Unit – II

1. What is stepper motor?

A stepper motor is a digital actuator whose input is in the form of programmed energization of the stator windings and whose output is in the form of discrete angular rotation.

2. Define the term step angle. [May/June 2007, May 2008, Nov/Dec 2013 April/May 2013]

Step angle is defined as the angle through which the stepper motor shaft rotates for each command pulse. It is denoted as β.

Formula for step angle (β)

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

$$\beta = \frac{360}{mN_r}$$

Where

N_s – No. of stator poles or stator teeth
N_r – No. of rotor poles or rotor teeth
m – No. of stator phases

3. What are the main features of stepper motor which are responsible for its wide spread use? [April/May 2008 Nov/Dec 2013]

1) It can driven open loop without feedback
2) It is mechanically simple
3) It requires little or no maintenance
4) Responds directly to digital control signals, so stepper motors are natural choice for digital computer controls.

4. Give the classification of stepper motor. [Nov/Dec 2009 April/May 2010]

1) Variable reluctance stepper motor:

(i) Single Stack
(ii) Multi Stack

2) Permanent Magnet Stepper Motor

(i) Hybrid Stepper motor
(ii) Claw pole Motor.

5. Define slewing. [Nov/Dec 2009 April/May 2010]

The stepper motor may be operate at very high stepping rates i.e., 25000 steps per second. A stepper motor operates at high speeds is called slewing.

6. **Write down the formula for motor speed of stepper motor.**

Motor speed

$$n = \frac{\beta \times f}{360°} \text{rps}$$

Where

β - Step angle

f – Stepping frequency or pulse rate in pulses per second (pps)

7. **Define resolution.**

It is defined as the number of steps needed to complete one revolution of the rotor shaft.

8. **State some applications of stepper motor.[May 2017]**

1) Floppy diskdrives
2) Quartzwatches
3) Camera shutter operation
4) Dot matrix and line printers
5) Machine toolapplications
6) Robotics

9. **What are the advantages and disadvantages of stepper motor? (Nov/Dec-13)**

Advantages:

1) It can driven open loop without feedback.
2) Responds directly to digital control signals, so stepper motors are natural choice for digital computer controls.
3) It is mechanically simple.
4) It requires little or no maintenance.

Disadvantages:

1) Low efficiency with ordinarycontroller.
2) Fixed stepangle.
3) Limited ability to handle large inertiaload
4) Limited power output and sizesavailable.

10. **What are the different modes of excitation in a stepper motor? [May/June 2012]**

1. 1 - Phase on or full - stepoperation
2. 2-phaseonmode
3. Half- step operation (Alternate 1-phase on and 2-phase onmode)
4. Micro steppingoperation

11. **What is meant by full-step operation? Nov/Dec-14**

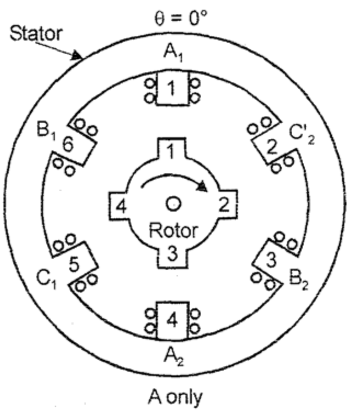
It is the one-phase on mode operation. It means, at that time only one winding is energized. By energizing one stator winding, the rotor rotates some angle. It is the full-step operation.

12. What is meant by half- step operation? Nov/Dec-14

It is the alternate one-phase on and 2-phase on mode operation. Here, the rotor rotate an each step angle is half of the full-step angle.

13. Sketch the diagram of a VR stepper motor

VR Stepper motor



14. What is meant by micro stepping in stepper motor? [Apr/May 2015]

Micro stepping means, the step angle of the VR stepper motor is very small. It is also called mini - stepping. It can be achieved by two phases simultaneously as in 2-phase on mode but with the two currents deliberately made unequal.

15. What is the main application of micro stepping VR stepper motor? [Nov/Dec2014]

Micro stepping is mainly used where very fine resolution is required. The applications are printing and photo type setting. AVR stepper motor with micro stepping provides very smooth low - speed operation and high resolution.

16. What is a multi - stack VR steppermotor?

Micro stepping of VR stepper motor can be achieved by using multi stack VR stepper motion. It has three separate magnetically isolated sections or stacks. Here the rotor a stator toothis equal.

17. What are the advantages and disadvantages of VR steppermotor?

Advantages

1) Low rotorinertia
2) High torque to inertiaratio
3) Lightweight

4) Capable of high steppingrate.
5) Ability tofreewheel

Disadvantages

1) Normally available in 3.6° to 30 step angles.
2) No detente torque available with windings de – energized

18. What are the advantages & disadvantages of permanent magnet stepper motor?

Advantages:

1) Low powerrequirement
2) High detente torque as compared to VRmotor
3) Rotor do not require external excitingcurrent
4) It produces more torque per ampere statorcurrent

Disadvantages:

1) Motor has higherinertia
2) Sloweracceleration

19. What is hybrid stepper motor? [Nov/Dec2007,2011]

The hybrid motor is operated with the combined principles of the permanent and variable reluctance motor in order to achieve a small step angle and a high torque from a small size.

20. What are the advantages and disadvantages of hybrid steppermotor?

Advantages:

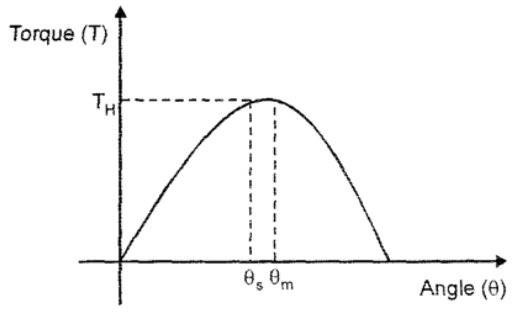
1) Less tendency toresonate
2) Provide detent torque with windingsde-energized
3) Higher holding torquecapability
4) High stepping rate capability

Disadvantages:

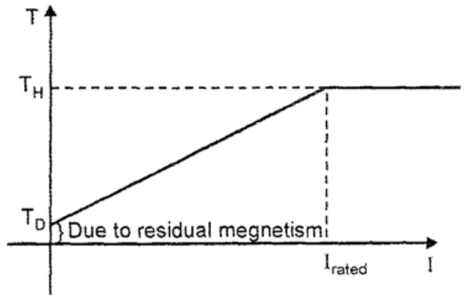
1) Higher inertia and weight due to presence of rotormagnet.
2) Performance affected by change in magneticstrength.

21. **Draw the typical static characteristics of a steppermotor**

T-θ Characteristic



T-I Characteristic



22. **Differential between VR, PM and hybrid stepper motor.**

S. No	VR Stepper motor	PM Stepper motor	Hybrid stepper motor
1	Low rotor inertia Less	High inertia	High inertia
2	Less weight	More weight	More weight
3	No detente torque available windings de-energized	Provides detente torque	Provides detente torque with windings de-energized
4	Rotor is no permanent magnet	Rotor is permanent magnet	Rotor is permanent magnet
5	Rotor is a salient pole type	Rotor is a cylindrical type	Rotor is a salient pole type

23. Define holding torque. [Nov/Dec 2007 April/May 2011]

Holding torque is the maximum load torque which the energized stepper motor can withstand without slipping from equilibrium position.

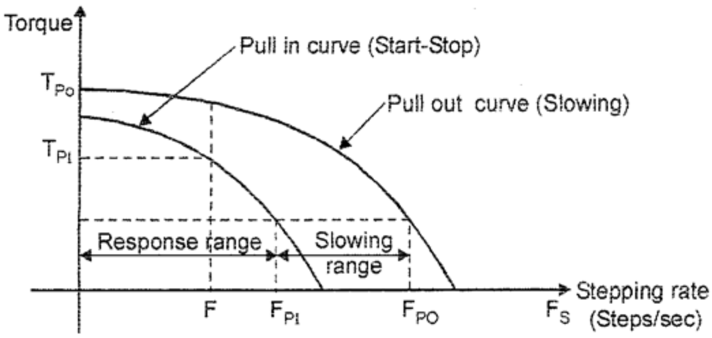
24. Define detent torque. [May/June 2007 May 2011]

Detente torque is the maximum load torque which is unenergized stepper motor can with stand without slipping. It is also known as cogging torque.

25. Define torque constant. [Nov/Dec 2012]

Torque constant of the stepper motor is defined as the initial slope of the torque current curve of the stepper motor. It is also called as torque sensitivity.

26. Draw the typical dynamic characteristics of a stepper motor.



27. Define pull-in torque.

It is the maximum torque the stepper motor can develop in start - stop mode at a given stepping rate F (steps/sec), without losing synchronism.

28. Define pull-out torque.

It is the maximum torque the stepper motor can develop at a given stepping rate F (steps/sec), without losing synchronism.

29. Define pull-in rate.

It is the maximum stepping rate at which the stepper motor will start or stop, without losing synchronism, against a given load torque.

30. Define pull-out rate.

It is the maximum stepping rate at which the stepper motor will slow, without losing synchronism against a given load torque.

31. What is a response range?

It is the range of stepping rates at which the stepper motor can start or stop with losing synchronism, at a given load torque. Response range spans stepping rates the pull in rate.

32. What is a slewing range?

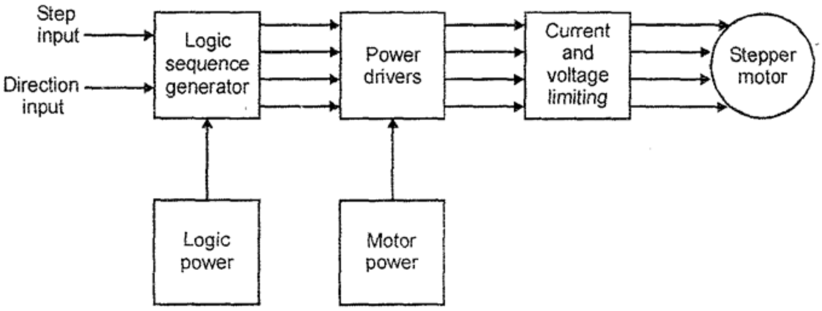
It is the range of stepping rates at which the stepper motor can run in the slow mode, with losing synchronism, at a given load torque.

The slewing range spans stepping rates

33. What is synchronism in stepper motor?

It is the one-to-one correspondence between the number of pulses applied to stepper motor controller and the number of steps through which the motor has actually moved.

34. Draw the block diagram of the drive system of a stepping motor



35. What is logic sequencer?

Logic sequence generator generates programmed logic sequences require for operation of a stepper motor.

36. What is meant by power drive circuit in stepper motor?

[May/June 2013]

The output from the logic sequence generator signals are low level signals which are too weak to energize stepper motor windings. To increase the voltage, current and power levels of the logic sequence output by using power semiconductor switching circuit. This circuit is called power drive circuit.

37. Distinguish the half step and full step operations of a stepping motor. [Nov/Dec-14]

Half Step	Full Step
It is the alternate one-phase on and 2-phase on mode operation. Here, the rotor rotate an each step angle is half of the full-step angle	It means, at that time only one winding is energized. By energizing one stator winding, the rotor rotates some angle. It is the full-step operation.

38. Write the principles of operation of a VR motor.

[Nov/Dec-14]

The reluctance in the airgap can be varied based on the excitation of winding's excitation. The torque exerted by the reluctance motor because of the tendency of the salient poles to align themselves in the minimum reluctance position. This torque is called reluctance torque

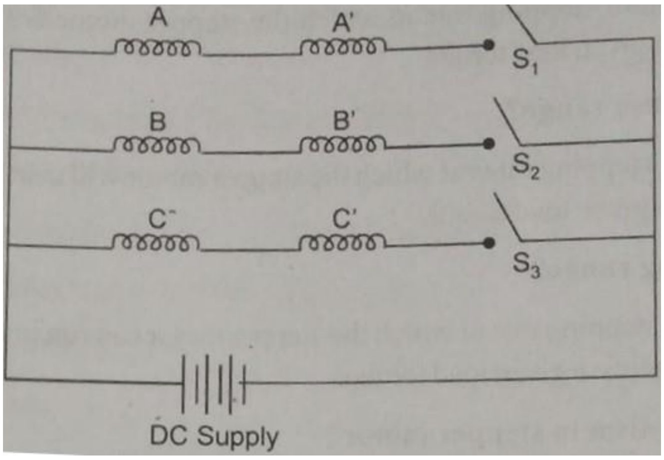
39. Compare single stack and multi stack configuration in stepping motors. [May/June 2012]

In Single Stack: Stator is single stack of steel laminations winding would wound around poles. Stator and rotor poles may be different. The rotating step angle is 30°.

