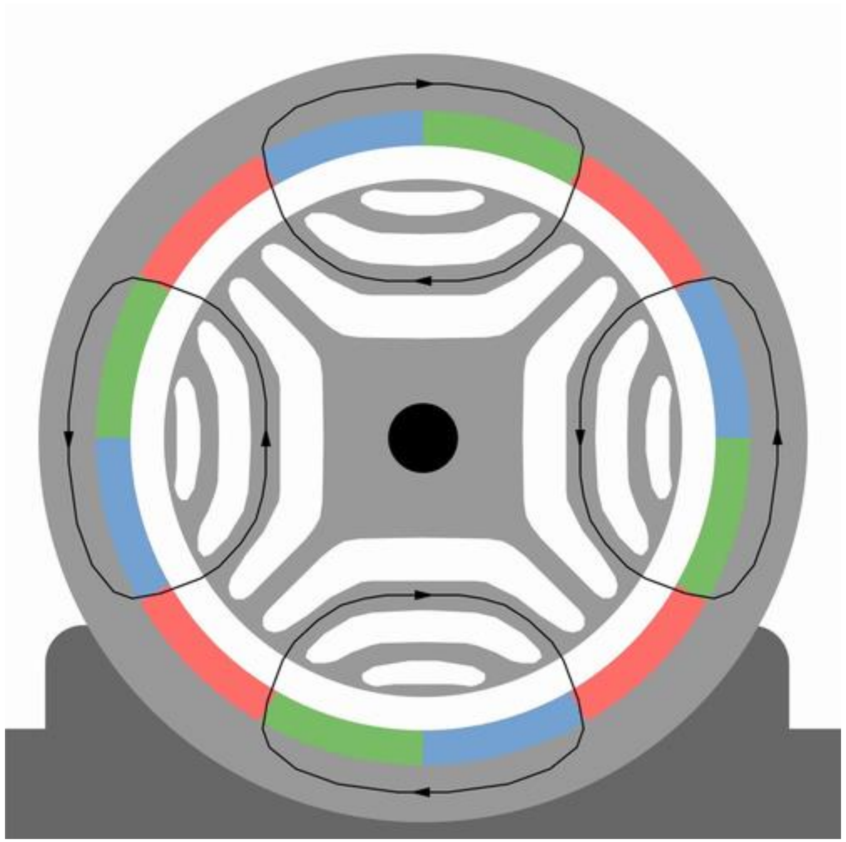


AC Motor Synchronous Speed Formula

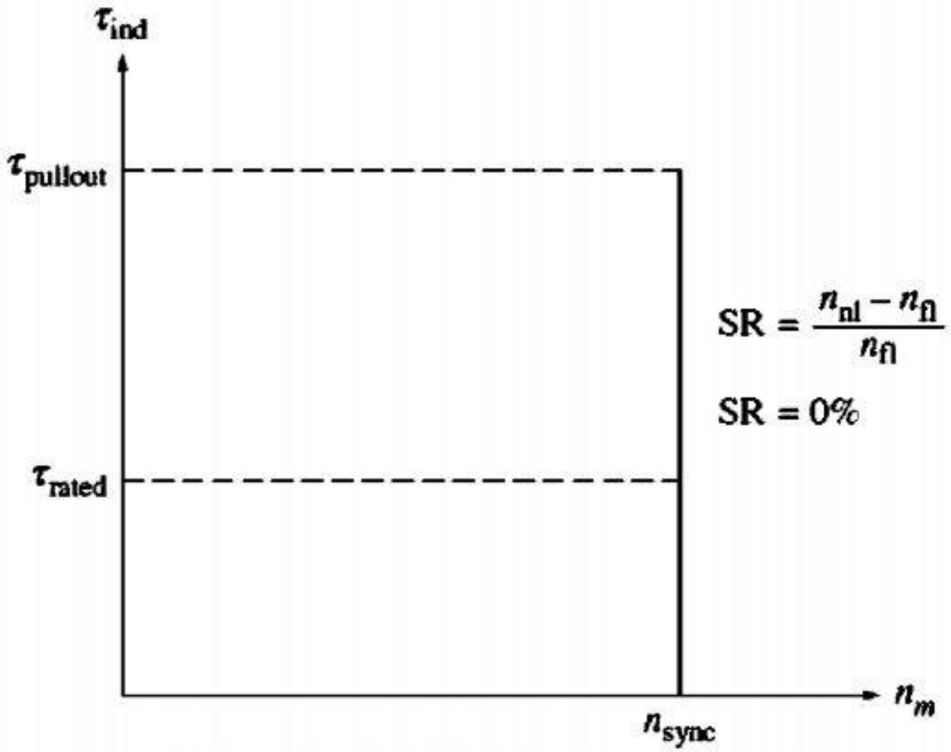
$$n_s = \frac{120f}{p}$$

Here, n_s is the synchronous speed
f is line voltage frequency in Hz
P is the number of poles

