UNIT II

STEPPER MOTORS

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AP / EEE

RMD ENGINEERING COLLEGE

STEPPER MOTORS

STEPPER MOTORS

- A stepper motor is a “pulse-driven” motor that changes the angular position of the rotor in “steps”
- Define
  - β = the step angle (per input pulse)
  - Resolution = the number of steps/revolution
  - θ = total angle traveled by the rotor
    - = β X No of steps
  - n = the shaft speed = $(\beta \times f_p) / 360°$
    - f_p = No of pulses/second

TERMINOLOGIES USED IN STEPPER MOTOR

- Step angle
- Resolution
- Stepping rate
- Hold position
- Detent position
- Stepping error
- Position Error

Stepper Motor – Types, Advantages And Applications

Introduction:

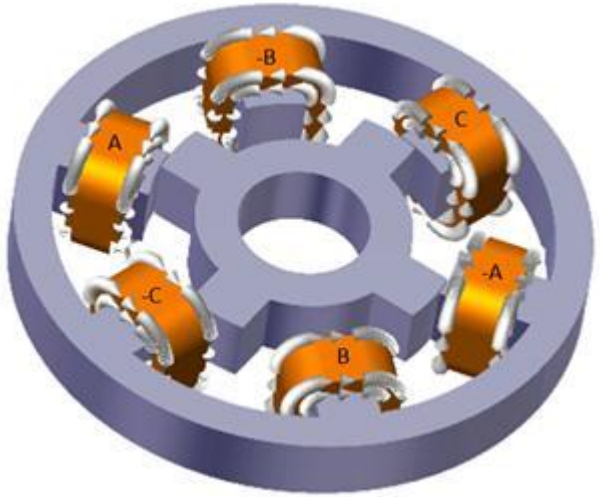
- A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses.

- The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied

Stepper Motor – Types, Advantages And Applications

About Stepper Motor

- The stepper motor uses the theory of operation for magnets to make the motor shaft turn a precise distance when a pulse of electricity is provided. The stator has eight poles, and the rotor has six poles. The rotor will require 24 pulses of electricity to move the 24 steps to make one complete revolution. Another way to say this is that the rotor will move precisely 15° for each pulse of electricity that the motor receives.



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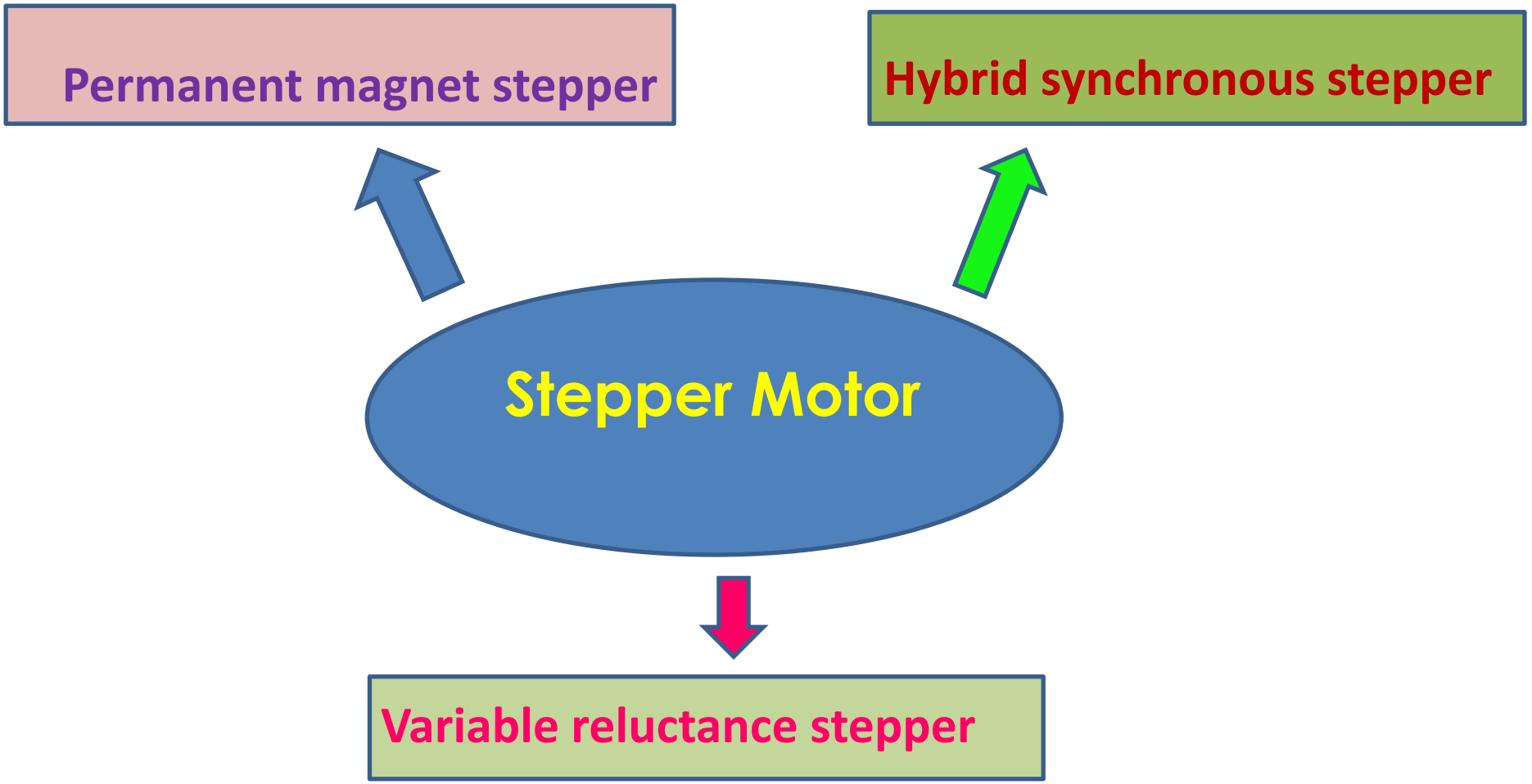
Stepper Motor – Types, Advantages And Applications

There are three main types of stepper motors, they are:



Stepper Motor – Types, Advantages And Applications

Permanent Magnet Stepper Motor

- Permanent magnet motors use a permanent magnet (PM) in the rotor.
- It operate on the attraction or repulsion between the rotor PM and the stator electromagnets.

Stepper Motor – Types, Advantages And Applications

Variable Reluctance Stepper Motor

- Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.

Stepper Motor – Types, Advantages And Applications

Hybrid Synchronous Stepper Motor

- Hybrid stepper motors are named because they use a combination of permanent magnet (PM) and variable reluctance (VR) techniques to achieve maximum power in a small package size.

Stepper Motor – Types, Advantages And Applications

Operation of Stepper Motor

- Stepper motors operate differently from DC brush motors.
- It rotate when voltage is applied to their terminals.
- Stepper motors effectively have multiple toothed electromagnets arranged around a central gear-shaped piece of iron.
- The electromagnets are energized by an external control circuit.
- To make the motor shaft turn, first one electromagnet is given power.

Stepper Motor – Types, Advantages And Applications

Operation of Stepper Motor

- It makes the gear's teeth magnetically attracted to the electromagnet's teeth.
- The point when the gear's teeth are thus aligned to the first electromagnet, they are slightly offset from the next electromagnet.
- When the next electromagnet is turned ON and the first is turned OFF.
- The gear rotates slightly to align with the next one and from there the process is repeated.

Stepper Motor – Types, Advantages And Applications

Operation of Stepper Motor

- Each of those slight rotations is called a step, with an integer number of steps making a full rotation.
- In that way, the motor can be turned by a precise.
- Stepper motor doesn’t rotate continuously, they rotate in steps.
- There are 4 coils with 90o angle between each other fixed on the stator.
- The stepper motor connections are determined by the way the coils are interconnected.

Stepper Motor – Types, Advantages And Applications

Operation of Stepper Motor

- In stepper motor, the coils are not connected together.
- The motor has 90o rotation step with the coils being energized in a cyclic order.
- Which determining the shaft rotation direction.
- The working of this motor is shown by operating the switch.

Stepper Motor – Types, Advantages And Applications

Operation of Stepper Motor

- The coils are activated in series in 1 sec intervals.
- The shaft rotates 90o each time the next coil is activated.
- Its low speed torque will vary directly with current.

Stepper Motor – Types, Advantages And Applications

Stepper Motor Control by Varying Clock Pulses

- Stepper motor control circuit is a simple and low-cost circuit, mainly used in low power applications.
- The circuit is shown in figure, which consist 555 timers IC as stable multi-vibrator.
- The frequency is calculated by using below given relationship:
- Frequency = 1/T = 1.45/(RA + 2RB)C Where RA = RB = R2 = R3 = 4.7 kilo-ohm and C = C2 = 100 µF.

Stepper Motor – Types, Advantages And Applications

Stepper Motor Advantages

- The rotation angle of the motor is proportional to the input pulse.
- The motor has full torque at standstill.
- Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
- Excellent response to starting, stopping and reversing.

Stepper Motor – Types, Advantages And Applications

Stepper Motor Advantages

- Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
- The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
- It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
- A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Stepper Motor – Types, Advantages And Applications

Stepper Motor Disadvantages

- Resonances can occur if not properly controlled.
- Not easy to operate at extremely high speeds.

Stepper Motor – Types, Advantages And Applications

Applications

- Industrial Machines – Stepper motors are used in automotive gauges and machine tooling automated production equipment's.
- Security – new surveillance products for the security industry.
- Medical – Stepper motors are used inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators and blood analysis machinery.
- Consumer Electronics – Stepper motors in cameras for automatic digital camera focus and zoom functions.