Multi stack: it is divided along its axis into a number of stacks each energized by separate phase. Number of stacks and phases will be 3-7. Stator and rotor poles are equal. The rotating step angle is 10°.

40. Draw the equivalent circuit of a winding in stepper motor.

[Nov/Dec 2010 May 2017]



41. What is the step angle of a 4-pole stepper motor with 12 stator teeth and 3 rotor teeth? [April/May 2010]

Step angle $\theta_s\left(\text{or}\right)\beta = \frac{N_s \approx N_r}{N_s \cdot N_r} \times 360$

$= \frac{12-3}{12 \times 3} \times 360$

= 90°.

42. What is the step angle of a 4-phase stepper motor with 12 stator teeth and 3 rotor teeth?[April/May 2010]

No. of phases = 4

No. of teeth in rotor N_r = 3

Step angle $\theta_s = \frac{360}{\left(mN_r\right)}$

$= \frac{360}{3 \times 4} = 30°$

43. Name the various driver circuits used in stepper motor. [April/May 2015]

1) Resistance (or) L/R drive
2) Dual voltage (or) bi level driver drive.
3) Chopper driver circuit

44. Write the factors of stepper motor which are responsible for its wide spread use? [Nov/Dec 2013]

(a) When definite numbers of pulses are applied to the motor, the rotor rotates through definite known angle
(b) Control of stepper motor is simple because neither a position or a speed sensor nor feedback loops are required for stepper motor to make the output response to follow the input command.

45.Define lead angle.[Nov 2016]

The angle of difference between the phase to be de-energized to bring the stepper motor to the position of equilibrium(stopping the motor) and energisation of next phase winding to start the motor during closed loop operation is known as lead angle.

The relation between the rotor's present position and the phase(s) to be excited is specified in terms of lead angle.

46.What is the use of supressor circuits?[Nov 2016]

These circuits are used to ensure fast decay of current through the winding when the transistor is turned off.

Part -B

1. **Explain the construction and various modes of excitation of PM stepper motor. (16)**
[May 2014 May 2010 Nov 2016]

The permanent magnet stepper motor has a stator construction similar to that of single stack variable reluctance motor. The rotor is cylindrical and consists of permanent magnet poles made of high retentivity steel. The field coils of opposite poles are connected in series to have one phase winding.

Principle of operation:

(a) Single phase energization:

Two phases 4 pole stepper motor can be considered. When phase A is energised with positivevoltage applied, it sets up a magnetic field F_A in thedirection as shown in fig (a). The rotor will positionitself in such a way as to lockits N-pole to stator S-pole and vice versa.

Now phase A is de-energized and phase B is energized by applyingpositive voltage to it. Now F_A will be zero and stator magneticfield F_B willbe in the direction as shown in fig.(b). Then the rotor moves through 90° (step angle) in counter clockwisedirection so as to align with the stator field axis F_B.Rotor will position in such a way that its S-pole lock with stator N-pole.

Then phase Bis de-energized anda reverse voltage (-v) is applied tophase A.This results in the stator magnetic field FAas shown in fig.(c)

Now the rotor rotates through 90° in counter clockwise direction and aligns with $F_A$as shown in fig.(c).

Now phase A is de-energized and a reverse voltage (-v) is appliedto phase B. This results in the stator magnetic field F_B as shown in fig. (d). Rotor further rotates by 90° in counter clockwise direction and align with F_B vector.

The above sequence is single phase energizationsequencein which only one stator winding is energized at any time.

(b) Two phase energizations:

In thisinitially positive voltageis applied to phase A. This gives rise to a stator magnetic field vector $F_A$as shown in fig.(a). The rotor. N-pole lock with S-pole of stator and vice versa.

With winding A energized as before, positive voltage is applied to phase B causing pole B to be N-pole and B' to be S-pole. This produces another stator magnetic field F_B as shown in fig. (e). The resulting stator magneticfield will be + 45 degree from its former position.Hence rotor will move through a fixed angle of+ 45 degree as shownin fig.(e).

With winding B energized as before winding A be de-energized, F_A becomes zero, leaving F_B as before. The rotor, will move through another 45° to align itself with F_B as in fig. (b).

With phase B energized as before, a negative voltage is applied to phase A. This reverse stator magnetic field F_A as in fig.(f).The resulting vector F shifts byanother 45° causing the rotor to follow suit.

With phase Aenergized as before phase B is de-energized the vector- F_A alone be there and F_B = 0. The rotor occupies the position as shown in fig.(c).

With phase A energized as before, negativevoltage is applied to phaseB, the rotor occupies the position as shown in fig. (g).

With B phase energized as before as A phase is de-energized, the rotor occupies the position as shown in fig. (d).

With B phase energized as before and positivevoltage applied to A. The resulting vector F shifts the rotor by another 45° as shown in fig.(g).

Fig.(a, b, c and d) corresponds to single phase energization.

Fig. (e, f, g and h) corresponds to. two phaseenergizations.

Both the above sequences are four step sequences, since the rotor moves through 90°. With single phase sequence, rotor positions are ·90°, 180°, 270° and 360°, while rotor positions are 45°, .135°, 225° and .315° in the case of two phase sequence.

Fig.(a to h) constitute 8-stepsequence in which the rotor moves through 45° per step. Here one and two phases are energized alternatively. This sequence is known as mixed, hybrid (or) (1-2) sequence.

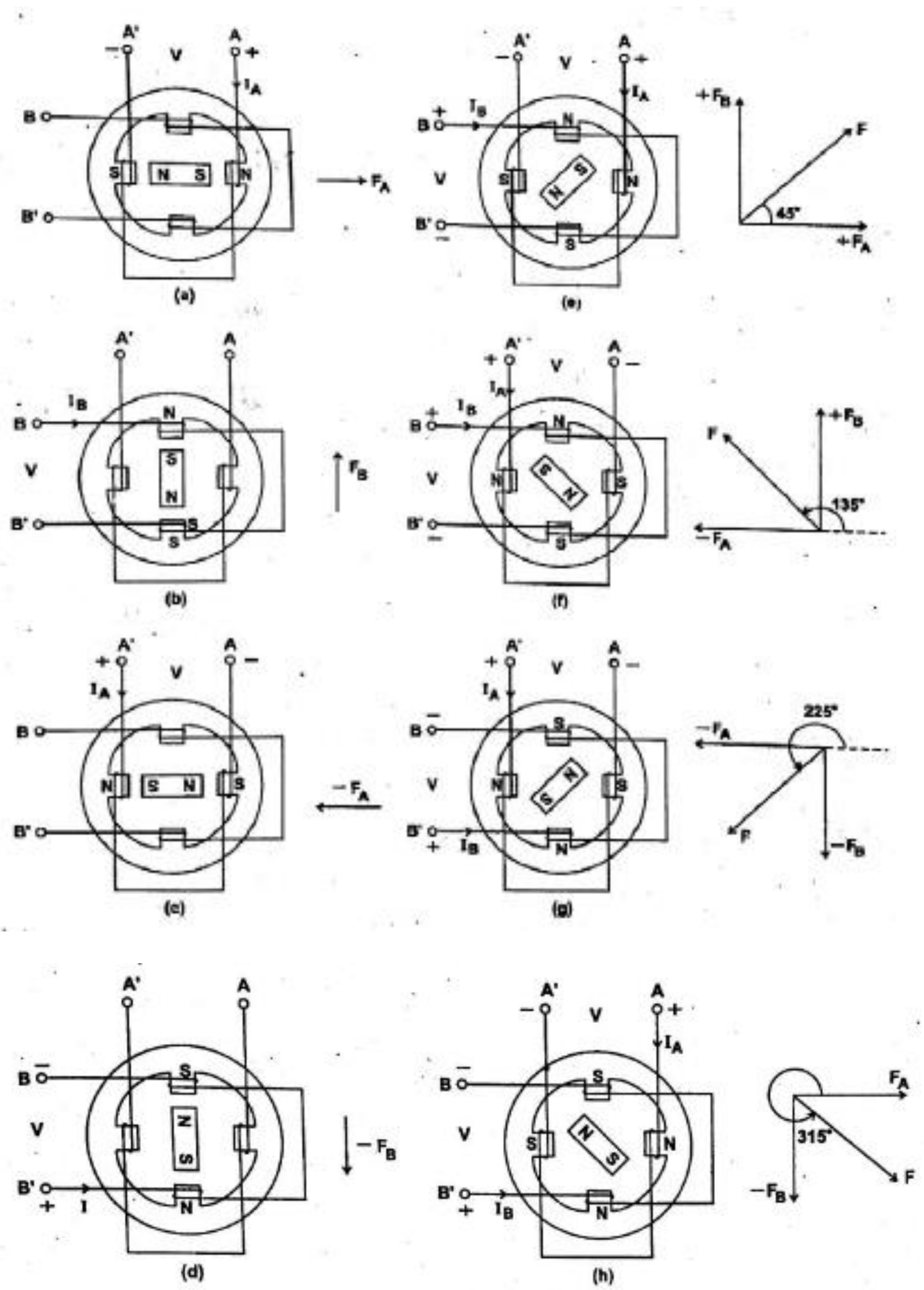
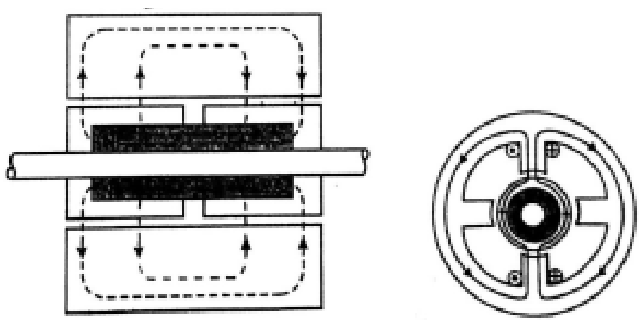


Fig. Principle of operation of PM motor

2. **Explain the construction and working principle of Hybrid Stepper motor. [May 2007 May 2008 Nov 2014]**
   Hybrid stepper motor:

Another type of stepping motor having permanent magnet in its rotor is the hybrid motor.The term "hybrid" derives from the fact that the motor is operated with the combined principles of the permanent and variable reluctance motors, in order to achieve a small step angle and a high torque from a small size. The stator core structure is the same as or very close to that of variable reluctance motors. The important feature is the rotor structure. A cylindrical or disk-shaped magnet lies in the rotor core and it is magnetized lengthwise to produce a unipolar field as shown in fig. (a). Each pole of the magnet is covered with uniformly toothed soft steel end caps. Teeth on the two end caps are misaligned with respect to each other by a half-toothed pitch. The toothed end caps are normally made of laminated silicon steel. The magnetic field generated by stator coil is a heteropolar field as shown in fig. b).



(a) (b)

Fig. Magnetic paths in a hybrid motor

(a) The flux due to the rotor's producing a unipolar field

(b) The heteropolar distributed flux due to the currents.

Principle of Operation:

Most widely used hybrid motor is the two phase type as shown in fig. This model has four poles and operate on one phase on excitation.

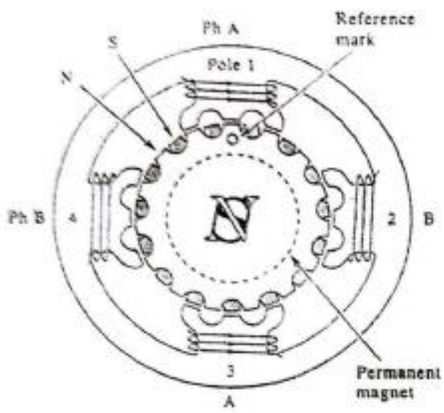


Fig.Cross-section of a two-phase hybrid motor.

