SOME STUFS ABOUT STEPPER MOTORS

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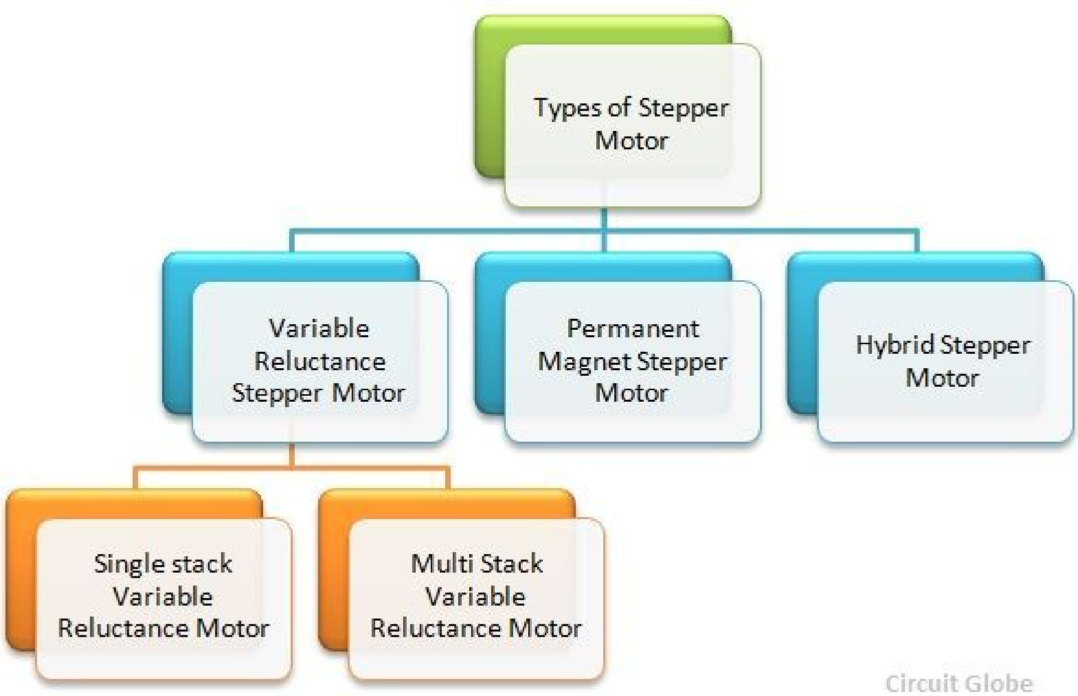
1-Stepper Motor

The name **Stepper Motor** itself shows that the rotor movement is in the form of various steps or discrete steps. It is also known as Stepping Motor. The number of pulses fed into the controller circuit determines the angular rotation of the motor. Each input pulse produces one step of the angular movement. The drive is considered as an analog to digital converter. It has an inbuilt logic, which causes appropriate windings to be energised and de-energized by the solid state switches in the required sequence.



There are three types of stepping motor based on the rotor arrangements. They are as follows:-

- Variable Reluctance (VR) Stepper Motor

The variable reluctance motor is divided into two types. They are known as Single stack variable reluctance motor and Multi-stack variable reluctance motor.

- Permanent Magnet (PM) Stepper Motor
- Hybrid Stepper Motor (combination of VR and PM type)

Step Angle in Stepper Motor

Definition: Step angle is defined as the angle which the rotor of a stepper motor moves when one pulse is applied to the input of the stator.

The positioning of a motor is decided by the step angle and is expressed in degrees. The resolution or the step number of a motor is the number of steps it makes in one revolution of the rotor. Smaller the step angle higher the resolution of the positioning of the stepper motor.

$$\text{Resolution} = \frac{\text{number of steps}}{\text{number of revolutions of the rotor}}$$

The accuracy of positioning of the objects by the motor depends on the resolution. Higher the resolution greater will be the accuracy. Some precision motors can make 1000 steps in one revolution with a step angle of 0.36 degrees. A standard motor will have a step angle of 1.8 degrees with 200 steps per revolution. The various step angles like 90, 45 and 15 degrees are common in simple motors.

The number of phases can vary from two to six. Small steps angle can be obtained by using slotted pole pieces.

Advantages of Stepper Motor

The various benefits of the Stepping Motor are as follows:-

- The motor is simple in construction, reliable.
- At the standstill condition, the motor has full torque.
- The motors are less costly.
- They require little maintenance.
- The stepper motor has an excellent and accurate starting, stopping and reversing response.

Disadvantages of Stepper Motor

The various disadvantages of the stepping motor are as follows:-

- The motor uses more current as compared to the DC motor.
- At the higher speed, the value of torque reduces.
- Lower efficiency.
- The Resonance condition arises and requires micro stepping.

- At the high speed, the control is not possible.