Stepper Motor – Types, Advantages And Applications

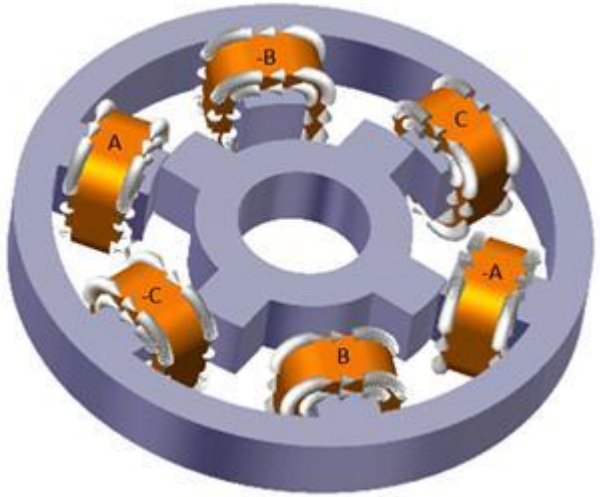
Conclusion

- A Stepper Motor or a step motor is a brushless synchronous motor which divides a full rotation into a number of steps. Unlike a brushless DC motor which rotates continuously when a fixed DC voltage is applied to it, a step motor rotates in discrete step angles. The stepper motor can be controlled with or without feedback.

Stepper Motor – Types, Advantages And Applications

About Stepper Motor

- The stepper motor uses the theory of operation for magnets to make the motor shaft turn a precise distance when a pulse of electricity is provided. The stator has eight poles, and the rotor has six poles. The rotor will require 24 pulses of electricity to move the 24 steps to make one complete revolution. Another way to say this is that the rotor will move precisely 15° for each pulse of electricity that the motor receives.



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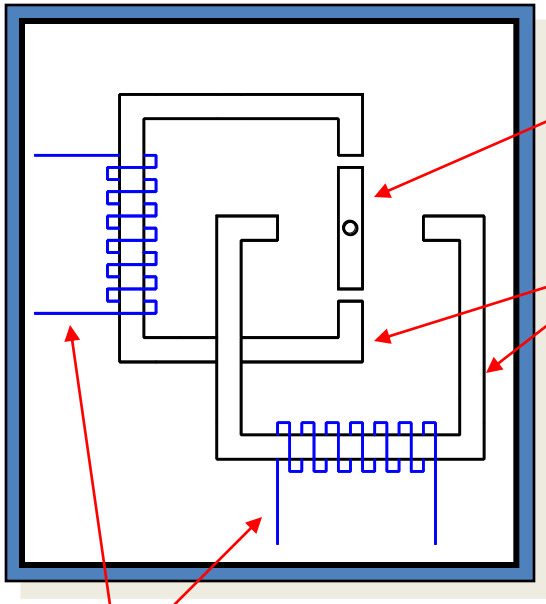