The coil in pole l and that in pole 3 are connected in series consistingof phase A, and pole 2 and 4 are for phase B.

Fig. shows the process of rotor journey as the winding currents are switched in one phase ON excitation.

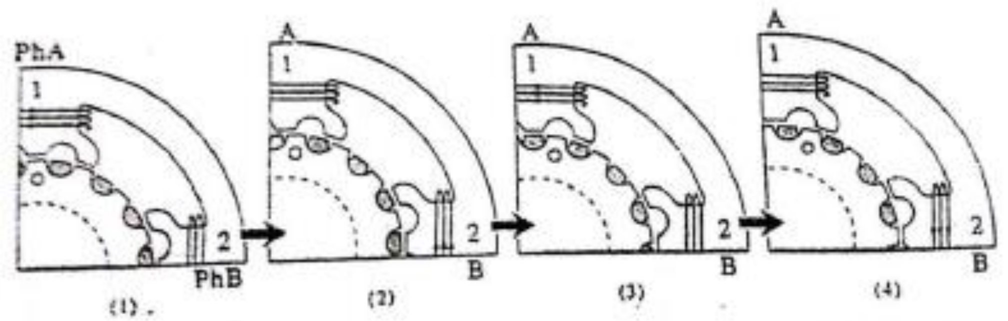


Fig. One-phase-on operation of a two-phase hybrid motor.

The poles of phase A are excited the teeth of pole 1 attract, some of the rotors north poles, while the teeth of pole 3 align with rotor's south poles. Current is then switched to phase B, the rotor will travel a quarter tooth pitch so that tooth alignment takes place in 2 and 4.

Next current is switched back to phase A but in opposite polarity to before, the rotor will make another quarter tooth journey. The tooth alignment occurs in opposite magnetic polarity to state 1.

When current is switched to phase B in opposite polarity state (4) occurs as a result of another quarter tooth pitch journey.

The structure of two phase motor considered in fig. will not produce force in a symmetrical manner with respect to the axis. The monitor having 8 poles in the stator shown in fig. considered as the structure in which torque in generated at a symmetrical position on the rotor surface.

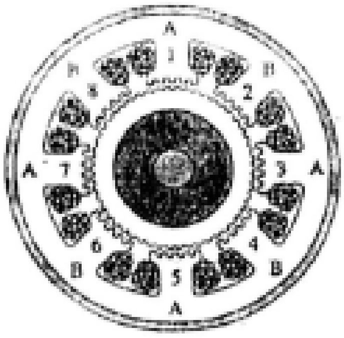


Fig. Two phase hybrid motor with 8 stator poles.

3. State and explain the static and dynamic characteristics of a stepper motor. [May 2010 May 2014 May 2015 Nov 2016]

Draw and explain the torque pulse rate characteristics of stepper motor.[May 2007 May 2010]

Explain torque verses stepping rate characteristics of a stepping motor. Also explain about slew rate and damping. [May 2008]

Characteristics of Stepper motor:

Stepper motor characteristics

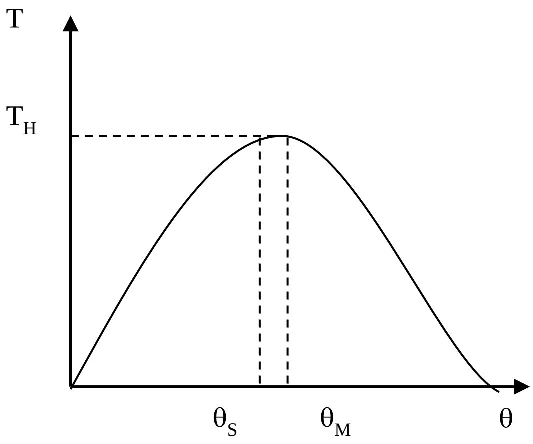
1. Static characteristics (stationary positions of the motor)
2. Dynamic characteristics (running conditions of motor)

(i) Torque displacement characteristics

(ii) Torque current characteristics

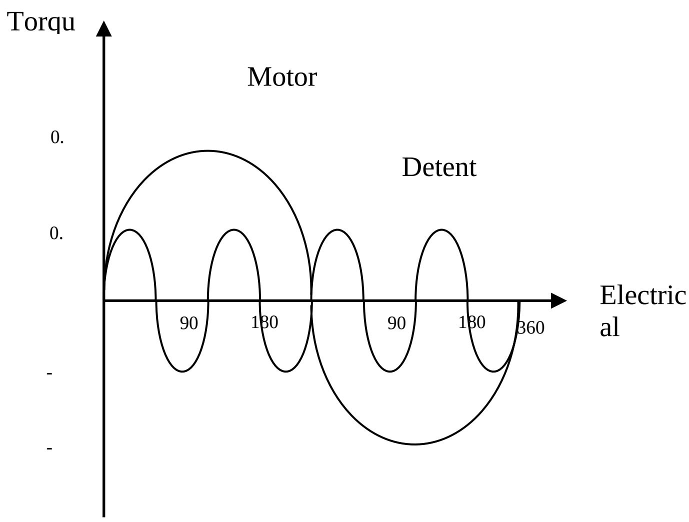
(i) Torque displacement characteristics

Electromagnetic torque (T) (vs) Displacement angle (θ)



(a) Holding Torque (T_H):

- It is the maximum load torques which the energized stepper motor can withstand without slipping from the equilibrium position.
- If the holding torque is exceeded the motor suddenly slips from the present equilibrium position and goes to the next static equilibrium position.
- It is the maximum load torque upto which the energized stepper motor can withstand without slipping.
- It is due to residual magnetism and it is 5-10% of holding torque. It is a fourth harmonic torque also known as caging torque.

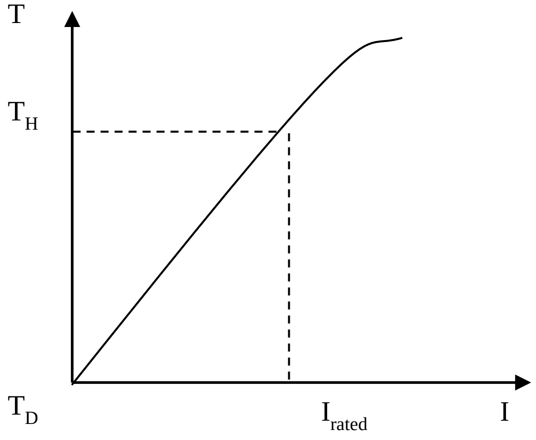


Motor torque and Detent torque

(ii) Torque current characteristics

- Relationship between TH and I (Holding torque)
- Initially curve is linear and then slope decreases as the magnetic circuit saturates.

Torque current curve



Unit (N_m/A)

Torque constant (K_T)

Initial slope of T.I curve also known as Torque sensitivity.

Dynamic characteristics:

- It gives the information regarding the torque stepping rate. The characteristics relating to motors which are in motion (or) about to start are called dynamic characteristics.
- Selection of stepping rate is important for proper controlling of stepper motor.
- A stepper motor is said to be operating in synchronism when there exists strictly one to one correspondence between number of pulses applied and the number of steps through which the motor has actually moved.
- In stepper motors when the stepping rate increases, the rotor gets less time to drive the load from one position to

other. If stepping rate is increased beyond certain limit, the rotor cannot follow the command and starts missing pulses.

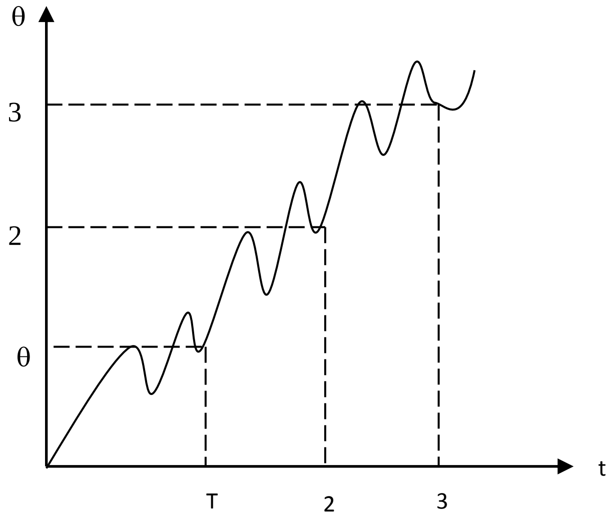
Two modes of operation:

(i) Start stop mode

(ii) Slewing mode

(i) Start stop mode

- This start stop mode is also called as pull in curve (or) single stopping rate mode.
- In this mode of operation, a second pulse is given to the stepper motor only after the rotor attained a steady (or) rest position due to first pulse
- The region of start-stop mode of operation depends on the torque developed and the stepping rate (or) stepping frequency of the stepper motor.



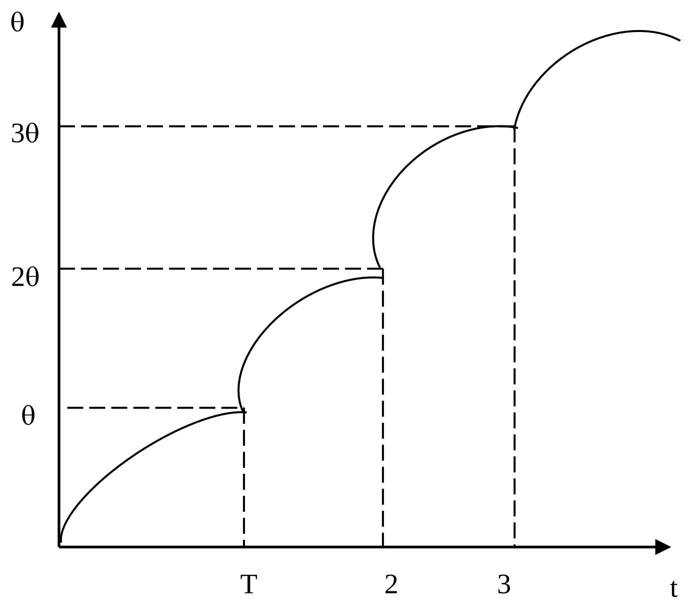
Start – Stop Mode of Operation

Slewing Mode:

- In start stop mode, the stepper motor always operate in synchronism and the motor can be started and stopped without losing synchronism.
- In slewing mode, the motor will be in synchronism but it

cannot be started (or) stopped without losing synchronism.

- To operate the motor in slewing mode, first the motor is to be started in start-stop mode and then to be transferred slewing mode.
- Similarly to stop the motor operating in slewing mode, first the motor is to be bought to the start stop mode and then to be stopped.
- In slewing mode of operation, the second pulse is given to the motor before the motor has attained steady (or) rest position due to the first pulse.
- Consequently, the motor can run as a much faster rate in slowing mode than in start stop mode.
- However, the motor cannot start slewing from rest nor it can stop immediately when the pulses applied have been stopped.