Induction AC motor



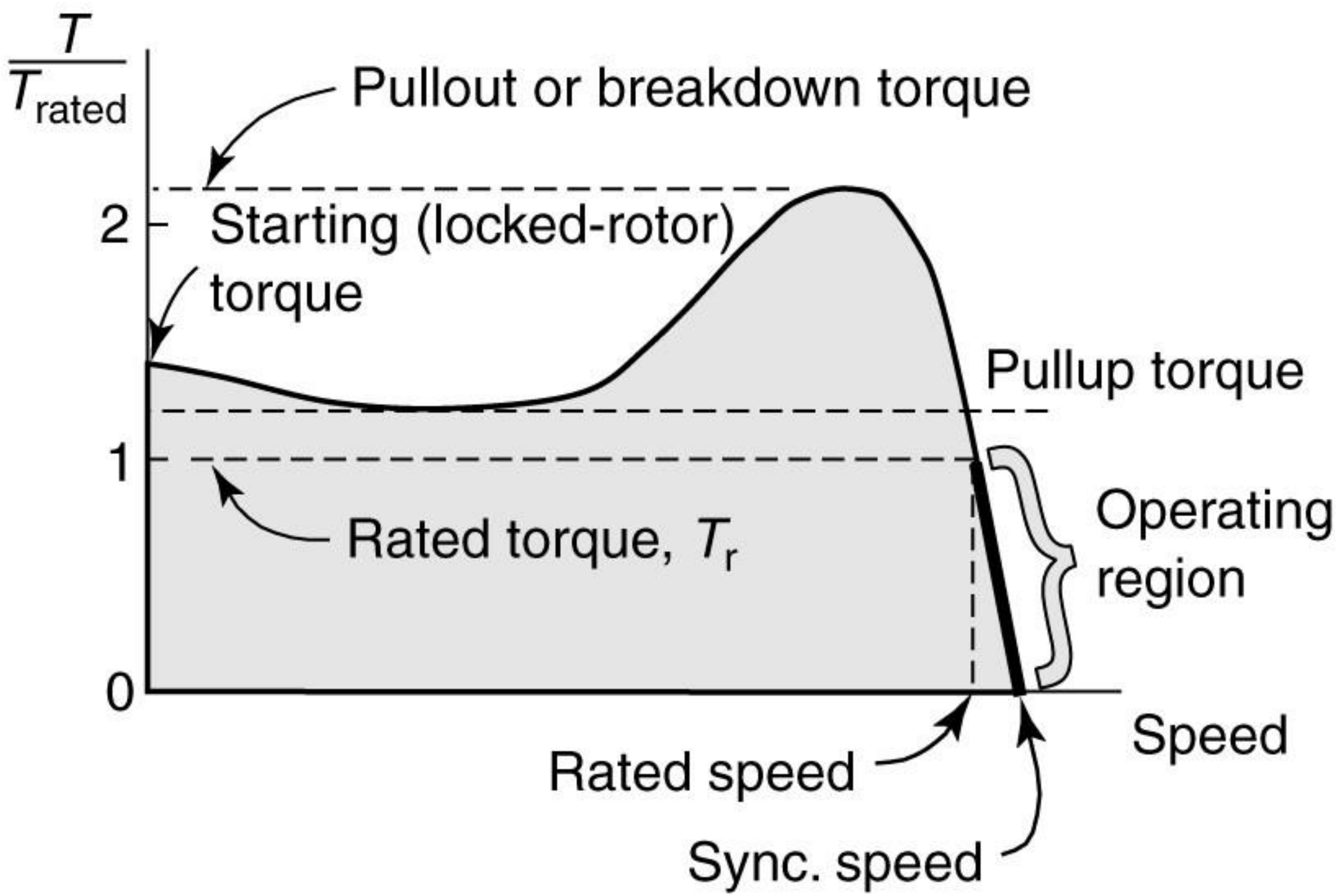
Synchronous Motor Torque-Speed Characteristic Curve



$$SR = \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100\%$$

$$SR = 0\%$$

The torque-speed characteristic of a synchronous motor. Since the speed of the motor is constant. its speed regulation is zero