Rotor

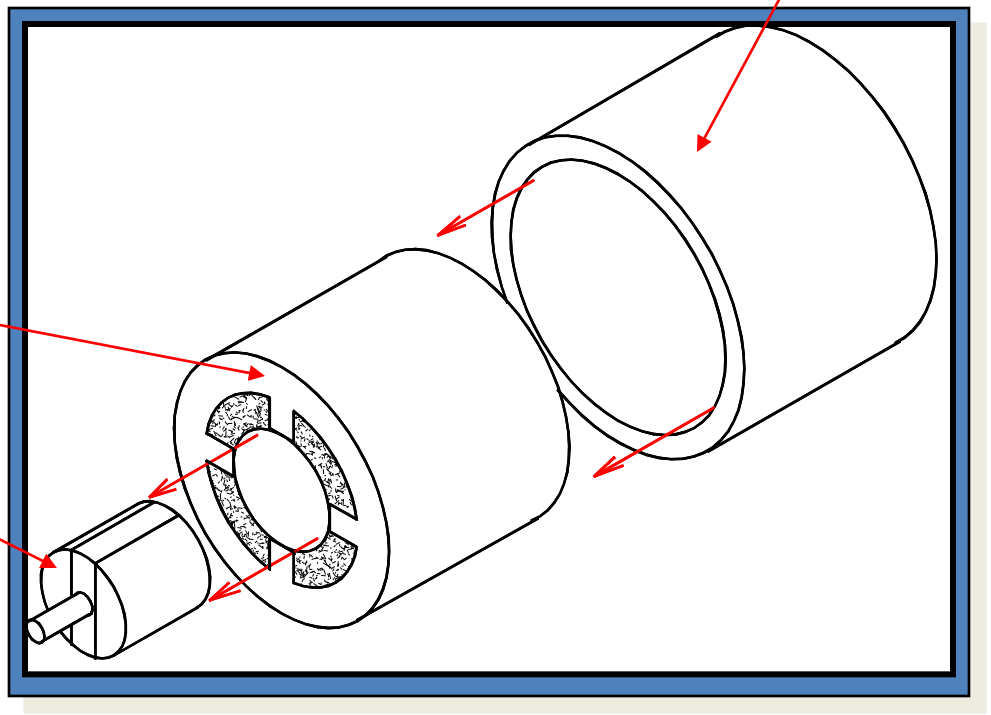
Stator

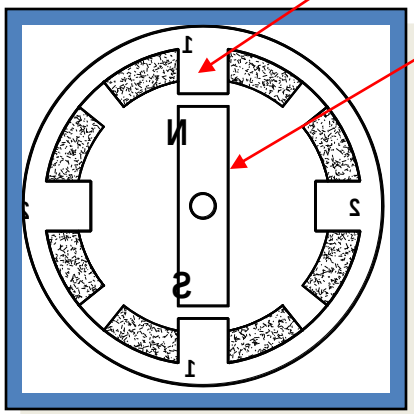
Coils

Outside Casing

Stator

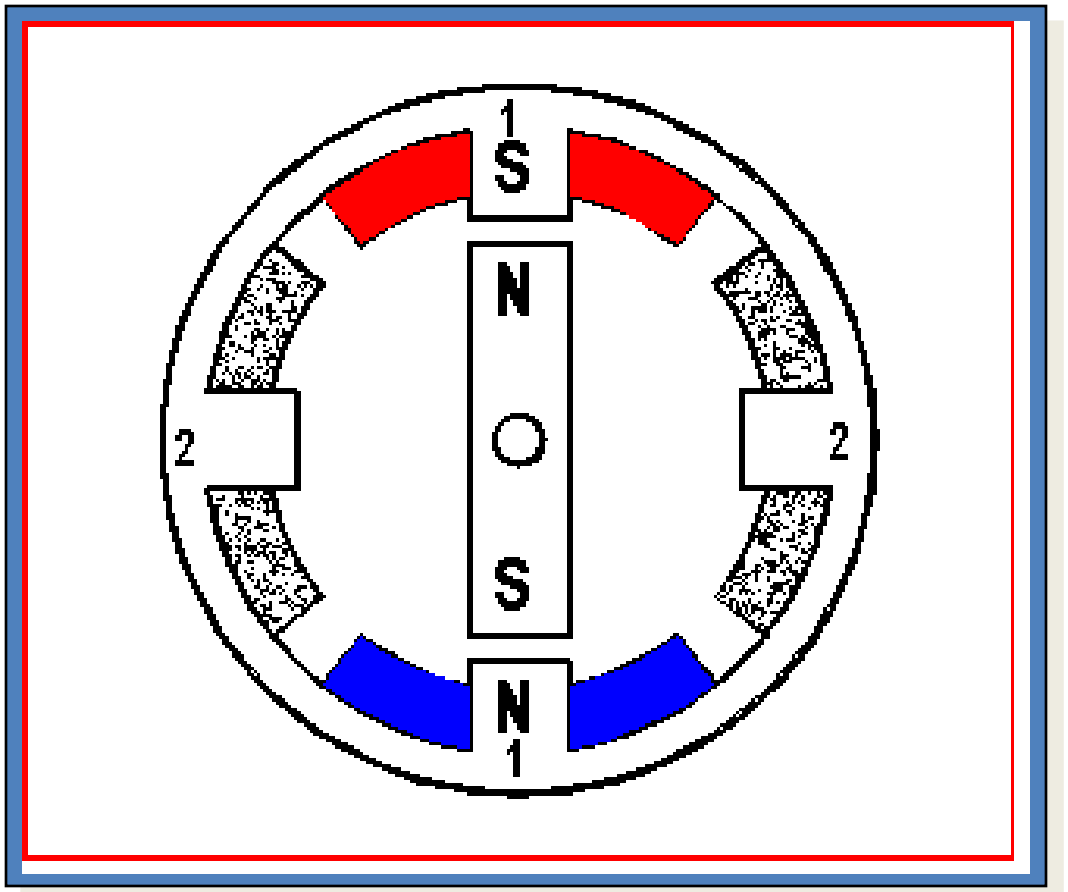
Rotor





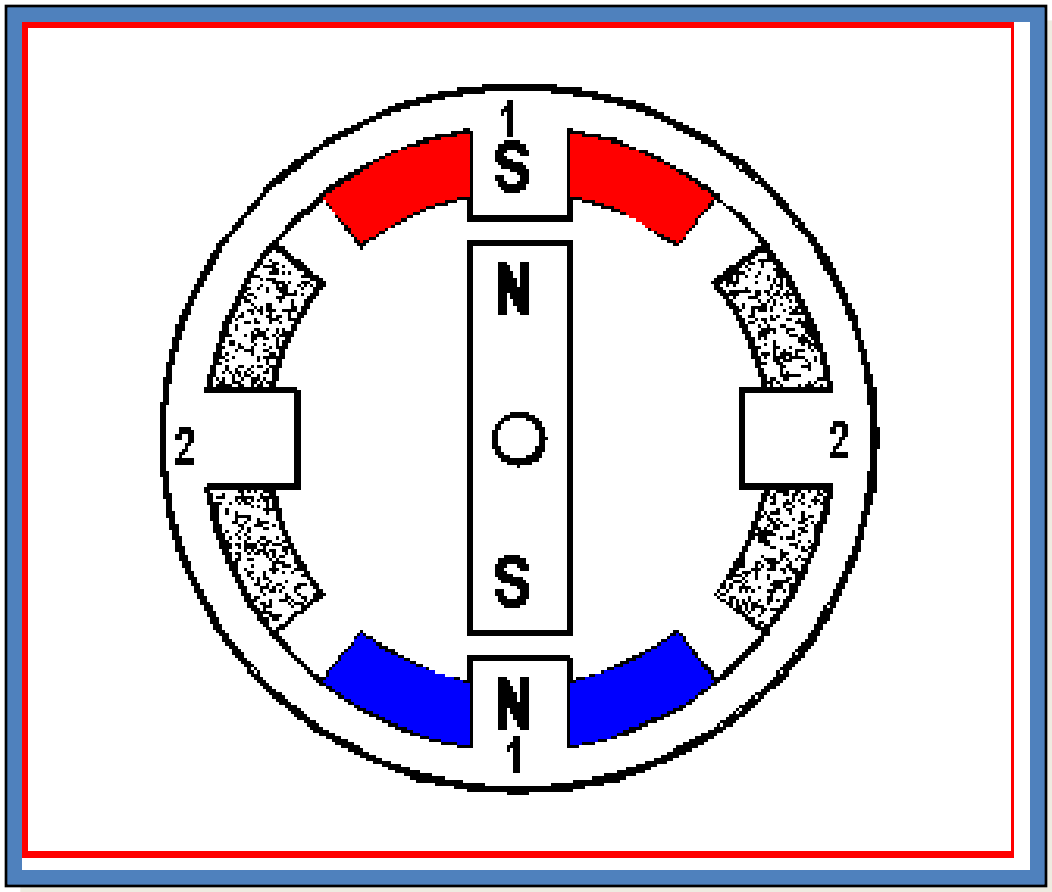
Internal components of a Stepper Motor

Full Step Operation



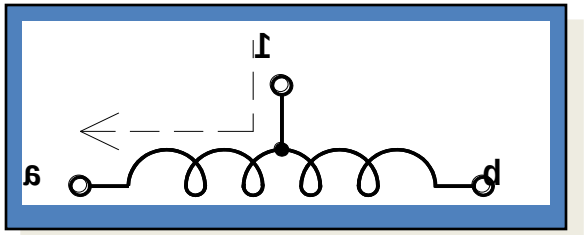
Four Steps per revolution i.e. 90 deg. steps.

Half Step Operation

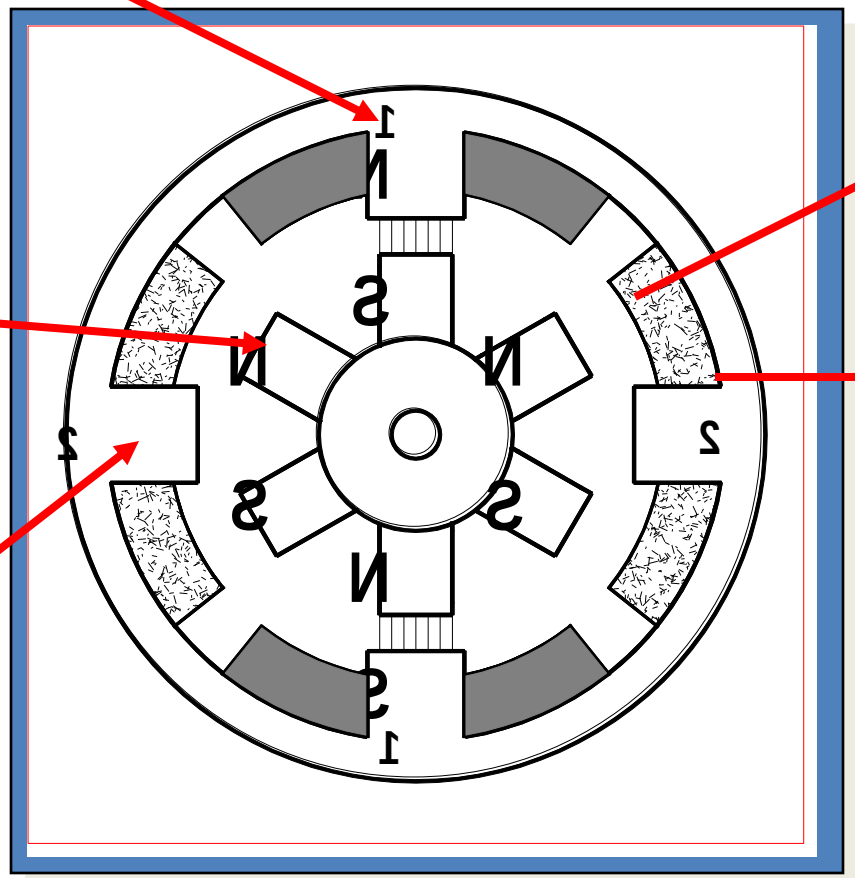


Eight steps per. revolution i.e. 45 deg. steps.

Winding number 1

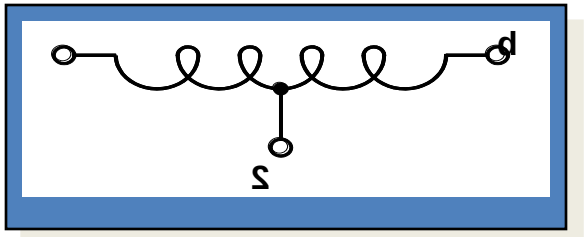


6 pole rotor

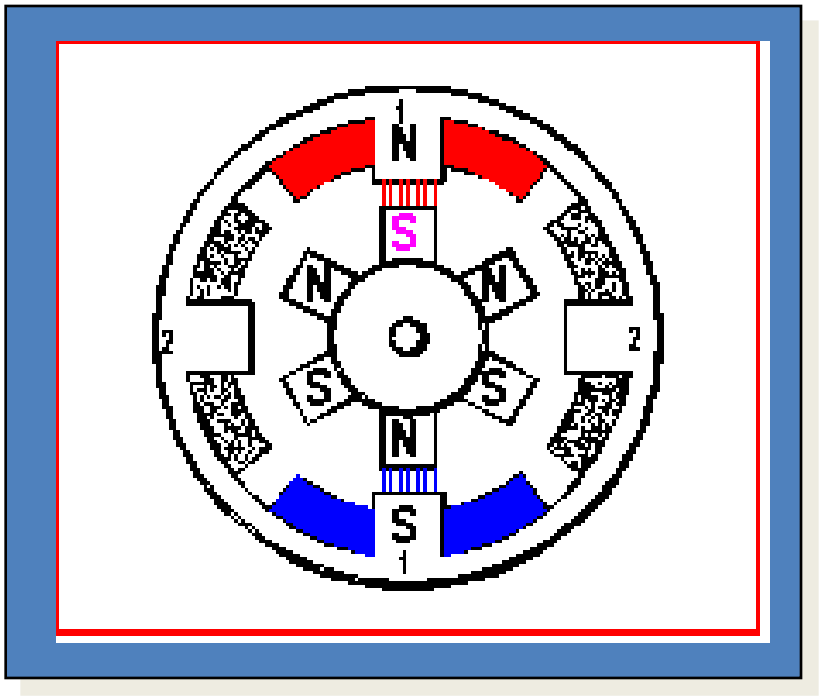


One step

Winding number 2

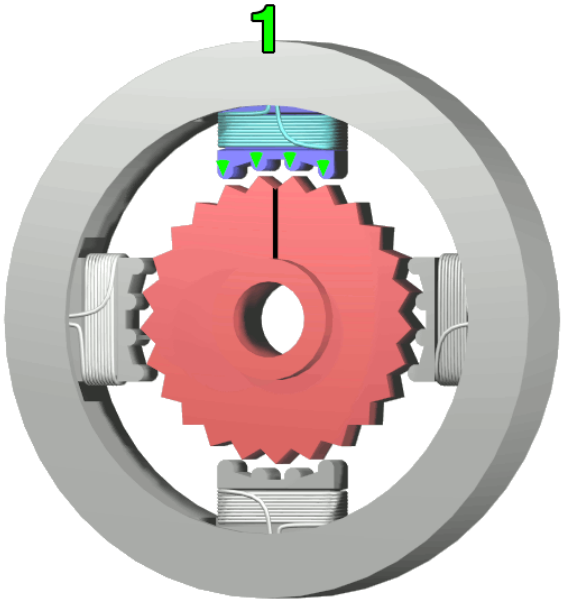


Six pole rotor, two electro magnets.

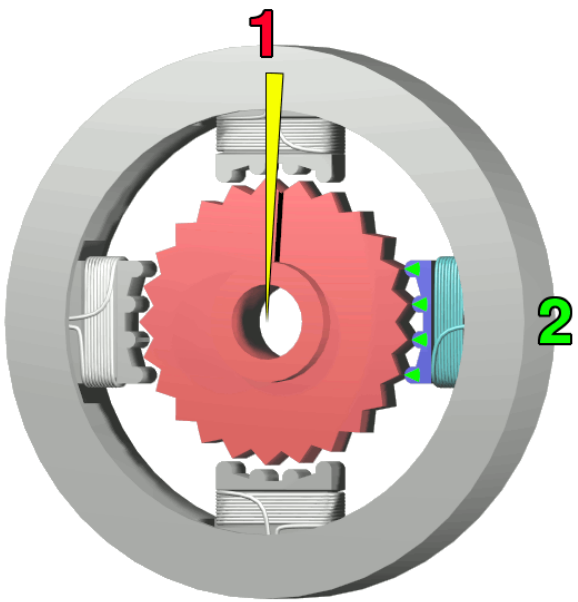


How many steps are required for one complete revolution?