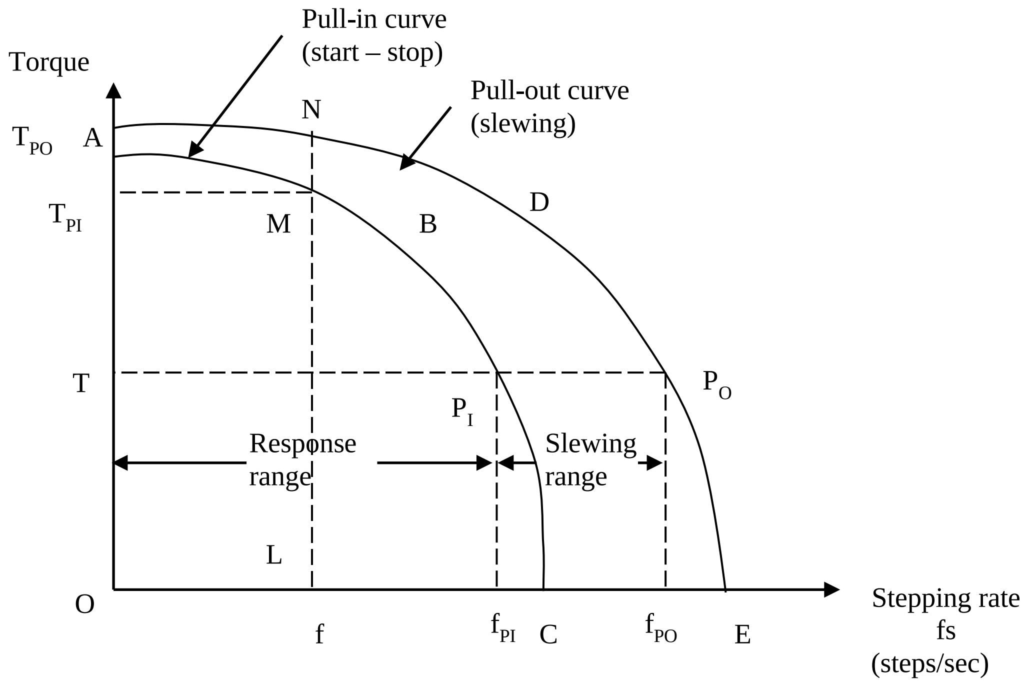
Slewing Mode of Operation

Torque – Speed Characteristics:

- Torque developed by the stepper motor and stepping rate characteristics for both mode of operation s are shown.

Curve ABC ⇒ “Pull-in characteristics”

Curve ADE ⇒ “Pull-out characteristics



Area “DABCD” ⇒**Region:** Start -stop mode of operation. At any operating point in the region the motor can start and stop without losing synchronism.

Area “ABCEDA” ⇒**Region:** Slewing mode of operation. At any operating point without losing synchronism to attain an operating point in the slewing mode at first the motor is to operate at a point in the start-stop mode any then stepping rate is increased to operate in slewing mode, similarly while switching off it is essential to operate the motor from slewing mode to start-stop mode before it is stopped.

Pull in torque:

It is the maximum torque developed by the stepper motor for a given stepping rate in the start-stop mode of operation without losing synchronism.

LM ⇒ pull in torque

TPI corresponding to the stopping rate f (i.e.,) OL.

Pull out torque:

It is the maximum torque developed by the stepper motor for a given stepping rate in the slewing mode without losing synchronism.

LN ⇒ pull out torque.

T_{po} corresponding to F (i,e,) DL.

Pull in range:

It is the maximum stepping rate at which the stepper motor can operate an start-stop mode developing a specific torque without losing synchronism.

P_1T_1⇒ pulls in range for a torque of T.

(i.e) or

This range is also known as response. Range of stepping rate for the given Torque T.

Pull out range:

It is the maximum stepping rate at which the stepper motor can operate in slewing mode developing a specified torque without losing synchronism.

P_1P_0⇒ pull out range for a torque of T.

Range P_1P_0 is known as slewing range.

Pull in rate (FP_I):

It is the maximum stepping rate at which the stepper motor will start or stop without losing synchronism against a given load torque T.

Pull out rate (FP_O):

It is the maximum stepping rate at which the stepper motor will slew, without missing steps, against load torque T.

Synchronism:

This term means one to one correspondence between the number of pulses applied to the stepper motor and the number of steps through which the motor has actually moved.

4. Explain in detail about different types of power drive circuits for stepper motor. [May 2014 May 2017]

(OR)

Draw the drive circuits for stepper motor and their characteristics. [Nov 2007]

(OR)

Write a detailed note on the bipolar dives for stepper motors. (8) [Nov 2012]

Power Driver Circuit:

The number of logic signals discussed above is equal to the number of phasesand the power circuitry is identical for all phases.Fig.(a) shows the simplest possible circuit of one phase consisting of a Darlington paircurrent amplifier and associated protection circuits.The switching waveform shown in fig.(c) is the typical R-L response with an exponential rise followed by a decay at the end of the pulses.

In view of the inductive switching operation, certain protective elements are introduced in the driver circuit. These are the inverter gate 7408, theforward biased diode D_1 and the free wheeling diode D_2. The inverter ICprovides some sort of isolation between the logic circuit and the power driver.

There are some problem with this simple power circuit. They can be understood by considering each phase winding as a RL circuit shown in fig. (b) subject to repetitiveswitching. On application ofa positive step voltage, thecurrent risesexponentially as

$$i(t) = I\left(1 - e^{-t/\tau}\right)$$

whereI = V/ R - rated current and

$\tau = L / R$ windingtime constant.

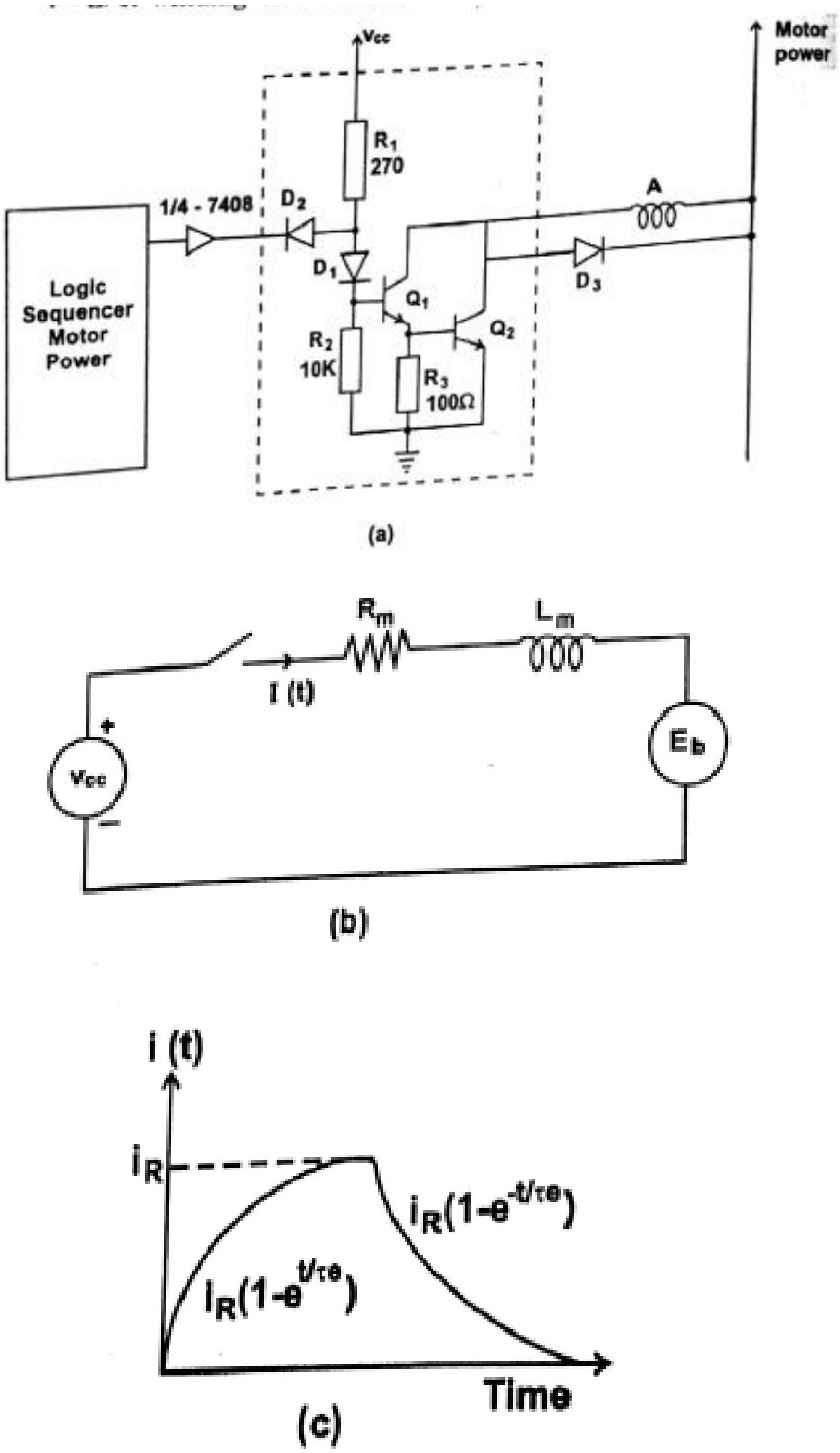


Fig. Power Driver Stage of Stepper Motor Controller

In practice, thetime constantτ limits the rise and fall of currentin thewinding. At low stepping rate, the current rises to the rated value in eachON interva1 andfalls to zero va1ue ineach OFF interval.However, as the switching rate increases, the current is not able. to rise to the steady state, nor fall to zero value within the on/off time intervals set bythe pulse waveform. This in effect, smoothens thewinding current reducing the swing as shown in fig. As a result, the torque developed by the motor gets reducedconsiderably and for higher frequencies, the motor just ‘vibrates’ or oscillates within onestep of the current mechanical position.

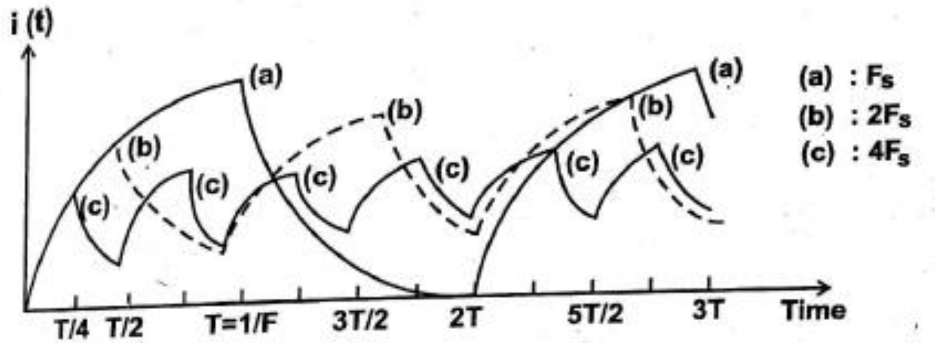


Fig. Effect of Increasing Stepping Rate on Current Swing.

In order to overcome these problems and to make improvement of currentbuild up several methods of drive circuits have been developed.

For example when a transistor is turned on to excite a phase, the power supply must overcome the effect of winding inductance beforedriving at the rated current since the inductancetends tooppose the current build up. Asswitching frequency increases the portion that the buildup time takes up within the switching cycle becomes large and it results in decreased torque and slow response.

Improvement of current buildup/special driver circuits:

(a) Resistance drive (L/R drive):

Here the initial slope of the current waveform is made higher by adding external resistance in each winding and applying a higher voltage proportionally. While this increases the rate of rise of the current, themaximum value remains unchanged as shown in fig.

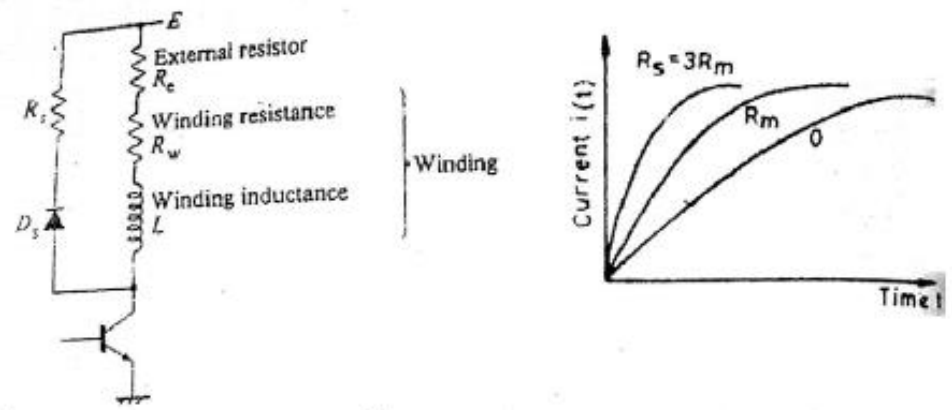


Fig. : L/R drive

The circuit time constant is now reduced and the motorisable develop normal torque even at high frequencies. The disadvantage of method this method is

(a) Flow of current through external resistance causes I^2 R losses and heating. This denotes a wastage of power as far as themotor is concerned.

