Stepper Motors

- The name stepper is used because this motor rotates through a fixed angular step in response to each input current pulse received by its controller.
- In recent years, there has been wide-spread demand of stepping motors because of the explosive growth of the computer industry.
- Their popularity is due to the fact that they can be controlled directly by computers, microprocessors and programmable controllers.

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Stepper Motors

- As we know, industrial motors are used to convert electric energy into mechanical energy but they cannot be used for precision positioning of an object or precision control of speed without using closed-loop feedback.
- Stepping motors are ideally suited for situations where either precise positioning or precise speed control or both are required in automation systems.
- The unique feature of a stepper motor is that its output shaft rotates in a series of discrete angular intervals or steps, one step being taken each time a command pulse is received.

Stepper Motors

- When a definite number of pulses are supplied, the shaft turns through a definite known angle. This fact makes the motor well-suited for open-loop position control because no feedback need be taken from the output shaft.
- Such motors develop torques ranging from 1 μN-m (in a tiny wrist watch motor of 3 mm diameter) up to 40 N-m in a motor of 15 cm diameter suitable for machine tool applications.
- Their power output ranges from about 1 W to a maximum of 2500 W.
- The only moving part in a stepping motor is its rotor which has no windings, commutator or brushes. This feature makes the motor quite robust and reliable.

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Stepper Motors

- Applications
  - Such motors are used for operation control in computer peripherals, textile industry, IC fabrications and robotics etc.
  - Applications requiring incremental motion are type writers, line printers, tape drives, floppy disk drives, numerically-controlled machine tools, process control systems and X-Y plotters.
  - Stepper motors also perform countless tasks outside the computer industry. It includes commercial, military and medical applications where these motors perform such functions as mixing, cutting, striking, metering, blending and purging.
  - They also take part in the manufacture of packed food stuffs, commercial end-products and even the production of science fiction movies

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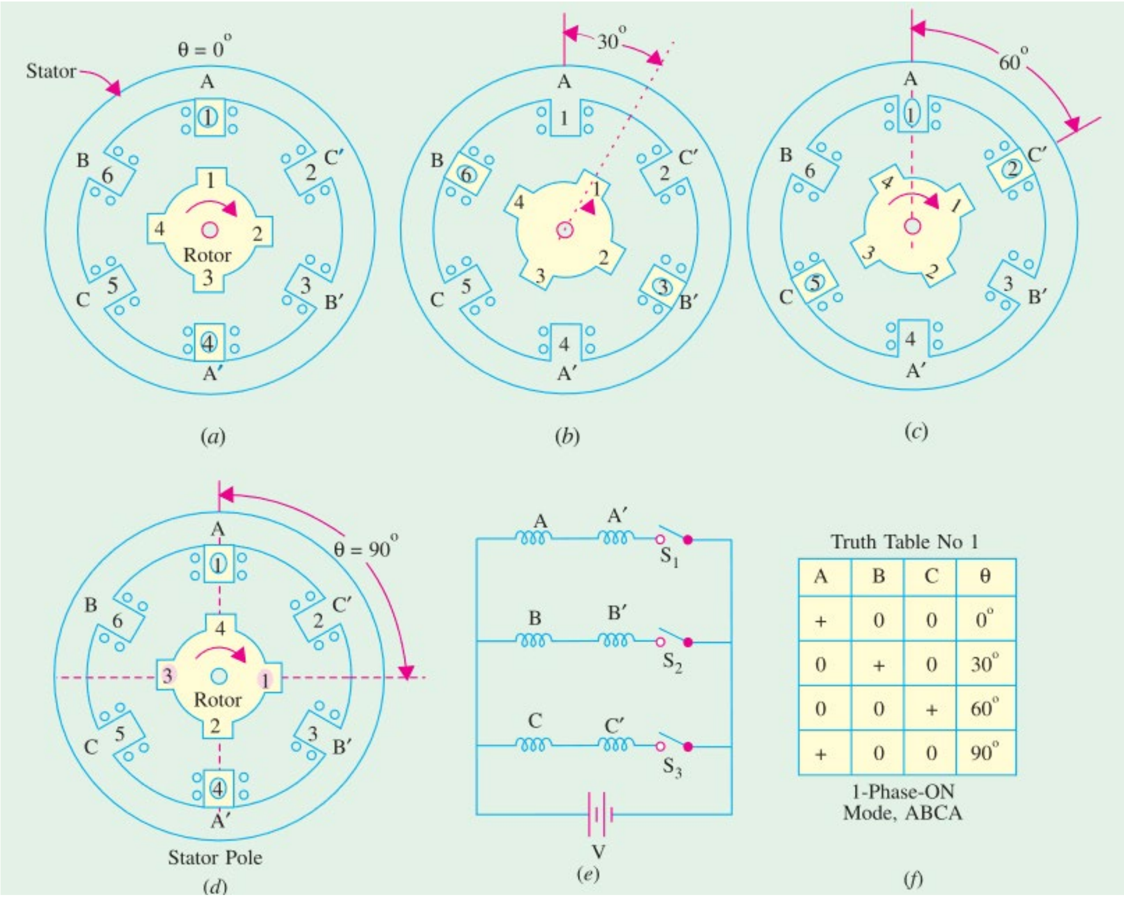
Stepper Motors

- Types of Stepper Motors
  1. Variable Reluctance Stepper Motor (VR Stepper Motor)
  2. Permanent Magnet Stepper Motor (PM Stepper Motor)
  3. Hybrid Stepper Motor