$\frac{T}{T_{rated}}$
Pullout or breakdown torque
2
Starting (locked-rotor)
torque
Pullup torque
1
Operating
region
Rated torque, T_r
0
Speed
Rated speed
Sync. speed

Advantages of AC Motor

1. Low cost.
2. Simple and rugged construction
3. Low maintenance.
4. High efficiency.
5. High starting torque (for certain models, but not for all).
6. Easy power distribution

Disadvantages of AC Motor

1. Complex speed control.
2. Poor low-speed performance.
3. Inherent slip

Introduction to AC Servo Motors

Servo Motors

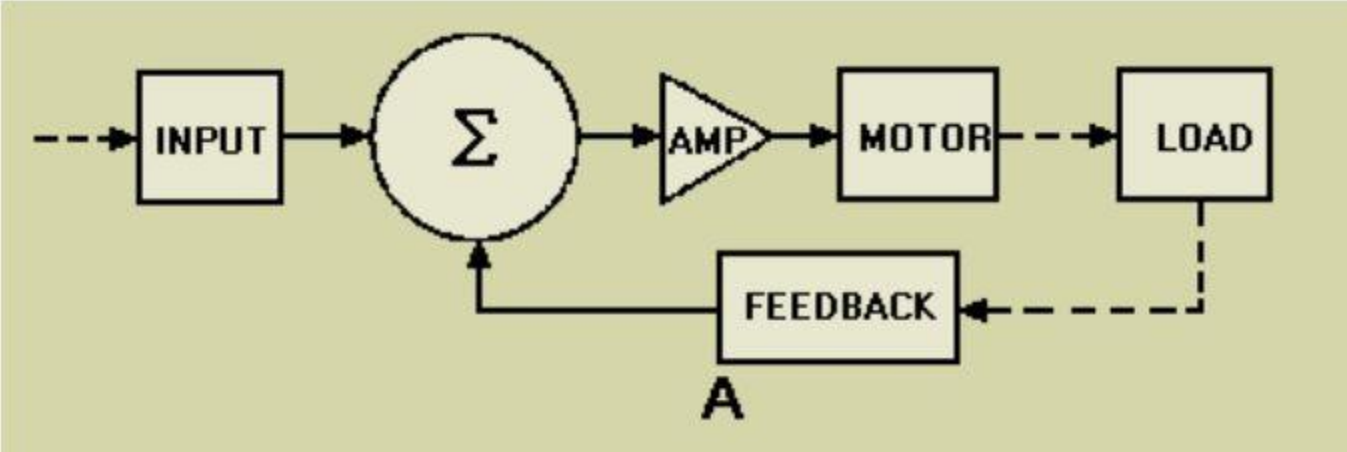


Fig.- Block Diagram Representation of Servo System.[6]

Types-

- DC Servo Motor- Brushed or Brushless.
- AC Servo Motor- Synchronous or Asynchronous.

AC Servo Motor

- An AC servo motor is a type of electric motor that is controlled for precise position, velocity, and acceleration. It operates using alternating current (AC) to create a rotating magnetic field and is commonly part of a closed-loop system.

- AC servo motors are crucial in applications requiring exact control of position and speed, such as robotics, automation, and CNC machinery.

Basic Working Principle

AC Motors

Servo Motors

Components of an AC Servo Motor System

- ❑ **Motor (Stator and Rotor):**
  - **Stator:** The stationary part where the AC current flows, generating a rotating magnetic field.
  - **Rotor:** The rotating component that aligns with the magnetic field and rotates to produce mechanical output.
- ❑ **Feedback Device:** Most commonly, an encoder or resolver is attached to the rotor shaft to measure the exact position or speed of the rotor.
- ❑ **Servo Drive (Controller):** The servo drive interprets commands from the controller and uses feedback from the encoder to adjust the motor's operation precisely.

AC Servo Motor Types

- **Synchronous AC Servo Motors:**
  - **Operation:** In these motors, the rotor speed is synchronized with the AC frequency.
  - **Applications:** Used in high-precision applications like medical equipment and CNC machinery.
- **Asynchronous (Induction) AC Servo Motors:**
  - **Operation:** The rotor speed lags behind the AC frequency slightly, allowing for variable speed control.
  - **Applications:** Often used in applications like conveyors and general industrial machinery.

Calculations- For Pulse+Direction Control

Required pulses for position= $d \times P/L$.Where,

D- Distance entered by the user in mm.

