DAYANANDA SAGAR COLLEGE OF ENGINEERING

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Department of Robotics and Artificial Intelligence

DRIVE SYSTEMS FOR ROBOTICS (22RI34)

UNIT 4: NOTES

ELECTRICAL DRIVES

III SEMESTER, B.E.

DEPARTMENT OF ROBOTICS AND ARTIFICIAL INTELLIGENCE

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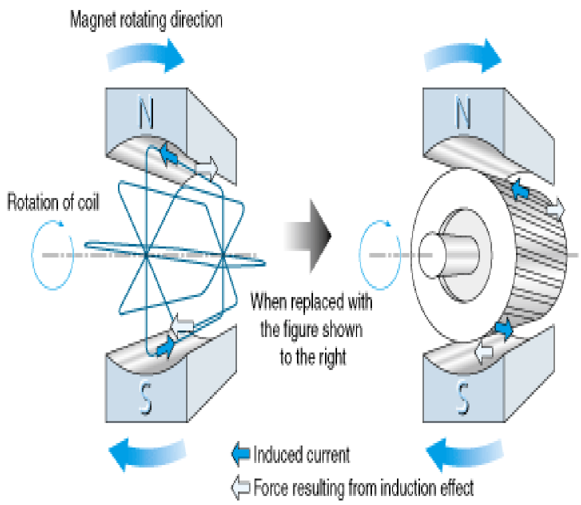
- **Introduction:**
- An electric motor is composed of a rotating centre, called the **rotor** and a stationary outside, and called the **stator.**
- These motors use the **attraction and repulsion** of **magnetic fields** to induce forces, and hence **induced force** leads to motion development.
- Typical electric motors use at least one electromagnetic coil, and sometimes permanent magnets to set up opposing fields.
- When a voltage is applied to these coils the results is a **torque and rotation of an output shaft.**
- There are variety of motor configuration that yields motors suitable for different applications.
- Most notably, as the **voltages** supplied to the motors will vary the **speeds and torques.**

Why does a Rotor Rotate?

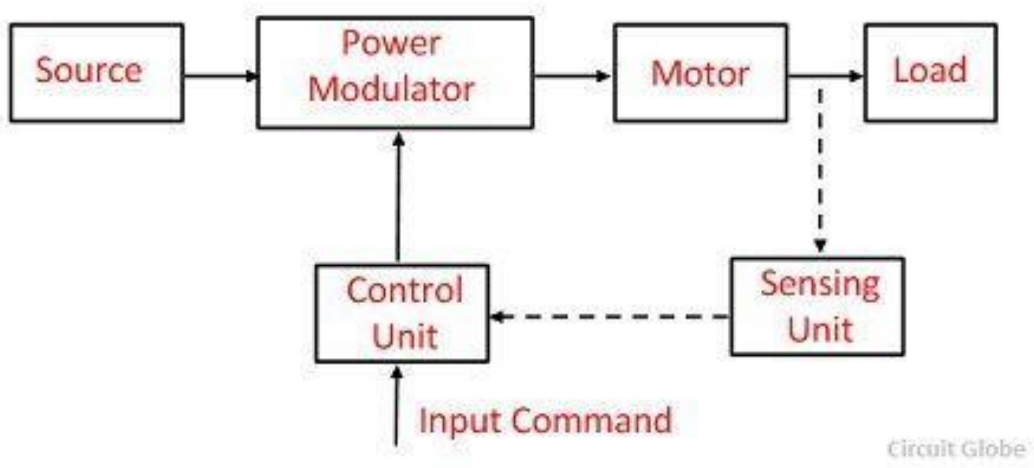
- If a 3-phase supply is fed to the stator windings of a 3-phase motor, ***a magnetic flux of constant magnitude***, ***rotating at synchronous speed*** *is set up.* At this point, the rotor is stationary.
- The rotating magnetic flux passes through the air gap between the stator & rotor and sweeps the stationary rotor conductors.
- *This rotating flux, as it sweeps, cuts the rotor conductors, thus causing an e.m.f to be induced in the rotor conductors.*
- As per the ***Faraday's law of electromagnetic induction***, it is this relative motion between the **rotating magnetic flux and the stationary rotor conductors**, which induces an **e.m.f on the rotor conductors, resulting in rotar rotation**
- **Induced emf produces rotar conduction leading to rotation**
- They operate using **principles of electromagnetism**, which shows that a force is applied when an electric current is present in a magnetic field.
- This **force creates a torque** on a loop of wire present in the magnetic field, which causes the motor to spin and perform useful work.



Electrical drive systems:

- Motion control is required in large number of industrial applications like Robotics-Automation applications, transportation systems, rolling mills, paper industries, textile mills, machine tools, fans pumps etc.
- Systems employed for motion controls are called drives, drives employing electric motors are known as electrical drives.
- **Advantages of Electrical Drive:** It is simple in construction and has less maintenance cost. Its speed control is easy and smooth. It is neat, clean, and free from any smoke or flue gases.

Electrical drive motor block diagram:



Description of Electric Drive System

- The source will send the electrical signal to the Power modulator, The power modulator regulates the output power of the source. It controls the power from the source to the motor in such a manner that motor transmits the speed-torque characteristic required by the load. During the transient operations like starting, braking and speed reversing the excessive current drawn from the source. This excessive current drawn from the source may overload it or may cause a voltage drop. Hence the power modulator restricts the source and motor current.
- The power modulator converts the energy according to the requirement of the motor e.g. if the source is DC and an induction motor is used then power modulator convert DC into AC. It also selects the mode of operation of the motor, i.e., motoring or braking.

- **Control Unit** – The control unit controls the power modulator which operates at small voltage and power levels. The control unit also operates the power modulator as desired. It also generates the commands for the protection of power modulator and motor. An input command signal which adjusts the operating point of the drive, from an input to the control unit.
- **Sensing Unit** – It senses the certain drive parameter like motor current and speed. It mainly required either for protection or for closed loop operation.