Stepper Motors

<u>1. VR Stepper Motor</u>

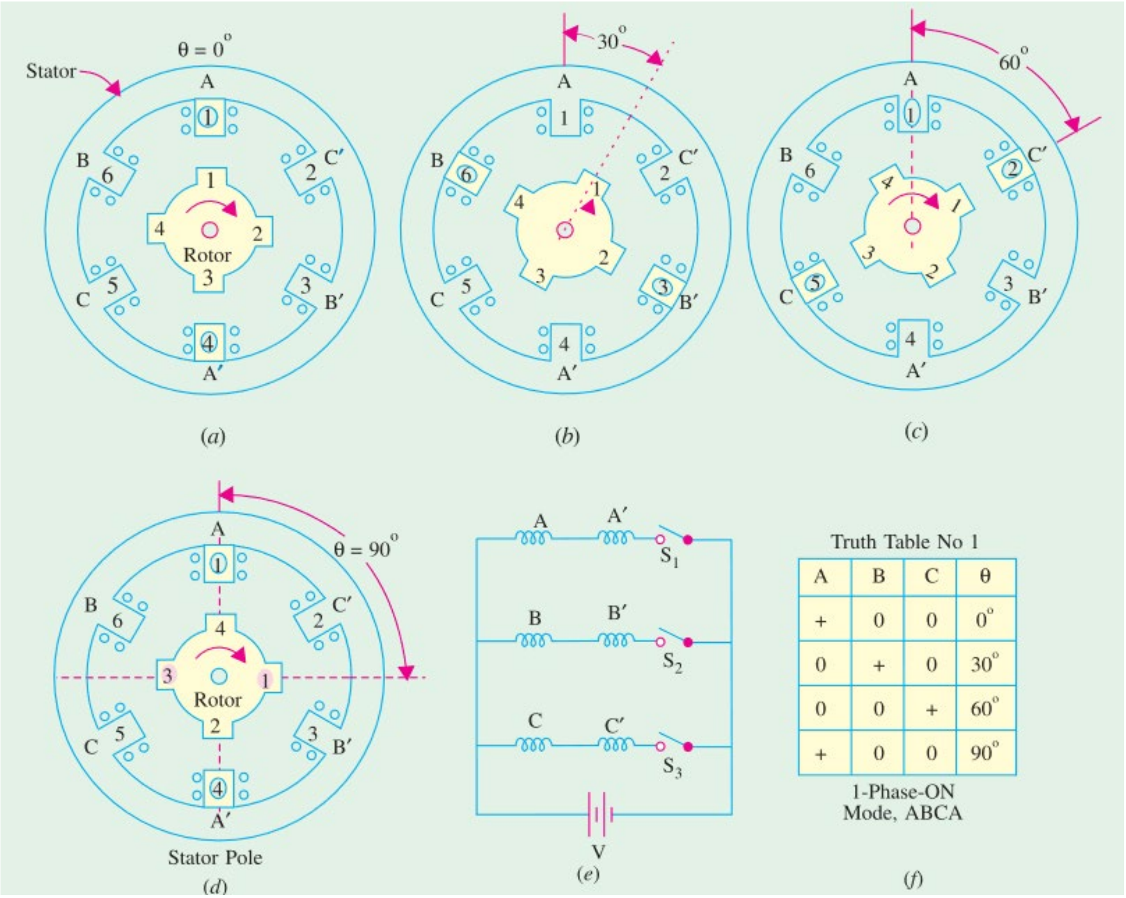
- It is constructed from ferromagnetic material with salient poles as shown in the figure.
- The stator is made from a stack of steel laminations and has equally-spaced projecting poles (or teeth) each wound with an exciting coil.
- The rotor which may be solid or laminated has four projecting teeth of the same width as the stator teeth.
- As seen, there are three independent stator circuits or phases A, B and C and each one can be energized by a direct current pulse from the drive circuit (not shown in the figure).



A	B	C	θ
+	0	0	0°
0	+	0	30°
0	0	+	60°
+	0	0	90°

Stepper Motors

- A simple circuit arrangement for supplying current to the stator coils in proper sequence is shown in Fig. (e).
- The six stator coils are connected in 2-coil groups to form three separate circuits called phases.
- Each phase has its own independent switch. Diametrically opposite pairs of stator coils are connected in series such that when one tooth becomes a N-pole, the other one becomes a S-pole. Although shown as mechanical switches in Fig. (e), in actual practice, switching of phase currents is done with the help of solid-state control.



A	B	C	θ
+	0	0	0°
0	+	0	30°
0	0	+	60°
+	0	0	90°

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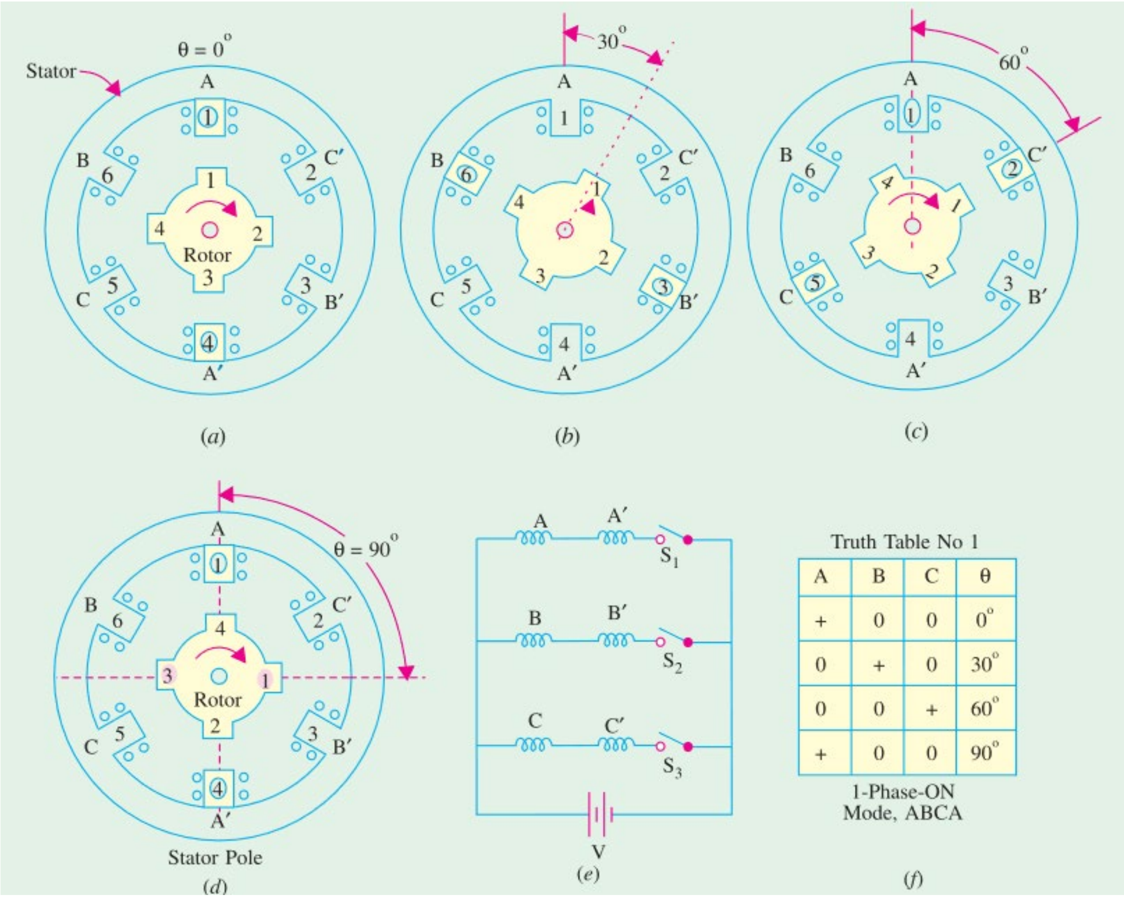
Stepper Motors