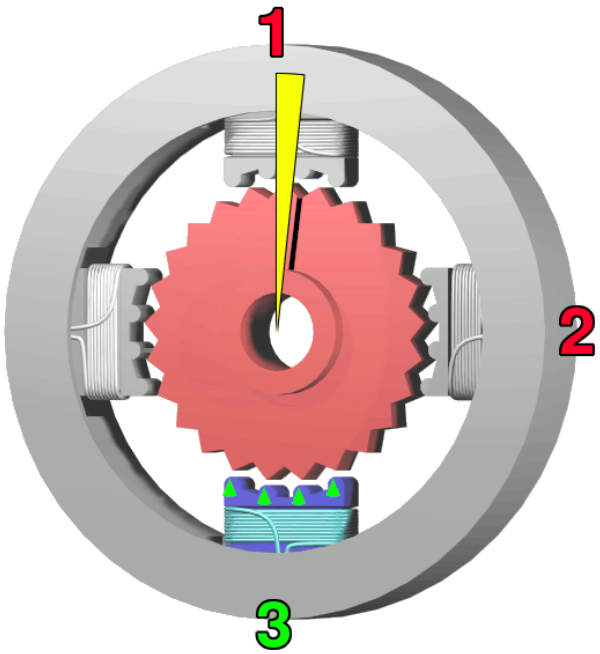
Practical Stepper motor operation



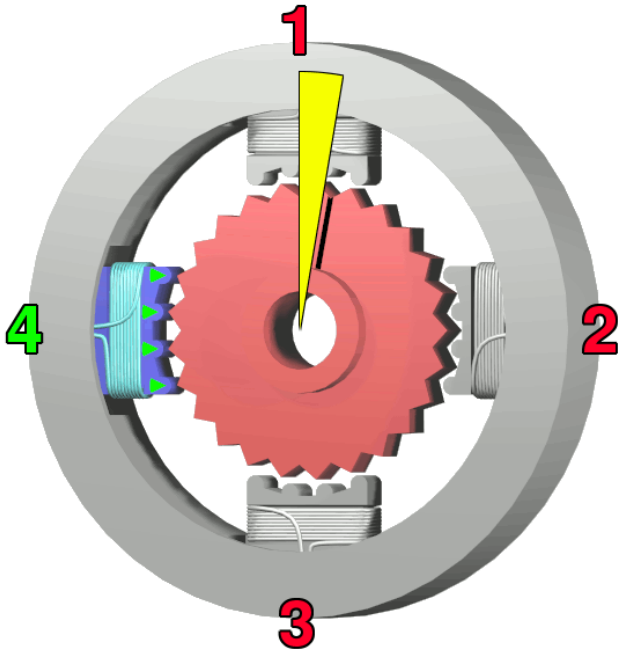
The top electromagnet (1) is turned on, attracting the nearest teeth of a gear-shaped iron rotor. With the teeth aligned to electromagnet 1, they will be slightly offset from electromagnet 2



The top electromagnet (1) is turned off, and the right electromagnet (2) is energized, pulling the nearest teeth slightly to the right. This results in a rotation of 3.6° in this example.

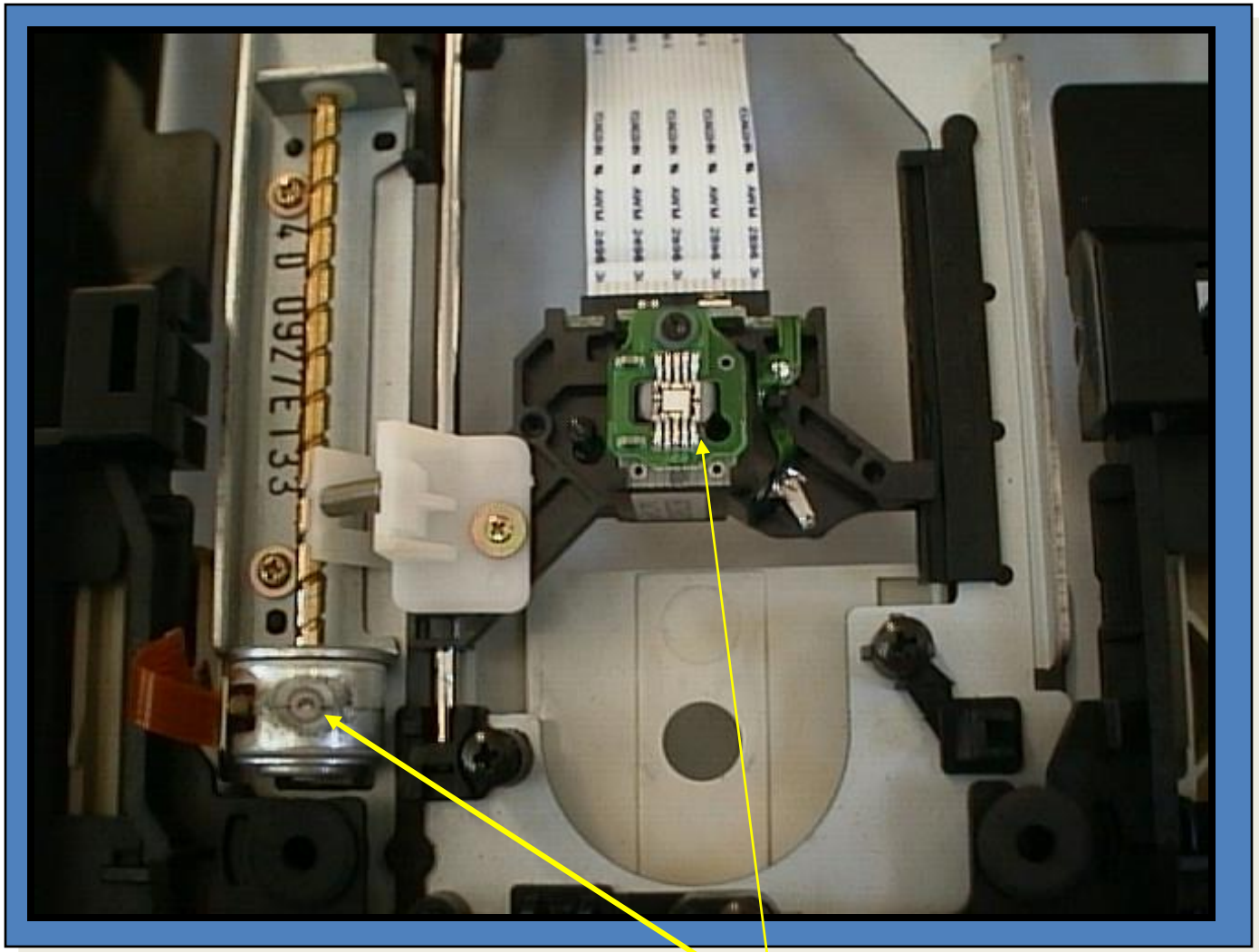


The bottom electromagnet (3) is energized; another 3.6° rotation occurs.



The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again enabled, the teeth in the sprocket will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation in this example.