Power Modulator:

- This modulator can be used to control the o/p power of the supply. The power controlling of the motor can be done in such a way that the electrical motor sends out the speed-torque feature which is necessary with the load. During the temporary operations, the extreme current will be drawn from the power source.
- The power modulator regulates power from the source to the motor.

- The control unit operates the power modulator, and the sensing unit measures drive parameters like motor current and speed.
- It controls the power from the source to the motor in such a manner that the motor transmits the speed-torque characteristic required by the load.

The functions of the power modulator are:

- Modulates flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load.
- It converts electrical energy of the source in the form suitable to the motor.
- Selects the mode of operation of the motor, i.e. motoring or Braking.
- It modulates flow of power from the source to the motor is impart speed−torque characteristics required by the load.
- It regulates source and motor currents within permissible values, such as starting, braking, and speed reversal conditions.
- Selects the mode of operation of motor, i.e., motoring or braking.
- Converts source energy in the form suitable to the motor.

Types of Power Modulators

In the electric drive system, the power modulators can be any one of the following:

- Controlled rectifiers (ac-to-dc converters)
- Inverters (dc-to-ac converters)
- AC voltage controllers (ac-to-ac converters)
- DC choppers (dc-to-dc converters)
- Frequency changers (Cycloconverters or PWM Inverters)

DC Servo Motor:

- The main components of DC Servo motors are motor and stator.
- Usually the rotor includes the armature and commutator assembly.
- The stator include the permanent magnet and brush assembly.
- When the current flows through the windings of the armature it sets up the magnetic field, opposing the field setup by the magnets.
- This produces torque on the rotor.
- As the rotor rotates, brush and the commutator assembly switch the current to the armature, so that field remains to one set of magnets.
- In this way the torque produced by the rotor is constant throughout the rotation.

- Since the field strength of the rotor is a function of correct through out it, it can shown that dc servo motor
- **$T_m(t)=K_m I_a(t)$**
- Where Tm is the torque, Ia is the current flowing through the armature, Km is the motor's torque constant.
- Back emf is also associated with DC servo motor, it is similar to DC generator or dc tachometer.
- The spinning armature produces voltage, this voltage is proportional to the angular velocity of the rotor.
- **$e_b(t)=K_b w(t)$**
- **e_b**= back emf (voltage), **K_b** is the voltage constant of the motor,**w** is the angular velocity.
- The effect of back-emf is to act as viscous damping of the motor, as the velocity increases the damping increases proportionately.
- If voltage is supplied across the motor terminals of **V_{in}** and the resistance of the armature were Ra, then the current through the armature would be **V_{in}/R_a.**
- This current produces the torque on the motor and causes the motor to spin.
- As the armature spins it generates back emf equal to **$K_b w(t)$ or $e_b(t)$.**
- The voltage must be subtracted from Vin in order to calculate the armature current. The actual armature current is

$$I_a(t)=\frac{V_{in}(t)-e_b(t)}{R_a}$$

- As the motor velocity increases, the back emf also increases accordingly.
- The current available to the armature decreases.
- The decreasing current reduces the torque generated by the rotor.
- As the torque decrease the acceleration of the rotor decreases as well.
- At a point **$e_b = V_{in}$,** a motor remains a steady state velocity(assuming that there is no external disturbances)

Servo Motor Characteristics:

1. Control aspect:

Position Control: They are designed for precise angular or linear positioning.

Velocity Control: For some specific application it is used to control the speed **of the motor.**

Torque Control: The servo motor can maintain also it can control the torque.

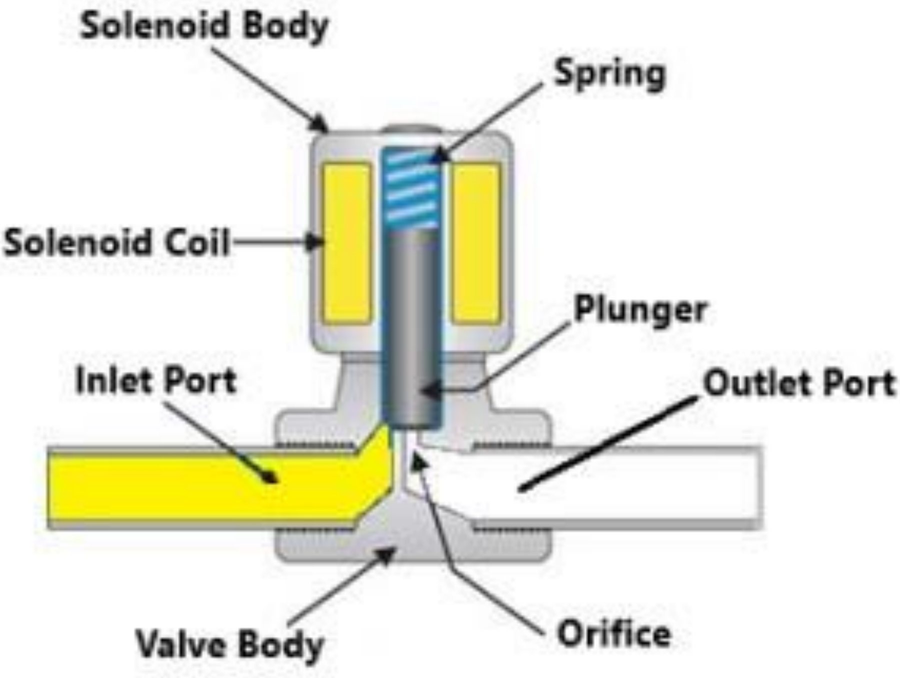
- **2.Feedback Mechanism:** It uses potentiometer and encoders to check the position, speed and torque, this also enable closed loop control system to develop accuracy and stability of the system.
- **3. Speed:** Servo motors can operate at a wide range of speeds. They are capable of rapid acceleration and deceleration.
- **4. Torque:** It can deliver high torque at low speeds, making them ideal for precise control tasks.
- **5.Size and Power:** It has variety of sizes, ranging from small micro-servos for lightweight applications to large industrial servos for heavy-duty tasks. Power vary based on size and application.
- **6.Precision:** High precision, often capable of controlling angles within a fraction of a degree.
- **7. Efficiency :** It is designed to optimize energy use, especially in applications requiring intermittent high performance.
- **Control Signals:** It uses Pulse Width Modulation (PWM) signals. Analog or digital control signals may be used, depending on the servo type.