- The angle through which the motor shaft rotates for each command pulse is called the **step angle** β.
- Smaller the step angle, greater the number of steps per revolution and higher the resolution or accuracy of positioning obtained.
- The step angles can be as small as 0.72^0 or as large as 90^0. But the most common step sizes are 1.8^0, 2.5^0, 7.5^0 and 15^0.
- The value of step angle can be expressed either in terms of the rotor and stator poles (teeth) N_r and N_s respectively or in terms of the number of stator phases (m) and the number of rotor teeth.



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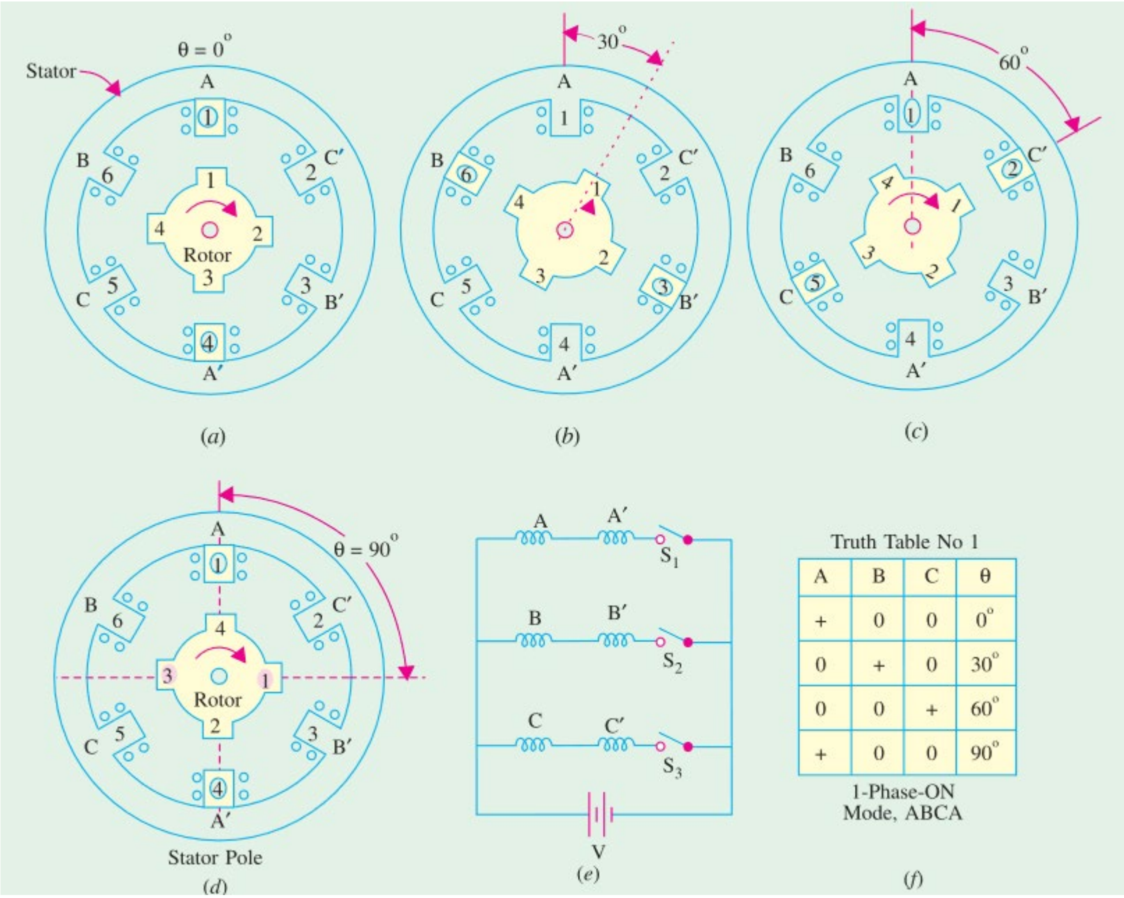
Stepper Motors

- The value of step angle can be expressed either in terms of the rotor and stator poles (teeth) N_r and N_s respectively or in terms of the number of stator phases (m) and the number of rotor teeth.