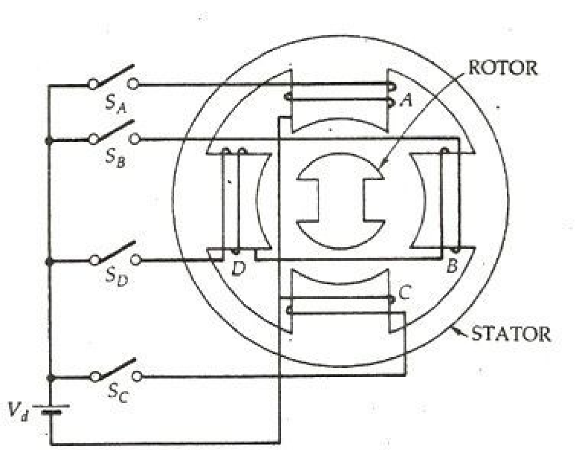
2-Variable Reluctance Stepper Motor

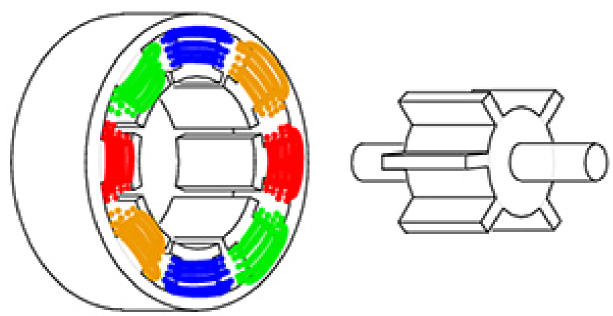
The principle of **Variable Reluctance Stepper Motor** is based on the property of the flux lines which capture the low reluctance path. The stator and the rotor of the motor are aligned in such a way that the magnetic reluctance is minimum. There are two types of the Variable Reluctance Stepper Motor. They are as follows

- Single Stack Variable Reluctance Motor
- Multi Stack Variable Reluctance Motor

Working of a Variable Reluctance Stepper Motor

A four phase or (4/2 pole), single stack variable reluctance stepper motor is shown below. Here, (4/2 pole) means that the stator has four poles and the rotor has two poles.





A variable reluctance stepper motor has an iron rotor with teeth that are attracted to the energized stator poles.

The four phases A, B, C and D are connected to the DC source with the help of a semiconductor, switches S_A, S_B, S_C and S_D respectively as shown in the above figure. The phase windings of the stator are energized in the sequence A, B, C, D, A. The rotor aligns itself with the axis of phase A as the winding A is energized. The rotor is stable in this position and cannot move until phase A is de-energized.

Now, the phase B is excited and phase A is disconnected. The rotor moves 90 degrees in the clockwise direction to align with the resultant air gap field which lies along the axis of phase B. Similarly the phase C is energized, and the phase B is disconnected, and the rotor moves again in 90 degrees to align itself with the axis of the phase

Thus, as the Phases are excited in the order as A, B, C, D, A, the rotor moves 90 degrees at each transition step in the clockwise direction. The rotor completes one revolution in 4 steps. The direction of the rotation depends on the sequence of switching the phase and does not depend on the direction of the current flowing through the phase. Thus, the direction can be reversed by changing the phase sequence like A, D, C, B, A.

The magnitude of the step angle of the variable reluctance motor is given as

$$\alpha = \frac{360^\circ}{m_s N_r}$$

Where,

- α is the step angle
- m_s is the number of stator phases
- N_r is the number of rotor teeth

The step angle is expressed as shown below.

$$\alpha = \frac{N_s - N_r}{N_s N_r} \text{ x } 360^\circ$$

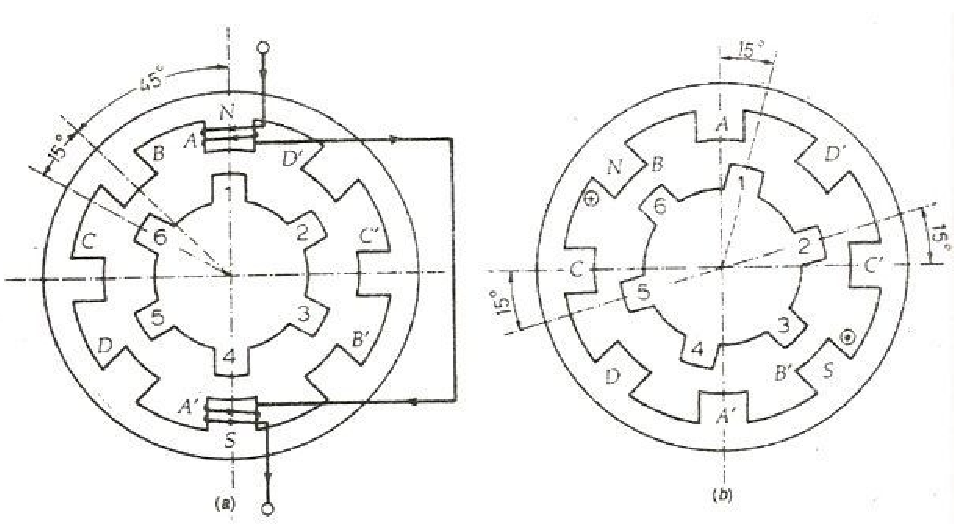
Where, N_S is the stator poles

The step angle can be reduced from 90 degrees to 45 degrees in a clockwise direction by exciting the phase in the sequence A, A+B, B, B+C, C, C+ D, D, D+A, A.

Similarly, if the sequence is reversed as A, A+D, D, D+C, C, C+B, B, B+A, A, the rotor rotates at step angle of 45 degrees in the anticlockwise direction.