Requirements of good Servo motors:

- **1. High Precision and Accuracy**
- **Smooth Position Control:** The servo motor should provide accurate angular or linear positioning.
- **Minimal Backlash:** Mechanical play in the system should be minimized for consistent positioning.
- **Fine Resolution:** High resolution in the encoder or feedback system enhances precision.
- **2. Fast Response Time**
- **Low Inertia:** The motor should accelerate and decelerate quickly.
- **High Torque-to-Weight Ratio:** Enables rapid responses to control inputs.
- **Efficient Dynamics:** The motor should react to commands with minimal lag.
- **3. High Torque Density**

- Ability to generate significant torque in a compact size, making it suitable for space-constrained applications.
- **4. Reliability and Durability**
- **Robust Build Quality:** Should withstand operational stresses, vibrations, and wear.
- **Temperature Resistance:** Ability to handle heat without performance degradation.
- **Long Life Cycle:** Designed for prolonged use without frequent maintenance.
- **5. Efficient Feedback Mechanism**
- Equipped with precise sensors (e.g., encoders, resolvers) for closed-loop control, ensuring accurate monitoring of position, speed, and torque.
- **6. Versatility**
- Compatibility with different control protocols and ease of integration with various systems.
- Support for multiple operating environments, such as industrial, automotive, or robotics.
- **7. Power Efficiency**
- Should operate with minimal energy wastage while delivering the required performance.
- **8. Stability**
- Should operate without overshooting or oscillations, especially in high-speed applications.
- **9. Noise and Vibration Reduction**
- Should run smoothly and quietly, especially in applications where noise is a concern, like robotics or medical equipment.
- **10. Safety Features**
- **Overload Protection:** Prevents damage during excessive loads.
- **Thermal Protection:** Safeguards against overheating.
- **Failsafe Operation:** Ensures safe behavior during power loss or system error.

- ## Solenoid actuators:
- A solenoid actuator is a type of electromechanical device that converts electrical energy into linear mechanical motion such as pull or push actions.
- It consists of a coil of wire, a movable plunger or armature, and a housing. It consists of on and off positions and in between there is no actions.
- When an electric current is passed through the coil, it creates a magnetic field, which pulls or pushes the plunger, creating the linear movement.



Key Components:

- **Coil**: A wire wound into a coil, typically made of copper. This is where the current flows, generating a magnetic field when energized.
- **Plunger (Armature)**: A movable ferromagnetic component that is attracted or repelled by the magnetic field.
- **Spring**: Often used to return the plunger to its original position when the solenoid is de-energized.
- **Housing**: The outer casing that contains and protects the solenoid components

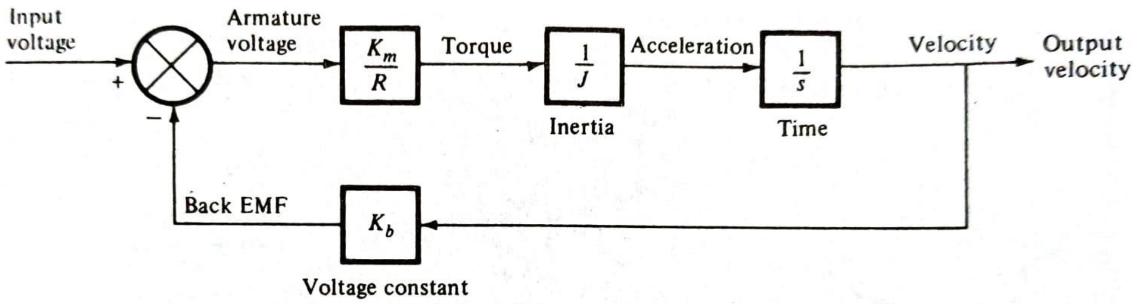
Operation:

An electric coil is placed around the plunger as shown in the figure. As soon as coil is electrically energyized, the magnetic field is created around it. This magnetic field or the energy developed tends to pull the plunger upwards towards the center of the coil. This helps the orifice to open and it will allow the medium to pass through the spacing within it. The valve(handle or electric coil) is connected in the process flow line which is the basic part for controlling the medium. This valve control the flow of fluid from inlet valve to the outlet valve.

Advantages:

1. Simple design with few moving parts, making them reliable.
2. Fast response time for switching applications.
3. Precise linear motion.

DC Motor Block Diagram:



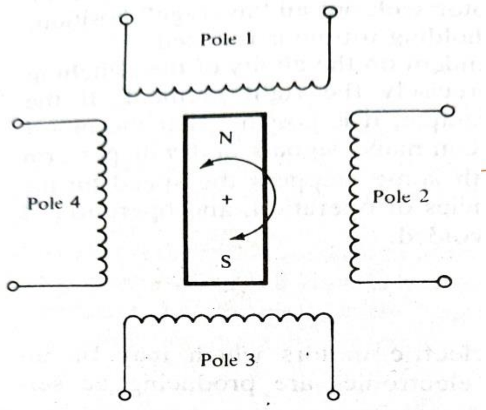
R = armature resistance

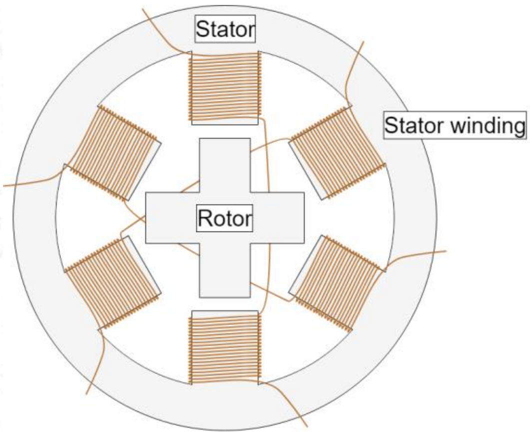
Figure 3-19 DC motor block diagram.