$$\beta = \frac{N_s - N_r}{N_s N_r} \times 360°$$

$$\beta = \frac{360°}{m N_r}$$

$$= \frac{360°}{\text{No. of stator phases} \times \text{No. of rotor teeth}}$$



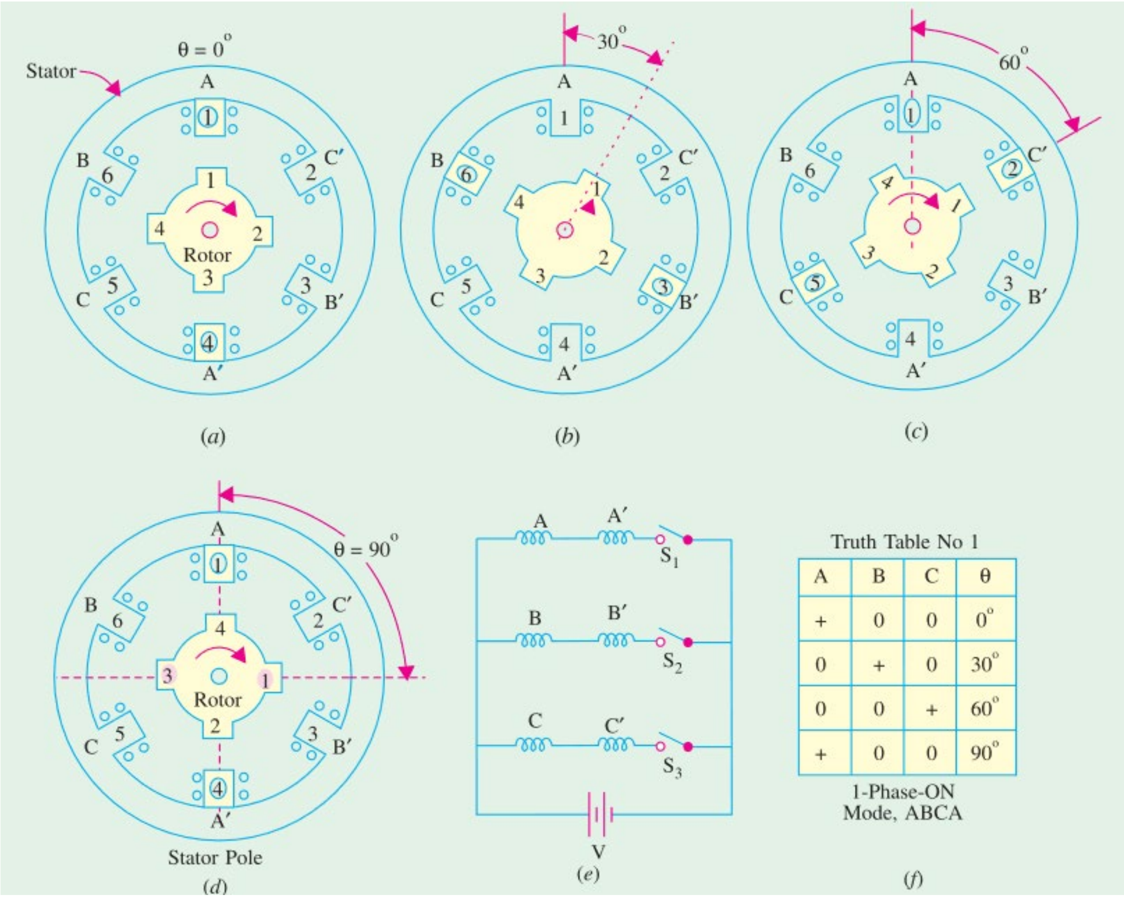
Stepper Motors

- Resolution is given by the number of steps needed to complete one revolution of the rotor shaft. Higher the resolution, greater the accuracy of positioning of objects by the motor

$$\text{Resolution} = \frac{\text{No. of steps}}{\text{revolution}} = \frac{360°}{\beta}$$

- If f is the stepping frequency (or pulse rate) in pulses per second (pps) and β is the step angle, then motor shaft speed is given by

$$\eta = \frac{\beta \times f}{360°} \text{ rev. per second}$$



A	B	C	θ
+	0	0	0°
0	+	0	30°
0	0	+	60°
+	0	0	90°

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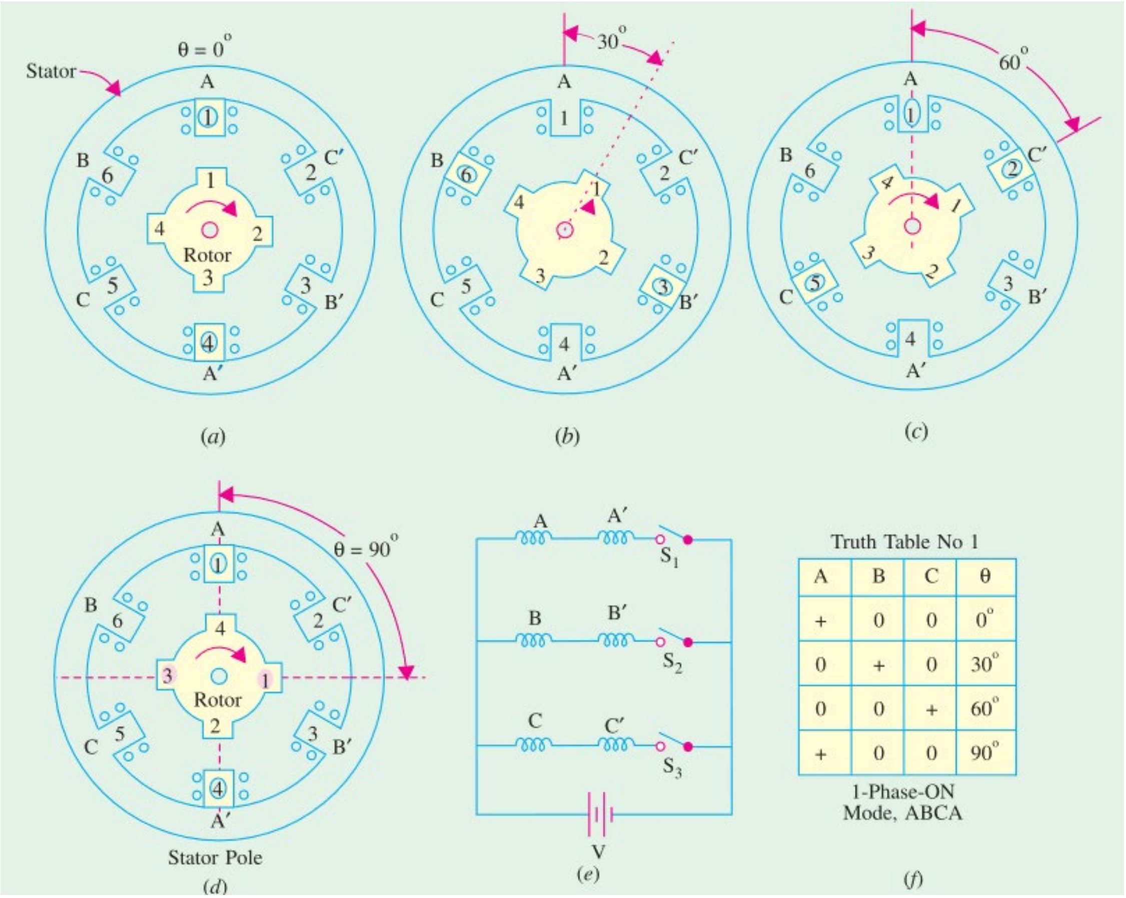
Stepper Motors

- When there is no current in the stator coils, the rotor is completely free to rotate.
- Energizing one or more stator coils causes the rotor to step forward (or backward) to a position that forms a path of least reluctance with the magnetized stator teeth.
- The step angle of this three-phase, four rotor teeth motor is $\beta = 360^0/(3 \times 4) = 30^0$