Here, (A+B) means that the phase windings A and B both are energized together. The resultant field is the midway of the two poles. i.e. it makes an angle of 45 degrees with the axis of the pole in the clockwise direction. This method of shifting excitation from one phase to another is known as Microstepping.By using Stepper Motor, lower values of the step angle can be obtained with numbers of poles on the stator.

Consider a 4 phase, (8/6 pole) single stack variable reluctance motor shown in the figure below.



The opposite poles are connected in series forming a 4 phases. The rotor as 6 poles. Here I am considering only phase A to make the connection simple. When the coil AA' is excited the rotor teeth 1 and 4 are aligned along the axis of the winding of the phase A. Thus, the rotor occupies the position as shown in the above figure (a).

Now, the phase A is de-energized, and the phase winding B is energized. The rotor teeth 3 and 6 get aligned along the axis of phase B. The rotor moves a step of phase angle of 15 degrees in the clockwise direction. Further, the phase B is de-energized, and the winding C is excited. The rotor moves again 15^{0} phase angle.

The sequence A, B, C, D, A is followed, and the four steps of rotation are completed, and the rotor moves 60 degrees in clockwise direction. For one complete revolution of the rotor 24 steps are required. Thus, any desired step angle can be obtained by choosing different combinations of the number of rotor teeth and stator exciting coils.

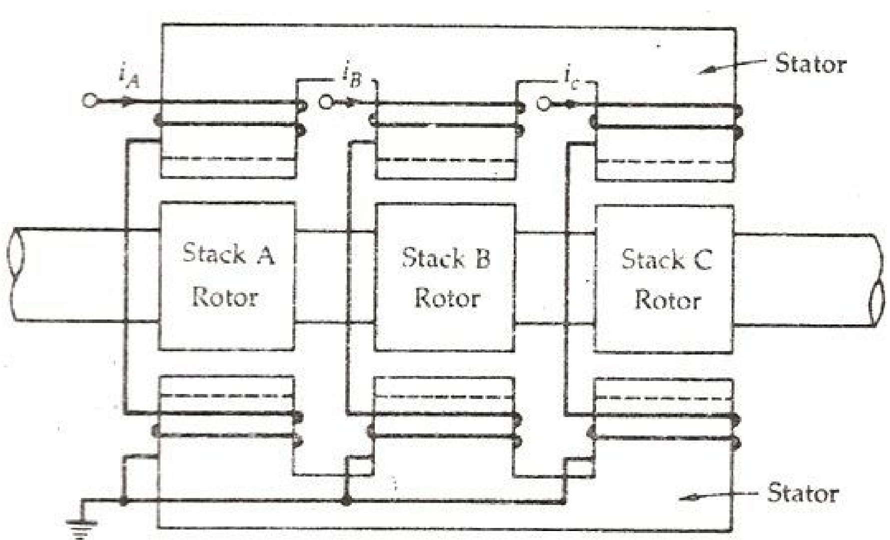
3-Single Stack Variable Reluctance Stepper Motor

A **single stack variable reluctance stepper motor** has a salient pole stator. The stator has a concentrated windings which are placed over the stator poles. The number of phases of the stator depends upon the connection of the stator coils. There are three or four windings. The rotor is made up of ferromagnetic materials and carries no windings.

The stator and rotor are made of high-quality magnetic materials having very high permeability. Thus, a very small exciting current is required. When a DC source is applied to the stator phase with the help of a semiconductor switch, a magnetic field is produced. The axis of the rotor aligns with the axis of the stator

4-Multi Stack Variable Reluctance Stepper Motor

A Multi Stack or m stack variable reluctance stepper motor is made up of m identical single stack variable reluctance motor. The rotor is mounted on the single shaft. The stator and rotor of the **Multi Stack Variable motor** have the same number of poles and hence, the same pole pitch.



All the stator poles are aligned in a Multi-Stack motor. But the rotor poles are displaced by 1/m of the pole pitch angle from each other. The stator windings of each stack forms one phase as the stator pole windings are excited simultaneously. Thus, the number of phases and the number of stacks are same.

Consider the cross-sectional view of the three stack motor parallel to the shaft is shown below.

There are 12 stator and rotor poles in each stack. The pole pitch for the 12 pole rotor is 30, and the step angle or the rotor pole teeth are displaced by 10 degrees from each other. The calculation is shown below.

Let N_r be the number of rotor teeth and m be the number of stacks or phases.

Hence, Tooth pitch is represented by the equation shown below.

$$T_p = \frac{360°}{N_r} \dots\dots..(1)$$

Therefore,

$$\text{Step angle} = \frac{360°}{m\,N_r} \dots\dots\dots(2)$$

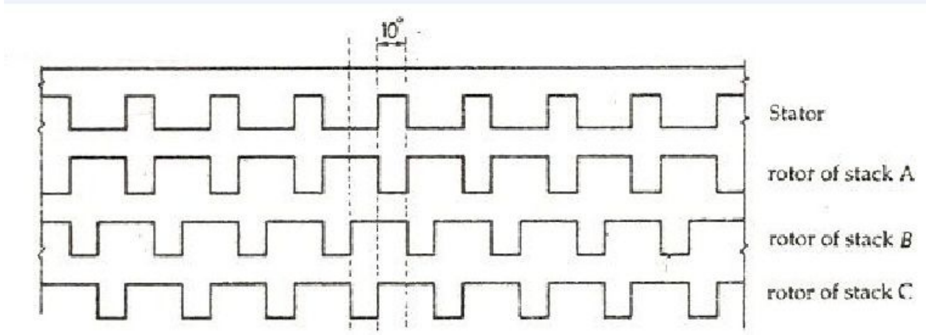
As there are 12 poles in the stator and rotor, thus the value of $N_r = 12$. Now, putting the value of N_r in the equation (1) we get