(b) In order to reach the same steady state current I_R as before, the voltage required to be applied is much higher than before. Hence this approach is suitable for small instrument stepper motors with current ratings of around100mA,andheatingisnot amajor problem.

(b) Dual voltage drive(or) Bilevel drive:

To reduce the power dissipation in· the driverandincrease performance of a stepping motor, a dual-voltage driver is used. The scheme for one phase is shown in fig.

When a step command pulse is given to the sequencer, a high level sign will be put out from one of the output terminal to excite a phase winding. On this

signalbothTr1andTr2areturnedon,andthehigher voltage E_H

willbeappliedtothe winding. The diode D_1 isnow reverse biased

to

isolatethelowervoltagesupplyfromthehighervoltagesupply. The

current build up quicklyduetothehighervoltageE_H. Thetime

constantof the monostable multivibratoris selected so that

transistor Tr 1 isturnedoff when the winding current exceeds the

ratedcurrentbyalittle. After the higher

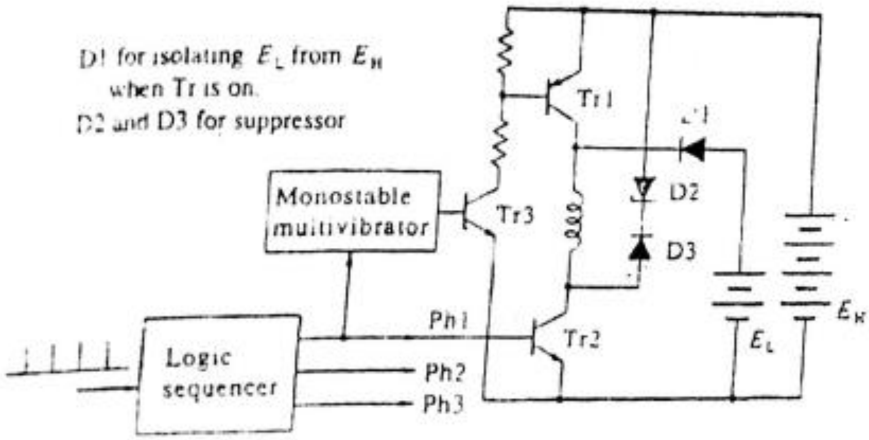


Fig. Improvement of current buildup by dual voltage drive

voltage source is cut offthe diode is forwardbiased andthe

winding current is supplied from the lower voltage supply. A

typical current waveform is shown in fig.

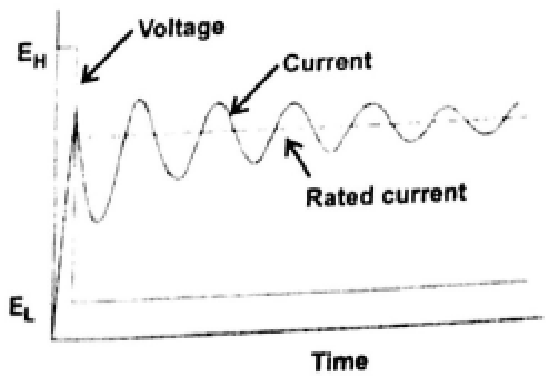


Fig. Voltage and current wave form In a dual voltage drive

When the dualvoltagemethodis employedforthetwo phaseon drive of a two phasehybridmotor,the circuitschemewillbe suchasthat shown in fig.Two transistorsT_{r1}& T_{r2}andtwo diodesD_1andD_2 are used for switching the highervoltage.Indualvoltage schemeasthe stepping rate is increased, the high voltage isturnedonfor agreaterpercentageof time.

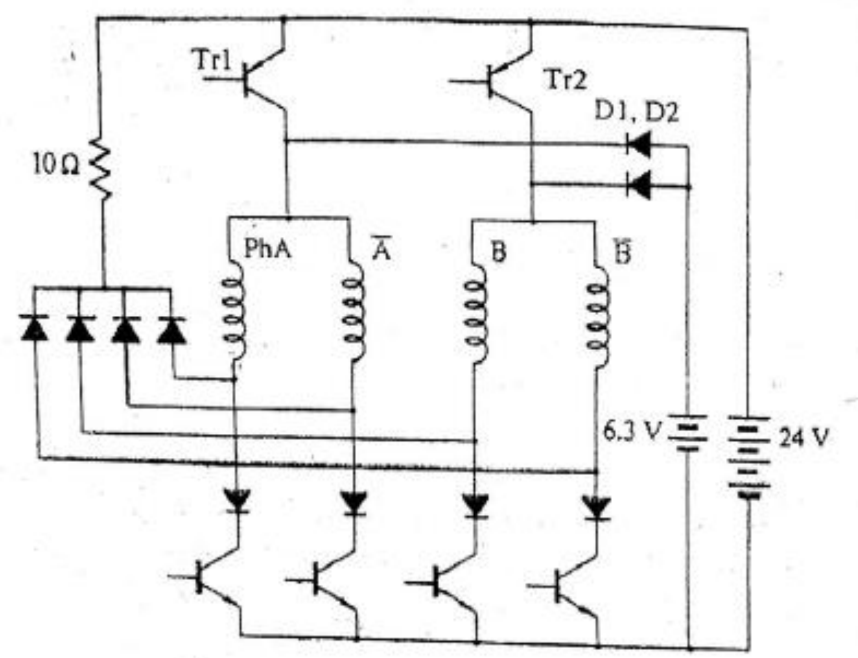


Fig. A dual-voltage driver for the two-phase-on arive of a two phase hybrid motor.

Fig. A dual-voltage driver for the two-phase-on arrive ofatwo phase hybrid motor.

This. drive isgoodandenergyefficient.. However it ismore complex as it requires two regulated power supplies E_H& E_L and two power transistor switches T_{r1}& T_{r2},andcomplex switching logic. Hence it isnot very popular.

(c) Chopper drive:

Here a higher voltage 5 to 10 timestheratedvalueisappliedto the phase winding as shown in fig. 2.50(a) and the currentis allowedtoraise very fast. As soon as the current reaches about 2 to 5% above therated current, the voltage is cut off, allowing the current to decrease exponentially. Again asthe currentreaches some 2 to5% belowtherated value, the voltage is applied again. The process is repeated some 5 - 6 times within the ON period before the phase isswitched off.During this period the currentoscillatesabout the rated value as shown infig.2.50(b). A minor modification istochoptheappliedde voltageat a highfrequencyof around1 kHz, with e desired duty cycle soasto obtaintheaverage on-state current equal the rated value.

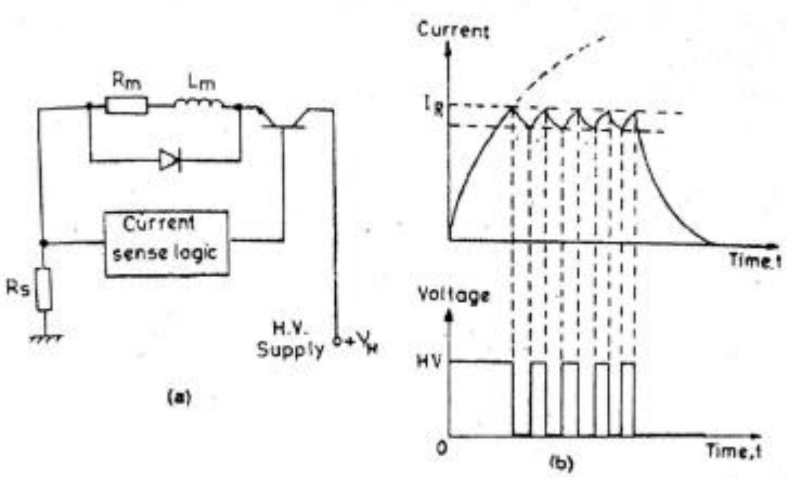


Fig. Chopper drive

The chopper drive is particularly suitable for high torque stepper motors. It is energy efficient like the bilevel drive but the control circuit is simpler.

Problems with driver circuits:

A winding on a stepping motor is inductive and appears as a combination of inductance and resistance in series. In addition as a motor revolves a counter emf is produced in the warning. The equivalent circuit to a winding is hence, such as that shown in fig. on designing a power driver one must take into account necessary factors and behavior of this kind of circuit. Firstly the worst case conditions of the stepping motor, power transistors,

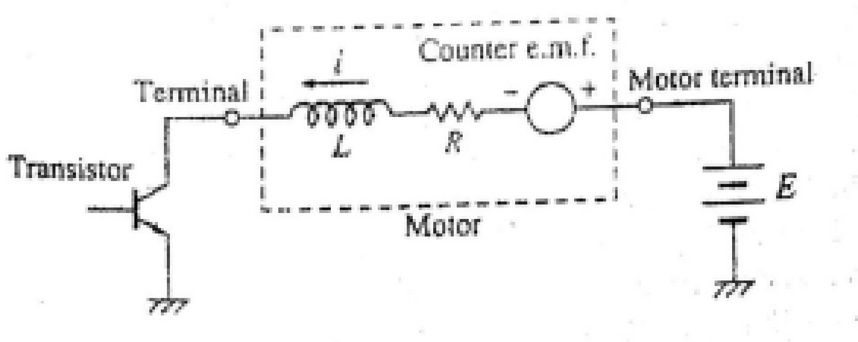


Fig. Equivalent circuit to a winding of a stepping motor.

and supply voltage must be considered. The motor parameters vary due to manufacturing tolerances and operating conditions. Since stepping motors are designed to deliver the highest power from the smallest size, the case temperature can be as high as about 100°C and the winding resistance therefore increases by 20 to 25 per cent.

5. Derive the reluctance torque of a stepper motor [May 2010 May 2015]

Theory of Torque Prediction:

(i) Flux linkages,

$$\lambda = N\phi \qquad e = N\frac{d\phi}{dt}$$

$$\lambda = Li \qquad e = L\frac{di}{dt}$$

(ii) Flux, $\phi = \frac{MMF}{Reluctance} = \frac{Ni}{s}$

Flux linkage, $\lambda = N\phi = \frac{N^2 i}{s}$

Inductance, $L = \frac{\text{Flux linkage}}{\text{current}} = \frac{\lambda}{i}$

$$= \frac{N^2 i}{si}$$

$$L = \frac{N^2}{s}$$

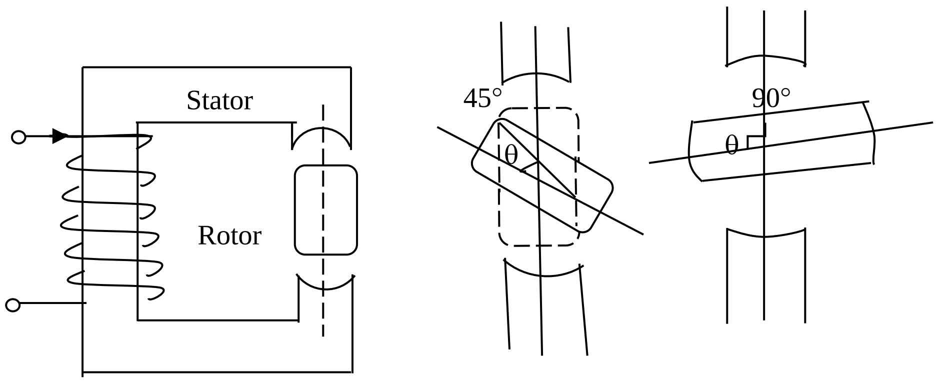
Flux linkages can be varied by,

(i) Varying flux (ϕ)

(ii) Varying the current "I"

(iii) Varying reluctance "s"

Consider a magnetic circuit as shown,



(a) (b) (c)

The stator consists of magnetic core with two pole arrangement stator core carries a coil rotor is also made up of ferrous material. The rotor core is similar to a two salient pole machine.