Stepper Motors

- Modes of operations
  - 1-phase-ON or Full-step Operation

    In this mode, only one phase is energized per each step

    Energizing sequence: A, B, C, A, B, … (Table 1)

    $$\beta = 30^0$$

  - 2-phase-ON Mode

    In this mode, two phases are energized simultaneously per each step

    Energizing sequence: AB, BC, CA, AB, BC, … (Table 2)

    $$\beta = 30^0$$

  - Half-step Operation

    This mode is obtained by exciting the phases alternately in the 1-phase-ON and 2-phase-ON modes

    Energizing sequence: A, AB, B, BC, C, CA, … (Table 3)

    $$\beta = 15^0$$

Truth Table No 1

A	B	C	θ
+	0	0	0°
0	+	0	30°
0	0	+	60°
+	0	0	90°

1-Phase-ON Mode, ABCA

Truth Table No. 2

A	B	C	q
+	+	0	15°
0	+	+	45°
+	0	+	75°
+	+	0	105°

2 Phase-ON Mode
AB, BC, CA, AB

Truth Table No. 3

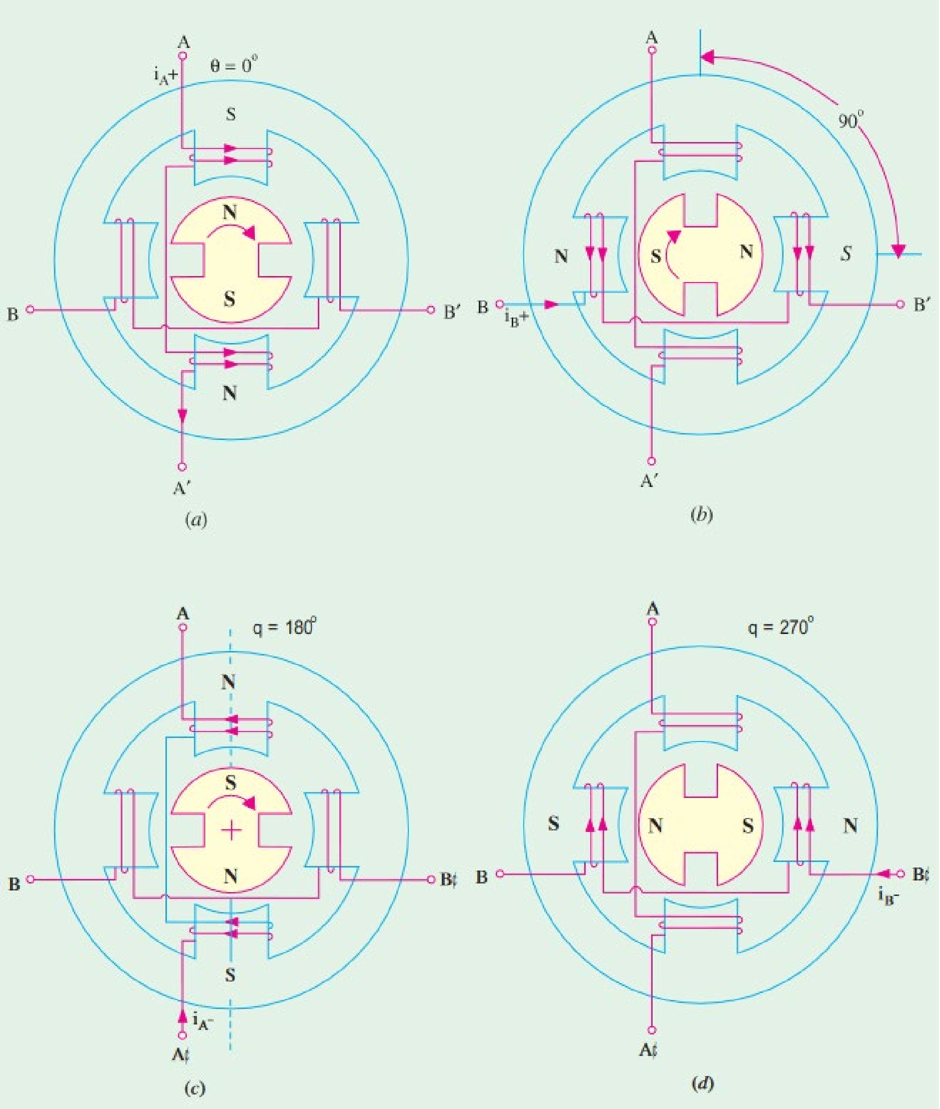
	A	B	C	q	
A	+	0	0	0°	
	+	+	0	15°	AB
B	0	+	0	30°	
	0	+	+	45°	BC
C	0	0	+	65°	
	+	0	+	75°	CA
A	+	0	0	90°	

Half-Stepping Alternate 1-Phase-On & 2-Phase-on Mode
A, AB, B, BC, C, CA, A

Stepper Motors

<u>2. PM Stepper Motor</u>

- Its stator construction is similar to that of the single-stack VR motor but the rotor is made of a permanent-magnet material like magnetically 'hard' ferrite.
- The stator has projecting poles but the rotor is cylindrical and has radially magnetized permanent magnets.
- The operating principle of such a motor can be understood with the help of Fig. (a) where the rotor has two poles and the stator has four poles. Since two stator poles are energized by one winding, the motor has two windings or phases marked A and B.