$$T_p = \frac{360°}{12} = 30° \dots\dots..(3)$$

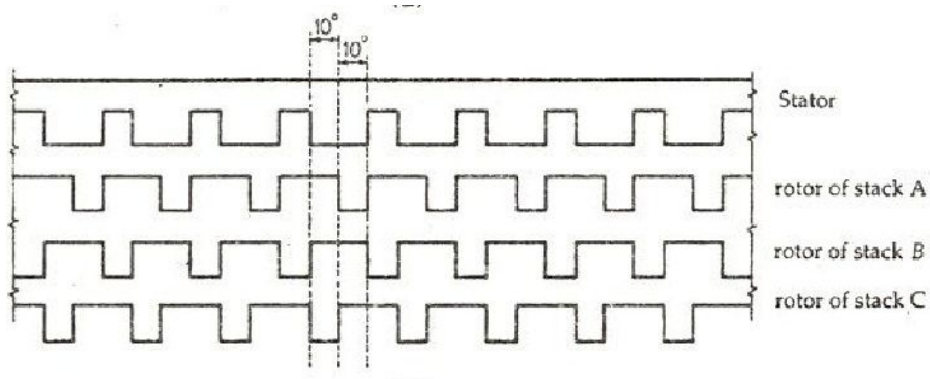
The value of m= 3. Therefore, the step angle will be calculated by putting the value of m in the equation (2).

$$\text{Step angle} = \frac{360°}{3 \times 12} = 10° \dots\dots\dots(4)$$

When the phase winding A is excited the rotor teeth of stack A are aligned with the stator teeth as shown in the figure below.



When phase A is de-energized, and phase B is excited, rotor teeth of the stack B are aligned with the stator teeth. The rotor movement is about 10 degrees in the anticlockwise direction. The motor moves one step which is equal to ½ of the pole pitch due to change of excitation from stack A to stack B. The figure below shows the position of the stator and rotor teeth when the phase B is excited.



Similarly, now phase B is de-energized, and phase C is excited. The rotor moves another step of 1/3 of the pole pitch in the anticlockwise direction. Again, another change in the excitation of the rotor takes place, and the stator and rotor teeth align it with stack A. However, during this whole process (A – B – C – A) the rotor has moved one rotor tooth pitch.

Multi Stack Variable Reluctance Stepper Motors are widely used to obtain smaller step angles in the range of 2 to 15 degrees. Both the Variable reluctance motor Single Stack and Multi Stack types have a high torque to inertia ratio.

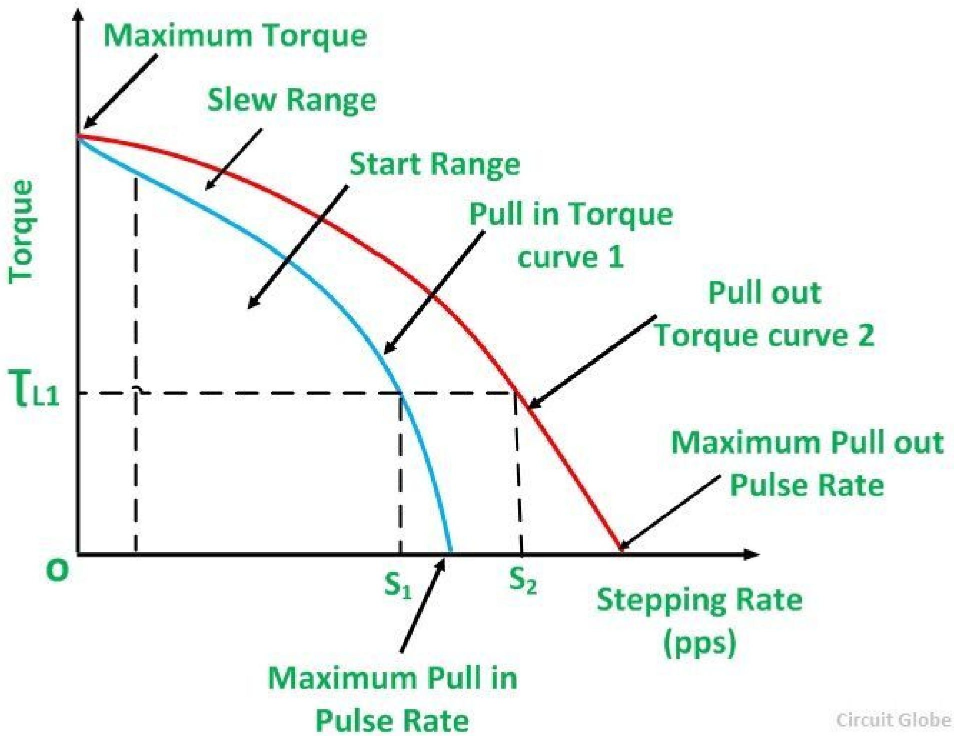
5-Stepper Motor Applications

The Stepper motor is manufactured in various sizes ranging from milliwatts to hundreds of watts. Its maximum torque value ranges up to 15 Newton Meter and the step angle ranges from 1.8 to 90 degrees. As already discussed earlier about What is a Stepper Motor? and the Step Angle. The **Stepper Motor Applications** have a wide range. Some of the applications are given below.