P- Pulses are required to rotate the motor through one (2500 pulses). L - Lead of lead screw (5 mm).

$Time\ delay = L/(v \times k)$ × 10^6 where,

V- User entered velocity

k-Pulses per rotation (2500 pulses)

Advantages of AC Servo Motor

1. High Precision and Accuracy: The use of feedback mechanisms and advanced control algorithms ensures precise control over position, speed, and acceleration.

2. High Efficiency: AC servo motors are highly efficient, making them suitable for energy-sensitive applications.

3. High Torque-to-Inertia Ratio: They provide high torque with low inertia, allowing for quick acceleration and deceleration.

4. Reliable and Robust: AC servo motors are designed to operate reliably in demanding environments, with long operational lifespans and minimal maintenance.

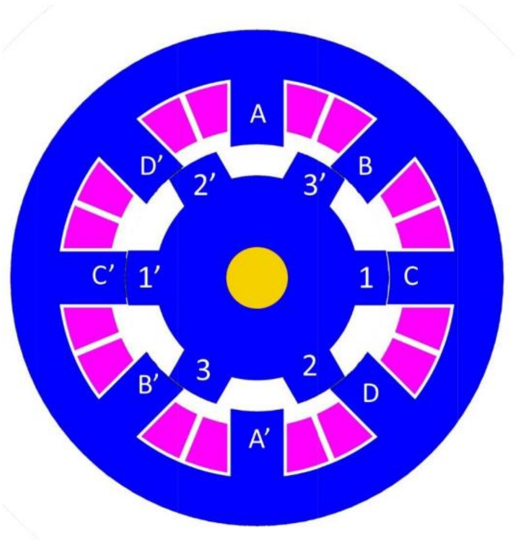
5. Smooth Operation: The advanced control systems provide smooth and stable operation, reducing vibrations and noise.

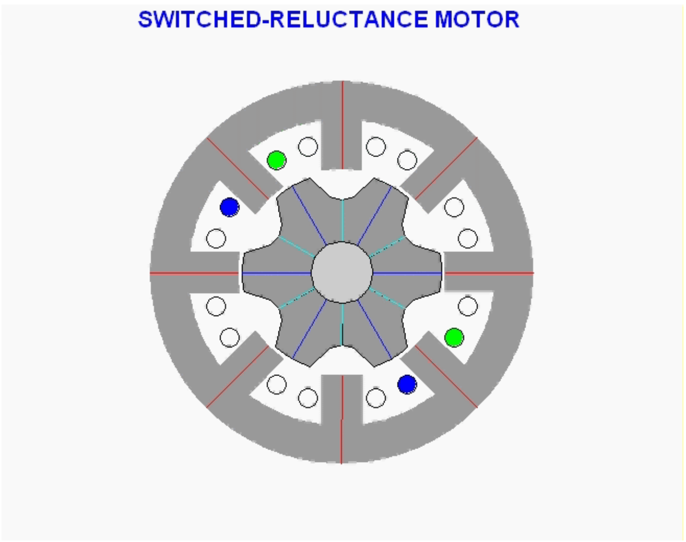
SWITCH RELUCTANCE MOTOR

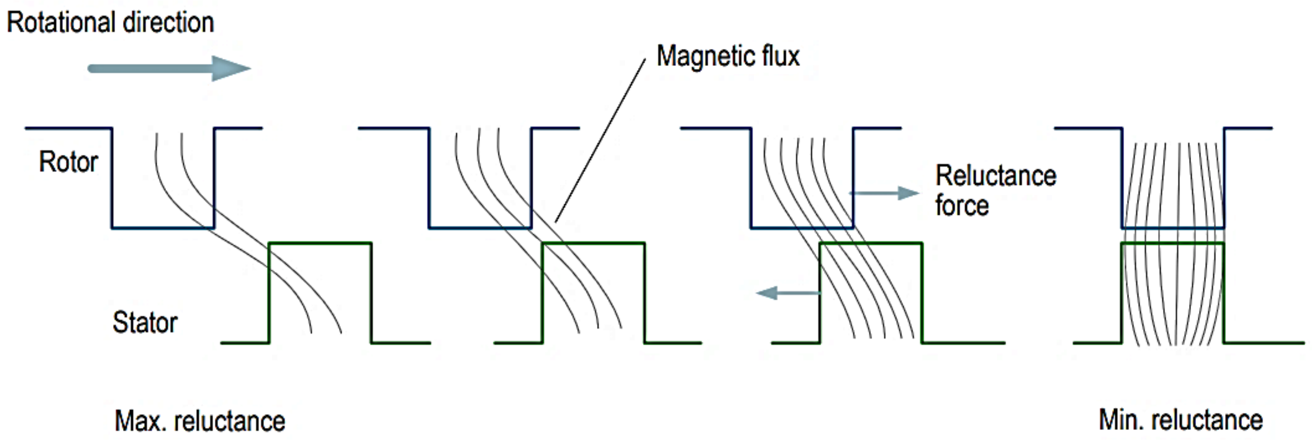
- At its core, an SRM is an electric motor that operates based on the principle of magnetic reluctance.
- Unlike conventional motors that use permanent magnets or electromagnetic windings on the rotor, SRMs have a rotor with no windings or magnets. Instead, the rotor is designed with multiple salient (protruding) poles, while the stator has winding coils.