- The working principle of a DC machine is when electric current flows through a coil within a magnetic field, and then the magnetic force generates a torque that rotates the dc motor.
- The basic working principle of a DC motor is that whenever a current-carrying it experiences a force, current carrying conductor is placed in a magnetic field, it produces mechanical force. This force is known as the Lorentz force, and it is responsible for the rotation of the motor's armature.
- The DC machines are classified into two types such as DC generator as well as DC motor.

Stepper Motor:

- Stepper motors (also called stepping motors) are a unique type of actuator and have been used mostly in computer peripherals.
- A stepper motor provides output in the form of discrete angular motion increments.
- It is actuated by series of discrete electrical pulses.
- For every electrical input there will be single-step rotation of the motor shaft.
- In robotics, stepper motors are relatively used in light duty applications.
- Typically stepper motors are used in open loop control systems rather than closed loop control systems.
- A stepper motor, also known as step motor or stepping motor, is an electrical motor that rotates in a series of small angular steps, instead of continuously. Stepper motors are a type of digital actuator.

- A stepper motor (or step motor) is a brushless DC Motor that divides a full rotation into a number of equal steps. Stepper motors are designed for positioning. Stepper motors convert electricity into rotation
- The motor's position can then be commanded to move and hold at required steps without any feedback sensor (an Open loop controller), as long as the motor is carefully sized to the application.
- 



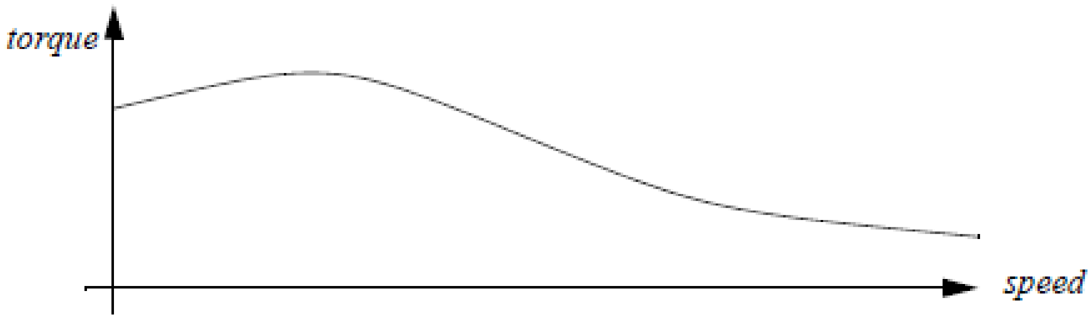
Stepper Motor Fundamentals of Operations:

- Stepper motors work on the principle of electromagnetism. There is a soft iron or magnetic rotor shaft surrounded by the electromagnetic stators.
- The rotor and stator have poles which may be teethed or not depending upon the type of stepper.
- It does not require feedback system when used in high reliability applications and when the dynamic conditions could lead to slip.
- By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field.
- After the current flows into the motor it breaks up a single full rotation into a number of much smaller (and essentially equal) part rotations, thus the motor actuates.
- Each of those rotations is called a "step", with an integer number of steps making a full rotation. In this way, the motor can be turned by a precise angle.
- The stator is made up of four electromagnetic poles and rotor is made up of two-pole permanent magnet.
- If electromagnetic stator poles are activated such a way that pole 1 in the figure is N (magnetic north pole) and pole 3 is S then the rotor is aliened as illustrated.
- If the stator is excited so that pole 4 is N and pole 2 is S, so that rotor makes 90° .

- By rapidly switching the current to the stator electronically, it is possible to make motion of the rotor appear continuous.
- The resolution (number of steps per revolution) of a stepper is determined by the number of poles in the stator and rotor.
- The relation between a stepper motor's resolution and its stepping angle is given by **n =A/360 ° ,** Where n is the resolution and A is the stepping angle.
- Here there is discrete nature of the stepper motor construction, where in it is not a straight line actuation.
- The torque developed in stepper motor is a function of the angle between the stator and rotor poles.
- The torque becomes maximum when is aligned, which is called holding torque.
- It is possible to increase the resolution of a stepper motor by the technique called half-stepping or micro-stepping.
- By applying current to more windings, then the rotor seeks the average position.
- The control of stepper motor is depended on the ability of switching, to windings at precisely at right time.
- If windings are switched too quickly , for example, the motor will not be able to **keep up** with command signals and will perform irrationally , in some cases it oscillates.
- With some stepper motors, the speed–torque relation degrades badly at certain frequencies of operations and operations of these frequencies must be avoided.

Output of Servo Motor:

The torque speed curve for the motors is shown in Figure below. In addition they have different static and dynamic holding torques. These motors are also prone to resonant conditions because of the stepped motion control. A stepper motor slips when the holding torque is overcome, or it is accelerated too fast. When the motor slips it will move a number of degrees from the current position.



There are two basic types of stepper motors,

1) ***Unipolar***
2) ***Bipolar***

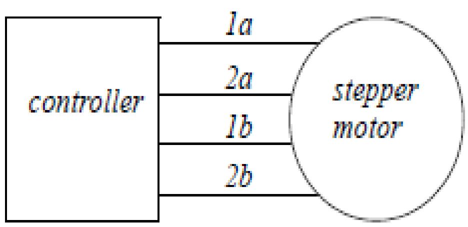
Unipolar:

A unipolar stepper motor has one winding with center tap per phase. Each section of windings is switched on for each direction of magnetic field.The unipolar uses centre tapped windings and can use a single power supply. The motors are turned by applying different voltages at the motor terminals. The motors are used with controllers that perform many of the basic control functions. At the minimum status the translator controller will take care of switching the coil voltages.