- As the stepper motor are digitally controlled using an input pulse, they are suitable for use with computer controlled systems.
- They are used in numeric control of machine tools.
- Used in tape drives, floppy disc drives, printers and electric watches.
- The stepper motor also use in X-Y plotter and robotics.
- It has wide application in textile industries and integrated circuit fabrications.
- The other applications of the Stepper Motor are in spacecrafts launched for scientific explorations of the planets etc.
- These motors also find a variety of commercial, medical and military applications and also used in the production of science fiction movies.
- Stepper motors of microwatts are used in the wrist watches.
- In the machine tool, the stepper motors with ratings of several tens of kilowatts is used

6-Characteristics of a Stepper Motor

The **Torque pulse rate Characteristics** of a Stepper Motor gives the variation of an electromagnetic torque as a function of stepping rate in pulse per second (PPS). There are two characteristic curves 1 and 2 shown in the figure below. Curve one is denoted by a blue colour line is known as the **Pull-in torque**. It shows the maximum stepping rate for the various values of the load torque at which the motor can start, synchronise, stop or reverse.



Similarly, the curve 2 represented by Red colour line is known as pullout torque characteristics. It shows the maximum stepping rate of the motor where it can run for the various values of load torque. But it cannot start, stop or reverse at this rate.

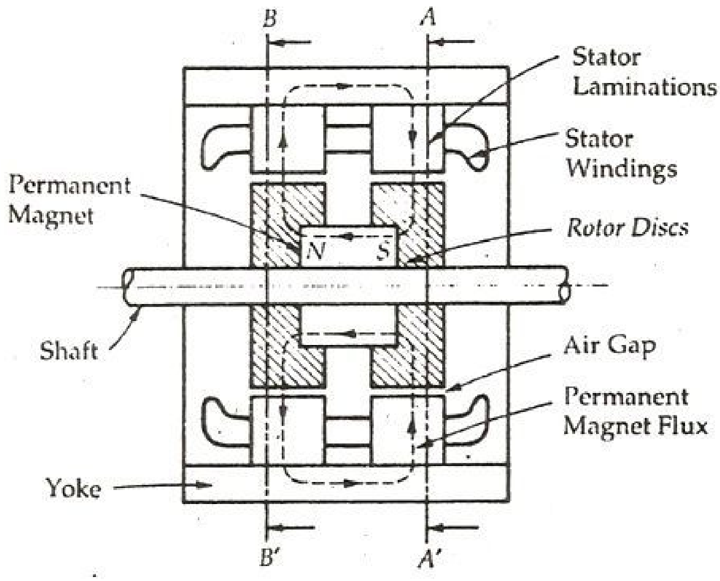
Let us understand this with the help of an example, considering the above curve.

The motor can start, synchronise and stop or reverse for the load torque $Ʈ_L$ if the pulse rate is less than S_1. The stepping rate can be increased for the same load as the rotor started the rotation and synchronised. Now, for the load $Ʈ_{L1}$, after starting and synchronising, the stepping rate can be increased up to S_2 without losing the synchronism.

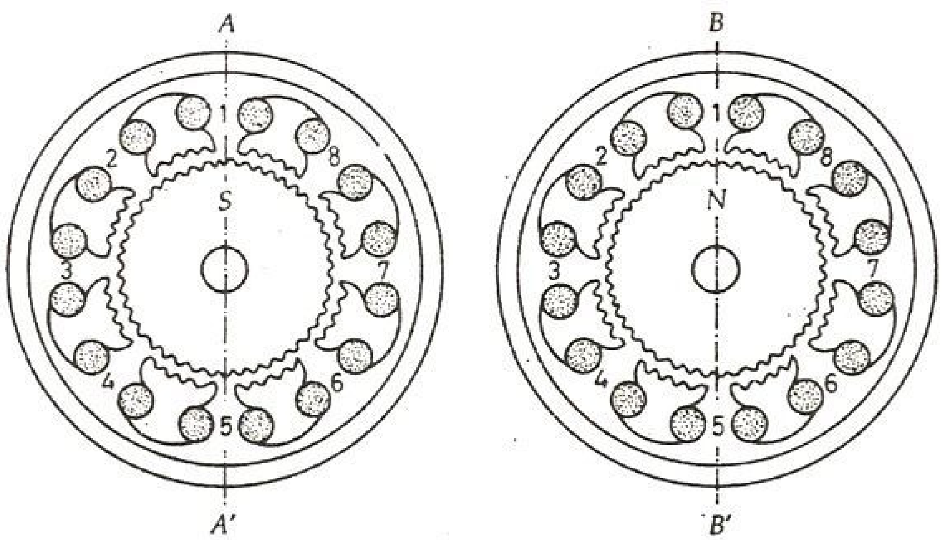
If the stepping rate is increased beyond S_2, the motor will lose synchronism. Thus, the area between curves 1 and 2 represents the various torque values, the range of stepping rate, which the motors follow without losing the synchronism when it has already been started and synchronised. This is known as **Slew Range**. The motor is said to operate in slewing mode.