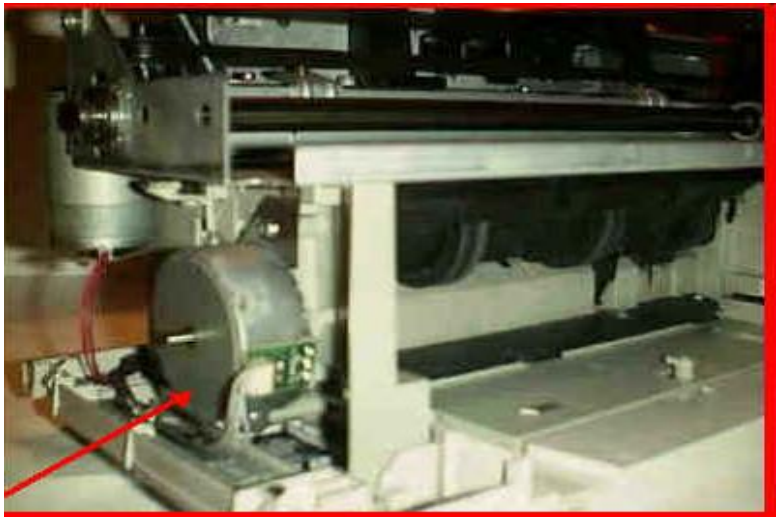
Stepper motor applications



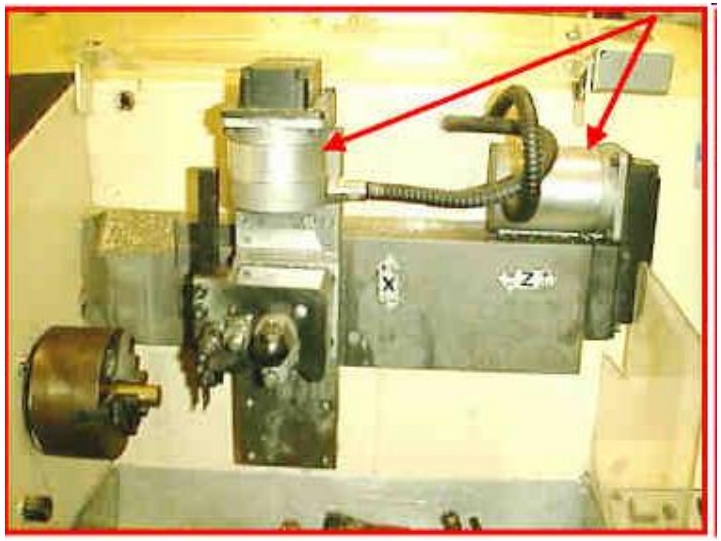
Stepping Motor to move read-write head

Stepper motor applications

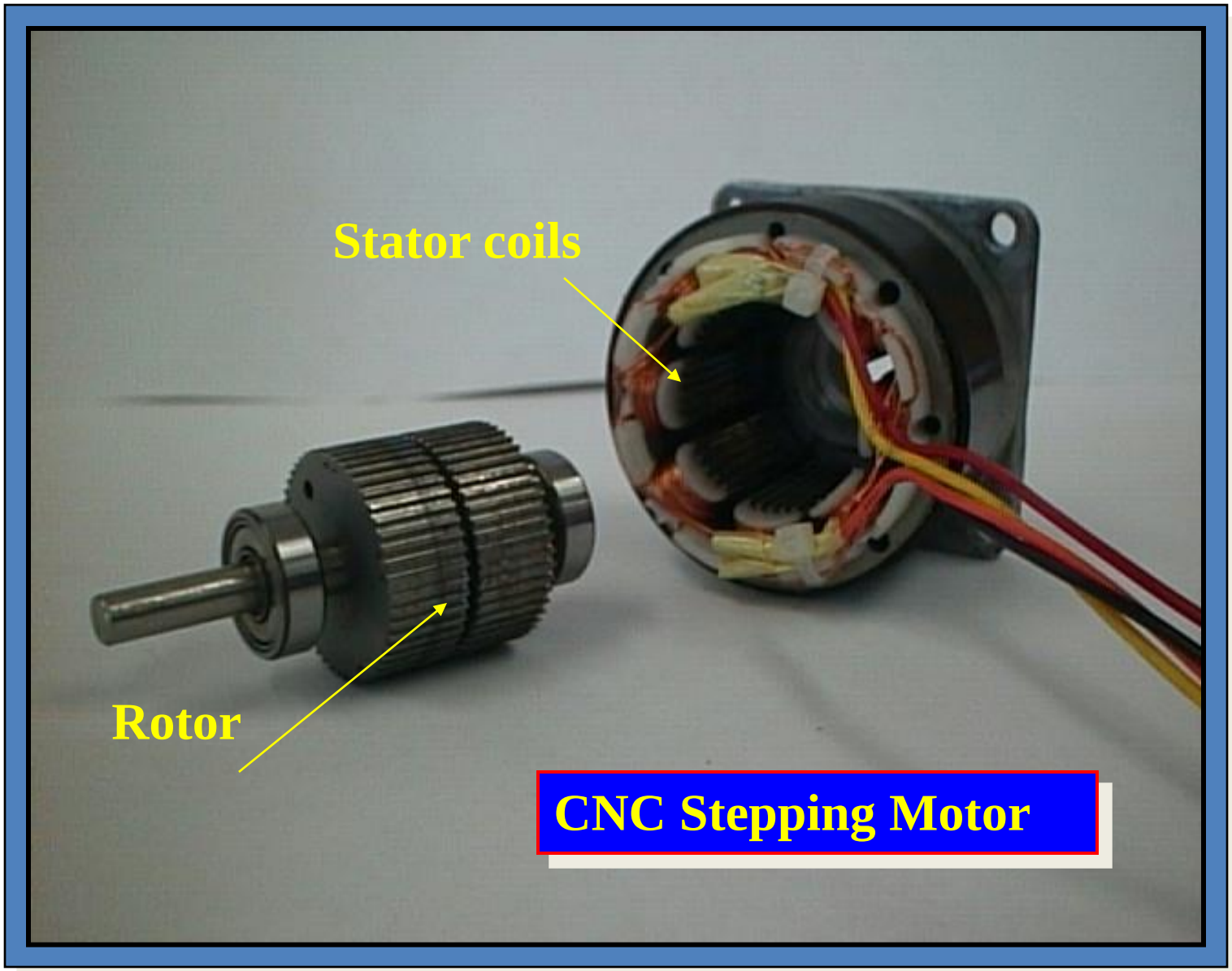
Paper feeder on printers



Stepper motors



CNC lathes


Stator coils
Rotor
CNC Stepping Motor

Advantages / Disadvantages

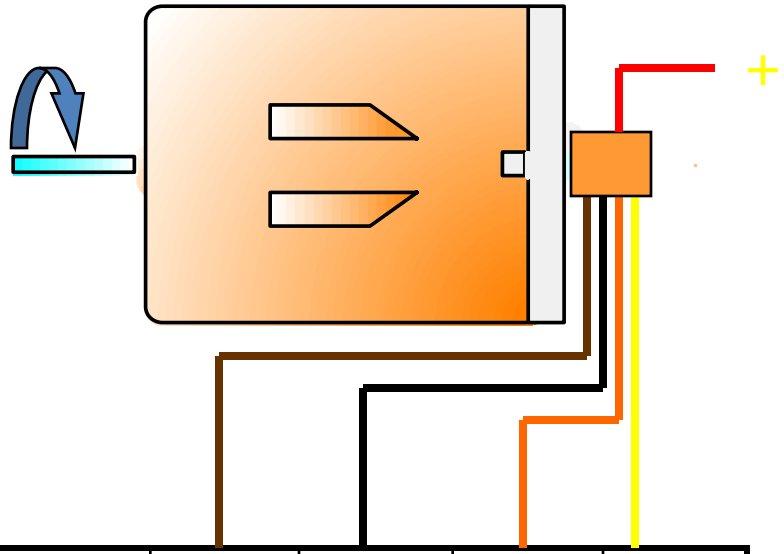
Advantages:-

- Low cost for control achieved
- Ruggedness
- Simplicity of construction
- Can operate in an open loop control system
- Low maintenance
- Less likely to stall or slip
- Will work in any environment

Disadvantages:-

- Require a dedicated control circuit
- Use more current than D.C. motors
- High torque output achieved at low speeds