Working of SR motor

- SRM is a double salient machine having poles on both rotor and stator as shown in figure.
- Each stator pole consists of a concentrated winding. The torque generation mechanism in SRM is based on varying reluctance.
- When a stator coil is energized, a magnetic field is produced around it and the rotor tends to move towards the stator pole to minimize the reluctance in the magnetic circuit.







Advantages of SR Motor

1. High-speed capability.
2. Simple and rugged construction.
3. Excellent fault tolerance.
4. High efficiency over a wide speed range.
5. High starting torque.

Disadvantages of SR Motor

1. Torque ripple and vibration.
2. Acoustic noise.
3. Requires a position sensor.
4. Complex control systems.

Notable Applications of SR Motor

Home Appliances (Dyson DC31 handheld vacuum cleaner)

Industrial Applications (HILTI TE 700 - AVR)

Electric Vehicles (Audi SQ7 Supercharger)

Fig. 16. Structure of Dyson digital motor [www.dyson.com.sg]

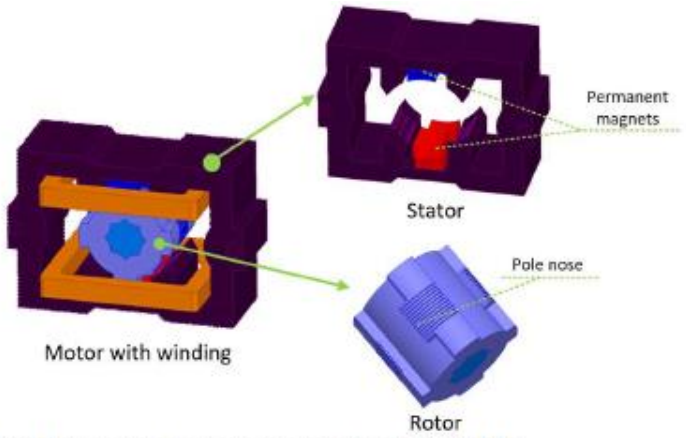


Fig. 17 SRM structure for hammer breaker (Hilti) [43]

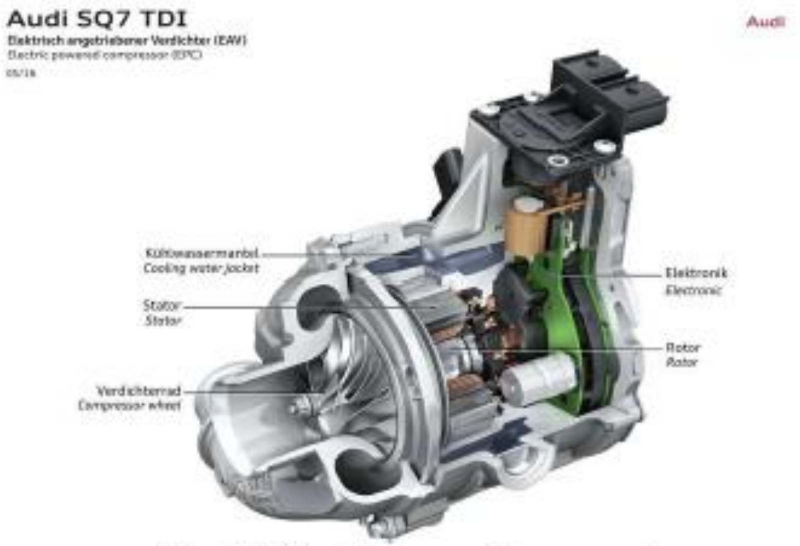


Fig. 19 Electric supercharger system