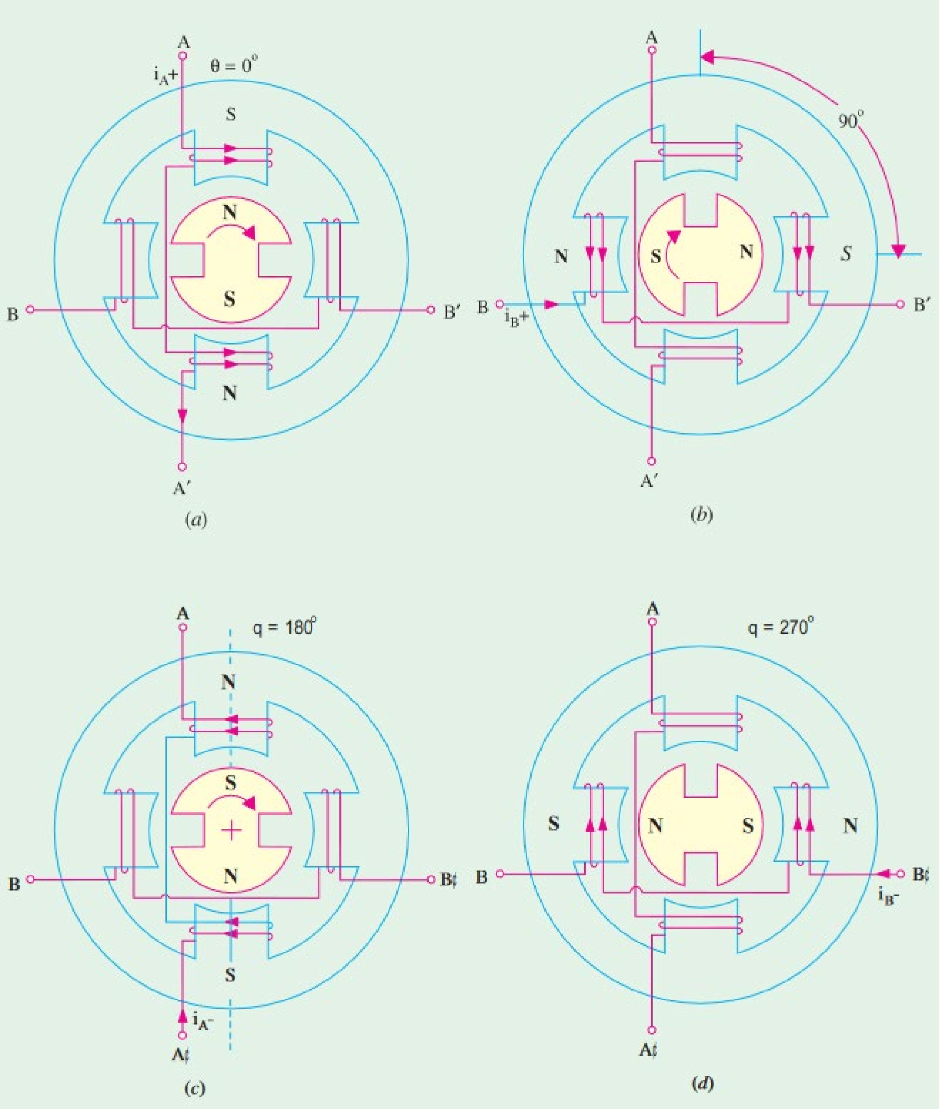
Stepper Motors

- The step angle of this motor

$$\beta = \frac{N_s - N_r}{N_s N_r} \times 360° = \frac{4-2}{4 \times 2} \times 360° = 90°$$

$$\beta = \frac{360°}{mN_r} = \frac{360°}{2 \times 2} = 90°$$

- *Advantages and Disadvantages*:
  - Since the permanent magnets of the motor do not require external exciting current, it has a low power requirement but possesses a high detent torque as compared to a VR stepper motor.
  - This motor has higher inertia and hence slower acceleration. However, it produces more torque per ampere stator current than a VR motor.
  - Since it is difficult to manufacture a small permanent-magnet rotor with large number of poles, the step size in such motors is relatively large ranging from 30º to 90º.



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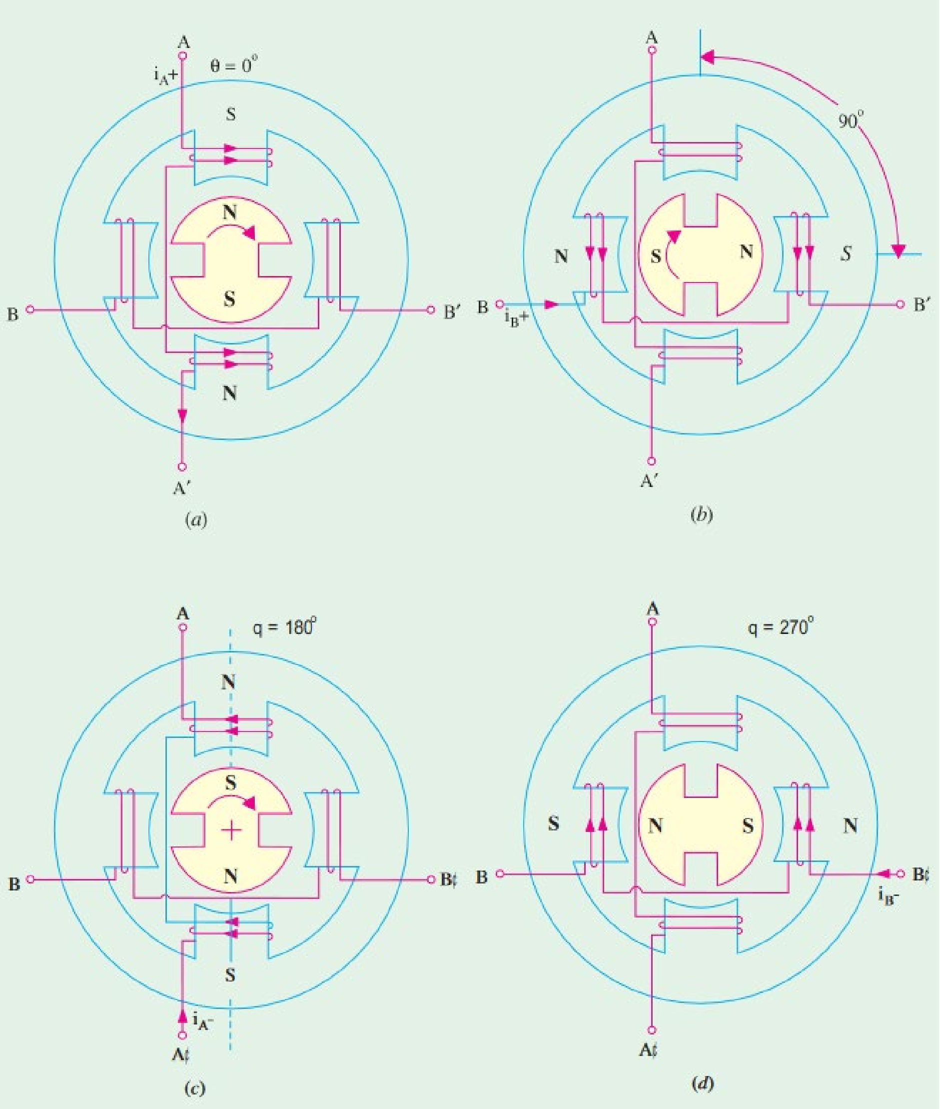
Stepper Motors