Control sequence to turn a stepper motor

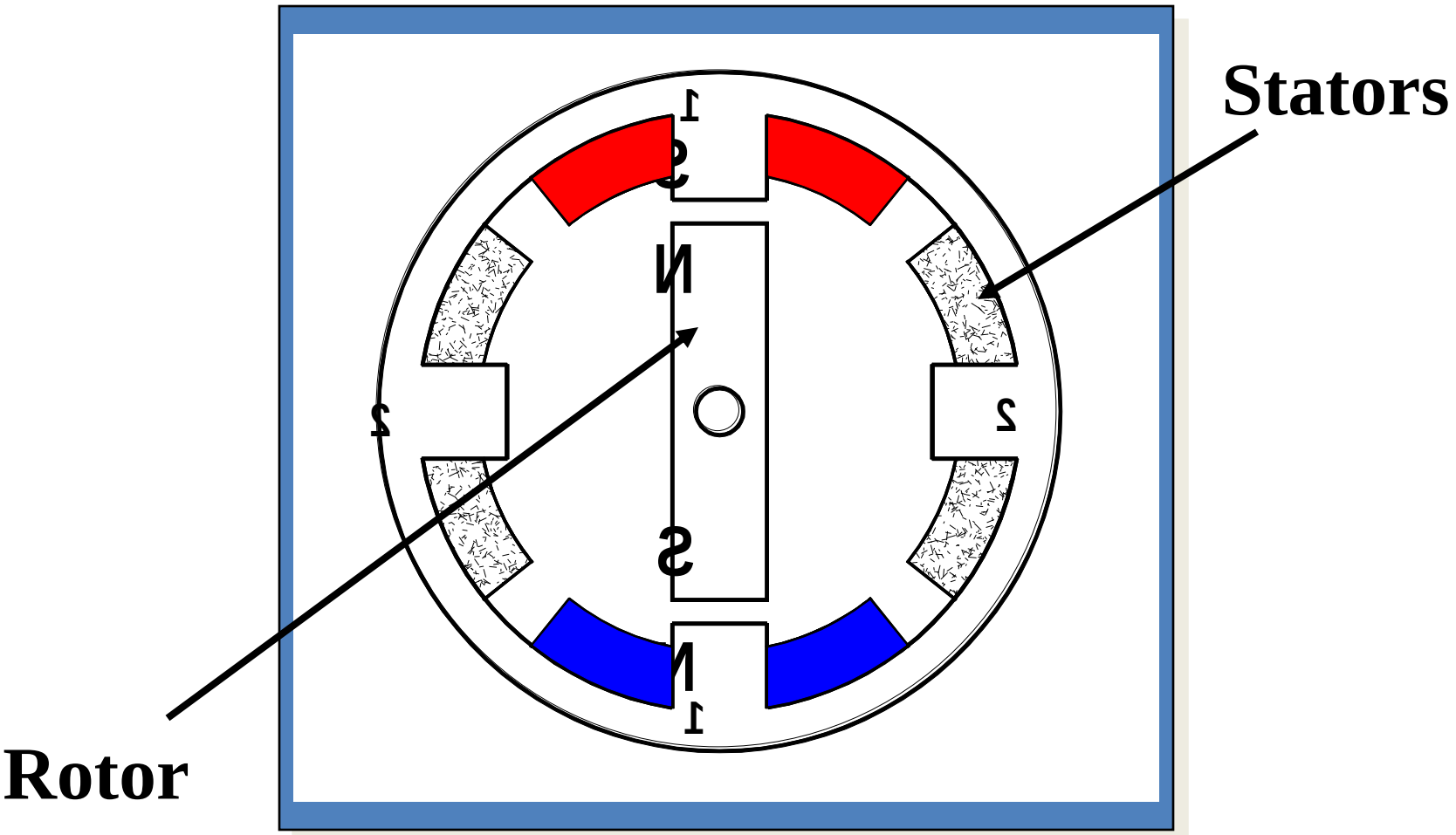


CW

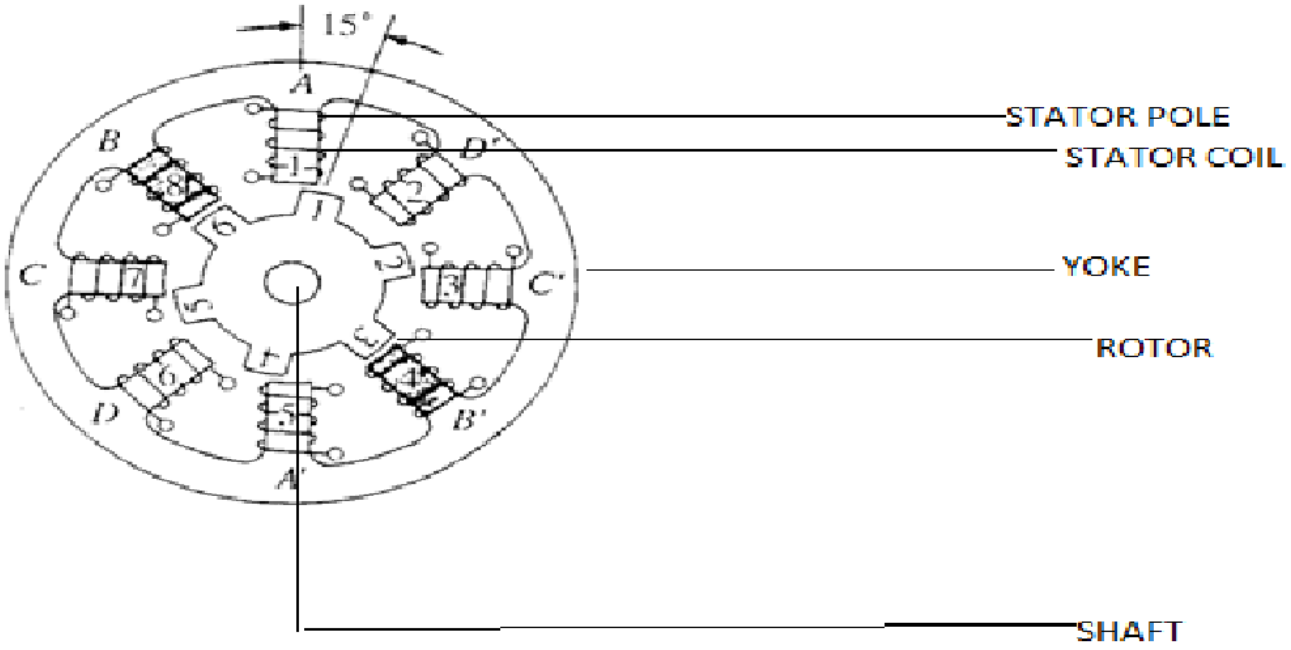
Step 1	0	0	1	1
Step 2	1	0	1	0
Step 3	1	1	0	0
Step 4	0	1	0	1

CCW

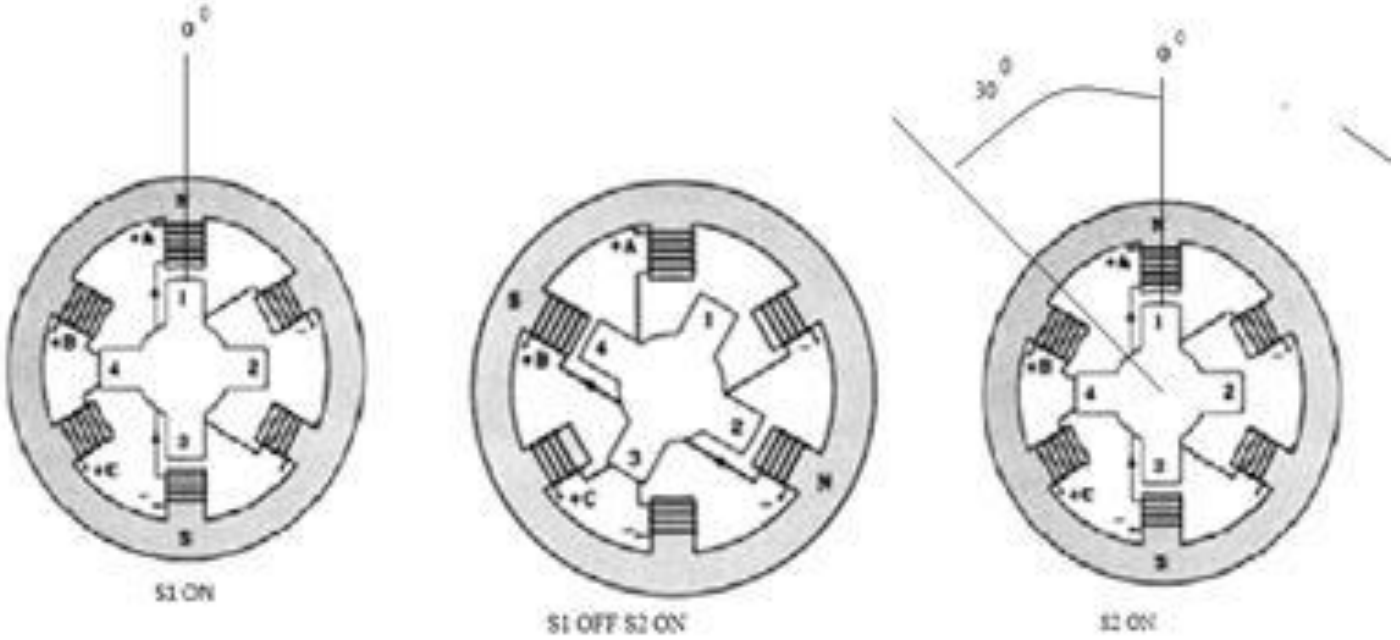
Cross Section of a Stepper Motor



Variable reluctance Stepper Motor – Construction



Variable reluctance Stepper Motor – working principle



Variable reluctance Stepper Motor – 1 phase ON mode

Counter Clockwise Rotation (CCW)

S1	S2	S3	θ
*	–	–	0
–	*	–	30
–	–	*	60
*	–	–	90
–	*	–	120
–	–	*	150
*	–	–	180
–	*	–	210
–	–	*	240
*	–	–	270
–	*	–	300
–	–	*	330
*	–	–	360

Clockwise Rotation (CW)

S1	S2	S3	θ
*	-	-	0
-	-	*	30
-	*	-	60
*	-	-	90
-	-	*	120
-	*	-	150
*	-	-	180
-	-	*	210
-	*	-	240
*	-	-	270
-	-	*	300
-	*	-	330
*	-	-	360

Variable reluctance Stepper Motor – Mode II: Two Phase on Mode

Counter Clockwise Rotation (CCW)

S1	S2	S3	θ°	
*	*	-	15°	AB
-	*	*	45°	BC
-	*	-	75°	CA
*	*	-	105°	AB
-	*	*	135°	BC
-	*	-	165°	CA
*	*	-	195°	AB
-	*	*	225°	BC
-	*	-	255°	CA
*	*	-	285°	AB

Clockwise Rotation (CW) **(C)**

	S1	S2	S3	θ
AC	-	*	-	15°
CB	-	*	*	45°
BA	*	*	-	75°
AC	-	*	-	105°
CB	-	*	*	135°
BA	*	*	-	165°
AC	-	*	-	195°
CB	-	*	*	225°
BA	*	*	-	255°
AC				285°

Variable reluctance Stepper Motor –
Mode III: Half step Mode

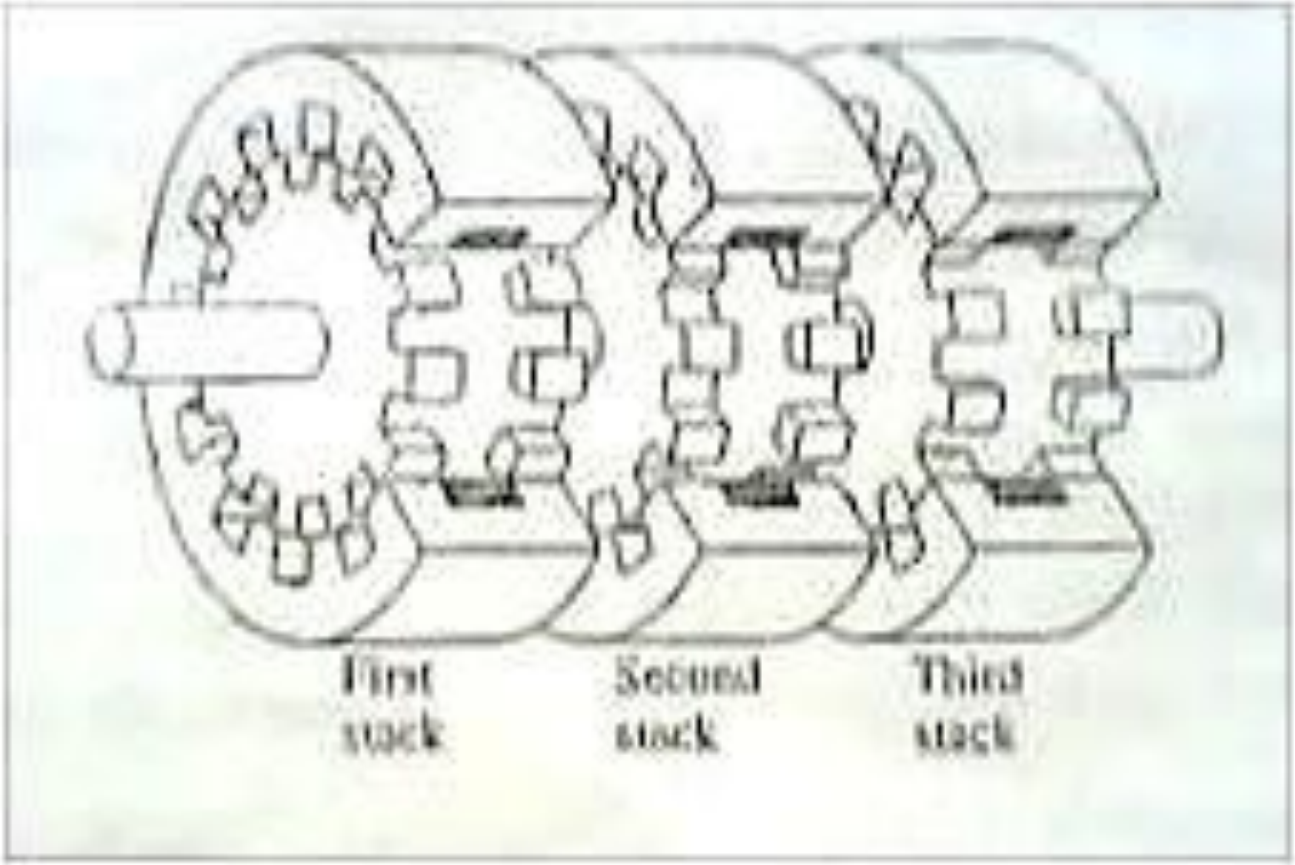
Counter ClockwiseRotation (CCW)