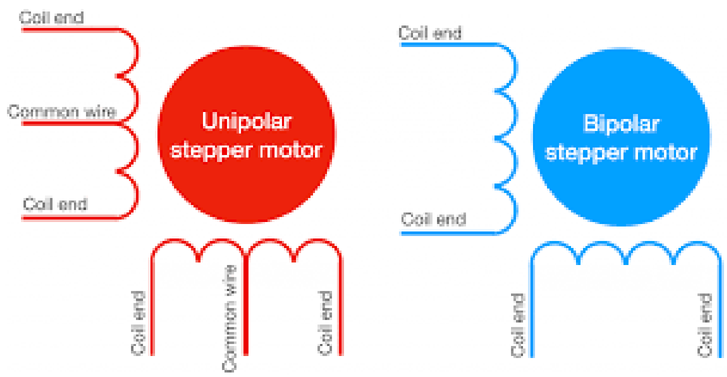
- A more sophisticated indexing controller will accept motion parameters, such as distance, and convert them to individual steps.
- A unipolar motor has twice the amount of wire in the same space, but only half used at any point in time, hence is 50% efficient (or approximately 70% of the torque output available).

- **Micro-stepping:**
- Other types of controllers also provide finer step resolutions with a process known as **micro-stepping.** Micro stepping is a way to make small steps even smaller in a stepper motor. The smaller the step, the higher the resolution and the better the vibration characteristics. In microstepping, a phase is not fully on or fully off.

It provides increased resolution without a sacrifice in top speed, and it provides smoother low speed motion. For example, to achieve a resolution of 5 microns with a full step system requires the use of a screw with a 1.0 mm lead. Normal microstepping levels are 2, 4, 8, 10, 16, 32, 64, etc. up to 256.

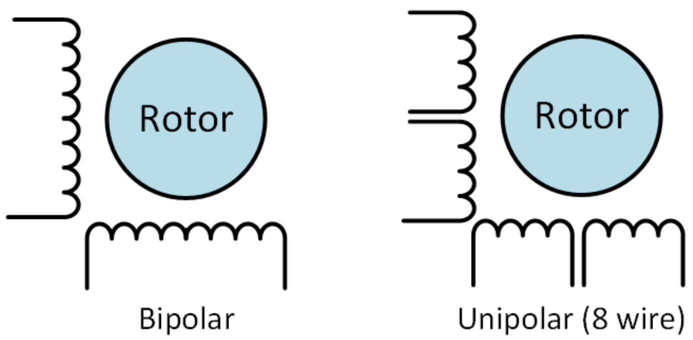


Step	1a	2a	1b	2b
1	1	0	1	0
2	0	1	1	0
3	0	1	0	1
4	1	0	0	1



- The bipolar motor is simpler but requires a positive and negative supply and more complex switching circuitry.
- Bipolar motors have a single winding per phase.
- The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement (an electronic circuit that switches the polarity of a voltage applied to a load).
- There are two leads per phase, none are common. Static friction effects using an H-bridge have been observed with certain drive topologies.
- This stepper signal at a higher frequency than the motor can respond to will reduce this "static friction" effect.
- Because windings are better utilized, they are more powerful than a unipolar motor of the same weight. This is due to the physical space occupied by the winding.
- Though a bipolar stepper motor is more complicated to drive, the abundance of driver chips means this is much less difficult to achieve.

In unipolar: the current always flows in the same direction. Each coil is dedicated to one current direction, meaning either the coil A+ or the coil A- is powered.
The coils A+ and A- are never powered together.
In bipolar: the current can flow in both directions in all coils.



D C Motor Drives characteristics:

- DC motors - have large torque and speed ranges
- Permanent magnet - variable speed
- Wound rotor and stator - series, shunt and compound (universal)
- Contactors are used to switch motor power on/off
- Drives can be used to vary motor speeds electrically. This can also be done with mechanical or hydraulic.

Popular drive categories:

Variable Frequency Drives (VFD) - vary the frequency of the power delivered to the motor to vary speed.

DC motor controllers - variable voltage or current to vary the motor speed

Eddy Current Clutches for DC motors - low efficiency, uses a moving iron drum and windings.

Important features of BLDC Motors:

Brushless Design:

As the name suggests, BLDC motors do not have brushes, which means less friction and less maintenance over time.

Electronic Commutation:

Instead of mechanical brushes, BLDC motors use an electronic controller to manage the switching of current in the windings of the stator to generate rotational motion in the rotor.

High Efficiency:

Due to the lack of brushes and the absence of mechanical friction, BLDC motors tend to be more efficient than brushed motors, with less energy lost as heat.

Longer Lifespan:

The absence of brushes reduces wear and tear, resulting in a longer operational life and less frequent maintenance.

Precise Control:

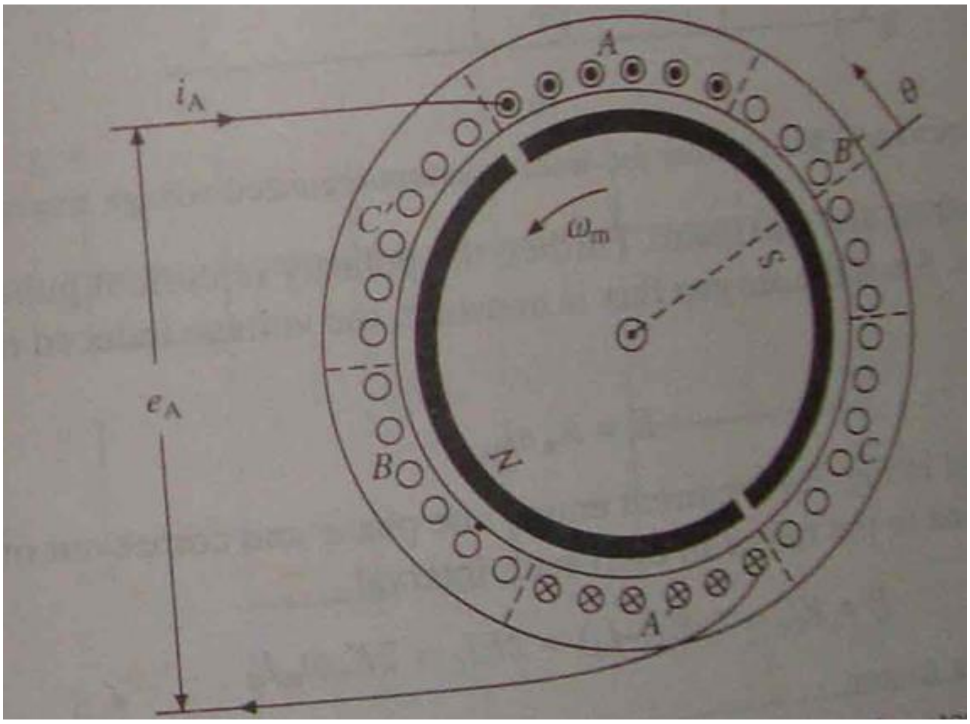
BLDC motors can be precisely controlled with modern electronics, allowing for smoother and more accurate speed control, which is important in applications like robotics, drones, and electric vehicles.