Working

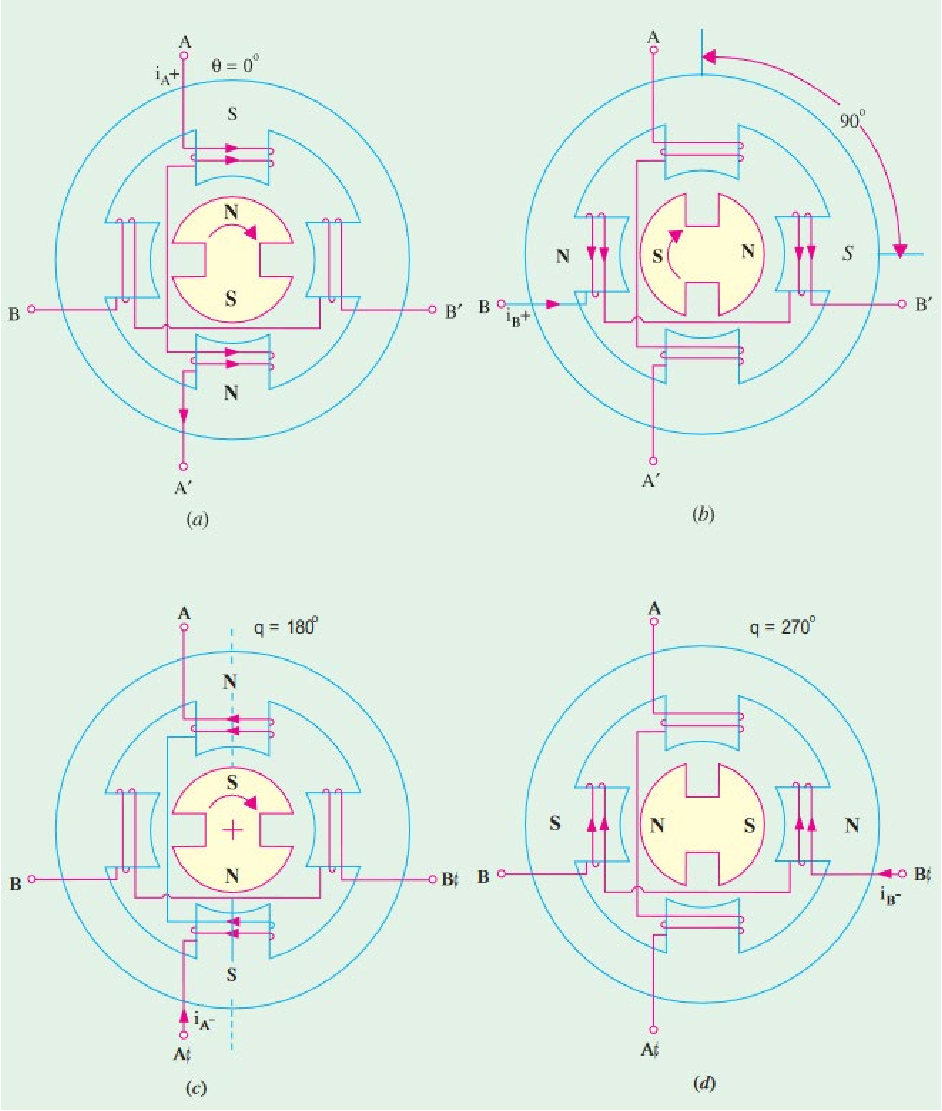
- When a particular stator phase is energized, the rotor magnetic poles move into alignment with the excited stator poles.
- The stator windings A and B can be excited with either polarity current (A^+ refers to positive current i_A^+ in the phase A and A^- to negative current i_A^-).
- Fig. (a) shows the condition when phase A is excited with positive current i_A^+ . Here, θ = 0º.
- If excitation is now switched to phase B as in Fig. (b), the rotor rotates by a full step of 90º in the clockwise direction.



Dr. Mahran Quraan

Stepper Motors

- Next, when phase A is excited with negative current i_A^-, the rotor turns through another 90º in CW direction as shown in Fig. (c).
- Similarly, excitation of phase B with i_B^- further turns the rotor through another 90º in the same direction as shown in Fig. (d).
- After this, excitation of phase A with i_A^+ makes the rotor turns through one complete revolution of 360º.



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Stepper Motors

- *Modes of operations*
  - 1-phase-ON or Full-step Operation

  In this mode, only one phase is energized per each step

  Energizing sequence: $A^+, B^+, A^-, B^-, A^+, B^+, \ldots$ (Table 1)

  $$\beta = 90^0$$

  - 2-phase-ON Mode

  In this mode, two phases are energized simultaneously per each step

  Energizing sequence: $A^+B^+, A^-B^+, A^-B^-, A^+B^-, \ldots$ (Table 2)

  $$\beta = 90^0$$

  - Half-step Operation

  This mode is obtained by exciting the phases alternately in the 1-phase-ON and 2-phase-ON modes

  Energizing sequence: $A^+, A^+B^+, B^+, A^-B^+, A^-, B^-, \ldots$ (Table 3)

  $$\beta = 45^0$$

Truth Table No. 1

A	B	q
+	0	0°
0	+	90°
-	0	180°
0	-	270°
+	0	0°

1-Phase-ON Mode

Truth Table No. 2

A	B	q
+	+	45°
-	+	135°
-	-	225°
+	-	315°
+	+	45°

1-Phase-ON Mode

Truth Table No. 3

A	B	q
+	0	0°
+	+	45°
0	+	90°
-	+	135°
-	0	180°
-	-	225°
0	-	270°
+	-	315°
+	0	0°

Alternate 1-Phase-On & 2-Phase-On Modes

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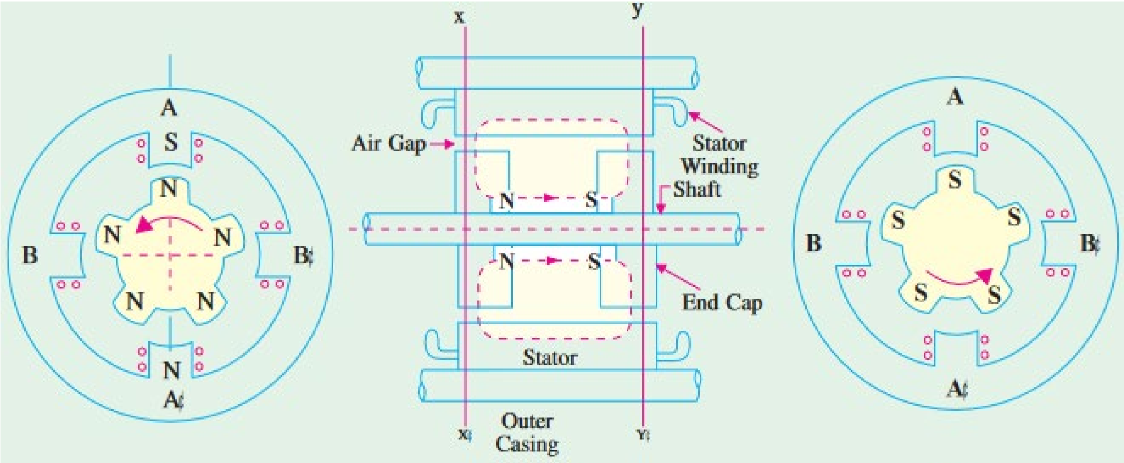
Stepper Motors