S1	S2	S3	θ	
*	–	–	0°	A°
*	*	–	15°	AB°
–	*	–	30°	B°
–	*	*	45°	BC°
–	–	*	60°	C°
*	–	*	75°	CA°
*	–	–	90°	A°
*	*	–	105°	AB°
–	*	–	120°	B°
–	*	*	135°	BC°
–	*	–	150°	C°
*	–	*	165°	CA°

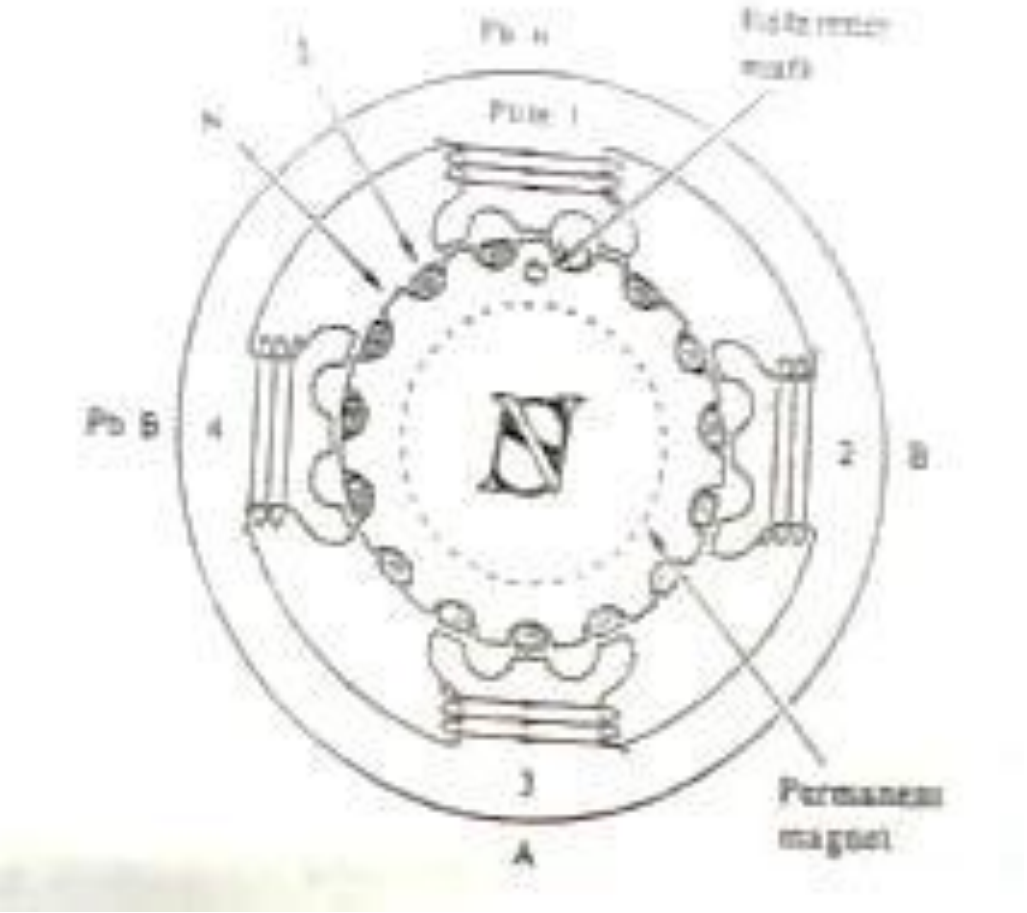
Clockwise Rotation (CW)

S1	S2	S3	θ	
*	-	-	0°	A°
*	-	*	15°	AB°
-	-	*	30°	B°
-	*	*	45°	BC°
-	-	*	60°	C°
-	*	-	75°	CA°
*	*	-	90°	A°
*	-	-	105°	AB°
*	-	*	120°	B°
-	-	-	135°	BC°
-	*	*	150°	C°
-	*	-	165°	CA°

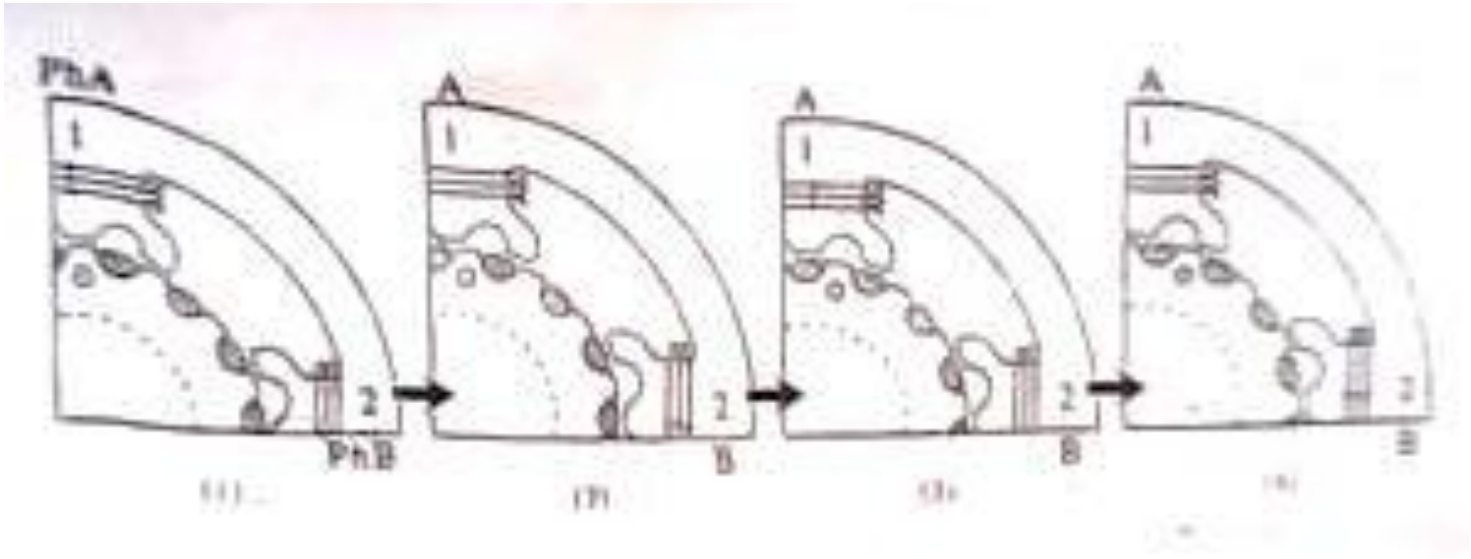
MULTISTACK VARIABLE RELUCTANCE STEPPER MOTOR



HYBRID STEPPER MOTOR



HYBRID STEPPER MOTOR



THEORY OF TORQUE PREDICTION

emf induced $e = -\frac{\partial y}{\partial t}$

Where $\lambda = N\Phi$ or $\lambda = Li$

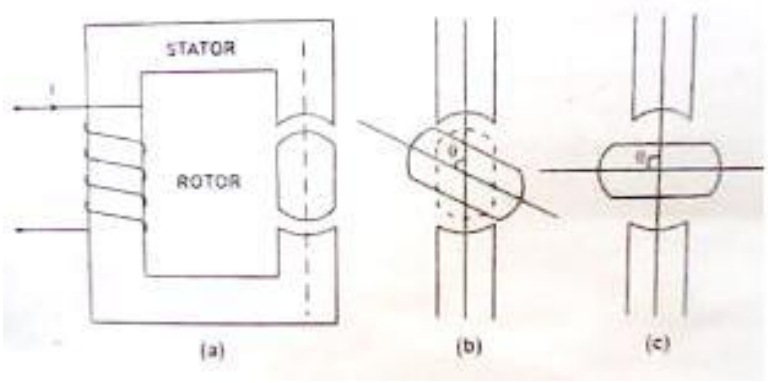
Therefore $e = -\frac{d}{dt}[Li]$

$$= -L\frac{\partial i}{\partial t} - i\frac{\partial L}{\partial t}$$

$$= -L\frac{\partial i}{\partial t} - i\frac{\partial L}{\partial \theta} \times \frac{\partial \theta}{\partial t}$$

$$= -L\frac{\partial i}{\partial t} - i\,\omega\frac{\partial L}{\partial \theta}$$

Magnitude of $e = L\frac{di}{dt} + \omega\, i\frac{\partial L}{\partial \theta}$



THEORY OF TORQUE PREDICTION

Power received from the electrical source = ei

$$\therefore ei = i\,L\frac{di}{dt} + \omega\, i^2\,\frac{\partial L}{\partial \theta}$$

Power due to change in stored energy

$$= Li\frac{di}{dt} + \frac{1}{2}\,\omega\, i^2\,\frac{\partial L}{\partial \theta}$$

Mechanical power developed

$$= i\,L\frac{di}{dt} + \omega\, i^2\,\frac{\partial L}{\partial \theta} + Li\frac{di}{dt} + \frac{1}{2}\,\omega\, i^2\,\frac{\partial L}{\partial \theta}$$

Mechanical power developed

$$Pm = \frac{1}{2}\,\omega i2\frac{\partial L}{\partial \theta}$$

$$Pm = \frac{2\pi NT}{60}$$

$$Pm = \omega T$$

Where $\omega = \frac{2\pi N}{60}$

THEORY OF TORQUE PREDICTION

Therefore reluctance torque $T = \frac{P_m}{\omega}$

Reluctance torque $T = \frac{1}{2} i^2 \frac{\partial L}{\partial \theta}$

Note:

* Torque corresponds to monitoring when $\frac{\partial L}{\partial \theta}$ is +ve.