Let the angle between the axis of stator pole and rotor pole be 0.

Case I: Angular displacement θ = 0°

The airgap between stator and rotor is very small. Therefore, the reluctance of the magnetic path is least.

$$s = \frac{l}{\mu A} \qquad \text{if } l \text{ is } \downarrow \Rightarrow s \text{ is } \downarrow \Rightarrow L \text{ is } \uparrow$$

Due to minimum reluctance, the inductance is maximum (L_{max})

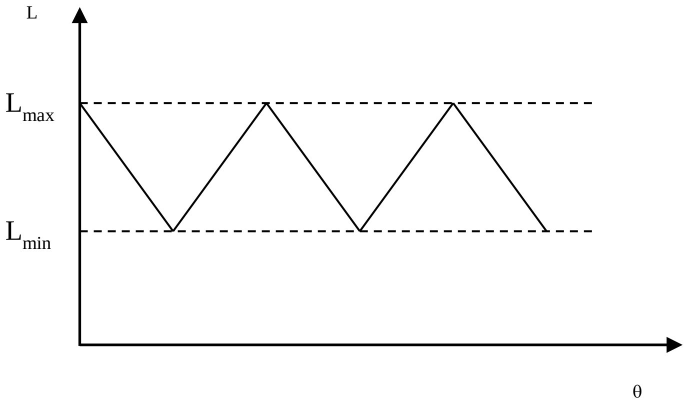
Case II: θ = 45°

In figure (b), in this only a portion of rotor poles cover the stator poles. ∴ Reluctance of the magnetic path is more than case I. Due to which the inductance becomes less than L_{max}

Case II: θ = 90°

The airgap between the stator and rotor has maximum values. $\therefore$ Reluctance has maximum value yielding minimum inductance (L_{min})

Variation in inductance with respect to the angle between the stator and rotor poles is



Variation in inductance w.r.t to 0

Derivation of reluctance torque:

As per faradays's law of electromagnetic induction an emf is induced in an electric circuit when there exists a change in flux linkage.

$$e = \frac{-d\lambda}{dt} \text{ where } \lambda = N\phi(\text{or})Li$$

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

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

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

Magnitude of $e = L\frac{\partial i}{\partial t} + i\omega\frac{\partial L}{\partial \theta} \qquad \rightarrow (1)$

Stored magnetic field energy,

$$\omega_e = \frac{1}{2}Li^2$$

The rate of change of energy transfer due to variation is stored energy (or) power.

$$\frac{d\omega_e}{dt} = \frac{1}{2} L \cdot 2i \frac{\partial i}{\partial t} + \frac{1}{2} i^2 \frac{\partial L}{\partial t} \qquad \rightarrow (2)$$

Mechanical power developed/consumed = power received from the electrical source – power due to change in stored energy in the inductor → (a)

Power received from the electrical source = ei from (1)

$$\therefore \qquad ei = iL \frac{\partial i}{\partial t} + \omega i^2 \frac{\partial L}{\partial \theta} \qquad \rightarrow (3)$$

Substitute (2) & (3) in (a)

Mechanical power developed

$$= \left[iL \frac{\partial i}{\partial t} + \omega i^2 \frac{\partial L}{\partial \theta} \right] - \left[Li \frac{\partial i}{\partial t} + \frac{1}{2} \omega i^2 \frac{\partial L}{\partial \theta} \right]$$

$$P_m = \frac{1}{2} \omega i^2 \frac{\partial L}{\partial \theta} \qquad \rightarrow (4)$$

$$P_m = \frac{2\pi NT}{60} = \omega T$$

$$\therefore \qquad T = \frac{P_m}{\omega} \qquad \rightarrow (5)$$

Sub (4) in (5),

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

Note:

(i) Torque ⇒ Motoring when $\frac{\partial L}{\partial \theta}$ is +ve

(ii) Torque ⇒ Generating when $\frac{\partial L}{\partial \theta}$ is -ve

(iii) Torque is αi^2.

6. With a neat block diagram explain microprocessor control of stepping motor.

[Nov 2013 May 2017]

Closed loop control of stepper motor:

In the drive systems, the step command pulses were given from an externalsource and it was expected that thestepping motor is able to followeverypulse.This type of operation is refereed to asthe open loop drive.

The open loop drive isattractiveand widely accepted in applications of speedand position controls. However, the performance of a stepping motor is limited under the open loop drive.For instance a stepping motor driven in the open loopmode may fai1 to fallow a pulsecommand when thefrequency of the pulse tram is too high or the inertial load is too heavy. Moreover the motor motion tends to be oscillatory in open loopdrives.

The performance of stepping motor can be improved to a great extentby employing position feedback and/or speed feedback to determine theproper phases to be switched at proper timings. This typeof controlistermedthe closed loop drive. ·

A simple closed loop operation of stepper motor is explained with block diagram fig

In closed loop control, a position sensor is needed for detecting the rotor position. Nowadays optical encoder is used and it is usually coupled to the motor shaft. The optical encoder coupled to the rotor detects the rotor position and supplies its information to thelogic sequencer.

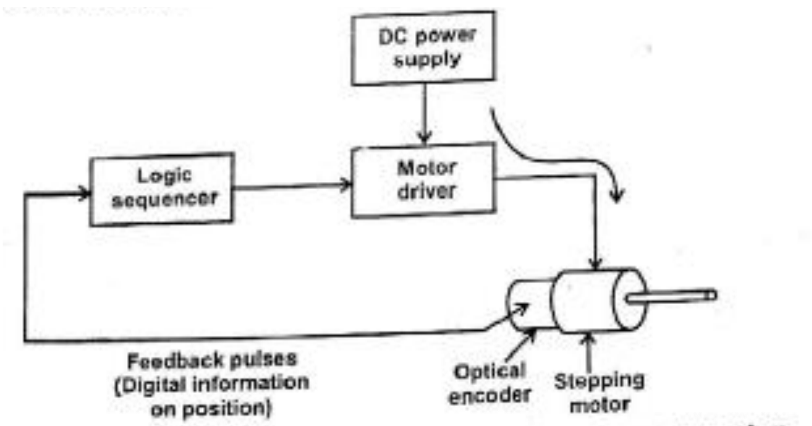


Fig. Simple closed loop operation of a stepper motor

Fig. Simple closed loop operation of a stepper motor

Then the logic sequence determines the proper phase(s) tobeexcited, taking account of position information. The relation between therotor's presentposition andthe phase(s) to be excited is specifiedinterms oflead angle.

In this example the motor is a three phase motor and the sequence of excitationis phase 1→phase → 2 → phase 3 in the singlephase on mode. Phase 1is now excitedandtherotor is stoppingatanequilibrium position. Then phase 2isexcitedandphase1isde-energizedto startthe motor. The leadangleisthis case is one step.

As soon as the positional encoder detects that the rotor reaches an equilibrium position of Ph(N), the logic sequencer set for operation of one step lead angle will generate the signal to turnonph (N + l)tocontinuethemotion.Thusasteppingmotor inaclosedloop systemrunslike a brushless DC motor in which the proper windings to be energised is/are automatically selectedbyapositionsensorincorporatedinorcoupledtothe motor.

Thespeedof a stepping motordriveninaclosedloop mode varies with load . The bigger the load the slower the speed. Position feedback mechanism using an opticalencoderisshownin fig.

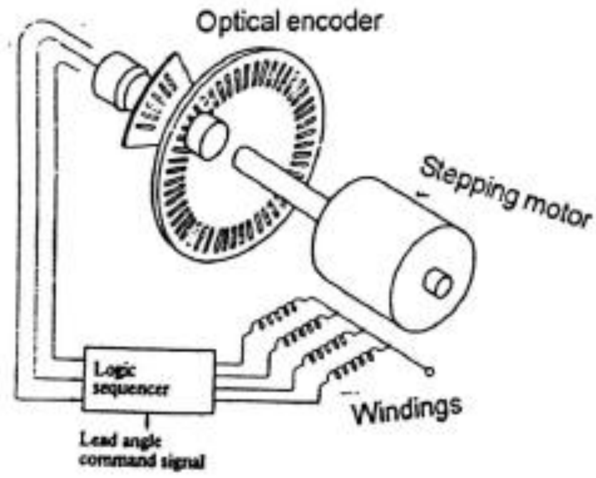


Fig. Position feedback mechanismusing anoptical encoder.

Closedloop operationsystem using microprocessor:

The outline ofthesystemusing microprocessor inshownin fig.

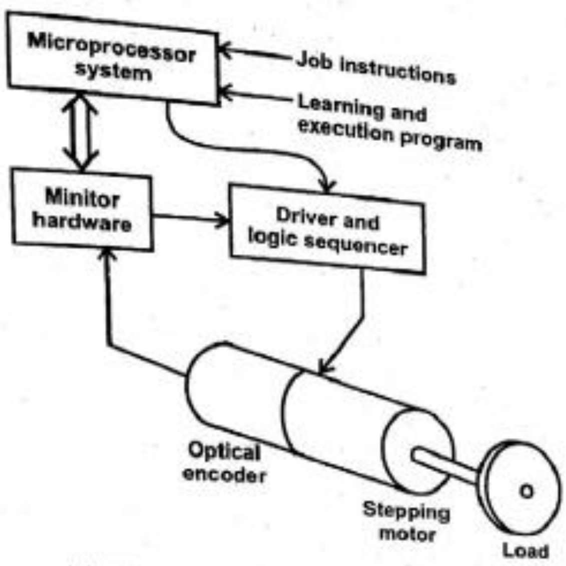


Fig. (a): Microprocessor based closed loop system.

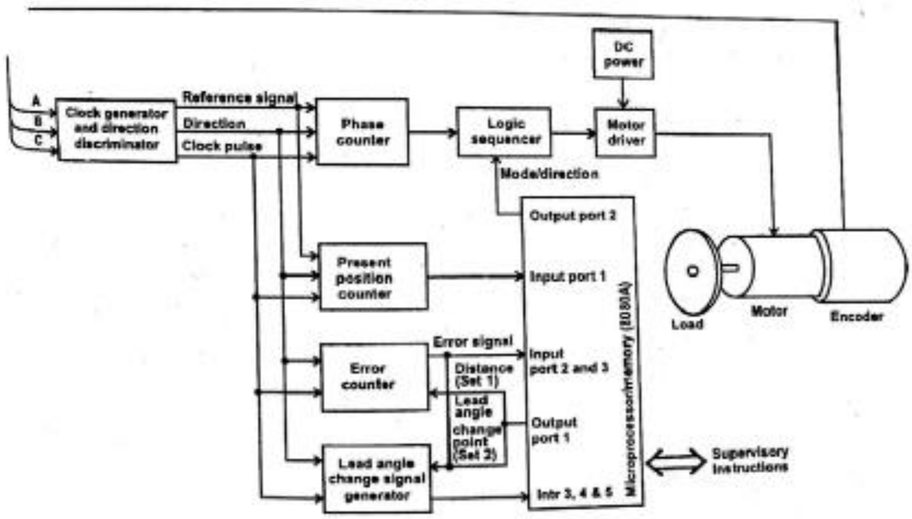


Fig. (b): Block diagram of system hardware.

The outline of the system has a dedicated logic sequences outside the microprocessor. A positional signal is feedback to the block of hardware with monitors the rotor movement and exchanges information with the microprocessor. The software must be programmed so that the microprocessor determines better timings for changing lead angles, based on the previous experience and present position / speed data. The microprocessor will finally after several executions find the optimal timings for each motion used.

7. Explain the working of single and multistack configured stepping motor. [May 2015 Nov 2016]

Multistack variable reluctance stepper motor:

Theseareusedtoobtainsmallest step sizes, typically intherange of 2° to 15°. Although three stacks are common a multistack motor may employ as many seven stacks. This type is also known as the cascade type. A cutaway view ofathreestackmotorisshowninfig.