3. Hybrid Stepper Motor

- It combines the features of the variable reluctance and permanent-magnet stepper motors.
- As compared to VR motor, hybrid motor requires less excitation to achieve a given torque. However, like a PM motor, this motor also develops good detent torque provided by the permanent-magnet flux. This torque holds the rotor stationary while the power is switched off. This fact is quite helpful because the motor can be left overnight without fear of its being accidentally moved to a new position.
- The rotor consists of a permanent-magnet that is magnetized axially to create a pair of poles marked N and S in Fig. (b).
- Two end-caps are fitted at both ends of this axial magnet. These end-caps consist of equal number of teeth which are magnetized by the respective polarities of the axial magnet.

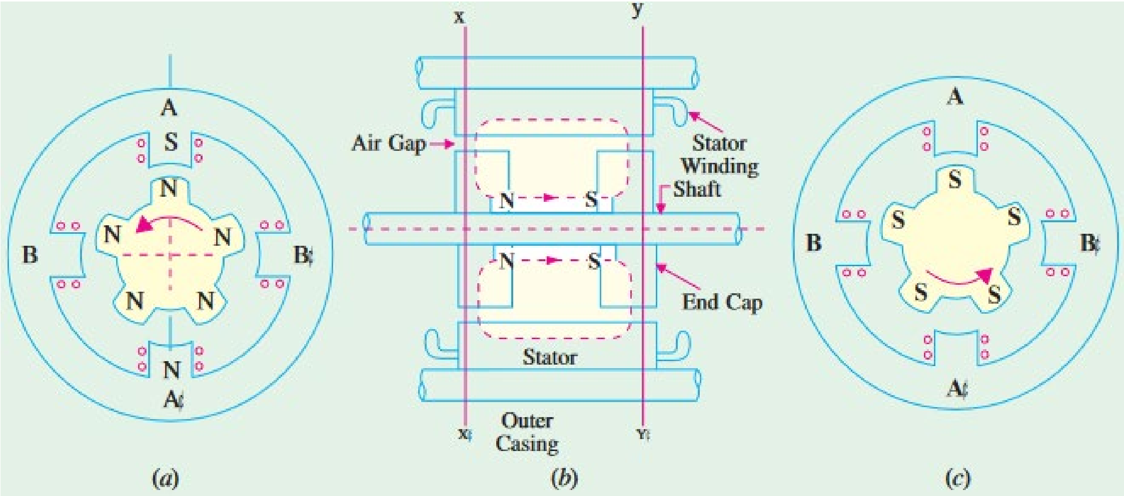


(a) (b) (c)

Stepper Motors

- The rotor teeth of one end-cap are offset by a half tooth pitch so that a tooth at one end-cap coincides with a slot at the other.
- The cross-sectional views perpendicular to the shaft along X-X′ and Y-Y′ axes are shown in Fig. (a) and (c) respectively.
- As seen, the stator consists of four stator poles which are excited by two stator windings in pairs. The rotor has five N-poles at one end and five S-poles at the other end of the axial magnet. The step angle of such a motor is

$$= (5 - 4) \times 360^{\circ} / (5 \times 4) = 18^{\circ}.$$



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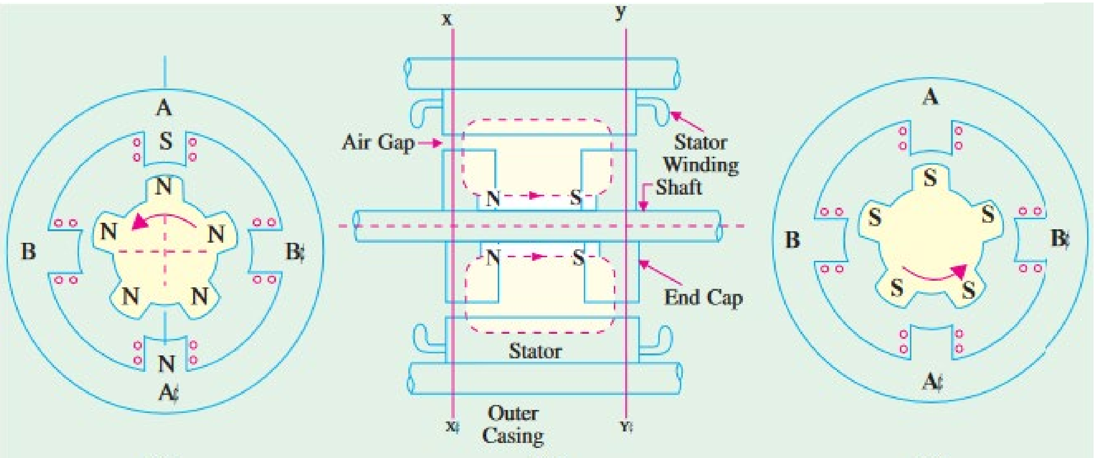
Stepper Motors

Working

- In Fig. (a), phase A is shown excited such that the top stator pole is a S-pole so that it attracts the top N-pole of the rotor and brings it in line with the A-A′ axis.
- To turn the rotor, phase A is denergized and phase B is excited positively. The rotor will turn in the CCW direction by a full step of 18º.
- Next, phase A and B are energized negatively one after the other to produce further rotations of 18º each in the same direction.
- For producing clockwise rotation, the phase sequence should be A+; B−; A−; B+; A+ etc.
- Practical hybrid stepping motors are built with more rotor poles in order to give higher angular resolution.



(a) (b) (c)

Truth Table

A	B	q
+	0	0°
0	+	18°
−	0	36°
0	−	54°
+	0	72°

1-Phase ON
Full-Step Mode