* Torque corresponds to generating when $\frac{\partial L}{\partial \theta}$ is -ve.

* Torque is proportional to i2 : Therefore it does not depend upon the direction of the current.

CHARACTERISTICS OF STEPPER MOTOR

- **STATIC CHARACTERISTICS**

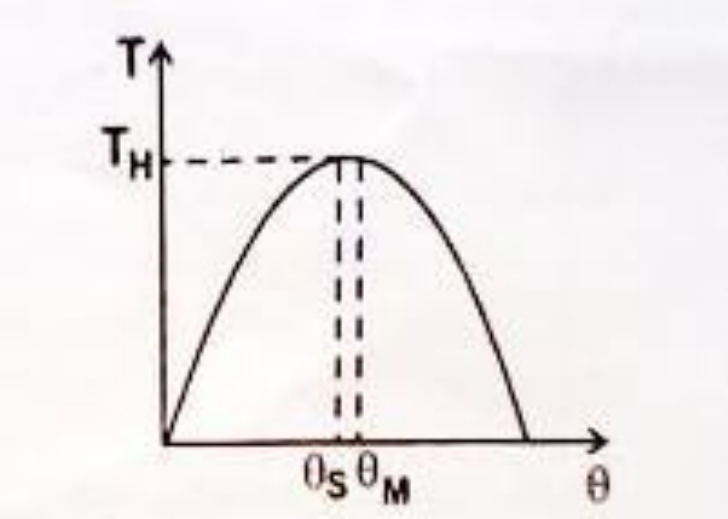
  (i) **Torque Angle curve**
  (ii) **Torque current curve**

- **DYNAMIC CHARACTERISTICS**

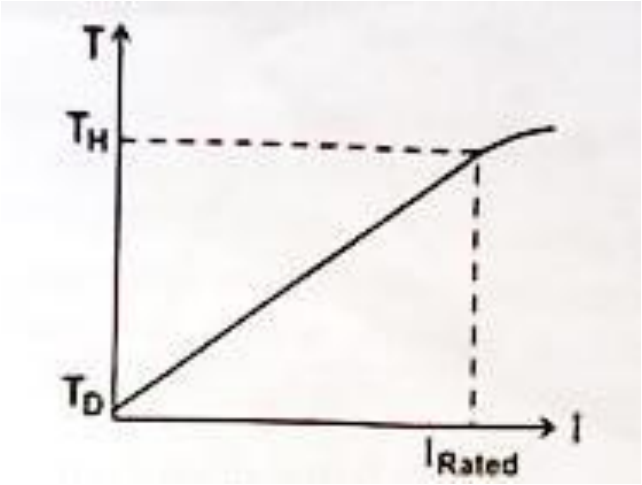
  (i) **Start-Stop mode**
  (ii) **Slewing mode**

STATIC CHARACTERISTICS

TORQUE-ANGLE CURVE

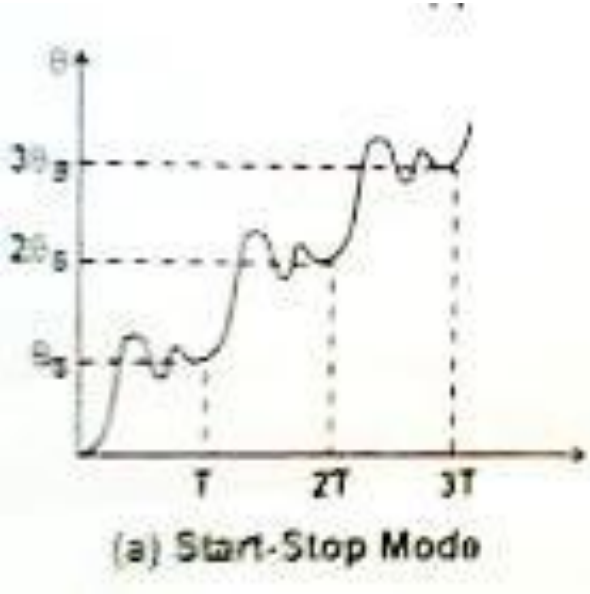


TORQUE- CURRENT CURVE



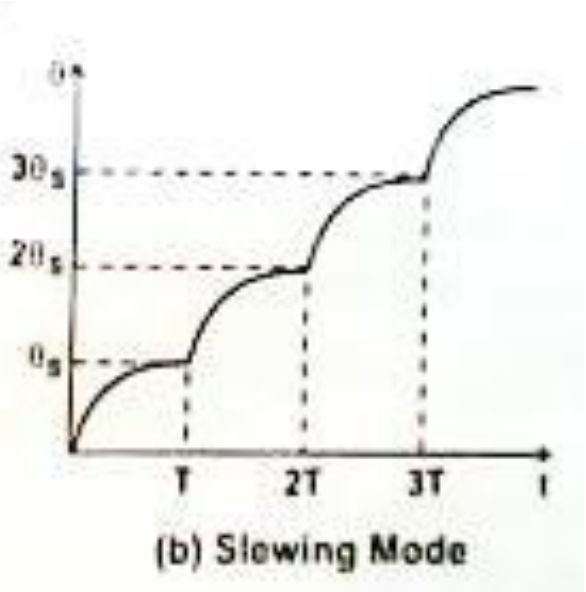
DYNAMIC CHARACTERISTICS

START – STOP MODE



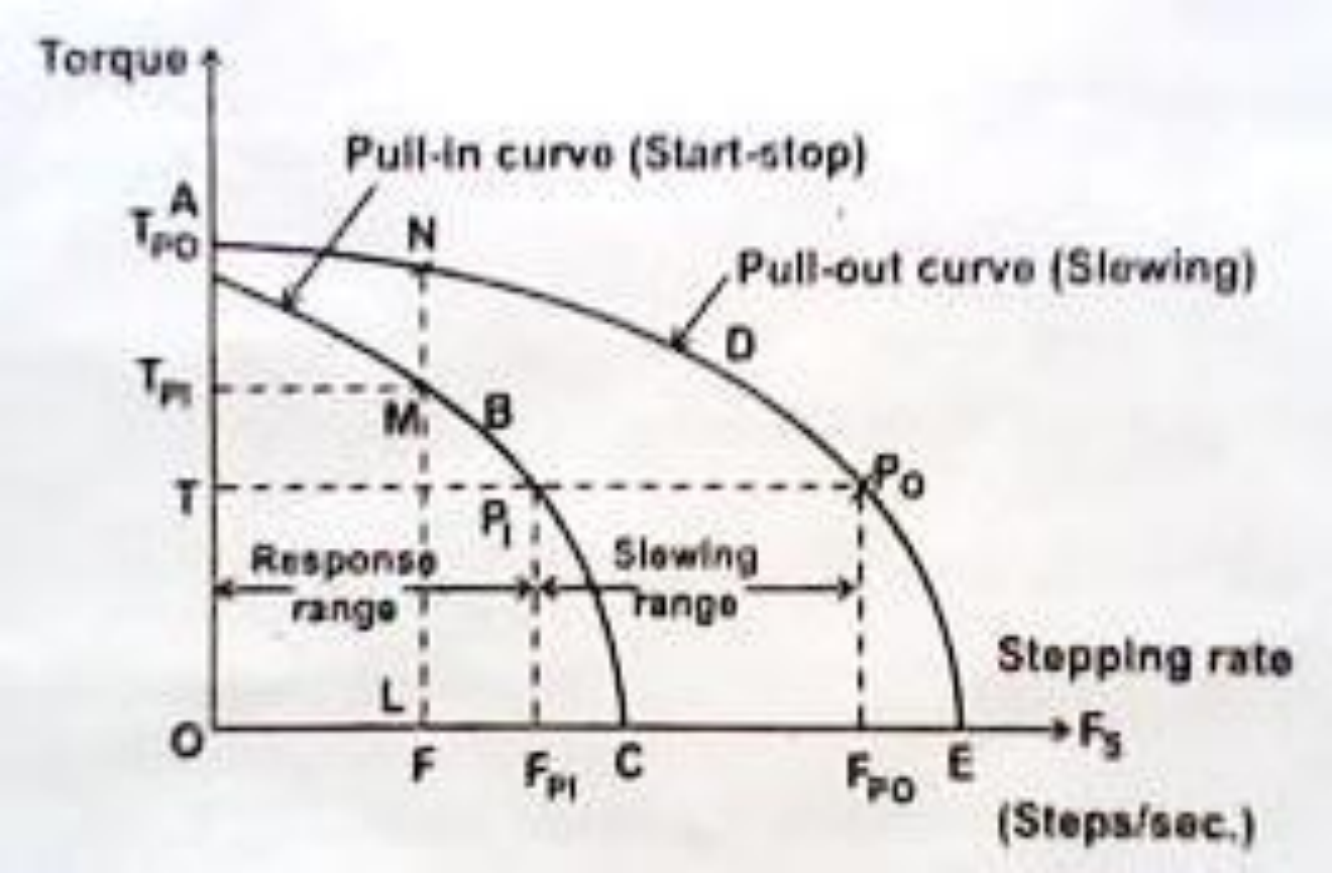
(a) Start-Stop Mode

SLEWING MODE



(b) Slewing Mode

TORQUE-SPEED CHARACTERISTICS



DRIVE SYSTEM AND CONTROL CIRCUITRY FOR STEPPER MOTOR

- DRIVE SYSTEM
- LOGIC SEQUENCER
- POWER DRIVER CIRCUIT
- IMPROVEMENT OF CURRENT BUILDUP/SPECIAL DRIVER CIRCUIT
- SUPPRESSOR CIRCUITS

APPLICATION OF STEPPER MOTOR

1. Instrumentation applications.
2. Computer peripherals & Office equipment's.
3. Numerical control of machine tools and robotics.
4. Applications in semiconductor technology.
5. Space vehicles and satellites.
6. Electro medical and
7. Miscellaneous applications.


Thank you!