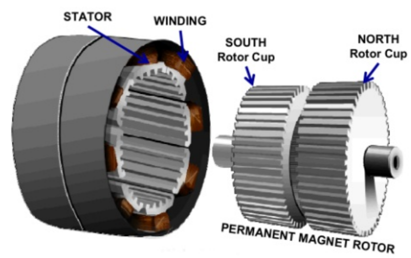
7-Hybrid Stepper Motor

The word Hybrid means combination or mixture. The **Hybrid Stepper Motor** is a combination of the features of the Variable Reluctance Stepper Motor and Permanent Magnet Stepper Motor. In the center of the rotor, an axial permanent magnet is provided. It is magnetized to produce a pair of poles as North (N) and South (S) as shown in the figure below.



At both the end of the axial magnet the end caps are provided, which contains an equal number of teeth which are magnetized by the magnet. The figure of the cross section of the two end caps of the rotor is shown below.





A hybrid stepper motor has a toothed rotor, made from two "cups" of opposite polarity, and an electromagnetic, toothed stator.

The stator has 8 poles, each of which has one coil and S number of teeth. There are 40 poles on the stator, and each end cap has 50 teeth. As the stator and rotor teeth are 40 and 50 respectively, the step angle is

$$\text{Step angle} = \frac{(50 - 40)\text{x } 360^\circ}{50 \text{ x } 40} = 1.8^\circ$$

expressed as shown below.

The rotor teeth are perfectly aligned with the stator teeth. The teeth of the two end caps are displaced from each other by half of the pole pitch. As the magnet is axially magnetized, all the teeth on the left and right end cap acquire polarity as south and north pole respectively.

The coils on poles 1, 3, 5 and 7 are connected in series to form phase A. Similarly, the coils on the poles 2, 4, 6 and 8 are connected in series to form phase B.

When Phase is excited by supplying a positive current, the stator poles 1 and 5 becomes South poles and stator pole 3 and 7 becomes north poles.

Now, when the Phase A is de-energized, and phase B is excited, the rotor will turn by a full step angle of 1.8º in the anticlockwise direction. The phase A is now energized negatively; the rotor moves further by 1.8º in the same anti-clockwise direction. Further rotation of the rotor requires phase B to be excited negatively.

Thus, to produce anticlockwise motion of the rotor the phases are energized in the following sequence +A, +B, -A, -B, +B, +A…….. For the clockwise rotation, the sequence is +A, -B, +B, +A……..

One of the main advantages of the Hybrid stepper motor is that, if the excitation of the motor is removed the rotor continues to remain locked in the same position as before the removal of the excitation. This is because of the Detent Torque produced by the permanent magnet.

Advantages of Hybrid Stepper Motor

The advantages of the Hybrid Stepper Motor are as follows:-

- The length of the step is smaller.
- It has greater torque.
- Provides Detent Torque with the de-energized windings.
- Higher efficiency at lower speed.
- Lower stepping rate.

Disadvantages of Hybrid Stepper Motor

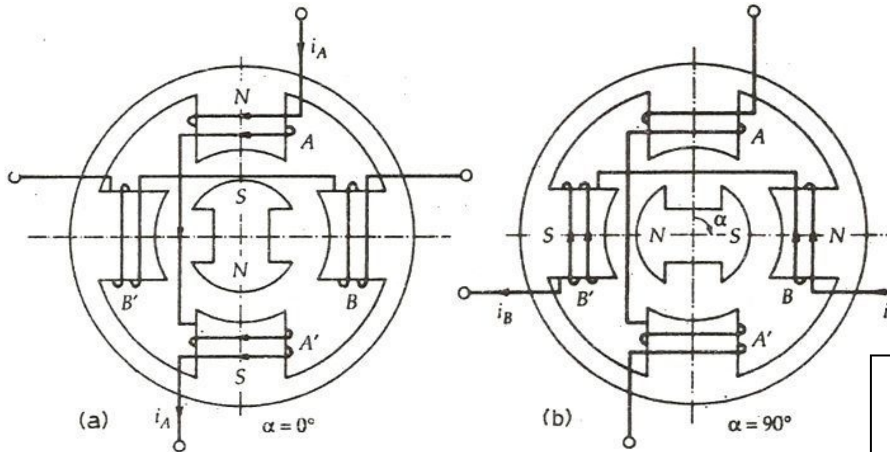
The Hybrid Stepper Motor has the following drawbacks.

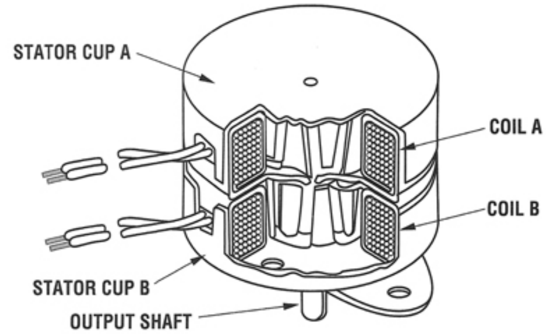
- Higher inertia.
- The weight of the motor is more because of the presence of the rotor magnet.
- If the magnetic strength is varied, the performance of the motor is effected.
- The cost of the Hybrid motor is more as compared to the Variable Reluctance Motor.