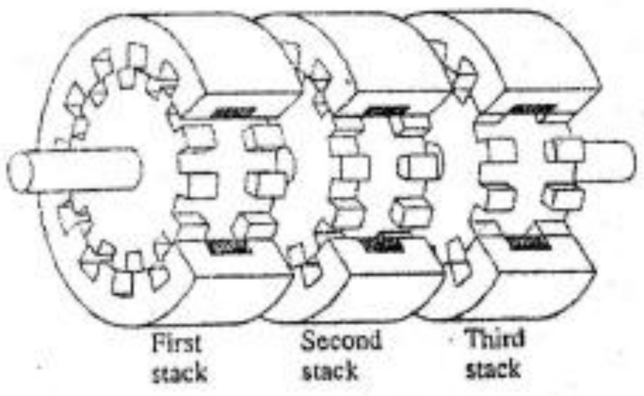


Fig. Construction of multi-stack VR motor.

A multistack (or m-stack) variable reluctance steppermotor can be considered to be made up of ‘m’ identical single stackvariablereluctance motors with their rotors mounted on asingle shaft. The stators and rotors have the same number of poles (or teeth)andtherefore same pole (tooth) pitch.For am-stackmotor,thestatorpoles(or teeth) in allm stacks arealigned,buttherotorpoles(teeth)aredisplacedby1/mofthepolepitchangle from one another. All the stator pole windings. in a given stack are excited simultaneously and,thereforethestator windingof each stack forms one phase. Thus themotorhasthesamenumberof phasesasnumber of stacks.

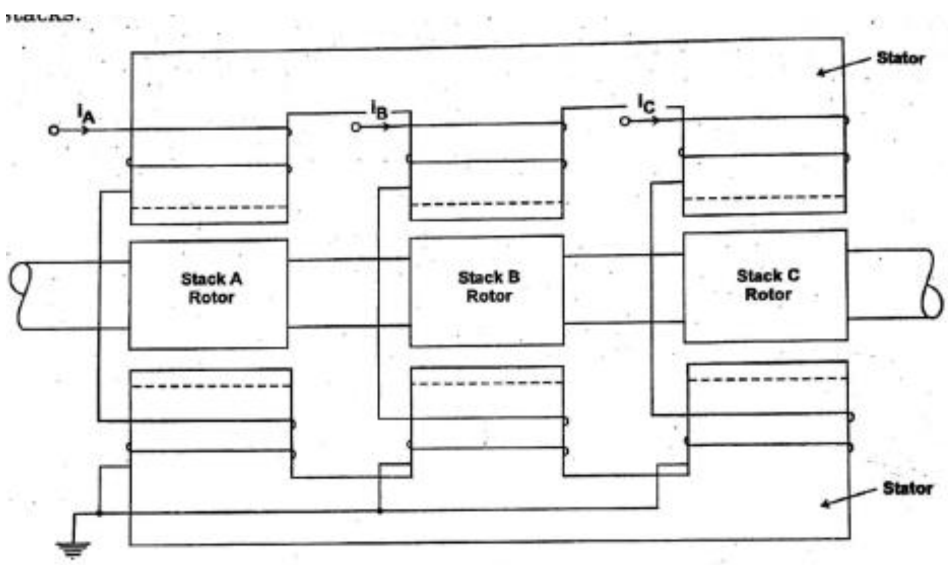


Fig. Cross-section of a 3-stack, VR stepper motor parallel to the shaft.

Figure shows thecrosssectionofathreestack(3-phase)motor parallel to the shaft.Ineachstack,statorand rotorshave12poles(teeth). Fora12pole rotor,polepitchis30°andtherefore,therotorpoles (teeth) aredisplacedfromeachotherby1/3rdofthepolepitchor10°.Thestator teeth in each stack are aligned. When the phase winding Aisexcitedrotor teethof stack A arealignedwiththestatorteethasshowninfig.2.8.

WhenphaseA is de-energisedandphase B isexcitedtherotorteeth of stackBare aligned withstatorteeth.Thisnew alignmentismadebythe rotor movement of 10° in theanticlockwisedirection. Thus the motor moves one step(equalto1/2polepitch) duetochangeof excitationfrom stack AtostackB

NextphaseBisde-energisedandphaseCisexcited.Therotor moves byanother step of 1/3rdofpole pitchintheanticlockwisedirection. Another change of excitation fromstack C to stack A will once more align the stator and rotor teeth in stack A. However during thisprocess ($A \rightarrow B \rightarrow C \rightarrow A$) the rotor has moved one rotor tooth pitch.

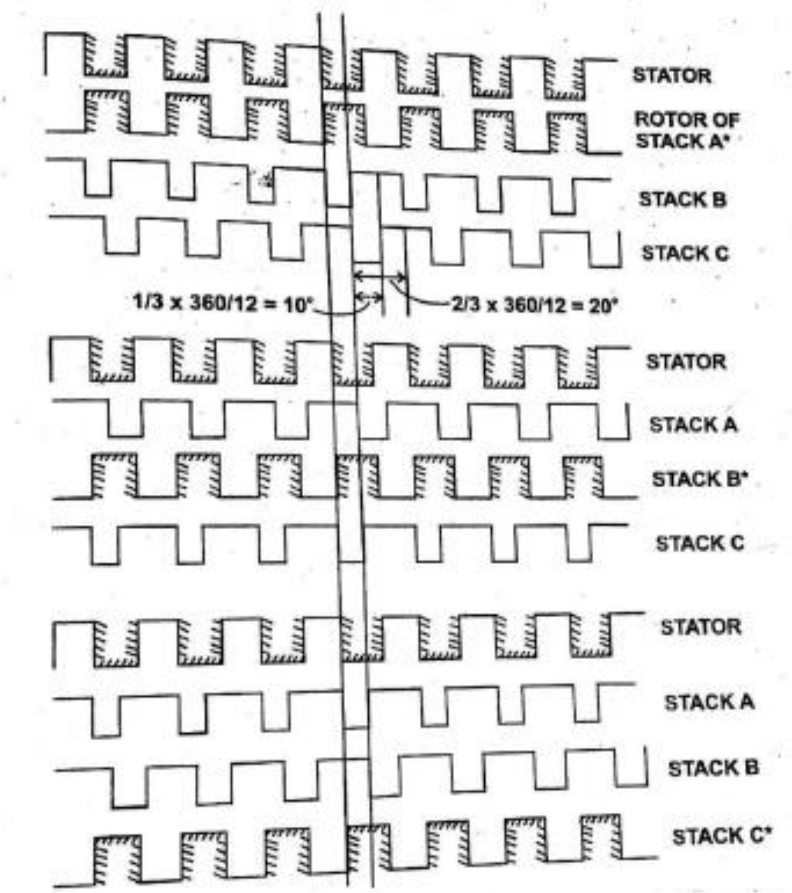


Fig.Positionofstator& rotor teeth of 3 stackVR motor

LetNrbethenumberofrotorteethand'm'thenumberofstacks or phases, then

$$\text{Tooth pitch } T_p = \frac{360}{Nr} \qquad ...1$$

$$\text{Step Angle } \alpha = \frac{360°}{mNr} \qquad ...2$$

In this case,

$$\text{Tooth pitch } T_p = \frac{360°}{12} = 30°$$

$$\text{Step Angle } \alpha = \frac{360}{3 \times 12} 10°$$

The variable reluctance motors, both single and multi stack types, have high torque to inertia ratio. The reduced inertia enables the VR motor to accelerate the load factor.

Step angle also given by $\alpha = \frac{N_s - N_r}{N_s N_r} \times 360$ ...3

Where N_s – Stator poles or stator teeth.

N_r – Rotor poles or rotor teeth.

8. Explain the construction and operation of VR stepper motor. Also explain about micro stepping. [Nov 2007 May 2008 Nov 2012 Nov 2013 May 2010 May 2017]

Singlestackvariablereluctance stepper motor:

Construction:

The VR stepper motor is characterized by the fact that there is no permanent magnet either on the rotor or thestator.Theconstructionofa 3-phaseVR steppermotorwith6poles on thestatorand 4 poles on the rotor isshowninfig.

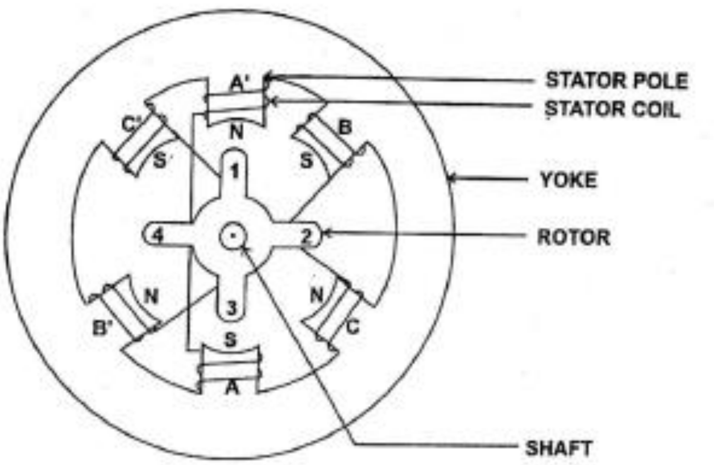


Fig.Cross sectionalview of variable reluctance motor

The stator is made up of silicon steel stampings with inward projected even or oddnumberof poles orteeth (usually thenumber of poles of stator is an even number). Each and every stator pole carries a field coil or exciting coil. In case of even number of poles the exciting coils of opposite poles are connected in series. The two coils are connected such that their MMF get added. The combination of two coils is known as phase winding.

The rotor is also made up of silicon steel stampings with outward projected poles and it does not have any electrical windings. The number of rotor poles should be different from that of stator in order to have self starting capability and bi-directional rotation. The width of'rotor teeth should be same as statorteeth. Solidsiliconsteelrotorsareextensivelyemployed.Both the stator and rotor materials must have high permeability and be capable of allowing a high magnetic flux to pass through them even if a low magnetomotive force is applied.

Electricalconnection:

Electrical connection of VR stepper motor is shown in fig. 2.2. Coils A and A' are connectedinseriesto formaphase winding.This phasewinding is connectedtoaDCsourcewith thehelpofasemiconductor switch S_1.Similarly BandB'andC andC' areconnectedto thesame source through semiconductor switches $S_2$and S_3 respectively. Themotorhas 3-phases a, b and c.

* a phase consist of A and A' coils
* b phase consist of B and B' coils
* c phase consist of C and C' coils

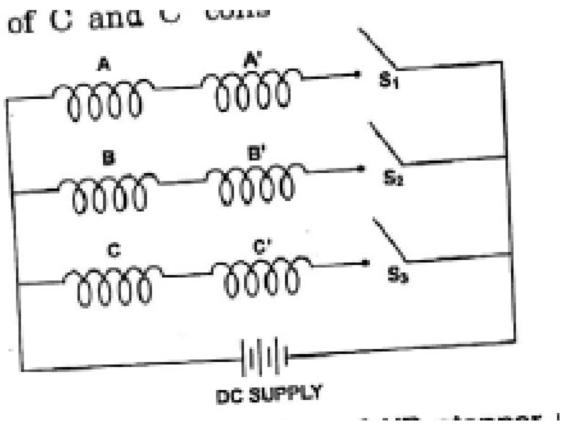


Fig. Electrical connection of VR stepper motor

Principleof operation:

It works on the principle of variable reluctance. The principle of operation of VR stepper motor can be explained by referring to fig.

Themotor has the following modes of operation.

(a) Mode I:Onephase ON orfull step operation:

In this mode of operation of stepper motor only onephaseisenergised atanytime.If currentisappliedtothecoilsofphasea(or)phasea is excited,thereluctancetorquecausestherotortoturnuntilitaligns with the axis of phase a. The axis of rotor poles 1 and3 areinalignmentwiththe axis of stator poles A and A'. Then $\underline{|\theta} = \theta°$.

The magnetic reluctance is minimised and this state provides a rest or equilibrium positionto therotor and rotor cannotmove untilphase a is energised.