Lower Noise:

BLDC motors tend to operate more quietly than brushed motors, which is important in applications where noise is a concern.

Brushless DC Motor:

BLDC motors (Brushless DC motors) are a type of electric motor that operates without the use of brushes. In conventional brushed DC motors, brushes are used to transfer current to the motor's rotor, but in BLDC motors, this function is replaced by electronic commutation, which eliminates the need for brushes and the associated wear and tear. This design offers several advantages over brushed motors. The BLDC motor has a permanent rotor with wide pole arc. The stator has three concentrated windings which are displaced 120 ˚ and each phase windings spans to 60˚ on each side. The voltage induced are shown in the figure.



- The 120˚ rotation of the motor from the pole is as shown in the figure.
- All top conductors of phase A will be linking to the south pole and all the bottom conductors of A, will be linking the north pole. Hence the voltage induced in phase A is same during 120˚ rotation.
- Beyond 120˚ some of the poles link north and some link the south poles.
- And the same process happens with the bottom conductors when it crosses bottom conductors.
- Hence the voltage induced in phase A linearly reverses in next 60˚ of rotation.
- An invertor fed (sinusoidal wave forms) trapezoidal PMAC(Permanent Magnet AC Motor) motor drive operating in a self controlled mode is called **Brushless DC Motor.**

- The current pulses are each 120˚ duration and are located in the regions where induced voltage is constant and maximum.
- The polarity of current pulses is same as that of induced voltage, hence air gap flux is constant, the voltage induced is proportional to the speed of the rotor.

  - **$E = K_e . \omega_m$**

- The torque developed by the motor is as follows
-

$$T = \frac{P}{\omega_m} = 2K_e I_d = K_T I_d$$

P= Power supplied to motor

Id= Dc current,

Ωm = actual speed

KT = Torque constant.

Ke- Voltage constant or back emf.

Typical Applications of BLDC Motor:

- **Electric Vehicles (EVs)**: Used in electric cars, bikes, and scooters for effective motion of the vehicle.
- **Aerospace & Drones**: In drones for precise control and high performance during the movement.
- **Home Appliances**: Used in fans, air conditioners, and other devices due to their reliability and better efficiency.
- **Industrial Equipment**: Employed in robotics, conveyors, and CNC machines where high precision and reliability are essential.
- **Medical Devices**: For pumps, actuators, and other critical applications that demand reliability and smooth operation.

Motor Catagories:

- **1.AC motors**
- **2.DC motors**

- **AC motors** – Rotate with relatively constant speeds proportional to the frequency of the supply power.
- **DC Motors:** 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
- **Induction motors** Induction motors are electric motors that use alternating current (AC), propelled by a magnetic field that rotates. They are made up of a rotor, a stator and coils that convert electrical energy into mechanical energy using electromagnetic induction.
- **Synchronous** - fixed speed, efficient.

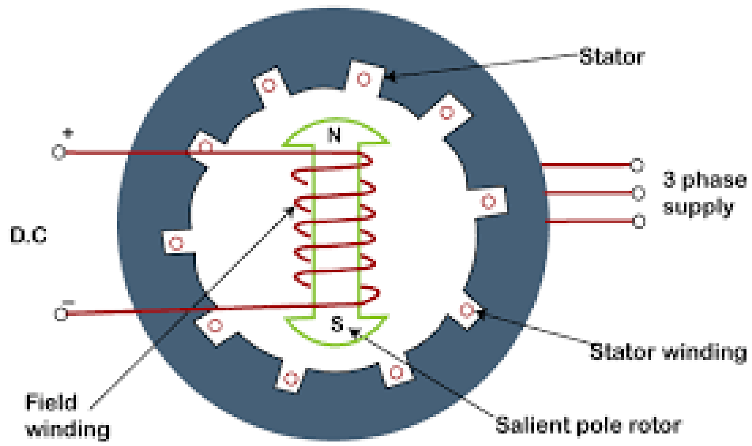
AC Motor Characteristics:

- AC motors exhibit highly coupled, nonlinear, and multivariable structures as opposed to much simpler decoupled structures of separately excited dc motors.
- The control of AC drives generally requires complex control algorithms that can be performed by microprocessors or microcomputers along with fast-switching power converters.
- The AC motors have a number of advantages; they are lightweight (20 to 40% lighter than equivalent dc motors), are inexpensive, and have low maintenance compared with DC motors.
- They require control of frequency, voltage, and current for variable-speed applications.
- The power converters, inverters, and ac voltage controllers can control the frequency, voltage, or current to meet the drive requirements.

Synchronous motor drives:

- A Synchronous motor is an AC electric Motor, wherein at steady state, the rotation of the motor shaft is synchronized with frequency of the current supply
- An electric motor that operates at a constant speed is known as a synchronous motor as the frequency of the AC voltage that is used and the rotor rotation are synchronized.
- The speed of the synchronous motors can be varied by varying the frequency of the source.

- The synchronous motors are frequently used in the constant speed applications such as conveyors, printing presses,CNC machines, timing, automation applications in packaging machines.
- The commonly used synchronous motors are wound field, permanent magnet, synchronous reluctance and hysteresis motors. All these motors have 3 phase windings which is intern connected to a AC supply.