8-Permanent Magnet Stepper Motor

The **Permanent Magnet Stepper Motor** has a stator construction similar to that of the single stack variable reluctance motor. The rotor consists of permanent magnet poles of high retentivity steel and is cylindrical in shape. The concentrating windings on diametrically opposite poles are connected in series to form a two phase winding on the stator.

The rotor poles align with the stator teeth depending on the excitation of the winding. The two coils AA' connected in series to form a winding of Phase A. Similarly the two coil BB' is connected in series forming a phase B windings.The figure below shows 4/2 Pole Permanent Magnet Stepper Motor.



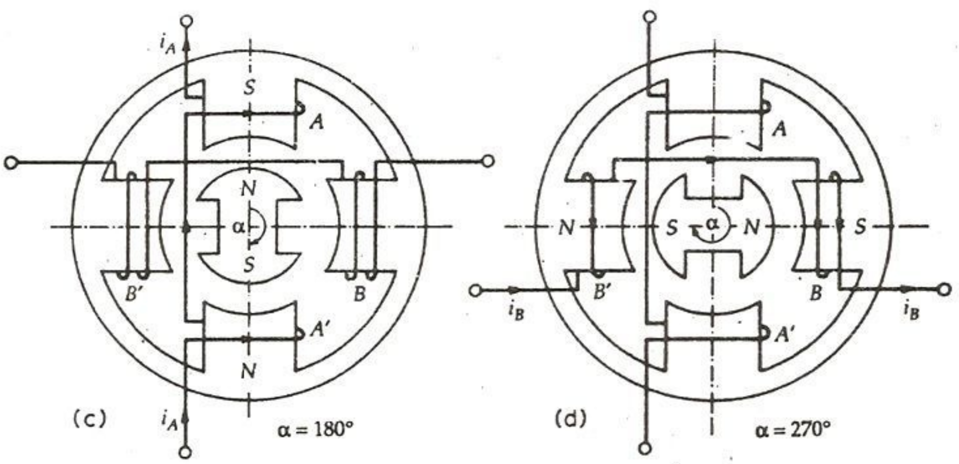


The most common design of a permanent magnet motor is also referred to as "can stack" or "tin can" design, because the stator consists of two coils contained in soft iron housings (i.e. "cans").

In figure (a) the current flows start to the end of phase A. The phase winding is denoted by A^+ and the current by i^+_A. The figure shows the condition when the phase winding is excited with the current i^+_A. The south pole of the rotor is attracted by the stator phase A. Thus, the magnetic axis of the stator and rotor coincide and $\alpha = 0^o$

Similarly, in the figure (b) the current flows from the start to the end at phase B. The current is denoted by i^+_B and the winding by B^+. Considering the figure (b), the windings of phase A does not carry any current and the phase B is excited by the i^+_B current. The stator pole attracts the rotor pole and the rotor moves by 90^o in the clockwise direction. Here $\alpha = 90^o$

The figure (c) below shows that the current flows from the end to the start of the phase A. This current is denoted by i^-_A and the winding is denoted by A^-. The current i^-_A is opposite to the current i^+_A. Here, phase B winding is de-energized and phase A winding is excited by the current i^-_A. The rotor moves further 90^o in clockwise direction and the $\alpha = 180^o$



In the above figure (d), the current flows from end to starting point of phase B. The current is represented by i^-_B and the winding by B^-. Phase A carries no current and the phase B is excited. The rotor again moves further 90^o and the value of $\alpha = 270^o$

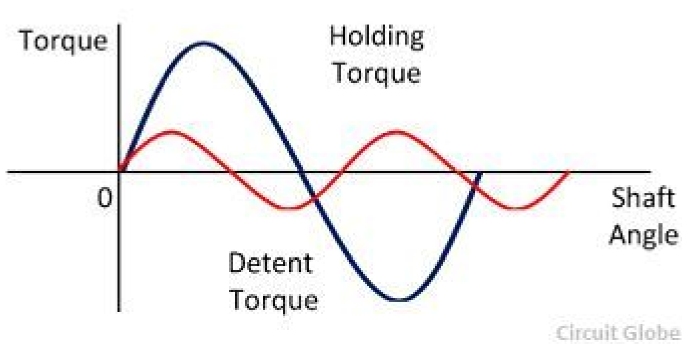
Completing the one revolution of the rotor for making $\alpha = 360^o$ the rotor moves further 90 degrees by de-energizing the winding of phase B and exciting the phase A. In the permanent magnet stepper motor the direction of the rotation depends on the polarity of the phase current.The sequence A^+, B^+, A^-, B^-, A^+ is followed by the clockwise movement of the rotor and for the anticlockwise movement, the sequence becomes $A^+ B^-$, A^-, B^+, A^+.

The permanent magnet rotor with large number of poles is difficult to make, therefore, stepper motors of this type are restricted to large step size in the range of 30 to 90º. They have higher inertia and therefore, lower acceleration than variable stepper motors. The Permanent Magnet stepper motor produces more torque than the Variable Reluctance Stepper Motor.

9-Detent Torque

Definition: Detent torque is defined as the torque at the maximum load that is applied to the shaft of the motor which is unexcited without causing continuous rotation. It is also known as **Restraining torque** and is produced in the rotor of the permanent magnet motor.