NextphasebisenergisedbyturningonthesemiconductorswitchS$_2$ andphase'a'isde-energisedbyturningoffS$_1$.Then therotor poles1 and 3and 2and4experiencetorquesinoppositedirection.Whentherotor and stator teeth are out of alignment in the excited phase the magnetic reluctance islarge.Thetorqueexperiencedby 1and3areinclockwisedirectionand that of2and4 isincounterclockwise(CCW)direction. The later is more than the former. As a resu1t the rotor makes an angular displacement of 30° in counter clockwisedirectionsothatBandB'and2and4inalignment.

This positionisshown in fig.(c).Thusasthephasesareexcited in sequencea, band ctherotorturnswithastep of 30° incounter clockwise direction. The direction of rotation can be reversed by reversing the switching sequence of thephases (i.e.) a,c and b etc. The direction of rotationdepends on the sequence in which phasewindings areenergised andis independent of the direction of currentsthroughthephase winding.

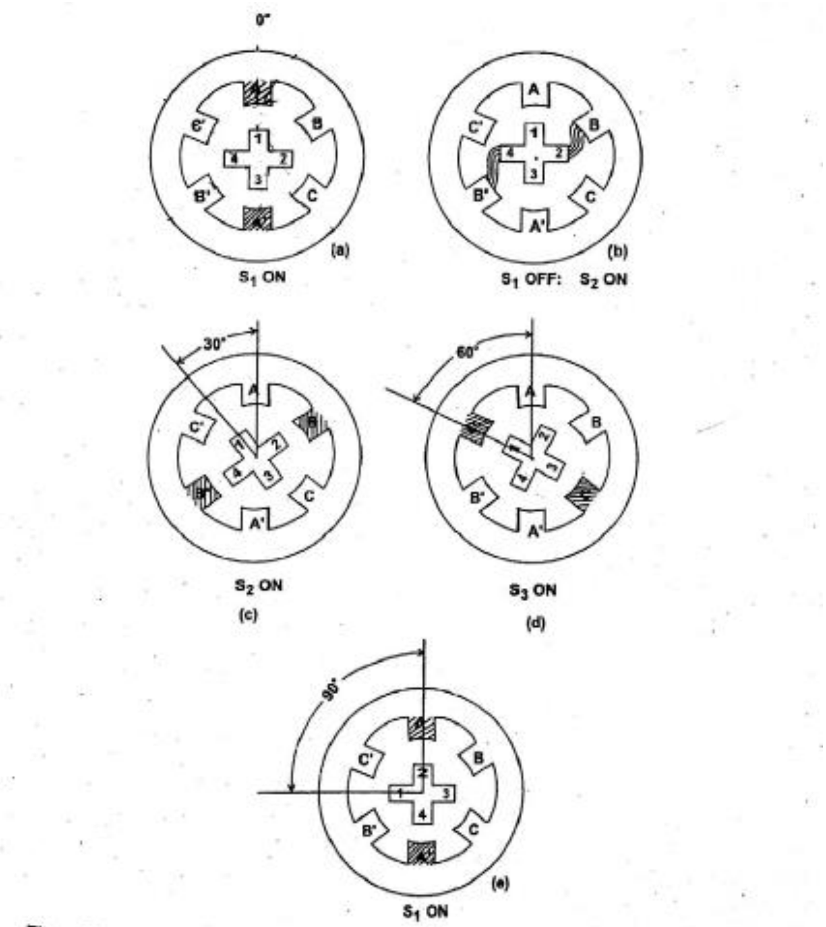


Fig. Step motions as switching sequence process in a 3-phase VR moto

The truth table formodeIoperationincounterclockwiseand clockwise directions aregiven in tables and respectively.

Table : Counter ClockwiseRotation (CCW)

S1	S2	S3	θ
*	-	-	0
-	*	-	30
-	-	*	60
*	-	-	90
-	*	-	120
...,	-	*	1 50
*	-	-	180
-	*	-	210
-	-	*	240
*	-	-	270

-	*	-	300
-	-	*	330
*	-	-	360

Table : Clockwise Rotation (CW)

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

(b) Mode II:Two phase on mode:

In thismodetwo statorphasesareexcitedsimultaneously. When phases a and b are energised together, the rotor experiences torque from both phases and comes to rest in a point midway between the two adjacent full step position. If the phasesbandc areexcited,therotoroccupiesaposition such thatanglebetweenAA' axisof statorand1-3 axisofrotorisequalto 45°.To reversethedirectionof rotation switching sequenceischanged(i.e.) a and b, a and c etc.Themain advantage ofthistypeofoperationis thattorque developed by the steppermotoris more than thatduetosingle phase ON mode of operation.

Truth table for mode II operation in counter clockwise and clockwise directionaregiven in table and respectively

Table : Counter ClockwiseRotation (CCW)

S_1	S_2	S_3	θ°	
•	•	-	15°	AB
-	•	•	45°	BC
*	-	*	75°	CA
•	•	-	105°	AB
-	*	*	135°	BC
*	-	*	165°	CA
*	*	-	195°	AB
-	*	*	225°	BC
*	-	*	255°	CA
*	*	-	285°	AB

Table : Clockwise Rotation (CW)

	S_1	S_2	S_3	θ°.
AC	*	-	*	15°
CB	-		● .	45.°
BA	*	*	-	75°
AC	*	-	*	105°
CB	-	•	*	135°
BA	*	*	-	165°
AC	*	-	*	195°
CB	-	*	*	22 0
BA	•	•	-'	255°
AC	•	-	•	285°

(c) Mode III: Half step mode:

InthistypeofmodeofoperationonephaseisONforsome duration and two phasesareON during some other duration.The stepangle canbe reduced from 30° to 15° by exciting phase in sequence a, a+ b,b, b + c, c etc.The technique of shifting excitationfromone phaseto another(i.e.) fromato b with an intermediate step of a+ b isknownashalf step and is used to realisesmallersteps. Continuoushalfsteppingproduces smoother· shaft rotation.

The truth table for mode IIIoperation incounter clock and clockwise directionaregivenintables and respectively.

Table : Counter ClockwiseRotation (CCW)

S_1	S_2	S_3	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

Table : Clockwise Rotation (CW)

	S_1	S_2	S_3	θ.
A°	*	-	-	0°
AC	*	-	*	15.°
C	-	-	*	30°
CB	-	*	*	45°

B	-	*	*	60°
BA	*	*	-	75°
A°	*	-	-	90°
AC	*	-	*	105°
C	-	-	*	120°
CB	-	*	*	135°
B	-	*	-	150°
BA	*	*	-	165°

Micro stepping control of stepper motor:

Stepper motor is a digital actuator which moves in steps of θ_S in response to inputpulses.Such incremental motion results inthe followinglimitations of the steppermotor.

1. Limited resolution:

As θ_S isthe smallestanglethroughwhichthesteppermotorcanmove, this has an effect on positioning accuracy of incremental servo system employing stepper motors because the stepper motor cannotpositiontheload toanaccuracyfinerthan θ_S.

2. Mid-frequency resonance:

APhenomenoninwhichthemotortorquesuddenly dropsto alowvalueatcertaininputpulsefrequenciesasshowninfig.Torque

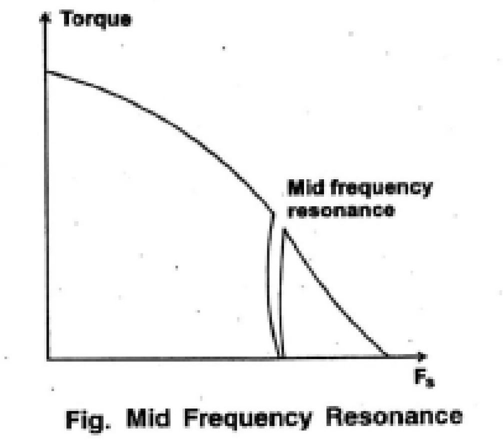


Fig.Mid Frequency Resonance

Anewprinciple known asmicrostepping control hasbeen developed with aviewofovercomingtheabovelimitations.Itenablesthesteppermotor to move throughatiny microstep of size $\Delta\theta°_s << \theta°_s$ full step angle is response toinput pulses.

Principleof microstepping:

Assume a two phase stepper motor operating in "One phase ON" sequence.Assume also thatonlyB_2windingis ONandcarryingcurrent $I_{B2} = I_R$, theratedphasecurrent.All theotherwindingsareOFF.In this state thestator magnetic field is along the positive real axis as shown infig. (a). Naturallythe rotor will also bein$\theta = 0°$ position.

When the next input pulse comes, B_2 is switched OFF while A_1 is switched ON. In this condition $I_{Al} = I_R$ while all the phase currents arezero. As a result the stator magnetic field rotates through 90° in counter clockwise directionasshown infig.(a).

The rotor follows suit by rotating through 90° in the process of aligning itself with stator magnetic field. Thus with a conventional controller the stator magnetic field rotates through 90° when a new input pulse is received causing therotorto rotate throughfull step.

However in microstepping we want the statormagneticfieldtorotate throughasmallangle$\theta s << 90°$inrespect to inputpulse.Thisisachieved by modulatingthecurrentthrough $B_2$and A_1 windingasshownin fig. (b) such thatwhile

$$I_{B2} = I_R \cos\theta \qquad \dots \text{la}$$

$$I_{A1} = I_R \sin\theta \qquad \dots \text{lb}$$

Then the resulting stator magnetic field will be at an angle$\theta°$withrespect to the positiverealaxis. Consequentlytherotorwillrotatethrough anangle $\theta° << 90°$.

This method of modulating currents through stator windings so as to obtain rotation of stator magnetic field through a small angle θ° to obtain microstepping action isknownasthemicrostepping.Althoughcurrents I_R cos θ andI_R sin θisflowing throughindividual stator windings, there resultantis I_R. The resulting stator magneticfieldhasthesame magnitude.Consequently the steppermotordevelopsthesametorqueasdevelopedunder one phase ON sequence.

There isno reduction inmotortorque on account of microstepping.

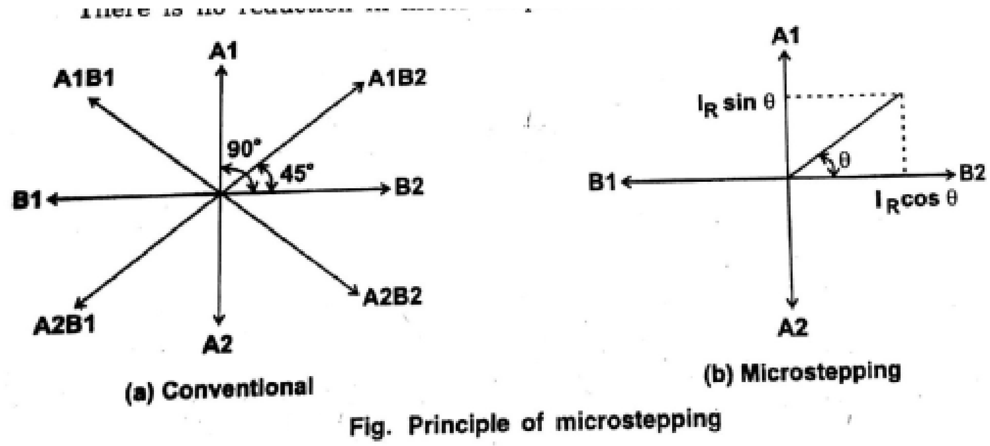


Fig. Principle of microstepping

1.Improvement inresolutionby afactorMSRMicro Stepping Ratio

MSR= 0s/ θs … 2

The valuesofMSRare5,10,25andinpowersof 2upto128.

The smallest angle through which the motor rotates per input pulse is

$$\Delta\theta = \left(\frac{1}{MSR}\right)\theta_S \qquad ... 3$$

2. Rapid motion at a microstepping rate (MFz) which is MSR times the full stepping rate (Fs).

3. DC motor like performance: Under microstepping control, the stepper motor moves rapidly at microstepping rate in tiny micro steps of size Δθ . The resulting motion is so smooth that it is practically in distinguishable from continuous motion of the DC motor.

4. Elimination of mid frequency resonance: On account of smooth and rapid motion under microstepping control, mid-frequency resonance are not excited.