Construction and Operations:

- Synchronous motors use electromagnets, as a stator of the motor creates the electromagnetic field, that rotates with time oscillations of current.
- A synchronous motor is one in which the rotor normally rotates at the same speed as the revolving field in the machine.
- When the rotor does mot rotate, the north pole of the rotor will be attracted towards the south poles of the RMF (Rotating Magnetic Field)and start to move in the same direction, the rotor has low inertia hence it has less speed.
- The Synchronous motors are not self starting as it has less inertia in the beginning.
- The wound field synchronous motor has as DC field windings which is supplied from DC source through slip rings and brushes.
- The rotor has cylindrical in contruction, have a higher mechanical strength and are employed in high power and high speed applications.
- A wound field synchronous motor (WFSM) works by creating a magnetic field in the rotor and stator, which interact to cause the rotor to rotate
- While the current is passes the rotor of the synchronous motor produces constant magnetic field, while the stator produces revolving magnetic field.

- The field coil is exited by 3 phase AC supply as shown in the figure. This will produce the revolving magnetic field which rotates at synchronous speed (Ns)
- The rotor is exited by the DC power supply hence it behaves like a permanent magnet. During the rotation same direction of RMF (Rotating Magnetic Field), the opposite poles of RMF will attract each other magnetically.
- Hence it makes the rotor to rotate in the same speed of RMF with revolving RMF the rotors are energized and electricity is induced in the motor and rotor starts to rotate just like an induction motor.
- The rotors is achieved with maximum speed then the coil is completely energized .
- The synchronous motor will produce constant speed irrespective motor load parameters.

Sychronous Speed:

$$N_s = \frac{120f}{P}$$

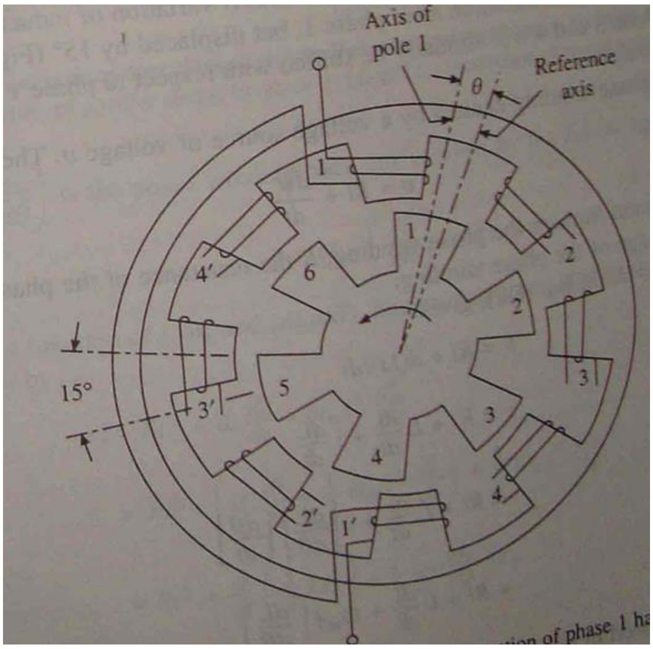
- Ns=RPM
- F= Frequency of Electricity in Hz
- P= No. of poles
- This relationship depicts that speed of the motors can be accurately controlled.
- Here low supply voltage and excitation voltage can effect the performance of the Synchronous motor.

Switches Reluctance motors (SRM):

- The switch reluctance motor (SRM) has both salient pole rotar and stator like variable reluctance stepper motor.
- They are designed for different applications and different performance parameters.
- The switch reluctance motors are used in variable speed drives and naturally designed to operate very efficiently for wide range of speed , torques, and requires rotor positioning sensing systems.

- In order to have self start capabilities and bidirectional control , the rotor of the SWR will has less number of poles than the stator.
- Where as the Synchronous reluctance motor has same number of poles on the stator and rotor.
- The SRM has a cylindrical windings with distributed windings.
- The switched reluctance motor stator has salient pole stator with concentrated coils like a DC motor.
- As rotor has no windings the SRM is more rugged than the squirrel cage induction motor.
- In SRM various combinations of rotor and stator pole is possible, the common type are as follows 8/6 and 6/4.
- As already stated the rotor has any windings, the stator has concentrated coils and diametrically opposite coils are connected, in either series or parallel to form one phase.
- Thus the motors with pole numbers 8/6 and 6/4 will have 4 and 3 phases respectively.

Four phase 8/6 Pole **Switches Reluctance motors(SRM) working principle:**

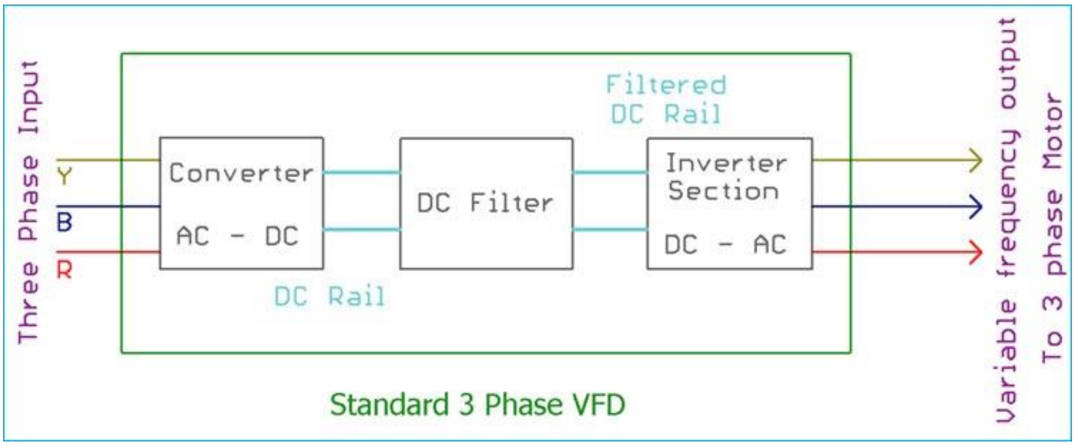


- When the stator phase is excited then the reluctance torque makes the rotor to move towards position of minimum reluctance.
- As the rotor reaches minimum reluctance then the excitation is shifted to the next phase, thus shifting the position of minimum reluctance is ahead of rotor.
- Hence with the help of position sensors the minimum reluctance is shifted from one phase to another phase and reluctance torque makes the rotor is continuously move.