The detent torque exists because of the residual magnetism in the Permanent magnetic material used for the construction of the rotor of the motor. It is produced when the stator coils are not energised. This torque prevents the rotor from Drifting when the motor supply is turned off.



The torque which is caused by the motor when the rated current flow across the winding is known as the holding torque. Detent torque is beneficial for stepping the motor. It also resists the momentum of the moving rotor and the friction in the rotating components. Such type of torque is range from 5 to 20% of the holding torque.

When the motor is unexcited the permanent magnet, and hybrid stepper motor develops a Detent torque confining the rotation of the rotor.

10-HYBRIDE SERVO DRIVER

KIT - Servo Moteur et Driver Nema 34 , 86HSE8N-BC38 + HSS86

Motor Parameter:

Motor Model	Step angle	Current	Resistance	Inductance	Holding torque	Motor length	Total length	Suitable driver	Encoder resolution
DW86HSE4N-BC38	1.8°	6.0A	0.45±10%Ω	3.7±20%mH	4.5 N.m	82mm	103mm	HSS86	1000ppr
DW86HSE8N-BC38	1.8°	6.0A	0.44±10%Ω	3.7±20%mH	8.0 N.m	118mm	139mm	HSS86	1000ppr
DW86HSE12N-BC38	1.8°	6.0A	0.45±10%Ω	5.2±20%mH	12.0 N.m	156mm	177mm	HSS86	1000ppr

Driver HSS86

Features:

1. Position error correction and never lose steps

2. Quick response and perfect acceleration, High torque at high speed

3. Automatic current adjustment based on load, lower temperature rising

4. Over-current, over-voltage and position ultra difference protection function

5. Pulses response frequency can reach 200KHZ

6. 16 kinds microsteps choice, highest 51200microsteps/rev.

7. Drive nema 34 series 4.5N.m, 8N.m, 12N.m closed loop stepper motor

8. Voltage range: AC20~80V or DC30~110V

Microstep selection:

Micorstep/rev	SW3	SW4	SW5	SW6
Default (400)	on	on	on	on
800	off	on	on	on
1600	on	off	on	on
3200	off	off	on	on
6400	on	on	off	on
12800	off	on	off	on
25600	on	off	off	on
51200	off	off	off	on
1000	on	on	on	off
2000	off	on	on	off
4000	on	off	on	off
5000	off	off	on	off
8000	on	on	off	off
10000	off	on	off	off
20000	on	off	off	off
40000	off	off	off	off

11-Formulas and calculation:

The speed:

The PWM signal powered by the Arduino clone is between 5000Hz and 25000Hz (under: noise, over: may cause overspeed problems) with a 50% duty cycle and **1 pulse moves 1 step.**

The speed in Rpm:

N=(60xf)/MicroSteps, N in rev/min, f in Hz or Step/s, MicroSteps in Steps/rev

Example of switches position: 3200 Steps/rev

SW1	SW2	SW3	SW4	SW5	SW6	
						OFF
						ON

For 5000Hz, N=60x5000/3200= 93,75 rpm

For 25000Hz, N=60x25000/3200= 468,75 rpm

In order to verify the good calculation (it's the set point of the speed), you can count the pulses on EA+ signal coming from the coder.

The position and turns: You need to count the step or the pulse of PWM signal (step_count).

PositionDEG = 360 * (step_count - (TURNcount * Microstep)) / Microstep;

PositionDEG in degree, TURNcount in rev, step_count in step, Microsteps in steps/rev

TURNcount = step_count / Microstep; TURNcount in rev, step_count in step, Microsteps in steps/rev

12-Matrix of serial MODBUS RTU addresses:

Arduino Clone MODBUS address	**Arduino Clone address line number in the MODBUS matrix**	**Descriptions**	**HMI items MODBUS address**
NOuse	0	No use	40000
CAM	1	Switch automatic/manual mode	40001
CCW	2	Counter clockwise or clockwise	40002
SPEEDPOT	3	Speed set point slider	40003
CCWlight	4	Light on CCW	40004
CWlight	5	Light on CW	40005
SWITCHvalue	6	Switch value to type wether SW3456 on or off, microstep by turn value for speed ranges	40006
DEGvalue	7	Degrees value displayed	40007
TURNvalue	8	Number of turn displayed	40008
SPEEDvalue	9	Speed value displayed	40009
BPPOM	10	BP yellow launching the POM sequence	40010
POMlight	11	Light on POM launched	40011
DCY	12	Run push button	40012
FCY	13	Stop push button	40013
LIGHTrun	14	Light on run	40014
LIGHTstop	15	Light on stop	40015

CSpeedPos	16	Selector switch for speed or position regulation	40016
SpeedpotSP	17	Speed set point displayed	40017
NBRturnSP	18	Number of turn set point to type	40018
DEGSP	19	Degrees rotation set point to type	40019
EMERGENCYlight	20	Light on emergency stop	40020
SWITCHsense	21	Selector switch to define CCW or CW	40021
ACKNOLEDGE	22	Nice switch to run/stop in manual mode	40022
LIGHTspeed	23	Light on speed mode regulation	40023
LIGHTpos	24	Light on position mode regulation	40024
FREQUENCY	25	PWM frequency displayed on HMI	40025