- Speed of the rotor depends on the average torque acting on the rotor which inturn depends on the magnitude of the phase currents.
- As the direction of the reluctance torque is independent of direction of phase currents, motor can be controlled by unidirectional phase currents.
- The direction of rotation can be changed by exiting the phases in reverse sequences.
- For example the sequence of phases 1-2-3-4-1 provides rotation in anticlockwise direction.
- If the sequence of phases 4-3-2-1-4 provides rotation in clockwise direction.
- If the phase is exited after crossing minimum reluctance then the rotor opposes torque and the speed also tend to decreases.
- This motor can also provide regenerative braking systems.

Variable Frequency Drives (VFD):

- A variable frequency drive is a device that regulates the speed and torque of an AC motor by altering the frequency and voltage of its power supply.
- The VDF, the motor speed can be controlled by varying the frequency.
- The voltage induced in the stator is proportional to the product of supply frequency and air gap flux within the motor.
- A VFD consists of a rectifier to convert AC power to DC, a capacitor to stabilize this DC power, and an inverter to convert the DC back to AC with variable frequency.
- A variable frequency drive (VFD) is a device that controls the speed and torque of an AC motor by adjusting the frequency and voltage of the power supply.
- A VFD can also regulate the acceleration and deceleration of the motor during start-up and stop, respectively. A VFD consists of three main components: a rectifier, an inverter, and a control system.
- By changing the frequency and voltage supplied to the motor, a VFD controls the speed and torque, adapting the motor’s performance to varying load requirements.
- VFDs improve energy efficiency by matching motor speed to the actual load, significantly reducing power consumption, especially in variable torque applications like pumps and fans.

- 

How VFD Functions?:

- **Input Power**: The VFD takes AC power from the grid.
- **Rectification**: Converts the AC power to DC.
- **Modulation**: Using pulse-width modulation (PWM), the VFD adjusts the frequency and voltage of the output AC power to match the required motor speed.
- ***Applications:***
- HVAC systems (fans, pumps, and compressors)
- Conveyor belts
- Industrial machinery (e.g., mixers, crushers)
- Elevators and escalators
- Water and wastewater treatment facilities.

- ### Direct Drive Actuator:

A direct drive motor can be defined as any type of motor where the load is directly connected to the motor. They do not require any mechanical transmission elements such as couplings; the motor directly drives the load. Using a direct drive motor eliminates the need for belts, gearboxes, and pulley systems.

The direct drive linear actuator is part of a servo mechanism consisting of five key elements – a coil or forcer, a magnet way or magnetic shaft, a feedback device, mechanical elements consisting of linear bearings and supports, and driven by a servo drive or controller. A Direct Drive Motor, is a type of permanent-magnet synchronous motor which directly drives the load. When using a this kind of motor, the use of a transmission or gearbox is eliminated. Therefore, the amount of moving parts in the system is reduced tremendously. This increases the efficiency and creates a quiet and highly dynamic operation as well as a very high lifetime of the system. Examples of Direct Drive Motors are torque motors, linear motors and certain types of BLDC motors.

Direct Drive Motors are very suitable for high speed, acceleration applications with fast starts and stops. This is because they only need low torque to accelerate the motor compared to geared motors, which have a lower torque to inertia ratio.

A Direct Drive Motor can be used for various applications, such as applications where a high positioning accuracy is needed. Moreover, these frameless motors are used for situations where small size, low weight, maximum power and optimal speed control is desired.

Advantages of a direct drive motor:

1. Cost Optimized Solution
2. High Dynamic Performance
3. High Torque to Power Ratio
4. High Position Accuracy
5. Ease of use.

Advantages of Electric Drives:

- **Efficiency**: Electric drives are highly efficient, converting more than twice the amount of electrical energy into mechanical energy than traditional internal combustion engines.
- **Energy optimization**: Electric drives adjust motor performance to load requirements, reducing energy waste.
- **Precise control**: Electric drives allow for precise control of speed, torque, and position.
- **Low maintenance**: Electrical drives have low maintenance costs.
- **Simple construction**: Electrical drives are simple in construction.

- **Compact**: Electrical drives are compact and require less space.
- **Long life**: Electrical drives have a long life.
- **Clean operation**: Electrical drives are clean and free from smoke or flue gases.
- **Easy installation**: Electrical drives can be installed at any desired convenient place.
- **Immediate start**: Electrical drives can be started immediately without any loss of time.
- **Cost-effective**
- Advantages of electrical drives include flexible control, operation in all motor quadrants, and lack of environmental pollution.
- **Simple design**
- High reliability
- Brushless construction
- Maintenance-free
- Enough overload capacity without loss of life of machine.
- Four quadrant operation.
- Modifiable torque-speed characteristics.
- No requirement of warming up period.
- Higher efficiency.
- Easy control.
- Clean operation, no pollution.
- Wide range of speed control.

Disadvantages:

- Low efficiency (Motor attracts a substantial amount of power regardless of the load)
- • Torque drops rapidly with speed (torque is inversely proportional of speed)
- • Prone to resonance* (Micro stepping allows for smooth motion)
- • No feedback to indicate missed steps
- • Low torque-to-inertia ratio
- • Cannot accelerate loads very rapidly
- • Motor gets very hot in high performance configurations
- • Motor will not “pick up” after momentary overload
- • Motor is noisy at moderate to high speeds
- • Low output power for size and weight.

Applications: Electrical drives are used in many applications, including transportation systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, and washing machines

- Aircraft
- Automotive
- Consumer Electronics and Office
- Gaming
- Industrial
- Medical
- Scientific Instruments
- Surveillance Systems.